Leapfrogging in China's Renewable Electricity Development Pathway?

The roles of policy frameworks, innovation and international cooperation partnerships
in fostering renewable electricity

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Abstract

The topic of this thesis is China's transition to a sustainable and low-carbon energy system based predominantly on renewable electricity supply. The specific focus is the concept of leapfrogging, frequently proposed as an alternative development strategy for China and other large developing countries to bypass the historical energy-intensive and polluting stages of development of the already industrialised countries. The thesis poses the question whether leapfrogging in China's renewable electricity sector occurred in the period from 2005 to 2010 and what the future potential for leapfrogging is.

The specific technology focus of the thesis is renewable electricity and to some lesser degree renewable energy for heating. In this context five main areas have been looked at in detail: decentralised renewable energy technologies for rural development, innovative capacity and development of China's emerging renewable energy companies, application of renewable electricity and electricity saving technologies in China's cities, application and use of renewable technologies for large-scale electricity generation and China's national energy system as a whole.

Two main bodies of theory are used as a conceptual framework to support the analysis: socio-technical innovation systems and global environmental governance with a focus on multi-stakeholder partnerships. This multi-disciplinary approach is applied to identify and analyse the roles of domestic policies, socio-technical innovation and international cooperation partnerships for renewable electricity development. In this context the thesis specifically analyses the effectiveness of China's national and local policy frameworks in facilitating transition processes and supporting innovation for renewable electricity development. Furthermore, the contribution of international cooperation initiatives and partnerships to renewable electricity development and leapfrogging is analysed.

The research results show that leapfrogging in China's renewable electricity development to date has occurred only in some selected cases. Environmental leapfrogging, a reduction of environmental impacts through renewable energies replacing fossil fuels, has not yet occurred.

China's policy frameworks and national targets have been crucial for fast development of renewable electricity technologies in the period 2005-2010. Further refinements and more ambition would be required to facilitate leapfrogging as national development strategy. China's institutional framework for energy governance is still fragmented, which impacts on the effectiveness and implementation of policies.

International partnerships for technology transfer, capacity building and policy dialogues are a key element in the transition to an energy system based on renewables and are interlinked with

China's national innovation system and support policies for renewable electricity. Despite China's rapid development of renewable electricity, further cooperation for technology transfer, specifically policy dialogues and capacity building, will be crucial in the future.

On a conceptual level, the research shows that the concept and definitions of leapfrogging so far are still very vague and would require further research in order to develop the concept of leapfrogging into an analytical framework and practical guiding principle for developing countries.

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List of Acronyms

ADB	Asian Development Bank
APREC	Asia Pacific Energy Research Centre
ARC	Aprovecho Research Center
BAU	Business as usual (scenario)
BRT	Bus rapid transit
CASS	Chinese Academy of Social Sciences
CBDR	Common but differentiated responsibilities
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CHP	Combined heat and power
CO ₂	Carbon dioxide
CNY	Chinese Yuan
CRESP	China Renewable Energy Scale-up Program
CSD	Commission on Sustainable Development
DNA	Designated National Authority
DSM	Demand side management
EDF	Environmental Defense Fund
EGTT	Expert Group on Technology Transfer
EKC	Environmental Kuznets Curve
ERI	Energy Research Institute, China
EU ETS	European emissions trading system
EV	Electric vehicle
E2W	Electric two-wheeler
FIT	Feed-in tariff scheme
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gases
GHP	Geothermal heat pump
GPPN	Global public policy network
GS	Gold Standard
GW	Gigawatt
ICP	Inter-country Joint Mitigation Plan
IEI	International Energy Initiative
IGES	Institute for Global Environmental Strategies
IPO	Initial public offering
IPR	Intellectual property rights
IRENA	International Renewable Energy Agency
JCFA	Joint Commitment Framework Agreements
kW	Kilowatt
LBNL	Lawrence Berkeley National Laboratory
LCZ	Low carbon zone
MEA	Multi-lateral environmental agreement
MEP	Ministry of Environmental Protection of China
MMS	Mandated market share
MoA	Chinese Ministry of Agriculture
MW	Megawatt
NDRC	China National Development and Reform Commission
NEA	China National Energy Administration
NGO	Non-governmental organisation

NIC	New industrialising economy
NREL	National Renewable Energy Laboratory
NPC	National People's Congress of China
NSI	National systems of innovation
NTE	New technology enterprises
OECD	Organisation for Economic Cooperation and Development
PoA	Programme of Activities (CDM)
PPP	Public-private partnership
PV	Photovoltaic
RAP	Regulatory Assistance Project
RED	Renewable Energy Development Programme (Sino-Danish)
REDP	Renewable Energy Development Programme (UNDP)
REEEP	Renewable Energy and Energy Efficiency Partnership
RPS	Renewable Portfolio Standard
SCE	Standard coal equivalent (a unit of energy)
SHP	Small hydro power
SSM	Shengzhou Stove Manufacturer
SSTECF	Sino-Singapore Eco-City Project
SWH	Solar water heater
TW	Terawatt
TWh	Terawatthour
TJ	Terajoule
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VER	Voluntary emissions reduction
WB	World Bank
WCD	World Commission on Dams
Wp	Watt peak
WWF	World Wide Fund

1. Introduction

1.1 Research Topic and objectives

This research thesis is concerned with the characteristics of China's transition pathway to a sustainable, low-carbon energy system based predominantly on renewable electricity supply. It takes the concept of "leapfrogging" as a framework to investigate whether leapfrogging is occurring in China's renewable electricity sector and what future potentials for leapfrogging might exist. In this analysis the relation between domestic policy frameworks, technological innovation and the contribution of international partnerships for renewable electricity cooperation for the time from the adoption of China's Renewable Energy Law in 2005 until the end of 2010 are emphasised. It specifically looks at renewable electricity technologies wind, solar PV, geothermal, biogas, and electricity saving technologies such as solar water heaters and heat pumps. Heat generation technologies and transport fuels are not included.

The hypothesis of this thesis is that leapfrogging, which has occurred in other cases such as Brazil's ethanol industry and in China's uptake of mobile telephony technology, is a potentially possible development pathway and strategy for China. To achieve leapfrogging in the electricity sector, domestic policy will be the most relevant factor driving innovation and investment, supported by international partnerships and collaboration.

Therefore, the specific objective of this PhD research thesis is to answer the following question:

- *In which areas of China's electricity sector development pathway is leapfrogging already occurring, what are the factors either contributing to it or impeding current and future leapfrogging developments and what are the roles of national innovation systems, energy policy and international partnerships in forging this unique pathway?*

The research methodology, theoretical framework and research findings of this thesis are presented according to the following structure: In Chapter 2 the methodology applied during field research in China, data collection and analysis will be described. Chapter 3 provides an overview of the concept of leapfrogging as it is used in various literatures. In addition, two theoretical frameworks, socio-technical innovation systems and environmental governance, which have been employed as a theoretical lenses for this research, are discussed.

Chapter 4 introduces five areas, or sectors, relevant for China's renewable electricity development, which were looked at in detail to see whether leapfrogging has occurred or not. Chapters 5 to 9 discuss and analyse the development of various renewable electricity technologies in these areas, together with relevant policies and international partnerships that facilitated the development. Furthermore, a critical assessment of whether leapfrogging has occurred, and what the future potentials are, is provided.

Chapter 5 deals with the first area, China's electricity sector in rural areas. Technologies discussed are solar photovoltaic (PV) home systems, household biogas digesters and efficient biomass cooking stoves.

The second area, analysed in Chapter 6, is concerned with renewable energy companies with a focus on manufacturers of wind turbine equipment, solar PV modules and solar water heaters (SWH). The third area is urban China, looking at the role and contribution of renewable electricity, including vehicle electrification, for sustainable urban development (Chapter 7). The fourth area, discussed in Chapter 8, is the large-scale deployment and use of 'new' renewable electricity technologies such as wind power, solar PV and energy saving technologies such as geothermal and solar water heaters. Chapter 9 discusses the overall stage of China's renewable electricity sector development in comparison to other countries, in view of the Chinese government's aspiration to be a world leader in renewable energy in the 21st century.

In all areas, the assessment proceeds on the basis that in the area described leapfrogging might or might not have been demonstrated in practice. To conclude the thesis, Chapter 10

provides a final discussion and conclusion on the research results.

The issue of finance and investments for renewable energy, although a crucial factor for technology development, is not discussed in detail in this thesis. Finance and investment for renewable energy was not chosen as a central part of the analysis and is outside the primary scope, even though it is recognised as significant factor, particularly for bringing new technologies from the R&D stage to commercialisation and the large-scale deployment of renewable energy.

1.2 Leapfrogging – a possible low-carbon development strategy for China?

The double challenge for developing countries like China is to continue raising living standards for their population and at the same time realising low-carbon development through technologies which do not further jeopardise climatic stability. Achieving continued poverty reduction and a low-carbon development pathway from the outset calls for “leapfrogging”, a concept and expression which is being increasingly used in the popular press. Usage of the concept also can be found to some degree in academic literatures on industrial innovation systems, national development strategies, and renewable energy technologies in the context of sustainable development (e.g. Goldemberg 1998),

It is specifically often used in the context of China and other large developing countries. For instance the International Energy Agency, in a study on successful examples of leapfrogging enabled through technology transfer, states that *‘developing countries need to “leapfrog” a technological generation or two if concentrations of GHGs are to be stabilised’* (IEA 2001).

Despite its popularity, the concept of leapfrogging is not well defined in the academic literature. Furthermore, scientific methodologies for analysis and indicators on how to determine whether developments can be classified as leapfrogging or not, are not developed.

In this thesis three main definitions of leapfrogging, which were identified through the

literature review (see section 3.1), are applied for analysis of China's renewable electricity development.

The first definition is technological leapfrogging which indicates the skipping of stages of technology generations. This type of leapfrogging applies, for example, to the adoption and use of new technologies (e.g. solar PV home systems instead of electricity supply through grid connection). It also applies to rapid progress through radical innovation of products and growth of industry sectors and companies manufacturing new technologies, including rapid innovation in manufacturing processes during which some stages might be skipped and new companies become industry leaders (e.g. Lee and Kim 2001). Technological leapfrogging can also apply to urban development if it proceeds in a series of successive 'jumps'. This would include the use of the latest building technologies and sustainable infrastructure from the outset. An example here is new buildings equipped with integrated renewable energy or energy saving technologies from the beginning. On a larger scale it would include cities designed as walkable and cyclable cities, supported mainly by public transport, rather than individual car based transport.

The second definition of leapfrogging concerns countries' national socio-economic development strategies, aiming to leapfrog ahead of other countries in terms of socio-economic and industrial development (e.g. Brezis at el. 1993). Indicators for leapfrogging based on this definition are a country's GDP, income levels and other macro socio-economic development indicators. Discussions on leapfrogging in this context are often accompanied by political rhetoric as comparisons among countries and industry sectors can lead to competitive attitudes (e.g. Borofsky 2009a; Friedman 2009; Chan, Y., 2009).

The third definition is "environmental leapfrogging", indicating that through the use of new technologies environmental impacts compared to business-as-usual development as experienced by industrialized countries are avoided (Goldemberg 1998). Environmental leapfrogging is closely related to the notion of "tunneling through the Kuznet's Curve" (Munasinghe 1999).

On the basis of these three different definitions, this thesis will investigate if similar

developments have occurred in relation to China's renewable electricity development.

In all leapfrogging strategies, which have the goal of technological innovation, reducing environmental impacts while simultaneously promoting increases in quality of life, renewable energy technology will be an important component, but other aspects will also require attention. Systems approaches looking beyond the energy sector by including related sectors offer additional potential for leapfrogging, especially in view of developments such as electrification of urban transportation vehicles and energy efficiency in buildings facilitated by smart metering. Achieving environmental leapfrogging, and providing overall reductions of environmental impacts while improving quality of life (e.g. through co-benefits such as reduced local air pollution), will very likely require the inclusion of other 'soft' factors that go beyond technology innovation, such as behavioural changes to enable sustainable consumption patterns and lifestyles.

Leapfrogging potentials exist in the energy sector, both in terms of available technology and economic viability. According to a range of scenarios for China's energy future, it would be possible for China to satisfy most of its increased electricity needs through renewables; wind power in particular has significant potential for China. For instance, a scenario developed by Greenpeace and the European Renewable Energy Council (Greenpeace & EREC 2007), although not considering leapfrogging, estimates that by 2050 more than 50 percent of the electricity produced in China could come from renewable energy sources. 'New' renewables, mainly wind and solar energy, would contribute 37% of electricity generation, which would be equal to about 450 GW wind power and 385 GW solar PV installed capacity. Through a conscious leapfrogging strategy this share could potentially be even higher.

McElroy et al. (2009) have even higher estimates for wind power. Based on their assessment the quantity of wind power installation that would generate electricity and deliver it profitably to the grid under the bidding and financial conditions currently in place in China would be about 640 GW over a 20-year period. This amount of electricity would allow replacing coal fired power stations and result in a reduction in CO₂ emissions of around 30%.

1.3 China's renewable energy development - current status

The figures on China's renewable energy development are indeed impressive: For instance, at the end of 2010 the country possessed 213 GW hydro power capacity (REN21 2011), more than 44.8 GW of wind power capacity, 893 MW of solar photovoltaic capacity and 24 MW of geothermal capacity (BP 2011). In 2010 the share of renewable energy (including hydro) accounted for 9.1% of China's final energy (REN21 2011). By the end of 2010 total electricity consumed from renewable sources amounted to 7,021.3 PJ (1,950.4TWh), including 6,828.7 PJ (1,896.9 TWh) from hydropower (both large and small), 151.2 PJ (42 TWh) from wind power (GWEC 2011), and 41.4 PJ (11.5 TWh) from solar PV, geothermal and modern biomass combined (BP 2011).

However, it is necessary to put these figures and developments into perspective by comparing them to conventional electricity generation capacity and fossil fuel consumption. By the end of 2009 China's total installed capacity for power generation had reached 874 GW. This figure is about 13.5 times higher than total capacity in 1978 at the start of China's economic modernisation process. The annual power generation capacity growth rate continues to be over 9 percent and the majority of energy supply continues to be based on fossil fuels, with about 70 percent of energy consumed being supplied by coal and about 18 percent by oil (BP 2011). The share of new renewables (excluding traditional biomass) is still comparatively low: of total primary energy consumption it stands at around 7.5 percent with large hydro power having the largest share (see Fig. 1)

Figure 1: Composition of China's primary energy consumption in 2010 (source: BP 2011)

Looking at the share of electricity from renewables, the picture is somewhat different. In 2009 it stood at 16 percent (including hydro), but without hydro it was significantly lower, only 0.8 percent (REN21 2011). Viewing the current share of renewable energy supply in China from this macro level perspective, it is obvious that the transition towards an energy sector based predominantly on renewable energy has just begun as the share of both renewable energy and electricity still seems to be insignificant in contrast to the share and continued growth of fossil fuels for power generation.

Despite the current very low share of renewables, especially 'new' renewables (wind, solar PV and modern biomass), China's renewable energy development nevertheless has taken off dramatically in absolute size in recent years. At the end of 2009, China had an installed renewable electricity capacity of 52.5 GW or 0.8% of total electricity (excluding large hydro above 50MW) (REN21 2011). The new renewables, particularly wind, have in the past years grown much faster than fossil fuel based energy generation. In 2005 renewable electricity grew by 14 percent, in 2008 by 17 percent (Li and Ma 2009) and from 2009 to 2010 by as much as 74.5 percent (BP 2011).

In summary, renewable energy is growing substantially faster than total energy supply, so the share of renewables in total primary **energy** supply is increasing steadily; moreover, the share of renewables in **electricity** supply is growing fast.

1.4 Renewable energy in the context of climate change

Although the development of renewable energy in China is fast, the current pace is not yet sufficient to meet the requirements of a fast transition to a decarbonised global economy. The global challenges of climate change and energy security have become the most important factors influencing global and national energy transition pathways, including China's.

Since 2000, annual CO₂ emissions in China have more than doubled to about 8 Gt and CO₂ emissions per capita have increased in China from 2.2 to 6.1 tonnes (Olivier and Peters 2010). Because of these developments, the country is experiencing a lot of pressure from the international community to address the growth of emissions. For example, its Copenhagen pledge has been described as 'inadequate' (Climate Action Tracker 2010). It is necessary to put Chinese emissions in perspective: China's per capita emissions are still well below those of US citizens, which were more than 17 tonnes CO₂ in 2009. In terms of China's annual per capita energy consumption, China is still low at 2 tonnes of oil equivalent compared to around 7 tonnes of oil equivalent in the United States. Furthermore, China's historical responsibility to the current problem is relatively low. Considering cumulative historical emissions for the period 1850 until 2002, China's emissions are around 7-8 percent of the global total, compared to the US cumulative emissions amounting to about 29-30 percent and the EU's to 26-27 percent (Baumert et al. 2005).

China has already committed to reduce emission intensity per unit of GDP by 40-45% by 2020 and associated its pledges with the Copenhagen Accord. While China's emission intensity target has been criticised as essentially business-as-usual (Levi 2009), it is still a significant target,

given China's current state of development. If realised, China's intensity target will result in emissions reduction in the order of reductions of 2.5 GtCO₂ in 2020 under the target, compared to the emissions reduction pledge of the United States, 17% over 2005 levels by 2020, resulting in a reduction of only about 0.8 GtCO₂ in 2020 (Athanasίου 2010).

From a global perspective aiming for overall environmental integrity, the target is unfortunately not sufficient to prevent dangerous climate change. Instead, a comprehensive environmental leapfrogging strategy will likely be necessary to achieve a more substantial dent in China's emissions and to change the global emissions trajectory. The potential for this alternative leapfrogging path exists for China because the country is not yet as 'locked-in' as many developed countries: most energy generation capacity, energy consuming assets and infrastructures have yet to be built – between 2005 and 2020 China's electricity-generation capacity is estimated as likely to increase by about 700 GW (not including replacement of capacity to be retired).

According to growing evidence and trends in predictive climate science, the effects of climate change will be greater and will occur faster than previously estimated, giving heightened reason for concern (Smith *et al.* 2009). To avoid dangerous climate change which could, among other interferences with the Earth's systems, cause instability in the ice sheets in Greenland and Antarctica, Indian Monsoon disruption or large scale methane outbursts in Siberia (Schellnhuber 2006), there is a growing view that it would be desirable to limit the global average surface temperature rise to below 1.5 degrees Celsius above pre-industrial levels (Hansen *et al.* 2008). However, this level of concentrations is likely to be very difficult to attain because of the momentum in economic and social systems, so attention is largely focused on the 'guardrail' of 2 degrees of warming, and the limit of 450ppm CO₂e. There is a widespread view among the scientific community (see for example The St James Palace Memorandum, 2009) that to avoid passing beyond this threshold of potential sensitivity in the climate system, major global efforts for early and strong reduction of anthropogenic global greenhouse gas emissions in a very short time

are required – global emissions should peak by 2015 – 2020, and be cut rapidly thereafter (WBGU 2009; Macintosh 2010).

In contrast to what climate scientists “propose”, current country pledges under the Copenhagen Accord, the outcome of the Copenhagen UN climate conference in 2009, are ‘paltry’ (Rogelj *et al.*, 2010) and likely to lead to a world with global emissions of 47.9 gigatonnes to 53.6 gigatonnes of carbon dioxide equivalents (GtCO₂e) per year by 2020 — about 10–20% higher than today’s levels. This would likely set the world on a trajectory of a greater than 50% chance that warming will exceed 3 °C by 2100. According to a recent joint study by leading climate change research institutes in the UK, if annual global emissions were no higher than about 48 GtCO₂e in 2020, rapid rates of annual reductions in global emissions, possibly as high as 4 or 5 percent per year, would be required to have a 50% chance of limiting global temperature increases below the level of 1.5 degrees (Ranger *et al.*, 2010), even with some significant risks associated with decades of temperature ‘overshooting’. In this case, global 2020 emissions levels would be in the magnitude of 40–44 GtCO₂e, depending on the assumed business-as-usual scenario. Therefore, to keep on the safe side, 2020 global annual emission levels should not exceed 44 GtCO₂e (Rogelj *et al.*, 2010).

1.5 Current status of the UNFCCC process and the role of developing countries

The ongoing process under the United Nations Framework Convention on Climate Change (UNFCCC) is the global forum under which governments are attempting to find an agreement on action to prevent dangerous climate change in form of a global treaty. However, after the Copenhagen climate conference, which did not achieve the expected new ambitious and legally binding global agreement for the post-2012 period, current official climate negotiations under the UNFCCC process are at the time of writing progressing only slowly without a significant

breakthrough in sight. It seems unlikely that the process will result in a comprehensive global climate treaty at the upcoming Conference of Parties in Cancun (COP16) end of 2010. It is even unlikely that the UN-led process will provide a fair, ambitious and legally binding climate treaty in the mid-term future. Furthermore, the global UN-led process is at the time of writing being seriously impacted by domestic US policy as the United States Senate abandoned plans to introduce a domestic climate bill in July 2010, and no climate legislation will therefore be passed before the mid-term elections in late 2010.

After the Copenhagen summit ended inconclusively in December 2009, China and other large developing countries were blamed by the western media and observers for the failure of the Copenhagen summit to produce ambitious outcomes (e.g. Lynas, 2009; Milliband, 2009). While China seems not to have contributed much to achieving an ambitious outcome in Copenhagen, the singular blame on China has been refuted in subsequent accounts of what happened in Copenhagen behind the scenes (e.g. Khor 2009). For instance, according to Ian Fry, negotiator for the Tuvalu government, "it's far too simplistic that we were 'played off' by China" and the perception that China strategically wrecked the negotiations is incorrect (Block 2010).

The increasing divergence and friction between developed and developing countries is to a large part due to the interpretation of the UNFCCC's principle of "common but differentiated responsibilities" (CBDR). This often quoted phrase indicates that all countries should take action to combat climate change, whilst the degree of action should be determined based on countries' contribution to current and past levels of atmospheric emissions and national capabilities. Based on a scientific perspective, due to their historical responsibility of more than 50% for the accumulated current stock of emissions, and high per capita emissions, Annex I industrialised countries, according to both the IPCC and UNFCCC, would need to take the lead in reducing drastically reducing emissions in the order of 25-40% by 2020 (IPCC 2007; UNFCCC 2007). To avoid exceeding 1.5 degrees of warming, reductions in the upper end of this range, close to 40%, would be necessary, which is also demanded by many environmental groups and least

developing countries most affected by climate change. The IPCC's and UNFCCC's recommendation for developing countries is a 'substantial deviation' of 20% below business-as-usual levels (IPCC 2007; UNFCCC 2007). This would require on the one hand strong national policies, and on the other hand strong international support in terms of additional finance, technology transfer and capacity building.

The climate change problem puts developing countries and large emerging economies like China in the very difficult situation that they need to continue to reduce poverty and improve people's living standards by developing their economies - and at the same time limit and reduce emissions. To achieve this feat of absolute decoupling of socio-economic development and GHG emissions, which has only been partly achieved in some European countries, but at the expense of exporting pollution to the developing world, developing countries basically have to move on to a low-carbon development path immediately, bypassing (or "tunneling through") the traditional high-polluting stages of development the industrialised countries of North America, Europe and Japan have gone through.

1.6 Support through international partnerships and cooperation

It is clear that Chinese government policy and domestic innovation has been the major driver for achieving the development of renewable energy seen so far. According to market research by the United Nations Environment Programme, China is already investing more than any other country in green technology sectors – in 2009 this figure amounted to more than US\$ 4 billion – in comparison the EU invested US\$ 2.9 billion in this sector (UNEP, SEFI & Bloomberg NEF 2010). Despite this strong domestic policy support, investment and growth in renewables already occurring, China and other developing countries cannot realise the transition on their own. In addition to strong domestic policy action and investment, international support and cooperation will likely be necessary to support China in the transition.

In the absence of an effective global climate change agreement and mechanisms that would deliver the necessary large-scale transfer of financing and technology to developing countries to support their energy transitions, alternative means of cooperation to support renewable energy developments in China and other countries will become increasingly important.

Currently the main global mechanism for technology cooperation and support of renewable electricity is the Clean Development Mechanism (CDM), but in its present form it is likely not sufficient to facilitate large-scale transfer of low-carbon energy technologies to developing countries. Already new forms and innovative approaches of bilateral cooperation are emerging to support the diffusion of renewable energy technologies and other mechanisms.

Furthermore, some new innovative partnerships, going beyond technology solutions addressing sustainability issues and instead focusing on issues such as low-carbon urbanisation are emerging. These partnerships often involve multiple stakeholders, including the business sector, non-governmental organisations, academia and think tanks. Win-win solutions which can create benefits for all partners involved are already emerging, but these would need to be replicated and scaled-up in order to contribute substantively to China's low-carbon transition pathway and to global climate protection.

These types of cooperation not only offer climate mitigation benefits, but also economic opportunities for the private sector in China and industrialised countries. In the context of climate change, industrialised countries do have responsibility, based on considerations of equity, fairness and historical responsibility, to support developing countries in their transition to a low-carbon economy.

However, China's unique position and status as emerging super-power rivaling industrialised countries in many fields, including renewable energy, makes cooperation or technology transfer increasingly difficult. Media reports about the rapid growth of China's renewable energy sector often portray such growth with concern and populist writers have characterised China's development in renewable energy technologies as 'the Sputnik of our day' and the notion of being

leapfrogged by China is frequently used as political rhetoric (Friedman 2009).

2. Methodology

In this thesis a predominantly qualitative mixed-method methodological approach was applied for data collection and analysis. The choice of this approach was determined by the multi-disciplinary subject and theoretical framework. The mixed-method approach has been suggested by Gallagher, Holdren, and Sagar (2006) in their review of the current status of energy technology innovation and to guide research on future energy challenges. In the environmental sciences, mixed-method approaches are increasingly used to ensure methodological triangulation. To some degree the methodology also drew on elements of ethnographic research, particular those elements relating to data collection through participant observation. The methodological research design and data collection resulted in more qualitative than quantitative data; therefore an embedded research design structure was used in which the quantitative data set provided a supportive, secondary role in the study, which is based primarily on qualitative data. The limited quantitative metrics collected were statistical information, including figures about financing and investment in renewable energy technology R&D, funding for partnership programmes and demonstration and deployment projects, numbers of capacity building training seminars, human resources, and similar data. Quantitative output metrics provided some measures with which to evaluate the outputs of technology transfer partnerships and included numbers indicating quantum of funding, technical papers, patents filed, technology produced, staff trained, megawatt (MW) of renewable energy capacity installed, and certified emissions reductions (CERs) generated through CDM projects.

While quantitative data are important to assess the current state of China's renewable energy development and partnerships, a range of significant factors, such as the dynamics between actors in partnerships that influence developments towards long-term future clean energy collaboration, are often difficult to quantify. A qualitative interdisciplinary assessment therefore was a vital part of the research, particularly in the description of partnerships and in

assessing the effectiveness, success and challenges of cooperation projects in China.

For this thesis, information was acquired from multiple sources and through four main types of methods. These included document and text based data, semi-structured formal interviews, informal communications and participant observation. The multiple method approach combining various techniques ensured methodological triangulation to confirm and improve data validity. I did not employ the method of surveying through questionnaires, mainly because there was not one large specific target group large enough to respond to a standardised set of questions and to generate statistically significant data. Overall, a range of variables were taken into account and this provides some confidence that the results and conclusions drawn from my research are reliable. The remainder of this section describes the methods used for data collection and data analysis.

2.1 Data collection methods

Field data were collected during the period from March 2008 until August 2010, predominantly in Beijing. Some of the data were collected in Tokyo during January 2009, in Copenhagen during December 2009, and in Bonn during June 2010. Energy data for statistical analysis were taken from different sources, including the BP Statistical View of World Energy , US Energy Information Administration, China Statistical Yearbook and World Bank databases.

Difficulties with data collection in China on renewable energy. Doing field research in China and collecting the information was not an easy feat. As a young foreign researcher with no professional connections in Beijing, it was not easy to find interview partners. In China, an introduction through others is generally needed before an interview is possible. In many cases even general information about decision making processes and data on energy related issues China are not publicly accessible and only available through contacts.

Being initially based at the China University of Political Science and Law (CUPL), which

does not have a focus on energy-related research, required many personal efforts to get to know some of the actors of Beijing's renewable energy scene. It took several months to establish names of relevant actors and make appointments for interviews. Many requests for interviews remained unanswered or were declined, especially with officials from government departments. Therefore collection of information also relied on opportunistic dialogues through personal communications and not through formal interviews. In general, many Chinese experts are still apprehensive about foreigners researching in detail China's energy issues, particularly about institutional arrangements, effectiveness of policy instruments and accuracy of data, as these areas are often still considered sensitive. Trust building with key contacts was an important element as both Chinese and foreigners are concerned about where and how the information provided might be used.

Document and text based data were the first major source for general qualitative and quantitative secondary information about the technological development of China's renewable energy industry, eco-innovation, policy developments, information about China's renewable energy companies, R&D efforts and innovation outputs of new products and technologies. Most document information collected was in the English language; in some cases where no English version was available original Chinese sources were used. Academic online databases Science Direct and Web of Knowledge, available through Victoria University's online library service, provided access to academic journals such as *Energy*, *Energy Policy*, *Renewable Energy* etc. which frequently feature scientific papers with authoritative information about China's energy and policy development. The advantage of online academic resources was that they were timely and often are not published in printed form available in Beijing.

Information collection through the internet was a first step in the sequence of text based information collection; however, this process was ongoing throughout the field research as developments in China's renewable energy sector have been very fast and new developments

occurred frequently. Online documents collected included online news articles, industry reports, speeches by politicians, technical and scientific reports, project summaries, environmental and climate change blogs. Internet search engines such as Google proved helpful in identifying up-to-date industry reports and news in the popular and scientific-technical press. The feature 'Google Alerts' has been an important tool to stay updated on renewable energy developments. Blogs by commentators on climate change and China's renewable energy issues were important sources of information¹, and for identifying organisations involved in partnerships and potential interview partners. Chinese government energy policy documents and regulations (often only the original Chinese language version is available) were accessed and collected through Internet research. The internet was also an important source for collecting information about partnerships. Specialist websites of organisations and programmes engaged in partnerships in China provided relevant information about ongoing and new collaborative initiatives. Other text based information in the form of hard copies collected as part of this research included reports, brochures and information material collected during conferences and seminars attended and industry exhibitions visited during the field research.

Semi-structured formal interviews² were another important method of data collection and mostly provided primary qualitative data on partnerships, expert opinions about China's energy development pathways, explanations of renewable energy policy developments, comments about the concept of leapfrogging and assessments of whether leapfrogging is happening in China's renewable energy sectors.

Altogether 13 semi-structured formal interviews with mainly foreign and some Chinese experts were conducted. Interviews were mostly conducted face-to-face with one, in some cases two, interview partners at a time. One of the interview partners was interviewed by phone. Interviews were conducted in English, German and Chinese and were digitally recorded. Most of

¹ For example www.greenleapforward.com or <http://www.frankhaugwitz.info/>

² A detailed list of interviewees and schedule is given in Annex 1. The interview guiding questions are provided in Annex 2.

the interviewees filled out the consent forms as required by the ethics committee of Victoria University of Wellington. However, there were issues relating to the informed participant consent forms as this practice seems not only uncommon in China, but also foreign experts working in China were in some cases not willing to fill out the form. Therefore, not all interview partners were asked to sign participant consent forms, as in some cases the judgment was made that it was not appropriate. In all cases, nevertheless, participants were informed about the purpose of the interview and the PhD research. Some participants chose to remain anonymous and participants were assured that their identity would not be disclosed in the thesis or any publication relating to the research.

The criteria for selecting key individuals were experience within the Chinese renewable energy sector and/or with relevant international cooperation partnerships. Factors for selection of participants included the need to have both Chinese and foreign interview partners. In addition to the interviewees consulted for the thesis, approximately twenty others were approached, but declined interviews. The main body of data about partnerships and cooperation was thus collected through open-ended semi-structured interviews with a set of pre-determined, but flexibly worded questions which were tailored to the specific organisations, partnerships and topic issues. The semi-structured interview also provided the opportunities to ask follow-up questions designed to probe more deeply into issues of interest arising from the answers of the participant. The interview questions were aimed at providing information not only on the past and current state of partnerships, but also information on recommendations for future partnerships and developments.

Cross-cultural interviewing issues were considered. The questions for the interview were specifically chosen to tap into the professional expertise, knowledge and experience of the interviewee. Interview data were audio recorded digitally and transcribed. The length of each interview was between 60 and 90 minutes.. All interview partners were given the interview transcript or the case study description or the partnership description that was developed on the basis of information given through interviews to check and correct, to prevent misrepresentation.

Personal communications were the third relevant method for information and data collection. As Chinese society is a relationship-oriented society, the establishment of long-term relationships with organisations and individuals proved to be important for collection of information. In total more than thirty personal communications were conducted, some of them repeatedly over a period of several months, during the course of this research. Personal communications and personal contacts proved to be very helpful to collect information about renewable energy policies and partnership projects from specialists, who would also express opinions about partnerships that would otherwise not be likely to have been mentioned in formal settings and voice recorded interviews. In this respect, personal communications proved more helpful than formal interviews. Furthermore, specific information collected through informal communications was very valuable for learning about the latest policy developments and, more importantly, the effectiveness of specific policy measures, the role of institutions, R&D and innovation.

Personal contacts were important to gain access to documents which were not available online. For instance, only after having established personal relationships was it possible to access internal documents of the partnership that provided project and/or research outcomes and results and other important information that would not otherwise have been available through internet research. These relationships were also helpful to keep up-to-date about new developments as the partnerships progressed.

Furthermore, direct involvement in organisations located in Beijing and cooperation projects related to environment, climate change and energy efficiency offered the chance to gain additional qualitative information and quantitative data through **participant observation methods**. Observation is deemed a crucial method in understanding other cultural backgrounds (Silverman 2005). Working in organisations' offices, from April 2008 to November 2008 at the

China Standard Certification Centre of the China Institute for Standardisation and as of September 2009 at the China Association for NGO Cooperation (CANGO), offered important practical insights and first-hand information into the daily workings and organisational processes of international cooperation projects. Participant observation provided opportunities to participate in meetings between Chinese and foreign project partners. Observation protocols provided a useful way to record descriptions of events and processes observed, as well as reflective notes about emerging codes and themes for partnerships that arose during the observation. Project documents accessed during participant observation provided additional quantitative information about specific projects of partnerships. Some of the information gained through this means was deemed to be confidential and could unfortunately not be used in the research.

Furthermore, China is increasingly hosting international events on renewable energy and climate change. Often these events, e.g. conferences or workshops, are important elements of partnerships, for instance for results dissemination. Participating in such events, where contacts and exchanges between Chinese and foreign stakeholders occur, offered additional opportunities for observation. During the course of field research more than two dozen such events and conferences were attended which provided the opportunity to observe the communication between Chinese and Western renewable energy professionals and academics as well as gathering further information in the form of conference proceedings and promotional documents.

2.2 Data analysis methods

For the analysis of the data collected, the selective coding approach of **grounded theory approach** (Strauss and Corbin, 1998) was used. Grounded theory was chosen as it has proven a flexible but robust approach for analysing data in exploratory studies such as this one. The grounded theory approach was used in the identification and development of the analysis framework to identify areas in which leapfrogging has occurred or sectors with leapfrogging

potential (see section 4.1).

One objective of the research was to evaluate whether the concept of leapfrogging conforms to empirical observations and data on China's renewable energy development. Selective coding, the process of choosing one category (leapfrogging) to be the core category, and relating other categories to that category, was applied. In this way the core category of leapfrogging, around which the final analysis is based, was related to other sub-categories.

During the field research period the textual data, interview notes and information collected through informal communications and participant observation were continuously read, re-read and reflected on. This process entailed careful comparison of quantitative data and qualitative information; in some instances text-based data could be compared to statements by interview partners and personal communication partners. Secondly, comparison between opinions and statements issued during formal interviews and statements made in informal conversations was made. As a result of this process several themes emerged and five areas in which leapfrogging is possible, and the interrelationships between these areas, emerged. The typology of leapfrogging was therefore developed in an inductive way. In this inductive process the method of back-casting was employed; this required consideration of a possible and desirable sustainable future situation to assess steps necessary for the attainment of that future state. Back-casting thus involved the identification of certain steps and a trajectory that might be designed in order to enable the future situation to be realised.

For the **discussion and analysis of renewable energy partnerships a qualitative case study approach** was chosen as it is commonly used in the study of multi-stakeholder programmes, events, processes, institutions and social groups. Case studies are commonly used to describe the institutional frameworks and organisations for 'partnerships for sustainability' (Olson *et al.*, 2006). Criteria for selection of relevant case studies included whether the partnership is representative of different partnership types identified in the literature review (multilateral, bi-lateral, PPP, industry joint venture, R&D collaboration, civil society collaboration,

multistakeholder initiative, etc.). Important criteria were also whether the partnership related to the theoretical framework in terms of involving multiple organisations, nested institutional multi-level arrangements, contribution to technology transfer, innovative approaches, etc. Through the case studies the characteristics of the current partnership and cooperation landscape in China was established. For the description of partnerships a narrative approach was applied, drawing to some degree on ethnographic research practices. The partnership case studies are both descriptive and explanatory.

At the outset of this research, an objective was to evaluate the effectiveness of partnerships. This turned out to be a more difficult challenge than expected. Partnership and project evaluation is a sensitive issue and it was difficult to collect sufficient qualitative and quantitative data to make thorough assessments about the effectiveness or success of a specific partnership. Partnership staff and experts were at times apprehensive about providing information which could negatively reflect on themselves and their stakeholders. Therefore, the evaluation of partnerships and assessing their effectiveness and contribution to China's renewable energy development or even specific types of leapfrogging was undertaken through **SWOT (Strengths, Weaknesses, Opportunities and Threats) analyses**. SWOT analysis is generally used as an analytical tool applied for understanding and improving decision-making for a variety of situations in business and organizations. While being used particularly for businesses, it can also be applied for other organisations, programmes or multi-stakeholder processes. The SWOT analysis headings provide a simple framework for reviewing strategy, position and direction of a partnership (Nathan 2007). SWOT analysis has also been used for regional energy planning with special focus on the contribution to renewable energy development (Terrados, Almonacid and Hontoria 2007). One of the problems with SWOT analysis for projects or partnerships is its subjectivity, even though the SWOT analyses are based on multiple sources including interviews, personal communications, and document and text analysis. In the context of this research and due to the current stage of renewable energy cooperation between China and other countries, SWOT analysis can

nevertheless be regarded as an appropriate method for partnership evaluation.

To conclude this chapter on methodology, a reflection on the researcher's **positionality** (Rose 1997) is necessary to put the research methodology and results into perspective. Despite the goal of being as objective as possible, in the process of data collection and analysis, the results and knowledge produced by this research are inevitably influenced by the researcher's still limited specific and partial view of the research subject. Furthermore, the researcher's cultural and educational background have certainly influenced the decisions what questions to ask interview partners, directing the flow of discourse, interpretation interview data, etc.

The data collection and analysis has also been strongly influenced by personal convictions and assumptions, although these are backed by a substantial body of scientific evidence, that fast sustainability transitions are necessary. The relationship between the researcher and the research subject is not one of distanced objectivity – as a long-term resident in China the author of this thesis has strong personal motivation to support a fast sustainability transition. Furthermore, as a foreigner with some, but still limited, understanding of China's national and local circumstances, producing representations of China and the country's policy development, the author found himself inextricably bound up with questions of authority, appropriate communication and representations, and the complex political positions generated by such questions. The presentation of data and results of the thesis has therefore been influenced by considerations of acceptance by different communities including international scientists, Chinese researchers and Chinese and international actors involved in cooperation partnerships with China.

There are different limitations to this research which need to be mentioned. The most relevant limitation is that of conducting energy-related research in China as a non-Chinese person. Energy and climate change issues are still politically sensitive issues, particularly the matters concerning policy developments. In making assessments about the effectiveness of regulations and 'reading' where policies and strategies are heading, requires in-depth knowledge and many

years experience in observation of China's energy development and beyond the scope of this thesis. Furthermore, the fast changing and highly political nature of policies and institutions in China weakens any policy conclusions and the sheer speed of change in the private sector in China's renewable energy sector makes it difficult tracking these developments. The difficulties of accessing reliable voices in conducting research and the need to protect confidences as part of long-term relationship building cannot be underestimated.

Research about energy cooperation partnerships, particularly when it comes to assessing effectiveness or limitations of existing partnerships is perceived as sensitive from both Chinese and international experts. Reliance on and reliability of secondary and tertiary quantitative data is another limitation of this research, as is the limited use of Chinese literature sources. Although quantitative data from a variety of sources were sourced, some of these data might prove to be inaccurate or will get updated after publication of the thesis, particularly secondary statistical data. Other limitations include the issue of positionality of the researcher conducting interviews, collecting and evaluating data, which is discussed in some more detail in the methodology part. Despite these limitations, the results of this research produced a number of interesting findings which have the potential to contribute to a better understanding of different elements relevant for environmental leapfrogging in China.

3. Theoretical Framework

This thesis investigates the development of China's renewable electricity sector and tries to answer the question if leapfrogging development has occurred. In this thesis three main definitions of leapfrogging, which were identified through the literature review (see Section 3.1), are applied as framework for analysis of China's renewable electricity development.

The first definition is technological leapfrogging in the context of innovation which indicates the skipping of stages of technology generations (Section 3.1.1). This type of leapfrogging applies, for example, to the adoption and use of new technologies (e.g. solar PV home systems instead electricity supply through grid connection). It also applies to rapid progress through radical innovation of products and growth of industry sectors and companies manufacturing new technologies, including rapid innovation in manufacturing processes during which some stages might be skipped and new companies become industry leaders (e.g. Lee and Kim 2001). Technological leapfrogging can also apply to urban development proceeds in a series of successive 'jumps'. This would include the use of latest building technologies and sustainable infrastructure from the outset. An example are new buildings equipped with integrated renewable energy or energy saving technologies from the beginning. On a larger scale it would include cities designed as walkable and cycle cities, supported by mainly public transport, rather than individual car based transport.

The second definition of leapfrogging (Section 3.1.2) concerns country's national socio-economic development strategies, aiming to leapfrogging ahead of other countries in terms of socio-economic development (e.g. Brezis et al. 1993). Indicators for leapfrogging based on this definition are a country's GDP and other macro socio-economic development indicators. Discussions on leapfrogging in this context are often accompanied by political rhetoric as comparisons among countries lead to competitive attitudes (e.g. Borofsky 2009a; Friedman 2009).

The third definition is "environmental leapfrogging" (Section 3.1.2), indicating that through

the use of new technologies environmental impacts compared to business-as-usual development as experienced by industrialized countries are avoided (e.g. Goldemberg 1998). Environmental leapfrogging is closely related to the notion of “tunneling through the Kuznet’s Curve” (Munasinghe 1999).

Whilst the concept of leapfrogging is relatively straightforward and easy to grasp in theory, in practice it has proven to be a very complex issue and not well defined in the literature. For this reason the literature review (Section 3.1) will first introduce and discuss the particulars of the concept and identify related issues and corresponding theoretical frameworks that need to be considered for understanding and evaluating the processes of leapfrogging.

As leapfrogging does not constitute a theory or literature in itself, two additional theoretical frameworks for analysis of the role of China’s national institutions and policy frameworks and the contribution of international cooperation through various types of transnational multi-stakeholder initiatives (also known as partnerships), to support renewable electricity developments in China, are applied. The theoretical framework of this study can be broadly located within the emerging discipline of sustainability science (Clark 2007), a broadly conceived science which draws on multi-disciplinary approaches that can include, for example, complex systems theory, innovation theory, cultural studies, political science and industrial ecology. Following the direction of this broad approach, this thesis combines different concepts and theories, each relevant for distinct parts of the research. The multi-disciplinary approach emphasises the connections between different strands of theoretical frameworks (see Fig.2).

Figure 2: Conceptual research focus and structure of the theoretical framework

The first block of additional theory reviewed deals with literature on socio-technical innovation system theories (Section 3.2). The main concepts introduced and discussed in this context are national systems of innovation (NSIs), multi-level socio-technical systems and transition management. These concepts provide a suitable theoretical framework for a systems perspective analysis of institutional structures shaping China's renewable energy system, innovation policies, actor networks, and the interplay between companies, public institutions and technology development. All these aspects are relevant for understanding China's national energy transition and the potential for leapfrogging.

Secondly, as a major theoretical discourse dealing with issues of international cooperation for sustainable development and climate protection, the literature on partnerships for sustainability as one element of global environmental governance (GEG) has been reviewed (Section 3.3). Particular foci are the concept of agency, the role of non-state actors and multi-stakeholder initiatives, particularly those that can act as enabling mechanisms for renewable energy technology cooperation. These concepts are important to add a global dimension and

understand the domestic-global nexus of China's renewable energy system development. It complements the findings about national institutional arrangements and policy frameworks and can help to explain how far external influences such as international actor networks and GEG issues support or hinder the ability of a developing country, in this case China, to leapfrog.

Other theories and concepts that could have been used for this thesis, but have not been chosen are, for example, that of socio-ecological systems (e.g. Berkes and Folke 1998). The thesis does not explicitly focus on biofuels or large scale biomass generation. For the discussion on these types of renewable energy technologies the socio-ecological systems approach would have been more significant, for instance to describe and analyse the impacts on local ecosystems through production of biofuel crops. It also does not specifically consider literature on eco-innovation. Furthermore, specific literature on technology transfer is not included.

Bringing these different stands of theory and concepts together and thereby bridging the gap between two different disciplines, one being more technically company oriented, the other being more internationally and institutionally focused, is one of the goals of this thesis. This multi-disciplinary approach can identify crucial issues relevant for accelerating renewable energy development. For China these include, on the one hand, the domestic issues within China that affect the transition towards a sustainable energy future, such as China's policy framework, existing institutions and organisations, innovative capacity of private sector companies, current status of renewable energy companies and examples of where energy transition has already occurred in China. On the other hand, the thesis aims to link and integrate these internal domestic issues with the analysis of international initiatives for climate change mitigation, technology transfer for renewable energy technology and existing partnerships. Furthermore, this research aims to add new knowledge to existing concepts and discussions, particularly relating to the concept of leapfrogging and the role of sustainability partnerships for global environmental governance. On a practical level, this multi-disciplinary framework is necessary to achieve a subsidiary goal of this thesis, which is identification of opportunities for improved collaboration

and partnerships between China and developed countries to promote development towards realisation of a renewable energy system globally.

3.1 Leapfrogging – a possible low-carbon development strategy for China?

“But is this ‘leapfrogging’, particularly by emerging economies, while theoretically possible and practically desirable, really going to happen?” (Tukker 2005)

Alternative low-carbon energy scenarios for China were briefly discussed in the introduction chapter. These scenarios would need to be realised for both China’s sustainable development and global climate stabilisation, and are based on the assumptions that fast technological transitions and even ‘leapfrogging’ in the energy sector are possible. The following section reviews the existing literature on the concept of leapfrogging and identifies several specific characteristics and three definitions of leapfrogging.

3.1.1 Technological leapfrogging in industrial innovation

The concept of leapfrogging has its origin in the context of economic growth theories and industrial-organisation innovation studies with specific focus on competition among firms. It is based on the notion of ‘gales of creative destruction’ (Schumpeter 1942). The hypothesis proposes that companies holding monopolies based on incumbent technologies have less incentive to innovate than potential rivals, and therefore they eventually lose their technological leadership role when new radical technological innovations are adopted by new firms which are ready to take the risks, and radical innovations eventually become the new technological paradigm. For example, in the specific context of research and development (R&D) in the race for patents among firms, an early study by Fudenberg et al (1983) shows how lagging companies

can, under certain conditions, such as when leading companies lack information about competitors' technological progress or when internal incentives and investment to innovate further are missing, surpass leading competitors by leaping ahead in the patent race. An example is the Japanese car industry which in the early 2000s has shown signs of leaping ahead of the US and European car industry in the development of plug-in hybrid-vehicle technologies (Maynard 2009).

Experiences from South Korean industries show that technological leapfrogging development did occur. For selected industries in Korea, the question of whether there have been cases of leapfrogging (see Fig. 3) and, if so, what the conditions for these instances were, has been analysed by Lee and Kim (2001). While not all industry sectors in Korea have been successful in catching-up, Kim and Lee conclude that leapfrogging occurred in several cases.

Based on analysis of data on market shares and technological capabilities, two cases are identified and classified as leapfrogging: path-creating catch-up in mobile phone technology, and path-skipping catch-up in D-RAM and automobile technologies. The study also shows that functioning domestic and international markets were crucial for accumulation of knowledge from the experience of production. Government had an important role in protecting the domestic market and providing export subsidies. In addition, important R&D projects and diffusion of new innovative technologies to enable leapfrogging involved both private and public capacities. Furthermore, catch-up was not solely driven by endogenous growth of knowledge and skills, but initially by collaboration with and licensing from foreign companies, underlining the importance of access to the external knowledge base through technology transfer (Lee and Kim 2001).

Figure 3: Three patterns of technological catch-up (Source: Lee and Kim 2001)³

According to Wong (1999), some firms from the late-industrialising countries Korea, Taiwan and Singapore during the 1990s opted for the difficult strategy of becoming a product technology pioneer or product innovator in the global market. In this strategy, firms sought to leapfrog others by becoming pioneers of new products through radical product technology innovation, and to establish their innovations as the dominant designs through subsequent rapid incremental innovations. Although this is actually widely regarded as the normal innovation strategy for firms from the advanced countries, it is the most difficult strategy for latecomer firms from late industrialising countries to aspire to as they need to overcome two inherent disadvantages compared to already advanced companies: distance from lead-user markets and distance from the main sources of advanced science and technological know-how.

The opportunities and examples of technological leapfrogging are also invoked in more general development literature, stressing in particular the potential of ICT application in developing countries to reduce the digital divide (Steinmueller 2001). Technological leapfrogging in the production and use of ICTs has occurred in many developing countries, one example being

³ In leapfrogging II, the two technologies C+ and D+ represent new variations of technologies C and D standing in competition with their technological predecessors.

the rapid diffusion of mobile phone technology, and Steinmueller's study supports this. The focus here is not so much on the competitiveness among companies, but the rapid adoption of ICT technologies.

Pre-conditions for successful leapfrogging for companies in developing countries include not only access to equipment and know-how, but also so-called 'absorptive capacity'⁴ of industries and enterprises to make productive use of latest ICTs. "In all cases, the problems of absorptive capacity are irreducible prerequisites for success in technological leapfrogging" (Steinmueller 2001, 206). An often stated example of successful leapfrogging in telecommunications technology is China's jumping over the stage of copper wire technology straight into the digital age of communication.

3.1.2 Leapfrogging as national development strategy and policy device

The concept of leapfrogging has subsequently also been applied not only to innovation on the company level, but also to assess economic and technological competition between countries. Brezis et al (1993) investigated the hypothesis that countries leading in technology and economic development tend to focus on incremental improvements of existing technologies and not adopt radically new technologies that might offer higher potential. By being locked in, a leader country may be surpassed by competing countries. While this does not need to happen, several conditions contribute to this kind of leapfrogging of leadership: large differences in labour costs which allow lagging countries to enter and compete in the market; the new technology initially being less productive than the established technology; experience and knowledge of the old technology being largely irrelevant to the new technology; and the new technology ultimately offering higher productivity than the incumbent technology.

Examples are the take-up of innovative cotton spinning technology by England in the 17th

⁴ The concept of 'absorptive capacity' means the ability of people or organisations to turn information into knowledge by assimilating it into existing conceptual knowledge frameworks, and thereby shaping, molding and developing existing process and ways of doing things (Cohen & Levinthal 1990).

century and the subsequent shift of the economic centre from Holland to England, or the emergence of industrial growth centres through automobile production in the US and Germany at the turn of 20th century, ending Britain's technological and economic leadership position (Soete 1985). Brezis et al (1993) also propose the hypothesis that regional or local leapfrogging is more likely to occur than national leapfrogging. The reasons are the localisation of technological innovation, industry clusters, close personal contacts and exchange of experience between personnel of geographically related firms.

In the 21st century, Israel is an example of a country which has set itself a leapfrogging strategy. The "Israel 15" Vision aims to transform Israel in to one of the top fifteen countries in terms of economic competitiveness and quality of life until 2025.⁵ As Israel is already ranked 1st in the world in R&D spending it is in a good position for a leapfrog. The country is apparently well prepared to improve the sophistication of its exports and to take 'strategic bets. According to Grinstein (2008), Countries can achieve leapfrogging by constantly improving the sophistication of their export package. This can happen by improving the quality of existing products, producing and exporting more sophisticated products, or inventing new products. For this reason, the sophistication of a country's export package affects the rate of its future economic growth. Israel will, however, have difficulty leapfrogging by only increasing the quality of existing products. In order to leapfrog Israel must invent new products. These steps require coordination and close cooperation between the government and the private sector, and 'strategic bets' on new products. Furthermore, socio-economic leapfrog requires trust and cooperation between the private and public sectors to identify absent public inputs. In countries that have succeeded in leapfrogging, the government has turned into a 'problem solving agency' (Grinstein 2008).

While these discussions on leapfrogging concern mainly technological development based on observations in western industrialised countries, the fast economic transformations of developing countries into emerging economies in Asia has spurred interest in the mechanisms

⁵ Israel 15 Vision statement: <http://www.elka.org.il/Uploads/dbsAttachedFiles/abstract.pdf>

behind the region's rapid economic growth and technological development. Rather than seeing technological and economic catch-up as following a fixed track of development but with increased speed, the idea of leapfrogging poses the idea that developing countries as latecomers to industrialisation may be able to bypass older vintages of technology. For example, Soete (1985) argued that newly industrialising countries (NICs) in Asia during the 1980s had the potential to leapfrog and to assume technological leadership in the emerging sector of microelectronics.

Hobday (1994) investigated the early success of Singapore's electronics industry, now the country's largest industrial sector. He refutes the applicability of leapfrogging in this context, for the reason that Singapore's technological capabilities in electronics were accumulated through an evolutionary process of gradual learning and cumulative competences, rather than through leapfrogging. In the semiconductor and consumer electronics industries, already established local companies entered the new sectors through rather slow diversification of their operations. The contribution of trans-national corporations in Singapore's economy was important to some degree; however, they began with 'pre-electronic' production activities and technological progress and knowledge transfer to TNC subsidiaries occurred gradually, rather than in leaps or radical jumps. This shows that simplistic notions of leapfrogging have to be challenged. The concept cannot, obviously, be applied across the board in Asian developing countries.

3.1.3 *Environmental Leapfrogging*

In the context of sustainable development for developing countries, which includes the consideration of environmental issues such as degradation of eco-systems, resource depletion or growing GHG emissions, the concept of technological leapfrogging has been extended by the concept of *environmental* leapfrogging. This definition does not so much focus on leapfrogging in terms of competitiveness and global market shares of industry sectors, but proposes an environmentally-oriented alternative to industrial development-as-catching-up measured solely by

growth of GDP. Environmental leapfrogging is considered especially relevant for emerging economies like China, India, Brazil, Mexico and South Africa, where the fastest economic growth, population increase and industrialisation appear likely to take place over the next decades.

Environmental leapfrogging is particularly important in regard to the development of energy infrastructures in developing countries. In contrast to already industrialised countries where the physical techno-economic and social-institutional infrastructures of energy generation and use are already fully developed and often locked-in, developing countries and emerging economies are currently still in the process of installing and expanding their energy generation and energy use systems, to support economic growth and to raise living standards. In the context of climate change mitigation, sustainable energy leapfrogging means that these countries would have only a limited need to replace existing carbon-intensive energy plant with clean and renewable technologies, and would essentially have the opportunity to design a sustainable energy system from the outset. The concept offers, at least in theory, the prospect that developing countries can avoid replicating the historical conventional and polluting development trajectory of the industrial West and shape their own development to meet their own needs and requirements (Goldemberg 1998).

A closely related concept is that of 'tunnelling through' the Environmental Kuznets Curve (EKC) proposed by Munasinghe (1999). The EKC seeks to relate the state of the environment to the stage of industrial development, implying that during the initial stages of industrial development less attention is paid to resource depletion, pollution levels and emissions. Only after a certain level of development is achieved, measured by per capita income levels, and societies enter a post-industrial stage where demand for environmental quality increases, are the environmental impacts caused by industrialisation addressed. In contrast, Munasinghe proposes that developing countries could learn from the experiences of industrialised nations, and restructure growth and development to address potentially irreversible environmental damages from an early stage and thereby 'tunnel' through any prospective EKC. Environmental quality

thereby does not have to get worse before it gets better and crossing safe limits or environmental thresholds can be avoided. To achieve 'tunnelling through the EKC' will require active and early employment of policies for environmental protection and sustainable growth. Examples of such measures are environmental standards and regulations, the elimination of economic imperfections such as policy distortions encouraging excessive extraction and export of natural resources and addressing market failures arising from the absence of environmental externalities in prices.

It should be noted that the use of the EKC in this context of environmental leapfrogging does not imply support of the general concept of the EKC. From a global systemic perspective which considers global value chains and trade flows, the concept has proven to be problematic. For instance, according to Rothmans (1998), the environmental improvements in industrialised countries are not the result of reduction of environmental impacts. Instead, consumer societies in industrialised countries have distanced themselves from environmental degradation from production which increasingly occurs in developing countries (Davis and Caldeira 2010). So far, industrialised countries have not achieved an 'outgrowing' of their environmental problems. Similarly, Bagliani et al. (2008), taking a consumption-based approach to the EKC using the environmental footprint indicator, have not been able to identify a de-linking between economic growth and environmental degradation.

The stylised bell-shaped graph of the EKC is commonly used to depict the concept of leapfrogging, such as by UNEP-DTIE (2006) and Berrah et al (2007) to show the development of China's energy intensity and energy efficiency potentials. Thus, although in principle the concepts of leapfrogging (focused on jumping technological generations) and tunnelling through (focused on pollution) are distinct, in practice they tend to be conflated (see Fig.4).

Figure 4: The process of ‘tunnelling through’ the EKC using strategies for sustainability
 (Sources: Munasinghe 1999; UNEP-DTIE 2006; Berrah *et al.* 2007; Japan Ministry of the Environment 2007)

Some recent research has looked more closely at the idea of environmental leapfrogging. Sauter and Watson (2008) distinguish three different types of environmental leapfrogging: leapfrogging as part of the entire development pathways of countries, leapfrogging through industrial development, and leapfrogging via the adoption and use of new technologies. Their study also emphasises the importance of a sufficient level of absorptive capacity – i.e. the ability to adopt, manage and develop new technologies – as a core condition for successful leapfrogging. The concept of absorptive capacity is complex – it includes technological capabilities (i.e. the resources for generating and managing technical change), knowledge and skills, as well as supportive institutions in terms of laws and regulation, but also informal habits and routines.

The concept of environmental leapfrogging also includes a social development dimension which should not be neglected. The diffusion and application of environmental technologies not only reduces environmental impacts, such as those from CO₂ emissions, but at the same time

can contribute to sustainable economic development and the realisation of the Millennium Development Goals (MDGs). For example, currently nearly one third of the world population still has no access to electricity and another third has only poor access. Reliance on traditional biomass fuels for cooking and heating can have a serious impact on health and the environment. There is not only a direct positive link between sustainable renewable energy technologies and climate change mitigation, but also between clean energy and health, education and gender equity outcomes (Modi *et al.* 2004, Haines *et al.* 2007)

3.1.4 From concepts to empirical observation: Is leapfrogging happening?

Just as there is debate about industry sectors in developing countries leapfrogging ahead of industrialised countries in terms of competitiveness and market shares, opinions are divided about the applicability of the concept of leapfrogging, and particularly environmental leapfrogging, in newly industrialising / developing countries. While some consider it both possible and necessary (e.g. Goldemberg 1998, 2000, Choucri 1998, Tukker 2005, see more details below), for others the concept is problematic and has attracted considerable scepticism. Empirical evidence on technological change in many developing countries tends to lend more support to the idea of slow incremental technological changes, rather than radical changes and leapfrogging (Perkins 2003, Ho 2005, Rock 2008).

For instance, Goldemberg (1998, 2000), drawing on the experiences of the Brazilian ethanol industry and modern biomass energy in rural areas, considers it feasible that populations in developing countries can skip stages of development and leapfrog to higher rungs on the energy technology ladder, or even reach new rungs that have not yet been accessed by industrialised countries. For delivering modern sustainable energy services to rural areas, past efforts have

often been ineffective and inefficient. New approaches and policies which would create and foster competitive market conditions while providing measures to protect the public interest are considered a way forward. Policies that support investment in and spur demand for sustainable technologies and energy services are particularly important. The example of the Brazilian ethanol programme, where ethanol produced from sugarcane for transportation replaces gasoline, while not without critics (Smeets *et al.* 2006), provides some evidence that leapfrogging is a possible alternative to business-as-usual development. But such cleaner energy technology leapfrogging requires strong government policies and good technological capabilities in order to achieve widespread deployment.

Choucri (1998) also supports the idea that leapfrogging in developing countries is a realistic option. The question for Choucri is not whether leapfrogging is possible or not. He considers it 'a strategic, pragmatic, and practical imperative, which focuses attention on actions to avoid "old-fashioned" technology' and, underlining the urgency of the problem, states that 'the quest for technology "leapfrogging" becomes a necessity, not a choice' (Choucri 1998, p. 43). This is also emphasised by the IEA in a study on successful examples of leapfrogging through technology transfer (IEA 2001, p.2):

Developing countries need to "leapfrog" a technological generation or two if concentrations of GHGs are to be stabilised. ...[Their] infrastructure and economies are not as dependent on fossil fuels as the industrialised countries are. They can, therefore, avoid the fossil-fuel trap and move directly to environmentally-sound technologies.

For this alternative development to take place, effective national and local institutional mechanisms to facilitate technological change and administrative capacities to foster knowledge-building are necessary. A narrow focus on technology alone is not deemed sufficient as the embeddedness of technology into the socio-institutional context implies that leapfrogging must take place in broad terms, even including policy and organisational structures (Sauter & Watson

2008). Choucri (1998) further emphasises the importance of organisational collaboration between the three sectors of scientific education and research, business and industry, and government, to increase the likelihood and robustness of leapfrogging.

Finally, on the international level the importance of technology cooperation and technology transfer for leapfrogging is salient. This is an issue many commentators and researchers seem to agree on (e.g. Choucri 1998, Goldemberg 1998, Ockwell et al. 2007, Sauter and Watson 2008, World Bank 2008). Such cooperation is more effective if it targets the latest innovations and frontier technologies, rather than outdated and polluting equipment, products and processes. Before any leapfrogging is possible in the development and manufacture of new technologies in developing latecomer countries, access to cutting-edge technologies is necessary for firms and organisations in these countries to upgrade their technological capabilities and adapt new technologies to the local context. Involvement of international organisations can also reduce the risk associated with innovation and newly developed technologies.

According to Choucri (1998), prior to the global diffusion of environmental technologies, there must first take place global diffusion of *information* on these technologies. Information exchange on technologies, knowledge networking and exchange of best practices on a global level are consequently considered the most decisive first step. He identifies three crucial and interconnected priorities:

- (a) strengthen technology capacity by reducing technology gaps and raising institutional performance;
- (b) acquire knowledge about “best technologies” as well as knowledge-networking mechanisms and processes;
- (c) maintain access to networks of knowledge as well as interactions with major knowledge and information providers.

Current development trends are not always encouraging, with environmental conditions

worsening in many developing countries and windows of opportunities closing fast (Beddoe *et al.* 2009). Nonetheless, Tukker (2005) considers that emerging economies and developing countries, in contrast to already developed countries which are locked-in in terms of infrastructure, skill sets and the symbolic meaning of practices, still have the opportunities and flexibility to encourage radical changes for sustainability. Leapfrogging will only occur if shifts in socio-technical regimes and large-scale systemic change, rather than system compliant solutions, can be made possible (see also Section 3.2). To make these changes happen, it is likely to be necessary to, first, develop foresight and indicative planning with regard to the desired direction of and approach to (sustainable) development, and second, to develop governance structures for taking the more sustainable direction, in a situation where societal or physical pressure is still relatively low.

To those sceptical of the concept, it seems that leapfrogging, especially leapfrogging leading to reductions of environmental pressures, is in most cases not occurring and many attempts to leapfrog in developing countries to date have failed. Perkins (2003) reviews existing conventional approaches and concludes that current efforts and methods are often too ambiguous, make simplistic assumptions about the technological possibilities and are characterised by incomplete understanding of the complex processes involved. For these reasons many attempts to leapfrog in developing countries have failed. Despite the shortcomings he considers leapfrogging to be an important possibility that should not be given up. Therefore, he provides suggestions to improve current approaches including more specific targets of leapfrogging, such as investment in targeted economic sectors that would make a significant contribution to leapfrogging objectives and long-term environmental goals. In addition, leapfrogging capabilities and technologies need to be supported by incentive regimes and public and private policy measures. Effective leapfrogging furthermore requires the promotion of cooperative partnerships between key actors on a national and international level. Long-term partnerships between actors in industrialised and developing countries involving R&D, development and manufacture of leapfrog technologies are especially important.

Similarly, Ho (2005) investigates leapfrogging in the context of greening of domestic industries in newly industrialising countries (NICs) in Asia. While the development of impoverished developing regions in Asia into strong and internationally competitive economies occurred over the last decades, NICs in Asia have been much less successful in terms of ecological sustainability and environmental protection. There are several structural factors at work that impede environmental leapfrogging in Asian NICs' industries: in particular, the implementation of policies that are expected to promote and facilitate environmental protection, such as decentralised, integrated, voluntary, participatory and market-based approaches may be absent in Asian NICs. The reason, Ho argues, is the nature of the Asian developmental State that makes it 'uncertain to what degree "soft" and market-based State regulation on the premises of a democratic polity would work within a newly industrialising context and a different political system' (Ho 2005, p. 213).

Furthermore, environmental technologies have mostly been developed and are owned by industries in the industrialised North, so that a substantive technology transfer from North to South would be involved to enable Asian NICs to leapfrog. An important question consequently is to what extent environmental technologies developed and owned by the North are sufficiently geared to the needs of users in the South, particularly those in the small-scale industrial sectors. This is particularly relevant for the industrial landscape in China which is dominated by small and medium-scale industries that almost always still operate on outmoded and highly polluting technologies. Another obstacle is the fact that so-called 'environmental industries' or 'green tech' enterprises are scattered, small-scale, have weak innovative capabilities, and low capital and knowledge. Therefore, the current capacity of China's environmental industries limits opportunities for the development of domestic leapfrog technologies. Ho sees the issue of environmental leapfrogging in industries as a challenge for public policy and proposes that 'the regulatory, interventionist strategies of the developmental state should make way for a more facilitative approach that allows for stronger self-regulation by industries...policy-making should

pro-actively embark on a leapfrogging development path, rather than the common, reactive approach of slow and incremental “muddling through” (Ho 2005, p. 223).

In the context of climate change, Unruh and Carrillo-Hermosilla (2006) argue that emerging economies and developing countries are unlikely to leapfrog carbon-intensive energy development. On the contrary, they argue, carbon lock-in appears to be globalising and will further constrain climate change mitigation options. Reasons for this include barriers or inertia in the institutional systems responsible for GHG emissions, which constrain apparently rational choices on the part of economic and political actors, and path-dependent processes driven by increasing returns to scale. Similar to the current status of energy development and the reductions necessary for climate stabilisation presented earlier, there seems to be a profound gap between what is required, expectations, and observed reality. According to Rock et al. (2008), in developing countries and emerging economies, socio-technical transitions towards sustainability are mostly incremental changes and improvements along existing development trajectories, and not radical innovations. It is emphasized that “it is vital to recognize sustainability transitions as hard slogs not leap frogs from one landscape and regime to the next” (2008, p.12).

In the same way, Ockwell et al. (2007) argue that the concept of leapfrogging has been widely discredited in terms of its ability to reflect the reality of processes of technological changes and learning on the firm level, which proceed in incremental changes rather than leaps. Nevertheless, regarding the idea of environmental leapfrogging in the context of low carbon technology transfer, Ockwell et al. (2007) still see potential to skip generations of technology in the application phase. In the context of low-carbon technologies such as SWH systems, and micro-generation technologies such as solar and wind, leapfrogging would essentially involve developing economies moving consciously to adopt the most advanced available low-carbon product technologies. A high degree of government engagement aimed at providing a wide range of effective policies, including incentives, to catalyse such a leapfrogging scenario, is deemed necessary.

3.2 Innovation theories and socio-technical systems

“Technology, of itself, has no power, does nothing. Only in association with human agency and social structures and organisations does technology fulfil functions.” (Geels 2002)

While technology will not be the only solution to climate change, technology will definitely be a crucial factor in the transition to sustainable future and for climate change mitigation and adaptation. While the use of current technologies can be said to be a major cause of the current disruption to the global climate system, there are also great expectations about the potential of technological innovation to help achieve reductions of CO₂ emissions. As the windows of opportunity are closing fast, radical innovation processes and fast technological changes that can enable leapfrogging towards low-carbon economic system are of particular interest. To make technology work for, rather than against, climate change mitigation, it is necessary to understand what technologies are, and how they develop, diffuse and work. As technologies are more than just tools and machines doing work, understanding needs to go beyond technical engineering knowledge and expertise to include the economic, social, cultural and institutional components of technologies.

One definition of technology that considers the relationship between technical features and social networks and institutional settings has been given by Hughes (1987) who coined the metaphor of a ‘seamless web’ in which four main elements of *physical* (technical) artifacts, *organisations* (e.g. manufacturing firms, investment banks, R&D laboratories), *scientific* elements (e.g. technical documents, books, articles), and *legislative* (institutional) artifacts (e.g. laws and policies) are combined in order to achieve functionalities. The characteristics and behaviour of a socio-technical system emerge from the interaction of these basic elements.

Berkhout (2008) takes a similar view, emphasising that to understand technological change it is necessary to analyse the institutions which give rise to technologies and determine their use, including markets, policies, norms and behaviours. Therefore, critical questions pertaining to

technical change and innovation need to consider incentive structures, power relations between actors, as well as interests and ideas within social networks.

For this thesis the interest in innovation theories and technical change lies not solely with the specific technological issues at a company level and the benefits for competitiveness and economic growth, but the means through which economic, social and institutional processes lead to new configurations of technologies within socio-technical systems, promoting sustainable development and, more specifically, a low-carbon energy infrastructure and economy. As technology is embedded within social networks and institutional settings, questions about innovation and technological transitions towards a low-carbon economy and sustainability not only concern technology researchers, engineers and product innovators, but need to concern those engaging with policies, incentive structures, and cultural norms as well as consumer behaviour, political power and corporate interests.

Currently, two main streams of literature deal with the analysis of radical innovation processes and fundamental transformations of entire economic sectors. These are the systems of innovation approach and the multi-level framework for analysing socio-technical systems. An integration of the two approaches of systems of innovation and the multi-level perspectives has been attempted by Markard and Truffer (2008) and is taken up in this thesis. The advantage of such an integrative approach is that it allows the identification of the specific characteristics of a national, regional or local system of innovation within a set boundary. At the same time, through the multi-level perspective, it becomes conceptually possible to link the innovation system to international and global trends influencing the system. The multi-level system therefore allows us to account for external actors and developments which influence a national or regional system of innovation. Therefore, the integration of approaches proves particularly useful for the investigation of linkages between local, national and global levels. Furthermore, sustainability concerns have not been a concern in the traditional innovation systems approaches. Sustainability is, however, one of the main concerns of the socio-technical system concept which is the conceptual basis for

the emerging research field of eco-innovation.

3.2.1 Systems of innovation and technological regimes

One of the main theoretical frameworks dealing with technical change and innovation is '**Systems of Innovation**,' defined as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations." (Edquist 1997, p.14). In contrast to neoclassical economic theory which regards innovation predominantly as an investment issue by rent-seeking agents, system innovation theorists follow the evolutionary economic school of the Austrian economist Joseph Schumpeter (1942), viewing innovation as the problem-solving outcome of actors strongly influenced by institutional frameworks and operating under conditions of uncertainty. Some of the major publications and milestones in the development and refinement of innovation theory building are, for example, Lundvall's theory of innovation and interactive learning (1992) and Nelson's comparative analysis of innovation systems (1993). While it is beyond the scope of this theoretical framework to go into detail about the different strands in innovation theory, it can be said that the existing framework is rather fragmented and offers a variety of definitions, conceptions and approaches describing and explaining innovation systems. Due to vagueness and the lack of rigour in describing the relations between variables, the innovation systems approach has not yet gained the status of a unified 'theory' (Edquist, 2001).

Despite this fragmentation, it has been common among many innovation scholars to adopt the '**national systems of innovation**' (NSI) approach which refers to a country's infrastructure, institutions and capacity for undertaking innovation-related activities such as R&D. This includes universities as well as networks of R&D facilities and expertise in the public and private sectors. An example is Freeman's study of the Japanese innovation system (1987) which defines an NSI as "the network of institutions in the public and private sectors whose activities and interactions

initiate, import, modify and diffuse new technologies.” (Freeman 1987). Sets of institutions which contribute to the generation, diffusion and development of new technologies include national macroeconomic regulation, financial systems, education and communication infrastructures, market conditions and social institutions. Policy plays a key role in establishing linkages between firms, R&D institutes and supporting institutions to promote innovation which can take the form of increasing absorptive capacity, increasing transfer capacity and establishing interconnections between parties (Gu and Lundvall 2006).

The concept of the nation state is central to the NSI approach and the main focus is “the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge...either located within or rooted inside the borders of a nation state” (Lundvall 1992). In the context of this thesis the NSI approach offers a suitable conceptual starting point to identify, describe and analyse aspects of China’s innovation system and how these relate to the development and diffusion of RE.

However, the NSI approach is limited due to its focus on national or regional scales. It has also been criticised for being quasi-static and focusing only on the social structure of innovation systems while neglecting the dynamics between and functions of different system elements, as well as interaction across different systems (Hekkert *et al.* 2007). Furthermore, with increasing economic globalisation, the dynamics of international business networks and cross-border technology have transformed the dynamics and factors influencing innovation.

In addition to the NSI approach, the application of the concept of the **‘technological regime’** is helpful for understanding leapfrogging potentials in developing countries. It was first defined by Nelson and Winter (1982) as the outcome of coordinated organisational and cognitive routines in innovation systems. The concept of routine was carried over from evolutionary economics and was at first applied to engineers and firms that share similar routine-based behaviour in the design and manufacturing processes. Lee and Kim define the technological regime as the “combination of technological opportunities, appropriability of innovations, cumulativeness of

technical advances, and the property of knowledge base” (2001, p. 462).

The concept of the technological regime has been further developed by the so-called 'Dutch School' of innovation theorists which includes scholars such as Arie Kemp, Boelie Elzen, Johan Schot, Rene Kemp and Frank Geels (Berkhout 2008). Kemp (1994) in particular elaborated on the concept of technological regime and Rip and Kemp (1998) widened the concept by defining it within the sociological category of rules, regulations and institutions and as taking more groups on board than the narrow focus of engineering communities:

A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures. (Rip and Kemp 1998, p.340).

By including the social and institutional aspects, the technical regime developed into the concept of socio-technical regimes (see below). While for many traditional innovation scholars the focus and main interest in innovation has mostly been the effect of innovation as a main driver of economic growth, for the scholars who developed the concept of socio-technical regimes, their research about socio-technological innovation has a major focus on sustainability – the need to respond to environmental challenges. It is therefore oriented towards path-creation with the goal of steering socio-technical regimes towards sustainability. This differentiation is relevant for this thesis as it helps to identify if innovations 'merely' achieve technological leapfrogging or environmental leapfrogging.

3.2.2 Socio-technical systems

Building on the concept of technological regime and including a systems science

perspective, innovation theorists nowadays increasingly seek to analyse the emergence and dynamics of large-scale, long-term socio-technical transformations as evolutionary processes, including technological, as well as economic, institutional and social dimensions employing multiple perspectives from economics, sociology and cognitive sciences (e.g. Nooteboom, 2006). This has led to the creation of the integrated term '**socio-technical systems**', first defined by Kemp *et al.* (2001; p. 272)

...as the grammar or rule set comprised in the complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology ...

Despite the fact that socio-technical regimes can be quite stable over long periods of time, they are constantly evolving, through internal dynamics and outside pressures. Within a socio-technical system, new and conventional technologies and practices are configured and re-configured by a range of new and existing actors, operating according to new and existing rules, interests and commitments. The advantage of the concept of the socio-technical regime is that this approach offers the potential to go analytically beyond the boundaries of industry sectors within the nation-state as prescribed by the traditional NSI approach and include practices, beliefs and institutions (Berkhout 2008)

Consistent with the requirements of a systems approach, particularly the need to analyse the interplay of different institutional and temporal scales, the evolutionary **multi-level perspective of socio-technical systems** and transitions seems to offer a suitable method to explore the structure and dynamics of innovation systems. The approach is a complement and extension to the concept of socio-technical regime and has again been developed and elaborated by the Dutch School, particularly by Kemp (1994, 1998), Rip and Kemp (1998), Geels and Kemp (2000) and Geels (2002). This integrative perspective aims to combine insights from the sociology

of technology and evolutionary economics. It tries further to capture the dynamic processes of innovation, or socio-technological transition, by setting the incumbent technology and system in relation to the emerging innovation. Thereby the focus lies not only on the initial phase of invention and innovation, but also on later stages of diffusion and societal embedding of new technologies. At the macro-level, the societal 'landscape' is shaped by deep structural factors such as macroeconomic drivers, material and spatial arrangements of cities, factories, highways, and electricity infrastructures, political culture, demography, natural environment, worldviews and paradigms. Changes on the landscape level do occur, but generally very slowly. At the meso-level of the multi-level perspective the 'regime' is located, which signifies the incumbent socio-technical system. Social norms, interests, rules and belief systems that underlie strategies of companies, organisations, and political institutions operate and compete on this level. The incubation rooms for emerging radical innovative technologies are located on the micro-level and are labeled 'niches', "discrete application domain (habitat) where actors are prepared to work with specific functionalities, accept such teething problems as higher costs, and are willing to invest in improvements of new technology and the development of new markets" (Hoogma et al. 2002, p.4).

Individual actors, e.g. SMEs, and local (business) practices are found here at the micro level, which is more fluid than the regime and variations from the mainstream and status quo develop more easily than at the regime level (see Fig. 5). Examples of such niches are organic farming practices in the agricultural sector, or specific renewable energy technologies in the energy sector. Generally speaking, technological transitions occur as the result of linkages and interactions among developments at these three levels. The central question this multi-level perspective tries to address is: under which circumstances and conditions do technological transitions emerge from the niche level and what are the particular patterns and mechanisms of the transition process?

Figure 5: Multi-level perspective of socio-technical regimes (Geels and Kemp 2000)

An important aspect of the concept is the focus on the dynamics within the system, in which constellations change constantly. Innovations which establish themselves at the micro level might in many cases not be able to make a breakthrough and change socio-technical regimes, not to speak of the landscape level. In the case of a failed regime transformation, the commonly known S-shaped innovation curve would be an inverted U-shaped curve (see Figure 6).

Figure 6: A dynamic multi-level perspective on technological transition (Geels 2002).

The role of ‘agency’, in other words the influence of social actors and their networks and the outcomes of their interdependencies, is considered to be a crucial factor in the changes and dynamics of socio-technical systems (Geels 2002). According to Smith et al. (2005) “socio-technical regimes themselves tend to be understood in terms of networks of actors and institutions clustered around the fulfilment of social and economic functions.” For the analysis of a socio-technical regime, a multitude of actors with complex and changing relationships need to be considered, including public authorities (national government, local municipalities, ministries, departments), producer networks, manufacturers, suppliers, financial institutions, insurance companies, venture capitalists, user groups, civil society groups, non-governmental organisations (NGOs) and research organisations (Figure 7).

Figure 7: The multi-actor network involved in socio-technical systems⁶ (Geels 2002)

⁶ The different sized circles in Fig 5 indicate different sizes of stakeholder groups. Note that this is only a schematic representation and does not indicate that, e.g. societal groups are less numerous or less connected than e.g. research networks.

The activities and expectations of actor groups can either create new configurations of a socio-technical regime or change the existing ones. They determine the stability, inertia or adaptive capacity of the system. There can be tensions or alignment of interest between the different groups. The interactions between actors and groups are coordinated and regulated by formal and informal institutions such as policies, technological processes, cultural and symbolic meanings and user practices and social habits. Placing the focus on the interaction, another important element in the analysis of socio-technical systems is co-evolution, a notion which is helpful in understanding interdependency between subsystems which are shaping but not determining each other. Applied to innovation the co-evolution concept is useful in understanding how technical change, and changes in actor networks and institutions occur.

The agency-based approach to understanding of regime change requires identifying what it is that delineates core regime 'members' from non-core members and outsider actors. Core members are generally influential in determining the internal configurations of a regime. However, at times when the normal functioning of the regime is under extreme stress, such as through new external pressures (e.g. climatic changes), peripheral members or even outsider actors (from the niche level or members of a different regime) may be able to intervene and transform the regime. Depending on agents' position and influence, a regime can act to facilitate or constrain agents' attempts to make changes.

Another important related concept in the context of socio-technical systems is that of **radical changes**, in contrast to **incremental changes**. The speed and effect of technological transitions is determined by the combination of radical and incremental innovations. Chris Freeman (1992) first drew attention to the difference between system compliant incremental innovations which lead to improvements in existing products and processes, and radical innovations which are disruptive interventions that yield new inventions and/or methods of production, and social

organisation. A series of radical innovations in different parts of the economy can lead to changes in socio-technological systems, for example through the adoption of a series of low carbon technologies (Stern 2006: Chapter 16).

However, changes of socio-technical regimes can only occur when a set of innovations has a pervasive effect on the whole economy. An example of this is the widespread uptake of digital information technology, which in the case of mobile phones in developing countries is also an example of leapfrogging development. Leapfrogging can be seen as a radical change, whereas system-compliant incremental improvements do not bring about leapfrogging. Only through radical changes can leapfrogging be achieved.

Unfortunately, it seems that the more radical the innovation developing in niche sectors, the greater is the uncertainty over whether it will be able to achieve diffusion and influence the regime level of the system (Berkhout 2008). Most mainstreamed innovations are incremental changes and directed to improving existing socio-technical arrangements and thereby supporting the regime. Incremental technical change occurs slowly, mostly through learning by doing (Brezis et al. 1993).

Radical innovations, in contrast, can lead to reconfigurations at the regime level. However, such reconfigurations do not occur easily, because the elements, actors and institutions in a socio-technical configuration are linked and aligned to each other. Radically new technologies are often faced with difficulties in diffusion, as this requires organisational, managerial and social innovation. Therefore established technologies are not easily replaced by radically new technologies, because the former are stabilised by their linkages to other elements (Geels 2002).

This has been termed (Freeman and Perez 1988) as a 'mis-match' between new technologies and the established socio-institutional framework, such as user preferences, consumer attitudes, organisational routines, supply chains and legislative environments. Radically new energy technologies face these difficulties because the inertia of established socio-technical configurations prevents their wide diffusion. In the words of Bashmakov (2007): 'While

overcoming “limits to growth”, one faces “limits of change”: social and economic inertia in the evolution of decision-making and behavioural patterns, as well as in replacing technologies and physical infra-structure.’

The S-shaped innovation curve introduced above (see Fig. 6) has been elaborated and complemented by Tukker (2005) in the context of radical and incremental changes. Incremental innovations can only offer system optimisation and system redesign (see Fig. 8). System redesign would certainly achieve major improvements in efficiency and reduction of environmental impacts. Cumulative system redesign over a number of technologies would eventually add up to system innovation. However, given the limited timeframe still available to achieve sustainable development and provide basic needs for an increasing global population, system innovation is required, which can only be achieved through radical changes going beyond system compliant improvements. Making a link to the concept of leapfrogging, only major system innovation could be considered leapfrogging in development, and, conversely, major systemic innovation might only be possible through leapfrogging, whereas system optimisation would not qualify and system redesign only partly.

Figure 8: System optimisation, redesign and innovation (after Tukker 2005)

The concept is also applicable in the context of developing countries and emerging economies. Tukker (2005) applies a multi-level system innovation model to distinguish stabilising and destabilising factors of the innovation and diffusion processes in emerging economies. Stabilising factors which in the case of systemic changes impede radical changes and transformation include existing worldviews, policy relations and geo-political realities on the macro level. On the meso (regimes) level, sunk material investments in, for example, infrastructure, and sunk immaterial investments in education, skills and routines act as stabilisers. Destabilising factors can, in contrast, facilitate faster systemic changes. These include, for example, the availability of disruptive technology development and innovation in niche sectors, sudden events such as economic crises changing the global landscape or gradual changes in worldviews and cultures.

The multi-level perspective on socio-technical systems can be and has been successfully applied to analyse the diffusion of renewable energy technologies. For instance, Jacobsson and Johnson (1998) apply a technology specific approach focusing on the competition between

different technological systems to analyse the diffusion process of renewable energy from Sweden and Germany. Consistent with the concept they identify three main elements of a technological system that are most relevant for the diffusion process:

1. The actors and their competence (particularly important are the “prime movers”).
2. The networks through which technological knowledge (tacit and explicit) is transferred.
3. The institutions (hard/legislation and soft/culture) which affect the specific path of technological development.

Furthermore, technical change in the two countries is considered endogenous to the economic system and requires inducement mechanisms. Reasons for this could be that technical innovations, such as renewables, often go against the perceived interest of dominant actors who try obstructing technical change. Taking examples of the diffusion of renewable energy from Sweden and Germany, it is argued that technical change towards sustainable energy requires strategic policy decisions and a period of ‘nurturing’ before it achieves a price/performance ratio that make it competitive in the market.

Similarly, Tsoutsos and Stamboulis (2004) apply the concepts of technological regime shift and radical change to identify a range of current barriers to the mass diffusion of renewable energy technology. To overcome these barriers, a strategic niche market approach to facilitate a faster transition is proposed. This involves creating conditions for interactive learning, providing an integrated approach to supply and demand, and linking technological development with institutional and organisational changes.

3.2.3 Transition management

Building on the multi-level approach of innovations in socio-technical systems, the

concept of 'transition management' as a multi-level model of governance for regime change is an element of discussions on pathways towards sustainable development. The concept of transition management has evolved from discussions about the linkages between institutions and technological innovation for sustainability. It is "a multi-level model of governance which shapes processes of co-evolution using visions, transition experiences and cycles of learning and adaptation" (Kemp et al. 2007). Other characteristics of this cooperative approach are emphasis on shared responsibility for processes, open agendas, network building, and government support and promotion. Transition management has been applied specifically in the context of the Dutch energy system and the transition to a low-carbon energy sector (Rotmans et al. 2001).

With a focus on embedded networks of actors, sustainable technology transitions can be understood as the changes mediated by the resources, interests and expectations of these actors. In transition management a special role is given not only to the actors belonging to a regime, but also to external social actors from beyond the existing regime. The regime transformation is guided principally by negotiation between these external actors with actors inside the regime, and by both in articulating pressure for change, and in providing the resources, capabilities and networks that condition the responses. While non-state actors of civil society and the business community have a special role in transition management, the coordination of the change has in the past often required robust intervention by states (Smith et al. 2005).

If a regime is largely identical with a national system of innovation, there is also an important role for foreign actors, such as companies and NGOs, to contribute towards regime change. Transition management is a framework that involves a significantly greater role for the State than is evident in liberal market economies such as those of, for example, the United States, Australia or New Zealand. Although the framework originated from the social-democratic European context, it fits well with the political governance structures evident in China and many developing countries. This makes the approach relevant for this thesis.

Being closely related to the multi-level system approach, transition management of socio-technical systems takes account of the interaction and processes between three levels (Kemp et al. 2007):

1. strategic (macro) level: processes of vision development, strategic discussions, long-term goal formulation
2. tactical (meso) level: processes of agenda building, negotiating, networking, coalition building
3. operational (micro) level: processes of experimenting, project building, implementation.

Furthermore, the concept of transition management can be used at different organisational aggregation levels, such as companies, sectors, countries and regions. In terms of social, economic and political organisation three levels are distinguished (Rothmans et al. 2001):

1. macro level (conglomerates of institutions and organisations such as nations and federations of states, some multinationals, United Nations)
2. meso level (networks, communities and organisations)
3. micro level (individual actors such as companies, environmental NGOs).

Considering the temporal sequential dimensions of transitions, four different transition ideal phases in modern transition processes are distinguished (see Fig. 9). These include:

- A pre-development phase of dynamic equilibrium where the status quo does not visibly change.
- A take-off phase where the process of change gets under way because the state of the system begins to shift.
- An acceleration phase where visible structural changes take place through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other. During the acceleration phase, there are collective learning processes, diffusion and embedding processes.
- A stabilisation phase where the speed of socio-technical change decreases and a new dynamic equilibrium is reached. A new socio-technical paradigm is established.

Figure 9: The four phases of socio-technical transitions (after Rotmans *et al.*, 2001)

Smith *et al* (2005) map two different contexts for transition based on two dimensions of change. The first dimension measures whether change is envisaged, intended and actively coordinated, for example through some higher level or top-down governance processes. Transition of the second dimension is the self-emergent outcome of the co-evolutionary behaviour of regime members involving only low levels of coordination through new macro-level steering mechanisms and institutions (Fig. 10).

Figure 10: Transition contexts as a function of degree of coordination to selection pressures and the locus of adaptive resources (Smith et al., 2005).

One of the main questions that have concerned many innovation theorists, and which is also of crucial importance for a transition management towards a sustainable energy infrastructure, is the issue of order, **lock-in and path dependence**⁷ in socio-technical change, or, in other words, why things tend to remain the same, rather than change. As technological innovations become more mature, certain procedures become standardised and the innovation becomes mainstreamed. As this leads to a more ordered and consolidated system, the dynamic of change and uncertainties are being reduced. At the same time forward momentum is being slowed down and inertia can set in. Once a technological paradigm has been established, it becomes very influential in determining problem solving patterns. This limits the possibilities of new learning and what is perceived as possible (Nelson and Winter 1977, Dosi 1988).

Furthermore, from an economic perspective, increasing returns to scale strengthen the technological paradigm. The focus of innovators and firms operating within the paradigm can become increasingly efficient in the way they are working with established technologies. While

⁷ Path dependency is also a key concept in institutional economics. The concept is useful to understand the problem of inflexible or inefficient institutions and economies. It explains why sub-optimal patterns of economic activity that produce stagnation persist. According to North (2001) "institutional path dependence exists because of the network externalities, economies of scope, and complementarities that exist within a given institutional matrix." This means that individuals and organisations that economically benefit from the given institutional and economic framework have a crucial interest in perpetuating the existing system.

this brings down technology costs, it can often lead to technological 'lock-in' and competing different and novel technologies that are not established are easily neglected or even excluded, even if they might be superior to the existing technologies.

A famous example of path dependency and technological lock-in is the QWERTY keyboard, still used in the digital age even though more user-friendly options are available. A less 'visible' factor behind path-dependency in technical change is related to cognitive aspects of the innovation process. Economic agents are characterized by bounded rationality, i.e. their behaviour is governed not by full optimization over the complete set of control variables, but by the process of trial-and-error, some search heuristics (embedded in the institutionalised routines of an organization), or optimization over a subset of control variables in a limited domain (Sanditov 2005).

The transition management approach has so far been used mainly in the context of developed countries, particularly the Netherlands, where it offers a promising approach for guiding systemic change towards sustainability, not only for the energy sector. Part of the aim of this research study is to find out whether the concept is useful to understand transitions and leapfrogging development in developing countries and emerging economies, in this case China, with a particular focus on transition of the energy system from one that is carbon-intensive towards one which is clean and sustainable. Of specific interest is whether the four transition phases can be observed in China's renewable electricity development. Furthermore, the thesis will give attention to the relationship between macro-level steering mechanisms and emergent transformations on niche levels.

3.3 Global environmental governance: partnerships for sustainability and technology cooperation

While there are already a number of strategic (international political) partnerships dealing with climate change – and specifically with developing country emissions – it is not clear whether they

will be able to achieve the enormous task of tackling these emissions in a manner consistent with global environmental and domestic developmental objectives. (Müller, Robinson and Zhang 2010)

In addition to innovation system theories and related concepts described above, as additional theoretical background for this thesis the theoretical field of global environmental governance (GEG) are considered. There are several reasons for this choice. First of all, in the literature referring to the concept of leapfrogging it has frequently been stated (e.g. by Choucri 1998, Goldemberg 1998, Ockwell et al. 2007, Sauter and Watson 2008, World Bank 2008) that international technology cooperation and assistance to developing countries are required to achieve leapfrogging.

Furthermore, from the perspective of innovation studies, particularly the approaches of socio-technical systems and eco-innovation, the interlinkages between the different stages of globalised value chains and levels need to be considered. Finally, accelerating national 'indigenous innovation' will likely not be sufficient to achieve leapfrogging in developing countries, given the relatively short time frame still available for decarbonisation of energy systems, and not appropriate given the global public good nature of low-carbon technologies. At the time of writing, public-private technology cooperation, like collaborative R&D programmes, between developed and developing countries and companies is weak and insufficient. Identifying and explaining the dynamics at a global system level requires taking into account cooperation between industrialised and developed countries and partnerships between various stakeholder groups.

GEG is a major emerging research field focusing on human-environment relations. It can be defined as “the sum of organisations, policy instruments, financing mechanisms, rules, procedures and norms that regulate the processes of global environmental protection” (Najam, Papa and Taiyab 2006). A particular focus is placed on institutions such as multilateral environmental agreements (MEAs), e.g. the UNFCCC and Kyoto Protocol in the case of climate change, and international organisations such as the United Nations Environment Programme

(UNEP). One important focus of GEG is the role of partnerships for sustainability and the emergence of new types of agency and of actors in addition to national governments and inter-governmental organisations, is of particular interest and relevance for this research thesis. These new types of actors exercising 'agency' are, among others, foremost the private sector and civil society environmental organisations (Najam, Papa and Taiyab 2006).

In the following section the emergence and phenomenon of the 'partnership paradigm' will be discussed in more detail, and the potential role of partnerships in facilitating renewable energy technology transfer as important factor supporting leapfrogging in China will be outlined.

3.3.1 The partnership paradigm

In the absence of a centralised global institution, such as a World Environment Organisation, equipped with the authority to implement effective action to address global environmental challenges, or an effective globally binding climate regime, multi-stakeholder partnerships of non-state actors are considered by many to be a vital new element in, and new form of governance for global sustainability – their contribution is important to operationalising GEG. Due to their voluntary, unrestricted, and implementation-oriented design, partnerships allow for various actors to operate around and with one another and are expected to continue to play an important role in GEG in the future (Mert 2010).

Particularly as traditional forms of cooperation such as bilateral agreements or MEAs, e.g. a global climate treaty, are becoming increasingly complex, they are being complemented by new types of initiatives and partnerships. These new forms of cooperation are also increasingly employed within a strategy of addressing cross-cutting issues of energy security, climate change mitigation and technology transfer.

In the literature one finds several terms that are often used synonymously, such as 'global partnerships', 'multi-stakeholder initiatives', 'independent cooperation networks' (Sugiyama and Ohshita 2006). The United Nations Commission on Sustainable Development (UN CSD) defines

such partnerships as “voluntary, multi-stakeholder initiatives aimed at implementing sustainable development goals of Agenda 21, Rio+5, and the Johannesburg Plan of Implementation”.

At a political level, the UN Conference on Environment and Development held in Rio de Janeiro in 1992 called for the creation of new forms of cooperation between states and social organisations. Partnerships were further promoted with the goal to increase NGO and business participation, in particular at the 2002 Johannesburg World Summit on Sustainable Development, where they became known as ‘Type II outcomes’ of the summit, complementing the traditional outcomes of the intergovernmental diplomatic process.

There are several reasons why partnerships are considered to be an important new development in governance. One is the assumption that multi-stakeholder partnerships as an innovative form of governance can address deficits and gaps of conventional inter-state politics. As partnerships can work around political sensitivities, since actors are not representing governments, they are not as easily sidetracked by political issues which often impede bilateral programmes (Sugiyama and Ohshita 2006). Partnerships are also said to have the potential to fill the so-called ‘participation gap’ by drawing in and bringing together non-state key actors from different levels who would otherwise not be able to participate in formal decision-making structures. This form of governance of transnational issues can provide direct access for marginalised stakeholders (for example women or indigenous people) to decision-making on transnational environmental issues (Andonova and Levy 2003; Martens 2007).

Networked structures have perceived advantages over hierarchical organisations in their ability to disseminate information, share knowledge and be less open to manipulation of information. According to Andonova and Levy (2003) “the greater the complexity and contestation of information and the greater the need to tap into local or specialized knowledge, the larger will be the comparative advantage of transnational networks over hierarchical institutions.” The various participants in multi-stakeholder partnerships are said to have different motivations for their engagement. While NGOs and civil society advocacy organisations have cautioned against

using the concept of Type II outcomes to deflect attention from the need to achieve progress on Type I intergovernmental agreements, they have nevertheless taken a proactive position. Partnerships offer a comparative advantage in the transnational governance process, enhance the resources of that process and provide a greater ability to influence the agenda and structure of partnership institutions (Andonova and Levy 2003).

Partnerships are thus being proposed as a new mode of global climate governance, a sub-aspect of GEG, but one of high importance, which has emerged in recent years in addition to the existing multilateral framework of the UNFCCC. The emerging climate partnerships are often situated within the nexus between international and bilateral climate diplomacy and the global carbon market (Bäckstrand 2008). The involvement of local actors, such as municipal governments working to implement climate protection at the local level, has been described by Betsill and Bulkeley (2005).

In the literature a range of **different partnership types** has been identified. However, as with defining the concept, creating a comprehensive typology of partnerships is problematic, because of the extreme variety of forms and shapes that these partnerships take (Creech and Paas 2008). The complexity of partnerships between individuals and organisations is increased by their dependence on the institutional landscape through which they are formed. New types of partnerships continue to evolve in accordance with complex and fast changing institutional surroundings. Identifying types of partnerships is nevertheless helpful to gain an overview. According to Martens (2007) and Bäckstrand (2008), multi-stakeholder partnerships for environmental and climate governance can, in principle, be divided according to several categories or functions as summarised below:

Categories of multi-stakeholder partnerships (after Martens 2007, and Bäckstrand 2008):

- **Influencing political and civil discourse (“advocacy”)**

- **Adopting international norms, regulations and standards (“standard setting”)**
- **Mobilising private and public finances (“financing”)**
- **Technical cooperation and service provision (“implementation”)**
- **Coordinating state and non-state activities in a particular sector (“coordination”)**

One type of partnership relevant for this research is that of R&D partnerships where institutions join together with the primary purpose of innovation of sustainable goods and services. Another important form of partnership is the public-private partnerships (PPP) which can take the form of a contract between a private sector entity and a government. In the context of PPPs the private partner receives a payment from the public sector and assumes the financial and administrative responsibilities to deliver the desired services. The public sector partner has the role to regulate and monitor the performance of the partnership. How the risks are spread between these partners is often contentious.

The **role of the private sector** in partnerships more generally has been identified as both an opportunity and a risk (Falkner 2003). On the one hand, the private sector has been motivated to participate in partnerships for private environmental governance by the opportunity for public and civil society support of innovative sustainable niche products or services which would otherwise be uncompetitive in the short run. Partnerships for the diffusion of renewable energy technologies in non-electrified poor regions of the world are an example. Partnership initiatives involving the private sector, e.g. for renewable energy, can potentially also help to increase UN institutions’ room to manoeuvre. However, corporations and their networks frequently lobby states during negotiations on MEAs, featuring prominently in the implementation of international accords. Strategies of corporate networks can hinder progress at the intergovernmental level, such as in UNFCCC negotiations. According to Falkner (2003) another risk of private environmental governance is that it strengthens the predominant liberal economic paradigm and promotes a

model of environmental governance based on market-mechanisms and global self-regulation that benefits the interests of powerful companies. For this thesis the role of private sector cooperation for renewable electricity technology transfer, innovation and capacity building is relevant.

In a number of areas of environmental governance the emergence of partnerships, or so-called global public policy networks, has been noted (Najam, Papa and Taiyab 2006). These networks are non-hierarchical, multi-stakeholder initiatives that bring together governments, international organizations, corporations, and civil society. The emergence of this mode of environmental governance is concerned with adaptive and pluralistic modes of decentralised action through involvement of multiple stakeholders. It have resulted from the realization that civil society on the one hand and the private sector on the other have important roles to play, alongside government.

However, neither NGOs nor the private sector are realistically substitutes for government action. They cannot replace government regulations, but they play an important role as catalysts and innovators. Martens (2007) sees the boom in multistakeholder partnerships as a sign of a crisis of purely intergovernmental diplomacy. There are also dangers inherent in the partnership paradigm, for example, the power of democratically legitimate public institutions can be weakened and potentially undermined through partnerships that may represent the interests of powerful business lobbies.

Caplan (2003) warns against the formation of partnerships for the sake of partnering. Partnerships cannot be seen as the main objective of development and environmental protection projects; rather, they should be seen as “a serious tool in the tool box”.

Taking the UN CSD database on partnerships (a basic inventory of registered partnerships based on self-reporting) as a starting point, Biermann *et al.* (2008) conducted a large-n analysis of partnerships regarding three governance gaps or deficits (regulatory, implementation and participation) that are repeatedly mentioned in the literature on multi-stakeholder partnerships and which partnerships are expected to address. The analysis shows partnerships so far fail to fill the

regulatory deficit as indicated by the large number of partnerships that exist in already strongly government-regulated areas such as water, energy or resource management. Furthermore, there currently exists a contradiction between the tasks of addressing the implementation gap and addressing the participation gap at the same time and to the same degree, for the reason that through the broadest possible participation the chances of effective implementation can be hampered by partners with opposing interests. Biermann et al (2007, p. 256) conclude that “the majority of partnerships strengthen the participation of those actors that already participate: governments, major international organizations and those civil society actors that have had a say in global governance already before the partnership phenomenon emerged. The balance of evidence suggests that those that have been marginalized before have also been marginalized in the partnership process.”

In the case of China, Chan, Lee and Chan (2008) explore the interplay between the domestic and the international side of China's environmental governance and show that China's participation in GEG is increasing. Although China is at this stage not setting the agenda for environmental governance issues, and so far takes a passive role complying with MEAs, efforts for GEG have had an impacts on China's domestic environmental governance structures and institutional development. Also, the partnership approach has become adopted by China and an increasing number of Chinese actors are beginning to take part in international partnerships (Chan 2009).

A large proportion of partnerships for sustainable development registered under the Commission for Sustainable Development are active in China, which also reflects the priority that the UN attaches to partnerships in China. At the same time, the emergence of partnerships in China has experienced constraints in different ways. Although China does not constitute an enabling environment for partnerships, the high number of partnerships for sustainable development active in China poses a paradox which can be explained by the observation that many partnerships have been adopted to suit the Chinese context. According to Chan (2009)

partnerships in China still often only have an experimental character; they are short term and have a limited topical scope. The general institutional landscape and regulatory environment is not conducive to partnerships, and in particular, partnerships including NGOs still meet with a number of impediments.

3.3.2 Partnerships for renewable energy technology collaboration

Of specific interest for this thesis are partnerships and networks promoting clean energy collaboration, particularly facilitating renewable energy technology transfer for developing countries. It has been noted many times that in order to support China and other developing countries to realise diffusion of clean energy technologies, with the goals of providing energy security, climate change mitigation and environmental sustainability, up-scaling strategic approaches for renewable and other low-carbon clean energy technology transfers will be crucial (e.g. Martinot et al., 1997; Metz et al., 2000; IPCC, 2007; Tomlinson et al., 2008).

Different “generations” of technology transfer mechanisms from the North to the South, including bilateral aid programmes between governments and MEAs such as Rio Declaration, Agenda 21 and the Kyoto Protocol have developed over recent decades. According to many observers these mechanisms have so far shown only limited levels of success. Technology transfer has in the past mainly been the domain of inter-company transfer and international official development assistance programmes of governments; multi-stakeholder partnerships for sustainable energy have only been emerging in recent years.

The need for technology transfer partnerships has not only been emphasised by the academic research community, but also in several MEAs, such as the Rio Declaration and Agenda 21. Principle 9 of the Rio Declaration on Environment and Development⁸ specifically addresses technology transfer: "States should cooperate to strengthen endogenous capacity-

⁸ Rio Declaration on Environment and Development:
<http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163>

building for sustainable development ... through exchanges of scientific and technological knowledge, and by enhancing the development, adaptation, diffusion and transfer of technologies."

Technology transfer has also been identified as a significant potential instrument for poverty reduction, sustainable development and climate change mitigation. Article 4.5 of the United Nations Framework Convention on Climate Change (UNFCCC) advises developed country Parties and other developed Parties included in Annex II to take "all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties".

Current multilateral agreements, and most important here are the UN Framework Convention on Climate Change and the Kyoto Protocol, do include provisions for transfer of technology to developing countries, in the case of the Kyoto Protocol through the Clean Development Mechanism (CDM). The CDM has a pioneering role in global climate governance as it is an example of the contemporary rise of network-like governance arrangements in the climate domain. It involves a multiplicity of international public and private actors, and balances between governmental steering and business self-regulation, multilateral institutions and local project practices. It is currently the most important vehicle for technology cooperation. However, it has so far shown only limited success as it has neither greatly accelerated the diffusion of low-carbon technologies in developing countries, nor has it increased participation of marginalised stakeholders such as local communities (Lövbrand et al. 2009). Its reputation has also been dogged by mismanagement that is partly a result of structural complexity.

The transfer and development of climate friendly technology is also a major concern for the Asian context. The current status of technology transfer and cooperation under multilateral agreements is deemed insufficient to meet the future challenges (IGES 2006). The need to find

innovative ways to facilitate technology development and transfer in a post-2012 climate regime is considered to be especially relevant. Concerns of Asian stakeholders over the current international and domestic regimes are numerous and range from limited collaborative R&D and slow pace of transfer of 'hard' technologies, lack of sufficient technology transfer under the current Kyoto Mechanisms, rigidity of the international intellectual property rights system, high costs and capital intensity of renewable energy technology, limitation of domestic and international fund availability and lack of domestic incentive mechanisms and enabling environments (IGES 2006).

Consequently, important questions concern the role of other forms of cooperation, e.g. multi-stakeholder partnerships, in contributing to the existing cooperation mechanisms and complementing existing provisions under multilateral agreements for climate mitigation in developing countries. Several commentators emphasise the constructive role of partnerships. For instance Justus and Philibert (2005) argue that international energy collaboration partnerships can help to improve the environmental performance of energy technologies by increasing momentum, sharing risks, exchanging knowledge and resources, sharing learning investments and harmonising standards. In addition to bilateral and multilateral approaches, particularly public-private partnerships have become a popular mechanism to accelerate technology innovation, because they leverage and channel public research funds to areas with expected high returns. The involvement of the private sector is considered important as the expertise and the extensive technical, financial and managerial resources of the private sector are required. In terms of more specific partnership design features for energy technology cooperation, public-private partnerships and other different types of partnerships and institutions need to be involved for successful collaboration.

Likewise, the Asia Pacific Energy Research Centre (APEREC 2008) sees international energy initiatives, "the process through which problems in energy-related areas that can be addressed through international cooperation are identified, respective goals are established, and appropriate mechanisms to achieve such goals are implemented", as important mechanism and

proposes six areas for cooperation: (1) infrastructure development; (2) financial mechanisms; (3) regulatory framework; (4) research and development; (5) information sharing, and (6) education and capacity building. Of these six cooperation areas only the first one entails the transfer of hardware whilst the others are related to 'soft' issues of institutional development and governance. Similarly, Ott (2008) identifies several kinds of possible energy partnerships and pinpoints three main areas of collaboration. These are joint RD&D and exchange of experiences, funding and diffusion of renewable and clean energy technologies, and cooperation for common standards and incentives.

The Expert Group on Technology Transfer, established in 2001 under the UNFCCC, also notes that an important cross-cutting element of technology transfer, alongside transfer of 'hardware', is capacity building (UNFCCC 2007a). So far, most of the formal approaches to capacity-building under the UNFCCC have tended to emphasise actions by governments and large donors, especially around innovation and development of technology. According to Forsyth (2005) other ways in which non-state actors can support capacity building and implement technology diffusion have not gained enough attention. Multi-stakeholder partnerships between investors, SMEs, local governments and local communities could potentially help technology transfer, capacity building and increase in trust.

Similarly, Sugiyama and Ohshita (2006) suggest that multi-stakeholder partnerships and independent international networks for energy collaboration can leverage expertise by forming partnerships across countries and organisations, which can include government agencies, industry, financial institutions, research institutions and non-profit organizations. An advantage over conventional bilateral cooperation is that partnerships are not representing governments; therefore they can work around political sensitivities. For example, non-state actors involved in parallel initiatives, or so-called 'track II' negotiations, to the technology transfer discussions under the UNFCCC process can by-pass the stalemate of official climate change negotiations.

3.3.3 Clean energy partnerships and China

Clean energy and low-carbon technology partnerships with China are attracting increasing interest. In the absence of a global climate agreement and technology transfer mechanisms apart from the above-mentioned CDM, many researchers and think tanks are spending increased efforts in designing and developing cooperation models which aim to increase the effectiveness and speed of diffusion of low-carbon technologies, most importantly renewable energy technologies. Prestin *et al.* (2010) examined recent or ongoing projects from 2005-2010 in China related to sustainable low carbon development by ten EU member states plus the European Commission. These projects fall into a range of categories (as shown in Fig. 11). The results show that over 50% of the grants provided for projects have been aimed at improving energy efficiency in industry. The next largest cooperation area concerns developing renewables, with a strong focus on solar PV and wind energy. Technology transfer has received almost no attention so far.

Figure 11: Relevant 'recent and ongoing' project grants in China from the European Union and EU member states (source: Prestin *et al.* 2010)

The reality of the current partnership focus stands in contrast to what many researchers

require to be a necessity. Fan et al. (2009) argue that international technology transfer would not only support the deployment of low-carbon technologies, but would also enhance the domestic innovation environment of China. To overcome the shortcomings of current cooperation mechanisms such as the CDM they propose 'Inter-country Joint Mitigation Plans' (ICPs). The central idea underpinning the ICP would be to broaden the channels, extent and stakeholder involvement of international cooperation. An ICP approach would also ensure technology transfer and finance from industrialised countries to China and other developing countries.

An ICP between China as host country and an industrialised country would include a national emission reduction plan with voluntary quantified targets, which could be aimed at specific sectors or projects, for example, building smarter electricity grids or developing infrastructure for electrical vehicles. Partner countries would support the projects through joint implementation. An ICP would not only establish emission targets, but also specify the technology and investment required to meet the targets. ICPs would also hold significant commercial opportunities for partner countries and companies because they can access the market of mitigation technologies in China while the ICP would ensure that the international rules on intellectual property rights are observed.

Although an ICP would potentially be very effective and support low-carbon development in China, Fan et al. (2010) also acknowledge that managing and operating an ICP would be complex and require the existence of adequate institutional capacity at the national level in host and partner countries, as well as at the international level through an institution established to assess the ICP proposals, support and coordinate negotiation, and supervise and assess the ICP implementation. Furthermore, the existence of an international fund, set up and operated by a multilateral agency to support the ICP process would be required. To make the concept of ICPs operational further research is needed on detailed implementation and management of ICPs, and to address issues such as sharing of costs and revenue and taxing of rent by governments.

A similar approach is explored by Müller, Robinson and Zhang (2010), who have assessed

the potential for addressing developing country emissions at scale through bilateral so-called Joint Commitment Framework Agreements (JCFAs). Under a JCFA the involvement of private sector actors through PPPs would play a major role. Strengthened government to government agreements could be used to reinforce the importance of IPR protection and encourage joint ventures. New innovations will require a range of different public and private actors to work together; in practice, this might not eventuate in the absence of government to government partnership. It is argued, for example, that under a Sino-European JCFA, European companies would be more likely to collaborate with Chinese enterprises, to transfer and jointly develop low carbon technologies and know-how. Given China's current priorities for the development of wind power, it is argued that opportunities for large-scale Sino-European collaboration exist, specifically for collaboration between European and Chinese enterprises in the areas related to wind park development, transmission extension and system operations.

One main purpose for such a partnership approach would be to provide assurance to the relevant private sector companies that the governments involved are fully committed to the scheme at the envisaged scale. This would reduce risks and also help to solve the difficult issue of IPRs and licensing. Müller, Robinson and Zhang (2010) propose to establish a 'Protect and Share' agreement under which government-to-government commitments to 'protect and share' low carbon technologies and encourage joint-ventures and public-private partnerships are given. This idea centres on addressing the twin needs for strengthened IPR protection for patent-holders on the one side, which are not necessarily only OECD-based companies, and the need for developing countries to access critical and much needed low-carbon technologies on the other. The IPR issue could also be solved through the introduction and enforcement of "use it or lose it agreements", whereby if the patent holder does not bring a technology to market and be willing to license it voluntarily, it can be forced to license a third party to prevent strategically withholding key technologies. However, potential enforcement fishhooks in such an arrangement remain to be explored.

Similarly, Smith-Gillespie (2010) explores EU-China models for low-carbon energy technology cooperation. As in other proposals described above it is argued that cooperation on low-carbon technology can yield a number of win-win opportunities – rather than being a zero-sum game. Smith-Gillespie identifies three areas of potential cooperation – innovation, market introduction, and market development. Any kind of EU-China cooperation partnership needs to take into account different sets of stakeholders, each with different interests and ways of working, as well as cultural and organisational differences that can pose practical challenges to collaboration. Innovation-focused cooperation opportunities are considered to be of particular importance as they accelerate the domestic development and commercialisation of new technologies.

To facilitate cooperation in the area of innovation, Smith-Gillespie notes that some Chinese technologies are already at similar levels of maturity in China as they are with global leaders. In this situation, there could be a common interest in joint development and cooperation to overcome financial and technical barriers to technology development and deployment. The key to this potential win-win situation may be to accelerate technologies towards commercialisation through joint R&D and co-investment in early stage technologies which would involve a degree of government support as well as private sector participation. Mutually beneficial cooperation continues to lie in initiatives aiming to overcome technical barriers to deployment. In innovation areas where China lags significantly behind, the key opportunity for cooperation may lie in facilitating China's access to this technology through market introduction by means of technology imports, licensing, foreign direct investment in local manufacturing facilities (either in the form of joint ventures or wholly-owned) and building domestic capabilities through technical support from foreign manufacturing equipment and component vendors. These proposed cooperation activities certainly are not new approaches, which might be an indication that many cooperation potentials have not been explored sufficiently in recent years.

Smith-Gillespie (2010) argues that the acquisition of low carbon technologies is only one of

several factors impacting the speed and scale of development and deployment of low-carbon technologies in China. A wide range of other challenges include the quality of the electricity grid, testing and certification of equipment or market risks due to lack of end-user awareness. Addressing these challenges would require adequate resources, strong institutions, and targeted policies and regulations – all potential areas for international cooperation and partnerships.

3.4 Summary literature review and research objectives

The literature review on the concept of leapfrogging highlights some important issues that have not attracted sufficient attention in the literature. First, there is no conceptual clarity about leapfrogging. The literature indicates that there are different types of leapfrogging, such as technological leapfrogging, leapfrogging as national development strategies and environmental leapfrogging, but the conditions under which certain types of leapfrogging occur are not yet systematically studied. According to the literature, environmental leapfrogging can be achieved through application of new environmental technologies to avoid the ‘classical’ resource and pollution intensive stages of development. Second, so far no thorough studies exist, except perhaps in the case of Brazil, on how leapfrogging in the energy sector through low-carbon technologies in developing countries can be achieved. There is a lack of empirical studies to identify the conditions under which leapfrogging has occurred or can be facilitated in the future.

The review of the different theories on system innovation, the first block of theory to underpin the leapfrogging concept, provides useful insight for understanding of leapfrogging. Important perspectives from the innovation theories which are applied for this thesis include the proposition that socio-technical regimes of transformation have both technological and social components which cannot be considered independently, but only as a coupled system. Other important concepts include the notion of the innovation curve, and the differentiation of macro (landscape), meso (regime) and micro (niche) levels of change necessary for leapfrogging.

Furthermore, the understanding of the role of national policies and institutions in innovation theory is important to support understanding of the conditions for leapfrogging. An understanding of which types of policies would develop and increase a country's domestic 'absorptive capacity' and companies' innovation skills is particularly relevant. Finally, the notion of agency and actor networks is relevant to understanding regime changes and sustainability transitions.

The notion of agency also links to the second block of theory – global environmental governance (GEG). The texts on leapfrogging emphasise the need for strong international cooperation and even support through technology transfer as an important factor to facilitate leapfrogging in developing countries. However, the exact type and nature of such cooperation are not specified. For this reason this thesis draws on the insights of GEG. The role of agency in GEG emphasises the emergence and need for partnerships and international cooperation initiatives involving multiple stakeholder including the private sector and civil society.

Renewable energy partnerships are a relatively new phenomenon in international cooperation for development and environmental protection and are concerned with finding the 'right' institutional arrangements and mechanisms for effective technology cooperation to facilitate renewable energy diffusion in developing countries.

Clean energy related partnerships and technology cooperation with China are of special importance for this thesis. In respect of China, the existing recent literature is mostly concerned with proposing a range of mechanisms and innovative approaches which still await concrete implementation (and subsequent assessment) in one way or another.

The hypothesis of this thesis is that leapfrogging, which has occurred in other cases such as Brazil's ethanol industry and in China's uptake of mobile telephony technology, is a possible development pathway and strategy for China. To achieve leapfrogging in the electricity sector, domestic policy will be the most relevant factor driving innovation and investment, supported by international partnerships and collaboration.

Therefore, the specific objective of this PhD research thesis is to answer the following

question:

- *In which areas of China's electricity sector development pathway is leapfrogging already occurring, what are the factors either contributing to it or impeding current and future leapfrogging developments and what is the relationship of national innovation systems, energy policy and international partnerships in forging this unique pathway?*

In the remainder of this thesis the developments of China's renewable electricity will be assessed and discussed within the framework of the innovation system-related concepts. Based on the innovation curve concept and the multi-level system thinking several areas for leapfrogging in China will be identified. Furthermore, the concepts of multi-level perspective and multi-actor networks will be applied to identify and distinguish leapfrogging developments on micro, meso and macro levels as well as the role and influence of different stakeholder groups in the transition processes. Furthermore, the NSI concept will be relevant for assessing the innovation of Chinese renewable electricity companies. The differentiation between radical and incremental changes will assist the assessment whether renewable energy developments in China are merely contributing to system optimisation or setting the path for complete system innovation of the energy sector. Furthermore, of special interest for the thesis is the interplay between China's domestic policy frameworks, industrial innovation and international cooperation programmes and their potential contribution to leapfrogging. To the role of existing partnerships, particularly those that support policy development and increase innovation capacity in China, the conceptual frameworks of GEG and relevant concepts are employed.

4. Renewable energy development in China

4.1 Five priority areas for China's renewable energy development

In the introduction chapter several studies and technology scenarios (e.g. McElroy et al. 2009; Greenpeace & EREC 2007) were mentioned, according to which a fast transition of China's energy sector to one that is predominantly based on renewable energy is a possible future. These studies argue that, from a theoretical modeling perspective, fast development of China's energy system through renewable energy technology is a future that is viable both technologically and economically.

In this chapter five main areas relevant for China's renewable electricity development are described, discussed and analysed in view of finding evidence for leapfrogging potentials. The five sectors are renewable energy in rural areas, innovation of renewable energy companies, renewable energy on city level, large-scale technology deployment and use and renewable energy in the context of China's overall energy development strategy.

The first area of renewable electricity in rural areas deals with installation of relatively low-tech renewable energy systems such as biogas household digesters, high-efficiency cooking stoves and solar PV home systems, which have occurred relatively early on in China. It is also the sector in which international cooperation in the form of development aid projects played an important role to first introduce renewable energy technology prototypes to China.

The second area for renewable energy development concerns companies. In this thesis it is discussed how a number Chinese companies have emerged in a very short time to become leading manufacturers of renewable energy equipment and significantly increased quality of their products in a relatively short period of time and gained important domestic market shares.

The third area is that of localised developments at city level. The focus here is on city level initiatives, particularly looking at cities and districts which are being designed from scratch. The results show that in the context of renewable energy in cities a real case can be made for

leapfrogging 'from rural village to eco-city', something that other countries have not done on this scale. The issue of vehicle electrification systems is also considered in this context.

The fourth area is large-scale deployment and use of new renewable electricity technologies such as wind, solar PV, or modern biomass, helping (in principle) the 'classical' resource and pollution intensive stages of electricity generation dominated by coal-fired power stations to be leapfrogged. This will require the establishment of new energy paradigm or, following the terminology of the socio-technical systems approach, a new energy "landscape".

The fifth area discussed in this thesis is the overall development of China's national renewable energy sector in comparison to other country's energy sectors and China's potential to establish itself as global leader in renewable, leapfrogging ahead of industrialised countries.

For the first three sectors particularly renewable electricity technology development as an emerging niche sector has been investigated. Sectors four and five require a wider integrated systems approach and macro level perspective, taking also into consideration issues like smart grid developments and political issues such as competition between countries.

Whilst this thesis focuses primarily on renewable electricity technologies, also considered are some non-electrical renewable energy technologies such as solar water heating, rural biogas as well as issues relating to vehicle electrification in cities. There is a strong connection between these technologies and renewable energy use (for example, solar water heating is a direct alternative to electrical water heating). These are key challenges to be tackled for the achievement of a low-carbon energy system in the long term.

In the detailed description and conceptual classification of these different sectors micro, meso and macro levels are distinguished, drawing on the multi-level socio-technical systems perspectives as introduced in the literature review (see section 3.2.2). The related concepts of niches, regimes and landscape are likewise used. Taking a systems perspective, not only technology innovation issues are considered, but so also are socio-economic and institutional

issues. For visual presentation the graphical presentation of the innovation curve and transition phases (e.g. Rotmans *et al.* 2001; Geels 2002; Tukker 2005) are used. The arrangement of the five sectors along the innovation curve implies a schematic development sequence where one sector indicates a stage or phase. It does, however, not imply that one phase has to be completed before the next one can begin. Generally speaking, the sectors at the beginning of the curve would experience renewable energy developments before the more advanced stages, but are not necessarily prerequisites for the following stages.

In China one can observe development of renewables in all of these five sectors at present, and none of them is yet completed. Nonetheless, renewables development in rural areas has been happening for a number of years, whereas renewables at city level and large-scale application are more recent phenomena (see Figure 12).

Figure 12: Priority areas of renewable energy development (source: author's assessment)

The sectors and transition stages of renewable energy development can also be visually and conceptually presented differently, using the concept of leapfrogging or the 'tunneling through' curve as introduced in the theoretical framework (section 3.1.3). In this presentation the departure

from the BAU development path of western industrialised countries begins with the use of renewable energy technologies to reduce fuel poverty and address rural development needs differently, in this case through off-grid renewable energy systems. The successful environmental leapfrog would be completed with renewable energy as a new energy paradigm, potentially before developed countries have completed the transition (see Fig. 13).

Figure 13: Priority areas for renewable electricity from the ‘tunneling through’ perspective
(source: author’s assessment)

Based on the outcomes of the research it can be argued that China’s renewable energy transition is already happening in a number of areas; however, the establishment of a new national energy paradigm based on renewable energy to significantly reduce environmental impacts through power generation constitutes the main challenge for the future, therefore environmental leapfrogging through renewable energy replacing conventional fossil fuel sources has not yet happened (see Chapter 10 for detailed discussion on research results).

4.2 China's renewable energy targets, policies and institutional framework conditions

The introduction (section 1.2) gave an overview of the current situation of China's renewable energy development. The following section will provide an overview and comparison of China's energy and renewable energy targets. It will also introduce and discuss the policy frameworks which have enabled the recent development of renewables from 2005 until end of 2010 and policy targets for the period to 2015 and 2020.

Table 1: China's energy supply mix (cumulative capacity and annual outputs) 2010 and estimates for 2015 and 2020⁹

	2010	2015	2020
Coal (billion tonnes)	1.8	2.7	3.4
Oil (megatonnes)	405	500	563
Gas (billion cu m)	89	260	300
Power capacity(GW)	874 (2009)	1350	1600
Electricity output (TWh)	4206.5	5400	6500
Coal, Oil, Gas capacity (GW)	652	900	1000
Coal, Oil, Gas output (TWh)	3000	4100	4600
Hydro capacity (GW)	196	250	320
Hydro output	721	780	1000

⁹ Data from Neng Yuan Ping Lun (2010), BP (2011), US Eenergy Information Administration and nextbigfuture.com (<http://nextbigfuture.com/2010/07/china-energy-mix-now-2015-and-2020.html>), citing various online sources citing China's National Energy Plans, including Shen and Chen (2010), WWEA (2010)

(TWh)			
Wind capacity (GW)	45	90	150
Wind output (TWh)	44	140	250
Nuclear power capacity (GW)	9	39	86
Nuclear power output (TWh)	73.9	280	580

According to China's *State Renewable Energy Medium- and Long-Term Development Programme*¹⁰, China plans to have renewable energy (including large hydro power) account for 15 percent of total energy consumption by 2020. While these figures and targets demonstrate an enormous and unprecedented growth rate, from a macro-perspective taking into consideration the growth rates in conventional fossil fuel based generation capacity, one can, however, not speak of leapfrogging development via technology adoption and use generally. At the end of 2009, overall energy generation capacity grew by more than 10 percent and reached a total of 874 GW, by 2020 the total energy generation capacity will be in the order of 1600-1700 GW (Neng Yuan Ping Lun 2010).

From a macro-level perspective fossil fuel-based generation is not being replaced by renewables, but renewables are instead complementary. From an environmental perspective the planned expansion of renewables is still not sufficient to achieve a significant reduction of emissions reductions, i.e. it is not sufficient to allow the absolute level of fossil fuel use to fall, reducing climate change impacts.

The renewable energy development targets certainly show elements of system re-design, but these are not yet sufficient to achieve a systemic radical change and wholesale system

¹⁰ *Ke Zai Sheng Neng Yuan Zhong Chang Qi Fa Zhan Gui Hua* (可再生能源中长期发展规划), (http://www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/t20070904_157352.htm). This programme will be discussed in more detail in 4.2

innovation departing from BAU development. After only five years of intensive renewable energy development in China, it might, however, be too early to make a final assessment of whether leapfrogging in energy sector technology as a whole can be achieved. The following section introduces and discusses relevant policies and institutional frameworks to identify which elements have been particularly relevant for the renewable energy development from the time 2005 to 2010 and shortcomings of regulations that would need to be addressed to achieve, or even surpass, the targets set for 2015 and 2020.

4.3 National renewable energy policy and institutional energy governance framework

China's power sector is not fully market-oriented and investment and operational decisions are highly influenced by central and provincial government policy. A multitude of different government agencies are the main actors shaping the transition pathway of China's energy system. Therefore, understanding of policy frameworks and decision making processes is highly important to make sense of China's renewable energy developments. The following subsection discusses China's main policy frameworks and analyses their effects in facilitating development of renewable energy. In addition to policies, this section will also discuss relevant institutional actors shaping the development of China's renewable energy leapfrogging and transition towards a sustainable energy system. The roles of relevant central government agencies and other stakeholders such as power sector companies and the State Grid Corporation are discussed. The issue of re-establishing a Ministry of Energy as a likely future institutional development will also be mentioned.

Overall, the country's uptake and fast diffusion of renewable energy technologies and development of a domestic market have grown significantly as a result of three major macro-level development plans and legislative frameworks: The 11th Five-Year Plan (2006 to 2010), the

Renewable Energy Law of 2005 and the Medium- and Long-Term Development Plan for Renewable Energy of 2007. In addition to these macro-level policy frameworks for renewable energy development, more than 20 other support policies and supportive administrative regulations were issued by the National People's Congress, State Council, NDRC, Ministry of Finance, State Electricity Regulatory Commission and other agencies since the introduction of the renewable energy Law (Zhao *et al.* 2010). These specific regulations have proven to be important for the effective implementation and realisation of the goals and targets set in macro-level development plans. While it is beyond the scope of this thesis to discuss all these regulations in detail, the most relevant are listed and described below (see Table 2).

Table 2: Overview of major plans, legislation and regulations for renewable energy development
(source: author's assessment based on various sources)

Policy	Date / period	Issued by	Main points
11 th Five-Year Plan (on energy and renewable energy development)	2006-2010 (energy development plan April 2007) (RE plan March 2008)	NDRC	10 GW wind power by 2010 (updated target)
Renewable Energy Law (and amendment to the renewable energy Law)	2005 (December 2009)	National People's Congress (NPC)	Introduction of: 1. 'cost-sharing scheme' 2. feed-in-tariff scheme 3. 'mandatory grid-connection system scheme' 4. national renewable energy targets Amendments: clarification of FIT and mandatory grid connection regulation
Medium- and Long-Term Development Plan for Renewable Energy	2007 – 2010/20	NDRC	National target of 10 percent renewable energy by 2010 and 15 percent renewable energy by 2020; six priority areas of RE; mandated market share (MMS) of 3% non-hydro renewable energy for power companies

4.3.1 China's National Five-Year Development Plans

China's key macro-economic growth strategies are outlined in the National Five-Year Plans,

the overarching policy guiding frameworks for the country's development. Renewable energy was included in both the 10th and 11th Five-Year Plans (2001–2005 and 2006–2010). The Plans essentially set targets and specific outcomes to be achieved for the five-year period, and additionally propose long-term objectives for the next 15 years. While the overall general Plans set the framework and are published at the beginning of each five-year period, additional sub-plans with more specific details, in this case on renewable energy, are published subsequently to facilitate implementation of the goals. They can also entail readjustments and refinements to the initial Plan.

Under the **11th Five-Year Plan for Energy Development**¹¹, published in April 2007, renewable energy (including large hydro) was expected to be equal to 2.7 billion tonnes standard coal equivalent by 2010. Most of this was achieved through large hydro power installations. New renewables without hydro power were still mentioned only marginally in the context of the overall energy development strategy. According to the Plan, renewable energy was expected to 'develop greatly' and increase its share of final primary energy consumption to 0.4 percent by 2010, compared to only 0.1 percent of 2005 levels. While the target entails a fourfold increase of renewable energy, in comparison to primary consumption of other energy sources such as coal, 66.1 percent of primary energy in 2005 and 63.0 percent in 2010, and oil, 20.5 percent in 2005 and 20 percent in 2010, renewable energy would, according to this Plan, still only play a marginal role in China's total primary energy consumption.

In another additional planning document issued in March 2008, the **11th Five Year Plan for Renewable Energy Development**¹², new renewables were addressed specifically. Within the one year since the publishing of the general plan for energy development, the target for

¹¹ Neng yuan fa zhan 'shi yi wu' gui hua (能源发展“十一五”规划) Chinese text: http://news.xinhuanet.com/fortune/2007-04/11/content_5960916.htm

¹² Ke zai sheng neng yuan fa zhan 'shi yi wu' gui hua (可再生能源发展“十一五”规划) http://www.sdpc.gov.cn/zcfb/zcfbtz/2008tongzhi/t20080318_198262.htm

renewable energy was raised quite significantly to 10% of electricity output (including large hydro) by 2010, equal to about 300 million tonnes standard coal equivalent (about 8,792 PJ). This increase in the target shows that Chinese policymakers had underestimated the speed of renewable energy development. According to the updated Plan, China would reach a total wind power production capacity level of 10 GW by 2010, which was again greatly surpassed by a factor of four. The building of about 30 large wind power plants and five wind power bases with 1 GW capacity each was also part of the plan.

Regarding solar energy, the Plan aimed for China to have SWH installed capacity reach 150 million square meters and solar PV capacity 300 MW by 2010. Furthermore, an increase in the production of biomass energy and increase in the supply of electricity from the burning of municipal solid waste and agricultural waste was laid out.

As discussed above, the target of 10 GW wind power production capacity for 2010 was already surpassed in early 2009, another strong sign that the market development of the renewable energy sector is faster than policy development. Furthermore, the additional details of the renewable energy Five-year Plan and the discussion of a wide range of obstacles that still need to be addressed, shows a new concern of high-level policymakers for renewable energy development. It can also be read as a sign of the increase in importance the government places on renewable energy development at this time. One important question regarding the targets set out under the plans is why they seem to be lower than what could be expected. The targets for renewable energy have so far been rather cautious and conservative. The actual numbers of renewable energy development achieved for the 10th Five Year Plan period were higher than outlined in the Plan; 100 GW hydro power, 1.2 GW wind power, 5.3 MW solar PV set in 2000 were all surpassed by 2005. The actual installed capacity was 110 GW hydro power, 1.26 GW wind power, and 7 MW solar PV. Regarding the 11th Five-year Plan, as mentioned above, at the end of 2009 the installed capacity of wind power with 26 GW installed capacity was significantly higher than the target initially set for 2010. The targets for the other types of renewable energy

are also expected to be higher than the targets set by the 11th Five-year Plan. There could be several reasons why the Plan's figures are lower than the achieved outcomes, such as pressure from actors with vested interests to not set targets too high. Furthermore, officials might be cautious in setting too ambitious targets, given that, if they did not achieve the targets, there might be political consequences.

From the perspective of leapfrogging as policy device, the Plans seem to have set the right framework conditions, but in terms of concrete targets, the numbers they have so far established have not been ambitious enough. To enable further leapfrogging, the coming targets under the 12th Five-year Plan would need to set much more ambitious goals for new renewable energy installations.

4.3.2 China's Renewable Energy Law

In 2006, as a first institutional response to the requirement of the 11th Five-year Plan to 'promote and support renewable energy production and consumption through favorable fiscal policies, tax structures, investment policies and a compulsory market share', a major political process to promote clean and efficient electricity in the transformation of China's energy sector was launched. The passing of the Renewable Energy Law¹³ on February 28th 2005 and its implementation on January 1st 2006 is an important institutional milestone. The renewable energy Law was designed as an overarching framework to 'promote the development and utilization of renewable energy, improve the energy structure, diversify energy supplies, safeguard energy security, protect the environment, and realize the sustainable development of the economy and society' (Article 1). It established a full set of legal structures and policy steps, and provided the legislative and policy framework for improvement of renewable energy development as well as a range of guidelines and regulations, some of which are further described in the following paragraphs.

¹³ Zhong hua ren min gong he guo ke zai sheng neng yuan fa (中华人民共和国可再生能源法) Chinese version: http://news.xinhuanet.com/energy/2008-06/18/content_8392646.htm

Four main schemes or provisions to guide renewable energy development in China are the cornerstones of the Renewable Energy Law. First is the “cost-sharing scheme” which requires that the additional cost of renewable energy generation, determined by the difference between the costs to the grid utilities of renewable energy and conventional electricity, is to be passed on in the electricity retail price and to be shared by all grid and end-users of electricity nationwide. It was initially averaged as a surcharge to users set by the government as 0.002 CNY (US cent 0.03) per kWh (in November 2009 the surcharge was re-set at 0.004 CNY per kWh¹⁴).

Second, and complementarily, the “feed-in tariff scheme” (FIT) requires that a fixed amount (differentiated according to each renewable energy technology) be added to the price for all renewable energy generation connected to the grid. Third, the “mandatory grid-connection system scheme” requires grid companies to purchase all electricity generated from renewable energy. Grid operators have the obligation to enter into agreements with licensed power generators, connect renewable energy to the grid and purchase generated electricity. Finally, the “national target system scheme” sets the 10 percent and 15 percent renewable energy targets for 2010 and 2020, respectively. The targets are linked to resource survey and development plans for renewable energy and have the goal of informing national action planning and furthering action towards mid- to long- term targets (see REN21 2009a).

In addition to these four main schemes, other economic incentives mentioned in the Renewable Energy Law include the establishment of a “Renewable Energy Development Fund” from the government budget to support scientific and technical research. Furthermore, financial institutions are encouraged to offer preferential loans for renewable energy development. Regarding legal responsibilities for authorities breaching regulations, the renewable energy Law stipulates penalties for violators (Beijing Review 2005, Ma and He 2008). The current surcharge for electricity consumers is 0.004CNY/KWh(USD \$0.00062/KWh). In 2010 between 10 – 11 billion

¹⁴ Guo Jia Fa Zhan Gai Ge Wei Guan Yu Tiao Zheng Hua Dong Dian Wang Dian Jia De Tong Zhi (国家发展改革委关于调整华东电网电价的通知) http://www.sdpc.gov.cn/zcfb/zcfbtz/2009tz/t20091120_314524.htm

CNY (USD \$1.56 – 1.72 billion) were collected in renewable energy surcharges nationwide, about 1-2 billion CNY (USD \$156.70 – 313.40 million) short of the total that had to be paid out for the government financed renewable energy projects, subsidy programmes and FITs.¹⁵

Many new energies, including wind and biomass power generation enjoy the renewable energy subsidies, solar power only accounts for a small proportion of the total. If the domestic solar market were to take off, then the deficit between revenues generated through the surcharge and expenditures for FITs, will increase. The government is therefore likely to increase the renewable energy surcharge to 0.008 CNY, possibly as early as 2012, in order to fill the funding gap and push forward development of the renewable energy market.¹⁶

Despite its innovative character and important role in stimulating diffusion of renewable energy in China, several limitations of the Renewable Energy Law have emerged since the first year of its implementation in 2006. Firstly, there has been criticism that the renewable energy Law is not facilitating development of renewable sources fast enough to meet demand, and new and creative solutions are needed to meet this challenge. The main difficulty in proper implementation of the Renewable Energy Law concerns inadequate pricing mechanisms, especially relating to transmission services and feed-in tariffs. Many details regarding pricing mechanisms remained very general and unspecified in the Law, leaving room for prices to be reset based upon a number of parameters. The FIT was at this stage only enforced directly for biomass power, whereas for wind and solar PV power a regional feed-in tariff system was applied based on a bidding price that varies by location (REN21 2009a).

Regarding the provision for grid connection, the law has so far failed to ensure that all renewable energy developments are grid connected. About 20%-30% of all wind farms built are currently not connected to the grid, so that grid electricity generation capacity is significantly less

¹⁵ Guo ji xin neng yuan wang 'zheng fu li tui guan fu fa zhan' (国际新能源网 '政府力推光伏发展') <http://newenergy.in-en.com/html/newenergy-14021402171120822.html>

¹⁶ Personal communication with Chris Lin, Tianwei Solar, Beijing, February 2011.

than installed capacity. This may also arise due to technical requirements, such as higher voltage needed for the grid, and the need for better grid power management. The Renewable Energy Law did not set a qualitative standard for grid strength, stating only that the grid companies will pay for 'all other transmission connection components', without any timeframe specified over which grid enhancements should be made by the grid company. This suggests that without further specification, existing 'bottlenecks' may not be overcome, preventing dispatch of electricity from renewable energy in some cases. Furthermore, the lack of communication between the government, the two national grid companies, power suppliers and wind farm developers will continue to hamper grid connection.

To address the shortcomings of the Renewable Energy Law, a draft amendment was submitted in August 2008. Under the draft amendment it was suggested that a government Fund for Renewable Energy Development aiming to support the industry and strengthen governmental macro-economic regulation would be financed by the surcharge on retail power tariffs, along with a contribution from the Ministry of Finance. The initial surcharge generated about 4.5 billion CNY (USD658.86 million) in the first year 2007 for power grid companies. However, since this surcharge was considered as revenue, grid companies had to pay about one-third of it as value-added and income taxes. Under the draft amendment from 2008, power grid companies will now receive all of the revenue generated from the surcharge, which would provide strong incentives to the grid companies who were working at a loss (REN21 2009a).

The State Council subsequently adopted the **Amendment to the Renewable Energy Law**¹⁷ on 27 December 2009 and the new law was enacted on April 1st 2010. The amendments do not alter the underlying policy goals of the original law; they do add additional detail to the existing framework to improve implementation of the law's underlying goals. In particular, the amended

¹⁷ Quan guo ren dai biao da hui chang wu wei yuan hui guan yu xiu gai "zhong hua ren min gong he guo ke zai sheng neng yuan fa" de jue ding (全国人民代表大会常务委员会关于修改《中华人民共和国可再生能源法》的决定) Available online at: http://www.npc.gov.cn/huiyi/cwh/1112/2009-12/26/content_1533217.htm

law addresses the existing difficulties of implementing the 'mandatory grid-connection system scheme' and dispatch of electricity generated from renewable energy technologies. The amendments are aimed at addressing the 'bottleneck' grid connection problem by creating a legal framework that requires grid companies to invest in expanding and strengthening their facilities. The amended law again emphasises the requirement of power companies and grid companies to purchase electricity produced by renewable energy generators. Power enterprises refusing to buy power produced by renewable energy generators can now be fined up to double the amount of the economic loss of the renewable energy company operating wind power or solar PV plants. The amendments and new requirements also state that grid companies need to meet a new type of target – a minimum proportion of the overall power they buy must be renewable energy power. This essentially provides for a system similar to the Renewable Portfolio Standards as used in the United States (Finamore 2010).

One other very important amendment to the Renewable Energy Law is how grid companies are compensated when purchasing renewable energy, basically addressing and clarifying the 'feed-in tariff scheme', which was covered by the old law but has so far not been successfully implemented due to lack of clarity on the relationships between enterprises. Following the recommendations made in 2008, the amendments lay out the details for establishing a Renewable Energy Development Fund. The surcharges will be pooled in this fund and the grid companies will seek reimbursement from the fund for the additional cost of purchasing electricity from renewable energy generators – including the costs associated with grid integration. Even after the amendments, of the main problems with the Renewable Energy Development Fund, administered by the State Grid Corporation, is that the use of the revenues generated is not transparent.

The changes also allow more national oversight of the preparation of sub-national

renewable energy development and utilization plans, and allow the government to invest in various renewable energy development projects, including R&D. The amendments clearly illustrate that China is serious with its renewable energy development plans and is working on overcoming some the barriers that have stood in the way of achieving this goal (Finamore 2010).

Furthermore, institutional responsibilities of government agencies are further clarified through the amendments. The energy supervision department of the State Council is to work with national electric power supervision organisations and the financial department to set the proportion of renewable power generation in total electric power generation, based on the national renewable energy development and utilization plans, and make detailed rules on the acquisition of renewable power (China CSR 2009).

Although the amendments have introduced important specifications and improvement to the 2006 Renewable Energy Law, according to experts more detailed implementing rules are anticipated. They will possibly include those relating to priority dispatch and full off-take of electricity generated from renewables, the operation and transparent management of the renewable energy development fund, and the national technology standards for the interconnection of renewable energy (Schulberg 2010).

4.3.3 Medium- and Long-Term Development Plan for Renewable Energy

Another important policy framework complementary to the Renewable Energy Law is the *Medium- and Long-Term Development Plan for Renewable Energy* from 2007. It emphasises the 10 percent and 15 percent national renewable energy targets for 2010 and 2020, respectively. More specifically, the Plan outlines six priority areas to be developed: hydropower, bioenergy, wind power, solar power, other renewables and renewables for rural development. Regarding total installed wind power capacity, under the development plan it was initially in 2007 mandated to reach 5 GW by 2010. The target was updated and increased to 10 GW in 2008 (although

actual capacity had already reached 12 GW by the end of 2008) and 30 GW in 2020. This wind energy target can be said to be the main aspect of the Plan.

Other technology specific targets under the Plan include an increase of installed capacity of hydropower which is supposed to reach 190 GW by 2010. Large and medium sized hydro power will account for 140 GW and small hydro for 50 GW. By 2020 installed hydro power capacity is planned to reach 300 GW, of which 225 GW is estimated to be medium and large scale, and 75 GW small hydro. The target for biomass is to have a total installed capacity of biomass power generation of 5.5 GW by 2010 and 30 GW by 2020. For solar PV, the target is to reach 300 MW by 2010 and 1.8 GW by 2020. For SWH the target is to have a total collector area of 150 million square meters by 2010; by 2020, the total collector area of SWH will reach about 300 million square meters. Under other renewable energies, geothermal heat pumps are emphasised. Through geothermal developments energy savings in the magnitude of 4 million tonnes of coal by 2010 and 12 million tonnes by 2020 are targeted. Interestingly, the plan also includes the construction of a 100 MW tidal power station by 2020.

In order to achieve the objectives and targets laid out, the Plan also describes a range of policies and measures that are to be adopted to support the development of renewables. Market mechanisms are considered to be important and the establishment of sustainable and stable market demand will be attempted through favorable price policies, mandated market share (MMS) policies, government investment, government concession programs, and other measures. The MMS policies, similar to Renewable Portfolio Standard (RPS) targets in other countries, state that in areas covered by large-scale power grids, the non-hydro renewables share of total generation has to reach 1 percent by 2010 and has to exceed 3 percent by 2020. Power generators with a self-owned installed capacity of over 5 GW are required to have a non-hydro renewables share of 3 percent by 2010 and more than 8 percent by 2020. This part of the Plan is, according to many experts, the most relevant and most frequently mentioned aspect of the Plan, implying that it will have a significant impact on renewable energy development (e.g. Liu and Kokko 2010).

Furthermore, for improvement of the market environment of renewable energy the Plan emphasises the grid connectivity responsibility of purchasing electricity from renewables, as already stated in the Renewable Energy Law. Through power tariffs and cost-sharing policies the renewable energy price policy system should be improved. To increase the fiscal support and tax incentives for renewables, a renewable energy fund is supposed to be established. The development and deployment of renewable energy technologies are to be supported through preferential tax policies and R&D for renewable energy technologies and equipment manufacturing through appropriate favourable tax policies for relevant enterprises.

Lastly, to accelerate technology improvement, innovation and industry development, the Plan stipulates that renewable energy technology should be included in the national scientific and technological development plans and high-tech programmes with that the relevant companies become technologically independent and have domestic innovation capabilities. By 2010 a basic system of renewable energy technologies and industry are to be established, so that equipment capabilities are based mainly on domestic manufacturing. By 2020, a relatively complete renewable energy technology and industry system will have been established, so that a domestic manufacturing capability, based mainly on China's own IPRs, will exist. This last section of the Plan is not only relevant for the application and adoption of renewable energy in China, but more importantly for the development of innovation capacity of companies.

4.3.4 Institutional framework of China's energy system

According to many observers of China's energy system transition, not only the specific policies, but the complete institutional framework and organisational structure of China's energy administration needs to be considered to assess the potential for achieving a fast transition in the energy system through adoption and use of renewable energy. The institutional framework is crucial to ensure the effective implementation of policies, foremost the implementation of the

Renewable Energy Law.

After the dissolution of the previous Ministry of Energy in 1993, China's energy institutions have undergone a series of restructurings. The institutional landscape at the time of writing is characterised by decentralised authority and multiple administrative departments among individual line ministries responsible for policies within their specific sectors. The capacity of China's national energy institutions overseeing the implementation of energy laws, energy sector reform processes and regulating electricity markets is still limited and institutions dealing with energy issues are said to be understaffed, with only about 750 individuals within the central government whose responsibilities in some way relate to energy policy (Cunningham 2007).

Policy making, supervision, and regulation of the sector do not appear to match the challenges it faces. Furthermore, the energy institutions are only loosely coordinated and lack communication among each other. Therefore, the enforcement of laws and regulations introduced above is deficient compared with countries that have smaller and less complex energy sectors (Cunningham 2007, Berrah et al 2007).

According to Wagner (2010), there are currently 57 institutions which in some way or another have influence on energy policymaking. Due to the complexity of the institutional framework, it is difficult even for experts to fully understand the exact roles and responsibilities of different institutions. The following section will describe the roles, functions and relationships of those institutions which can be considered most important for renewable energy policy making and enforcement (see Fig. 14).

Figure 14: Relationships and structure of selected institutions relevant for China's energy policy-making (after Rommeney 2008; Wagner 2010)

(*National Leading Working Group on Addressing Climate Change, Energy Saving, and Emission Reduction)

All institutions are under supervision of the State Council. Among the ministries and commissions, the **National Development and Reform Commission (NDRC)**, established in 2003, is considered one of the most relevant government institutions, particularly in all issues concerning economic development, which includes the reform and transition of the energy system. Of the 28 departments within the NDRC four have roles in energy policy management, namely the Policy Study Office, Development Planning, Resource Conservation and Environmental Protection, and the State Energy Bureau (SERN & REEEP 2010). Particularly the State Energy Bureau was initially responsible for most of the decisions relating to energy development.

In March 2008, as a result of the 11th National People's Congress (NPC), an institutional restructuring plan was carried out which reduced responsibilities, authority and influence of NDRC on energy policy making. Despite these institutional changes, NDRC and its related agencies are still the main energy institutions, also in terms of international energy cooperation programmes.

Most importantly, NDRC hosts the CDM National Designated Authority (DNA). Furthermore, the Energy Research Institute, China's national energy policy think tank, and the Department of Climate Change are directly under NDRC.

One of the main changes in the institutional framework in 2008 was the creation of the **National Energy Agency (NEA)**¹⁸. The NEA should initially have been an independent body taking the function of a Ministry of Energy. China's energy management was transferred from the NDRC's National Energy Leading Group to the NEA. However, because NDRC did not want to give up the control over the energy sector completely, NEA is still under the supervision and control of NDRC. Creating this regulatory agency is seen as a step toward further reforming State Council organs while strengthening management of the country's energy sector by setting up a unified national energy management regime. The NEA took up its duties in September 2008 with nine departments and 112 staff members. The NEA's major responsibilities include overseeing the oil, gas, coal and electric power industries. It also drafts industrial policies, supervises energy market developments, and manages the renewable energy industry. Regarding the important issue of energy prices, these will be proposed by NEA and submitted to the NDRC which continues to have the final say on energy price adjustments (Li 2008).

According to many commentators and observes consulted in the context of this research, the NEA will only be an interim solution, setting the foundation to evolve into a fully fledged Ministry of Energy in the years to come. Furthermore, regarding renewable energy development, the NEA will focus on developing the Inner Mongolia autonomous region, Gansu and Jiangsu provinces to become the sites of the country's first wind power clusters, designed with an electrical capacity of 10 GW each (as described in section 8.2). According to foreign wind energy developers, who have now to deal with the NEA in all matters concerning wind farm development, the new agency still requires more capabilities to effectively guide the wind energy sector. The

¹⁸ Guo Jia Neng Yuan Ju (国家能源局), in English sometimes also referred to as National Energy Bureau

responsible staff apparently often lack necessary basic understanding of wind energy to be able to effectively solve the current problems of the sector and scale-up the diffusion of wind energy technology.¹⁹

When discussing the role of the NEA, it is also helpful to at the same time discuss the role of the **State Grid Corporation**, (*Guo Jia Dian Wang*) the national body responsible for operation of the national electricity grid. As one of China's most influential state-owned enterprises, the relationship between the NEA, which is leading the country's renewable energy development strategy, and the State Grid is extremely relevant for the issue of grid integration or renewable energy – and characterised by increasing tension.²⁰ According to many observers of China's renewable energy development, these two bodies should be cooperating very closely, but instead they are engaging in inter-agency turf wars, which proves to be impacting very negatively on the process of grid integration of RE. The two processes of renewable energy deployment and grid integration are not aligned, with the latter one lacking significantly behind. The State Grid is in charge of the Renewable Energy Development Fund set up under the Renewable Energy Law. Local sub-bodies of the State Grid have authority to decide the use of the fund. These decision are in many cases not very transparent and criteria on which projects are funded are in many cases vague. For instance, the State Grid department based in Nanjing is in charge of the funds under the Golden Sun Project (see section 8.3.1) and in many cases personal relationships are necessary to be able to access these funds.

State Grid which has taken much of the main blame in recent years for not being capable of handling new alternative energy sources, such as wind and solar power, more effectively. State Grid has according to some commentators until now been blocking new renewable energy development because their intermittence and requiring backup energy pools. State Grid as the link between power supply and end users is has also begun to promote energy savings and

¹⁹ Personal communication with international and Chinese wind energy experts (who did not want to be identified by name), May 2009 & February 2010

²⁰ Ibid.

emissions reductions across the power sector while at the same time encouraging demand side management to raise end-user power use efficiency. The new focus stems from the realisation that generation and grid capacity will not be able to develop fast enough to meet the predicted doubling of China's electricity consumption by 2020. According to renewable energy experts, smart grid development (see section 9.2) is also going to be the new future area of energy cooperation between China and western industrialised countries in the next decade.²¹ This cooperation seems already to be beginning, for example, US companies General Electric and IBM have started significant investments in China to support and benefit economically from smart grid power distribution systems (Parkinson 2010).

In addition to the NEA, in January 2010 China's State Council announced the creation of the **National Energy Commission (NEC)** (*Guo Jia Neng Yuan Wei Yuan Hui*), which had been initially proposed during the first session of the 11th National Party Congress in 2008. While the NEA undertakes the day-to-day work, NEC as a Procedural Coordination Body of the State Council is supposed to provide mainly strategic oversight. NEC is responsible for energy development strategy and energy security, as well as coordinating domestic energy development and international cooperation. Even though renewable energy development is not specifically mentioned, the energy leading group will likely play an important role in ensuring that the set targets for renewable energy development will be met. The establishment of the NEC shows that energy has become one of the highest priorities of the Chinese government. The practical role of the NEC, particularly regarding its authority and responsibility, will be balanced with those of the multiple other government institutions with some influence over energy and climate policy. Energy policy will still need to be negotiated among the different competing interests – as is the case in most countries.

²¹ Interview with Dr. Uwe Weber, international advisor for the Sino-Danish RED Programme, Beijing, January 2010.

The **State Electricity Regulatory Commission (SERC)**²² is the main regulatory body for the electricity sector and was, like the NDRC, also established in 2003 by the State Council. Its role is to administer and regulate the national electric power sector. It is mainly responsible for the overall regulation and oversight of the national power sector, supervision of the reform process, establishment of a coherent system for regulatory organisation and exercising direct leadership over regional regulatory branches. One of its main characteristics is that as an institution directly under the State Council it is independent of NDRC and other ministries. SERC is delegated a leadership role by the State Council to be able to facilitate bargaining among the many institutional actors involved in energy policy-making. International cooperation and exchange with the Regulatory Assistance Programme (RAP) through the US-based Energy Foundation might have played some role in the establishment and design of the SERC.²³

SERC's main responsibility is to oversee and inspect the electricity market, prices and permits for operation of generation and transmission facilities. SERC also has the responsibility to solve conflicts between coal-industries and electricity generators regarding prices for coal and electricity. SERC also has a role in the implementation of the Renewable Energy Law, specifically the enforcement of requirement for power companies to purchase the maximum amount of electricity generated through renewables in their coverage areas. In 2007, SERC was given authority, measures, and responsibilities necessary to facilitate the integration of renewable sources into power systems and for renewable power facilities to receive government subsidies in power pricing rather than having to participate in competitive bidding (Ling 2007). Subsequently, SERC issued the 'Measures on supervising and administering the whole purchase by power grid enterprises of power generated by RE' in September 2007. However, SERC is considered to have so far only played a limited role in renewable energy development as most responsibilities lie within other departments (SERN & REEEP 2010). This might be one factor why grid integration of renewable energy still lacks significantly behind installed capacity.

²² <http://www.serc.gov.cn/english/index.htm> (国家电力监管委员会)

²³ Interview with Rick Weston, Regulatory Assistance Project, Beijing, Mai 2009

5 Renewable energy in rural China

As described in the introduction to the five sectors of the framework for investigation of China's renewable development (section 4.1), the first sector concerns China's rural renewable energy development. As noted in the literature review (Modi *et al.*, 2004), renewable energy development not only has environmental benefits, but also has a social and economic dimension and can contribute to improvements in living standards and poverty reduction, particularly in underdeveloped rural areas. Approximately 800 million Chinese people still live in rural areas, many still in circumstances characterised by hardship arising from low levels of development of human and physical capital.

Although most rural areas have access to electricity, electrification rate is about 98%, solid fuels such as coal and traditional biomass resources are a major source of rural household energy consumption, particularly for space heating and cooking. They are also one of the sources of rural environmental pollution and indoor air contamination, affecting health of women and children in particular (Peabody *et al.* 2005).

In China there are several examples of how successful renewable energy development has been achieved in rural areas and contributed to poverty reduction. The level of technological know-how required and the costs of production are comparatively low and can make significant contributions to better living standards. This type of renewable energy development in rural areas acts as an initial driving force which has kicked off micro-scale technology development. It has been occurring in China since as early as the 1980s, initially mainly through international development aid programmes of the UN and bilateral government cooperation projects.

However, the demand for affordable renewable energy in rural area is ongoing and local rural markets are developing. In the following section three clean and renewable energy technologies which are contributing to bottom-up renewable energy development are described in detail – improved biomass stoves, biogas anaerobic digestion technology and solar PV home systems.

Following the introduction of the technologies, relevant supporting policies and programmes for rural renewable energy development are discussed, together with several international partnerships in this area. An assessment whether leapfrogging has occurred will conclude this chapter.

5.1 Current renewable energy deployment in rural households

A relatively low-tech option for improving the health status of rural inhabitants using clean and renewable fuels for cooking and heating are **improved biomass stoves** for wood or crop residues in rural households, an alternative to conventional coal or firewood stoves, with around 20 million being sold each year in China (Wheldon and Rawlings 2007). A variety of technologies exist which help to control the flow of air, some partially gasifying the fuel, and then burning the gas with secondary air in order to burn the wood cleanly and transfer heat efficiently to the cooking pot. Some stove models can also provide hot water and heat radiators. Through the use of efficient stoves, savings of 40 to 50% of fuel wood, 50 to 70% of particulate emissions, and 50 to 60% of carbon monoxide emissions can be achieved, compared to cooking on open fires. The typical savings of CO₂ equivalent are in the order of 1 to 2 tonnes/year per stove. Some stove technologies use straw briquettes that can replace coal and thereby achieve reductions of over 8 tonnes/year of CO₂ equivalent (Wheldon and Rawlings 2009).

Despite the obvious environmental benefits, some obstacles still exist. One of them being higher costs compared to conventional coal stoves which lie at around 50 CNY. The full price of the efficient stoves is about 1,000 CNY. In some regions, customers pay the full price, in others the stoves are eligible for a government subsidy. The initial higher cost is however easily offset by the savings. Coal costs about 600 CNY/tonne and a typical household uses 3 to 4 tonnes per year. In contrast, biomass briquettes cost only 350 CNY/tonne. Household savings can be as high as 1,000 CNY per year, a significant amount for rural areas where annual agricultural incomes

average only 15,000 to 20,000 CNY (Wheldon and Rawlings 2007). This suggests a very short payback period on the investment cost of the efficient stove.

In addition to the high upfront costs, there are also other issues which could be called socio-technical problems and sometimes pose obstacles to the diffusion of the stoves. In particular, older people in rural areas who have used conventional means of cooking on open fires for many years are not easily convinced to make changes in their habits. In one case in rural Yunnan, where efficient stoves were distributed and installed through an international development aid project, about half the households switched back to their conventional means of cooking after a relatively short time, the main reason not being faulty technology, but users not being able to get used to the new efficient stoves.²⁴

Biogas anaerobic digestion technology is another option to reduce the use of traditional biomass and reduce associated environmental problems in the countryside. China has been using and developing biogas technologies since the 1920s and the number of household biogas plants in rural China is already the highest in the world. In 2005, about 17 million digesters with annual production of 6.5 billion m³ of biogas were installed, mostly in rural areas. By 2007, the number of biogas plants in operation increased to 26.5 million with an output of about 10.5 billion m³ (equivalent to more than 100 million tons of standard coal). The potential lies even higher: it is estimated that about 140 million rural households are suitable for construction of biogas digesters (Chen *et al.* 2009). Household biogas digesters are found throughout the country, but mainly in the Yangtze River Basin and Sichuan Province, which has the largest number of household biogas plants, approximately 3 million units. Most small-scale biogas plants in rural areas are operated by farmers which depend on raising livestock. Animal waste, mainly from pigsties, sometimes even combined with human excrement, can be fed into a biogas plant. Bacteria digest the slurry under anaerobic conditions (without oxygen). The decomposition yields biogas (which

²⁴ Personal communication with Tim Tennigkeit, German bio-energy expert working in Yunnan Province, September 2008.

typically consists of 60-70% methane and 30-35% carbon dioxide) and a semi-solid residue. These plants provide clean fuel for cooking and lighting, improve sanitation and hygiene and help prevent further environmental degradation. The solid residue from the plants is a valuable fertiliser. Other environmental benefits of the digesters include preventing effluent seeping into the groundwater, which reduces levels of pathogenic bacteria. Households which replace fuel wood with biogas can save about 1.5 to 2 tonnes of wood per year. Most small scale biogas digesters have a volume of 8m³ (some are 10-15m³) and provide enough gas for a two-ring stove and a light. Biogas appliances are manufactured in several parts of China and have contributed to creating new forms of employment in rural areas (Wheldon and Rawlings 2006).

These recent developments have brought biogas to the centre of a burgeoning “eco-economy” in some rural areas of China. A new occupation of biogas technicians has emerged, providing new employment opportunities for many unemployed farmers in rural areas who would otherwise migrate to cities. In addition to climate friendly energy generation and economic opportunities, biogas digester systems have health benefits through the reduction of parasitic diseases as they improve rural sanitary conditions. The public health sector can leverage the proliferation of rural biogas energy projects for long-term control of parasitic diseases (Remais et al., 2009). By 2020, about 300 million rural people in China are expected to use biogas as their main fuel. The annual production of biogas is projected to reach 25 billion cubic metres by 2020; biogas could provide energy to one quarter of households in rural areas and significantly reduce methane emissions from livestock (Li and Ho 2006; van Nes 2006).

Despite these positive trends, on the practical day-to-day level, biogas technology is not without problems. According to Chen *et al.* (2010), of the 26.5 million biogas digesters in China’s rural areas, only 60% are operating normally without major disruptions. Biogas digesters require regular maintenance such as de-sludging, or their performance suffers significantly. Cold weather can also reduce their efficiency, and often gas production falls off for one or two months during the coldest part of the winter. It is possible to combine biogas digesters with solar water heating

(SWH) technologies (see section 8.4 for detailed information on SWH technology) which can help heat biogas pits so they continue producing energy throughout the colder months (Huang and Gong 2010). The technology is on the one hand perceived to be more independent, but on the other hand perceived as less reliable than other available options - such as electricity from the grid. Despite the government support a major constraint on promoting biogas use and industry development lies in the lack of technical capacity for running and maintaining the digesters which as a result often become dysfunctional after only one or two years of operation.²⁵

Despite almost three decades of rapid economic growth, in 2005 about 30 million people living in remote rural and mountainous areas of western China still did not have access to electricity; most of them are among the lowest income earners (Zhang *et al.* 2009). Electricity supply plays a very important role in promoting social and economic development in remote rural and mountainous areas, and renewable electricity power generating options, such as micro hydro systems, and small-sized wind generating systems are often more cost-effective than the extension of conventional power grids. Despite being quite costly, the supply of **solar PV home systems** has proven to be a popular and effective option to provide electricity to remote areas in North-Western China, particularly the provinces Gansu, Qinghai, Xinjiang and Tibet which are among the poorest in the country, but have abundant solar resources. Many people in rural areas still live off the land by tending yaks or other animal husbandry. The remoteness of the region and the low population density mean that there is limited access to the electricity services which are readily available in the well developed eastern regions of China. Lighting is provided by kerosene and butter lamps, because few people in rural areas have grid electricity.

A typical solar-home-system consists of a PV module, battery, charge controller and sometimes an inverter. Systems in the range of 10 Watt Peak (Wp) to 20 Wp were common in the early 2000s; the size of systems is gradually increasing and 40 Wp systems have become

²⁵ Personal communication with environmentalist Deng Wen, expert from the NGO Sichuan Green River, December 2009.

common. Prices for rural PV home systems have decreased significantly over the last 15 years. While in the mid 1990s the average retail price of a 20 Wp system in western China was about 2,400 CNY (Wallace and Tsuo 1997), during recent development aid and government subsidy programmes²⁶ a typical 20 Wp system sold for around 900 to 1,000 CNY while a 75 to 90 Wp system sold for around 4,000 CNY. Without subsidies the prices are approximately 20% higher (Luo and Wang 2008). However, even at subsidised prices, such electricity remains expensive (currently it is around US\$6,500/kW) compared to grid-based electricity.

5.2 Support policies and programmes for rural renewable energy development

Government initiated programmes have been crucial for the promotion of the renewable energy and electricity technologies discussed above. Particularly the diffusion of solar PV home systems, due to the high cost and initial lack of local industries, required strong government support. The goal of early support programmes was to increase rural literacy rates, living standards and create local industries.

An example of an early government programme was the **China Brightness Programme**²⁷ launched by the State Development and Reform Commission in 1996. China's State Council allocated about or 400 million CNY to support the Brightness Program during the Tenth Five-Year Plan period (2001-2005). The programme provided electricity using both household and village systems and small scale wind with a focus on the remote provinces of Gansu, Qinghai, Inner Mongolia, Tibet, and Xinjiang. In total it provided electricity to about 23 million people who previously had no access to electricity (NREL 2004c). High costs for PV systems were shared by the users, local government grants, central government grants, and foreign grants. The project also included the establishment of local and national government bureaus of financing, technical

²⁶ An example is the China Renewable Energy Development Programme (REDP) which is described below in section 5.3

²⁷ *Zhong guo guang ming gong cheng xiang mu* (中国光明工程项目)

training systems for local technicians and engineers and production enterprises geared toward meeting electricity needs (Meisen and Cavino 2007). A further effect of the Brightness programme was that Chinese solar PV start-up companies such as Yingli, which is now one of the leading solar PV companies in China, were supported.

Government programmes In 2002 the NCRC implemented the **Township Electrification Programme**²⁸, which was aimed at solving power supply problems by using PV and small-scale wind electricity generation in more than 700 townships in seven western provinces (Tibet, Xinjiang, Qinghai, Gansu, Inner Mongolia, Shanxi and Sichuan). This programme has stimulated the regional PV industry and several production assembly lines have been established, rapidly increasing the annual production of solar cells to 100 MWp in 2007 from 20 MWp in 2002. Through five nationwide public tenders conducted in 2002 to select system integrators to design, procure and install PV and PV/wind systems, in total fifteen companies were selected, and have issued international tenders for PV, wind turbines, batteries and electronics (NREL 2004). The programme ended in 2005 and was being succeeded by a similar but larger China Village Electrification Programme which has brought renewable electricity to 3.5 million households in 10,000 villages by 2010, to be followed by full rural electrification by 2015. Several international and foreign organisations have been involved supporting this programme, the most prominent being the China Renewable Energy Development Project (REDP) (see section 5.3).

Not only solar PV home systems have received government support. Other national programmes targeting sustainable energy development in rural areas focus on biogas micro digesters. Since 2000 the Chinese government has promoted a subsidy programme for biogas micro digesters installation for rural farmer households and strengthened the institutional system for local biogas programmes. The Ministry of Agriculture (MOA) has been in charge of implementing rural household biogas subsidy programmes as governmental agency at the state

²⁸ *Song dian dao xiang xiang mu* (送电到乡项目)

level for policymaking, legislation issuing and formulating mid-term and long-term plan. The objectives of these national biogas promotion projects are four-fold: 1) to provide an incentive for increased animal production (cows, pigs, sheep), thereby increasing farmers' income; 2) to stop the illegal cutting of trees for firewood, addressing the issues of deforestation, serious soil erosion and low-level farm production; 3) to increase agricultural production by using biogas for cooking in the daytime and lighting in the evening; and 4) to improve the overall sanitation, health, and environmental conditions of these villages. (Li and Ho 2006, van Nes 2006).

In 2003 the MOA established the **National Plan of Rural Biogas Construction**²⁹ which had the goal to increase biogas use to a total of 40 million households by 2010 and close to 100 million by 2020. According to the plan total annual production of biogas would reach to 15.6 billion m³ (11.138Mt ce) in 2010 and 38.5 billion m³ (27.456Mt ce) in 2020 (Liu *et al.* 2008). As part of this plan a financial support system for rural household biogas projects was initiated. The programme is called 'Rural Biogas Construction State Debt Program Management Method' and invested 840 million CNY for the construction of household biogas in 22 provinces (including autonomous regions and municipalities) in 2003. In the following years the financial subsidy continued and provided 1 billion CNY for constructing rural household biogas digesters. In 2005, central investment in the construction of rural biogas funds rose to 2.5 billion CNY, of which 2 billion was slated for the construction of household biogas digesters and 0.5 billion for the construction of large and medium-sized biogas digesters (Chen *et al.*, 2010). For households this translates into receiving a government subsidy of between 800 to 1,200 CNY (about \$150) for each biogas digester, which covers about 20% ~35 % (varies by region) of the total cost for a biogas system installation which includes kitchen, toilet and swine pen renovations ("one digester, three renovations"). Even with the government subsidy, many poor rural households find it difficult to finance the rest of upfront installation costs.

Other smaller biogas promotion policies include the 'Management Act for Rural Biogas

²⁹ *Zhong guo nong cun zhao qi jian she fa zhan gui hua* (农村沼气建设发展规划)
<http://www.zhaoqiweb.com/zhaoqijishu/zhaoqifadian/a2009912131315.html>

Projects Sustained by National Debt' from May 2004, or provincial regulations such as the 2005 'Act for Rural Energy Projects Management of Hunan Province' and, also initiated in 2005, the 'Act for Biogas Development Promotion of Zhejiang Province'. In addition, a range of technical specifications for biogas technologies and standards for installation of systems have been established. At the same time, corresponding Rural Energy Offices have been setup in provinces, counties and towns, there are more than 30, 1,900 and 8,000 of such offices on the respective administrative levels. Despite these government subsidy supports, new institutions and new regulations, at time of writing only about 20% of the household biogas potential is being utilised in rural China (Chen *et al.* 2010). This shows that the regulatory frameworks, institutional structures and local markets are still in early stages of development and would still need to be improved to achieve the biogas production target for 2020 and scale-up rural biogas use to its full potential.

5.3 International cooperation and partnerships for rural renewable energy development

In addition to government programmes, international cooperation initiatives have been important to enable renewables development in China's rural areas. International initiatives have in some cases been the precursors for national programmes, such as the China Brightness Programme, which followed international efforts designed to bring electricity to rural areas.

A prominent and successful example of an international cooperation partnership is the **China Renewable Energy Development Project (REDP)** which was launched in 2001 by the National Development and Reform Commission (NDRC) and the World Bank (WB), with international grant financing provided by the Global Environment Facility (GEF) and support by UNDP. Previously, other GEF projects were linked with the Brightness Programme and Township Electrification Programme. The REDP project once more supported the Chinese government in their national rural and village electrification programmes with one of the main aims to promote the installation of photovoltaic (PV) solar home systems in remote off-grid homes in nine western

Chinese provinces. Furthermore, it has supported industry development and contributed to improving the quality of production of PV modules and other system components in China while keeping costs down. Finally, it facilitated cooperation between the PV sector in China and the rest of the world. Through providing subsidies of US\$1.50/Wp to US\$2.00/Wp on which reduced the retail price by about 25%, the REDP has enabled sales of over 402,000 photovoltaic (PV) solar-home systems to rural people who live off the land by tending yaks or other animals in remote areas of the West and North-West of China.

The peak year for the REDP programme was 2005, when 100,000 subsidised systems were sold and installed. Around 1.6 million people, who had little access to electricity previously, now have an improved quality of life through better lighting, communications and entertainment, with the portable systems ideally suited to the traditional lifestyle of the semi-nomadic users who are able to take them with their tents into the summer pasture in the hills. The REDP has also supported some PV village systems to provide electricity for public facilities such as schools, health centers, climate and weather monitoring stations as well as Buddhist temples. Furthermore, the programme created about 1,500 permanent jobs and 3,000 temporary ones in the over 30 partner companies. By the end of 2006, 50% of the sales of these companies were outside the REDP, showing that the support provided by the programme has stimulated a wider market, despite the relatively high cost. Demand for PV home systems is expected to continue to increase by 10 - 20% per year (Luo and Wang 2008)

To rapidly increase the availability of improved stoves, an innovative research-business partnership has formed between the US-based **Aprovecho Research Center (ARC)** and the **Shengzhou Stove Manufacturer (SSM)** in China. They collaborate to design and mass-produce efficient stoves for burning fuel wood and charcoal. The initial stove designs were developed by ARC, and SSM developed those first models further for mass production. The so-called 'Rocket' design concept uses precise internal dimensions to control the flow of air, in order to burn the wood cleanly and transfer heat efficiently to the cooking pot. SSM designed and set up the new

factory production line in 2007. Three main models developed so far with prices ex-factory from US\$3.50 to US\$12. SSM's production capacity now reached about 50,000/month. Interestingly, over 90% of sales have not been within China, but to Envirofit International, a US-based non-profit organisation which markets the stoves in India supported by the Shell Foundation. The stoves are also sold to distributors in South Africa, Tanzania, Madagascar, Argentina, Chile, and the Marshall Islands. The German Development Agency (GTZ) could be seen as third partner of this project as GTZ manages two development aid programmes in Southern Africa which are providing stoves for both rural and urban markets (Wheldon and Rawlings, 2009).

This example of cooperation shows that further technical developments and innovations combined with mass manufacturing capability of companies in China can provide affordable low-cost renewable energy products for other developing countries. It can be expected that such innovative research-business partnerships with Chinese manufacturers will also develop in the future for technologically more sophisticated renewable energy technologies such as wind turbines. This would support faster diffusion of renewable energy technologies globally and contribute to a faster global energy system transition.

The **Clean Development Mechanism (CDM)** (see also section 8.7.1), one of the three flexible mechanisms under the Kyoto Protocol, has potential to promote small-scale biogas digesters in China. Most biogas projects in China have so far only focused on large-scale projects. At its thirty-third meeting in July 2007, the CDM Executive Board approved several methodologies for small-scale programmatic projects. Regarding additionality, the current policy framework and subsidy programme for household biogas is a voluntary based policy. There are at this stage no regulations in China that requires mandatory changes of the current manure management systems and cooking methods of rural households. Therefore, the additionality criteria of the CDM would allow for projects that promote household biogas digesters in China.

An example project that at the time of writing was awaiting validation by the CDM Executive Board, is a small-scale sectoral programmatic CDM project, or programme of activities (PoA), is

the **Biogas Micro-digester Promoting Program for Rural Farmer Households in Chongqing, China.**³⁰ This PoA aims to install around 500,000 domestic biogas micro-digesters for low-income farmers' households in the Chongqing municipal area. In the Chongqing area there were already 820,000 farmer households with biogas digesters installed through the national subsidy programme at the end of 2007. There is still a large number of about 6.5 million farmer households that have potential to install biogas digesters. The PoA coordinator is Beijing Chizi Hengyuan Huanbao Keji, Co. Ltd. (BCHHK), overseas buyer of the certified emission reductions (CERs) is the Japanese PEAR Carbon Offset Initiative, Ltd. Local operators are the corresponding Rural Energy Offices of the counties/districts where project activities are implemented on the ground. The offices organize and oversee the installation of digester systems in households which so far treat swine and human manures in conventional waste pits.

The project promotes domestic biogas digesters for rural farmer households in Chongqing municipal area using the certified emission reductions (CERs) revenue as a subsidy which is additional or overlapping to the national biogas promotion programme described above. The project provides a subsidy of 1200 CNY/ household to diffuse rural biogas micro digesters with targeting households which are not covered by government subsidy. In total the project will leverage an additional 60 million CNY for biogas micro-digester promotion.

In addition, the project will strengthen the capacity of local biogas digester services and technical extension systems and improve service levels for operation and maintenance. This includes guidance on installation, supervision and cooking stove operation, provision of training and technical services to local farmers, provision of relevant facilities maintenance, and implementation of monitoring plan. A number of maintenance centers will be established along with the project, one digester repair and maintenance service center for per 300~500 households with at least one professional worker at every project village is planned.

³⁰ Information about the project is available at the UNFCCC CDM website:
<http://cdm.unfccc.int/ProgrammeOfActivities/Validation/DB/8VZ9ESO6M7057RIZMA19PEPVJWXZCA/view.html>

5.3.1 Summary and discussion

China has shown tremendous success in establishing high rates of electrification across the country, most notably in rural electrification. Rural electrification through off-grid renewable energy technologies such as solar PV or energy supply through small-scale biogas has provided for improvements in living standards. Overall, the increased diffusion of renewable energy technologies for rural areas will continue to be important to improve quality of life for rural populations, guarantee energy independence from centralised power generation and provide clean and renewable energy sources. However, costs per unit of energy remain relatively high with solutions such as PV, and reliability of biogas digestors remains an issue. A sustainable energy system will require further development and expansion of localised, small-scale renewable energy systems. Among these renewable energy technologies in rural areas only solar PV home systems would constitute a technological leapfrog, albeit an expensive one. Rural household biogas digestors currently still offer more opportunities for diffusion, but do not constitute technological leapfrogging.

Government support programmes for rural renewable energy development have focused mainly on providing financial subsidies promoting the uptake and installation of PV solar home or household biogas digesters. Government programmes could further support the training of a skilled renewable energy workforce in rural areas. For example, biogas technology literate staff continues to be in very short supply. Institutional development also seems necessary as small county-level rural energy offices are mostly understaffed and employees are often unable to adapt to the rapid developments taking place in the field of rural household biogas digester technology. Furthermore, as Chen *et al.* (2010) suggest, capacity building training could be conducted to raise the level of technical understanding of biogas customers in biogas utilization. Support measures could be taken to improve the follow-up services and management of biogas plants.

Regarding international partnerships, technological leapfrogging with positive effects on

living standards was achieved for a significantly large number of rural inhabitants through partnerships for solar PV. However, after the completion of the CRED Programme, no major new partnership involving international organisations seems to have been initiated to promote further diffusion in solar PV home systems - and might not in the future. This can be read as a sign that the previous projects together with government programmes have been successful in creating localised markets for further development of electrification through PV home systems and that Chinese domestic policy and government departments are expected to be able to solve these challenges without further international support. This traditional area of official development assistance seems no longer to be priority for international donors and cooperation initiatives have moved into other areas which are discussed in the following sections.

International cooperation under the CDM promoting the uptake of small-scale household biogas, and maybe even efficient stoves through programmatic CDM projects, could have significant potential for further acceleration of rural renewable energy systems, particularly biogas. Furthermore, the Chinese experience of renewable energy development in rural areas could contribute to replication through south-south cooperation with other less developed countries. The partnership between the Aprovecho Research Center (ARC), the Shengzhou Stove Manufacturer (SSM) and distributors in other developing countries shows that win-win-win situations are possible.

6 Development of China's renewable energy companies

As I have demonstrated in the previous chapter, China has already achieved overall growth in renewable energy technology deployment in rural areas and some localised industry growth through SMEs. This chapter investigates whether Chinese companies for other technologies such as wind, solar PV and SWH have undergone corresponding development and acquired corresponding technological capabilities. Particularly maturation of technological and innovative capacities of domestic companies is crucial for large-scale diffusion of renewable. The installation of the latest environmental technologies imported from industrialised countries or produced by companies headquartered in industrialised countries will not be sufficient to achieve diffusion in China wide enough to move these technologies beyond their niche status. Particularly the high cost of imported western or Japanese technologies is one major barrier to this. To achieve deployment of renewable energy beyond a niche status, Chinese companies need to be able to produce and develop these technologies domestically, and then take them to the market.

To assess the level of progress and maturity achieved at the company level, six levels of company development and the relevant criteria for achieving the different stages can be identified. These include manufacturing capabilities, the quality of products, domestic market shares, innovative capacity, international competitiveness and the overall environmental and social performance of the company and its products. These six elements are arranged in a sequence based on the innovation curve and each outcome can in broad terms be seen as the prerequisite for the next (see Fig. 15). A company's manufacturing capabilities is the basic precondition for any kind of a company's development. It is necessary to have achieved a high level of manufacturing capabilities before product and process quality can be attained. The ability to produce quality equipment is in turn required to achieve a sufficient share of the domestic Chinese market. The issue of innovative capacity, which in some cases can precede domestic market share, is

currently the most important of all for many Chinese renewable energy companies, as it will be crucial for companies' long-term strategies and for survival in the competitive future global market. The design of environmentally sustainable and socially responsible businesses is a final challenge most companies have not yet achieved – including international renewable energy companies operating in China.

Figure 15: Six levels of maturity development at the company level (source: author's assessment)

Companies' development does not take place in a vacuum and is influenced, supported or hindered through various factors and stakeholders. These can be both domestic stakeholders and international stakeholders. In the domestic arena national and local government support plays an important role in providing supportive policies and incentives. Domestic industry networks are also very significant to facilitate inter-firm technology and know-how transfer. One company's success stimulates other companies in the same city or region or even elsewhere in China in

allied industries. Regarding international influences, bilateral cooperation aid agreements have in some cases played an important role in kick-starting development of China's renewable energy companies. Foreign companies have engaged in technology transfer, e.g. through licensing agreements, and facilitated fast development of manufacturing capabilities and improvements in product quality. International companies can also make positive contributions to improvements of innovation capacity of renewable energy companies, particularly through joint research and development activities. These arrangements are ideally supported by bilateral government cooperation agreements to ensure appropriate IPR protection (see Fig. 16).

Figure 16: Stakeholder influence and support for companies to achieve maturity (source: author's assessment)

Two types of indicators need to be used to determine the level of maturity of a company. On the one hand, quantitative measures such as production output, patents registered, R&D spending, or company turnover give useful guidance. In addition to measuring these externally visible outcomes, it is argued here that it is essential to chart the qualitative dimensions that

support achievement of these outcomes, and to map how well they are - or are not - changing. This is necessary because looking only at the outward appearance of progress without looking into the underlying or supporting factors can be deceptive. For example, a company's manufacturing capability cannot only be determined by counting appropriate manufacturing facilities and equipment or counting annual production output -- to have a technically literate, skilled and flexible workforce that is able to use the equipment and fabricate quality products is equally important, but often this cannot be assessed quantitatively. Similarly, it is not sufficient to measure a company's annual R&D spending to assess its innovative capacity without investigating whether the company's management structures enable innovative and creative thinking or problem solving ability among employees. Indicators of qualitative drivers such as technical literacy and skills of the company's workforce, respect for other companies' IPRs, or management structures which allow free discussion of technical problems and innovative ideas are important factors to be considered.

However, collecting data on these indicators has proven to be difficult as it would require extensive and confidential interviews with companies' employees and management. It would also require spending time within the company to observe manufacturing processes, management meetings and the general working environments. Collecting this type of data was beyond the scope of this study. However, the research suggests that two of the cross-cutting drivers for all levels of company leapfrogging are, on the one hand, the ability to cooperate with international non-Chinese companies and organisations to access technologies and know-how, and, on the other hand, alignment with supportive domestic policy frameworks for niche industries.

In Table 3 the six levels of maturity development for companies and the respective external outcomes and underlying drivers are summarised.

Table 3: Drivers and outcomes of development towards maturity and sophistication at the company level (Source: author's assessment)

Company development stages	Externally visible outcomes	Drivers for innovation
Manufacturing capabilities	Appropriate manufacturing facilities and equipment	Technically literate work force
Product & process quality	Product and delivery reliability; error-free products	Adherence to standards and specifications; quality monitoring systems
Domestic market shares	Company sales, annual turnover	Certified product quality; branding & advertisement; consumer trust
Innovation capacity	R&D spending; number of patents registered	Management structures supporting innovative & creative thinking; networking and exchange of ideas between companies & research community
International competitiveness	Exports of equipment; overseas manufacturing facilities; Initial Public Offerings (IPOs)	Respect for other companies' IPRs; ability to operate in non-Chinese business environment (without government support & protection)
Environmental and socially sustainable business	Use of sustainable resources; end-of-life take-back schemes; product-service systems; green supply chain management	Achieving sustainability is long-term management strategy; top management support and priority; production approaches based on life cycle thinking; alignment with medium-term evolution of greener economy.

The remainder of this section describes and analyses the most important developments of companies in three main renewable electricity technology sectors in China – wind, solar PV and SWH, the latter being an important electricity saving technology. For the analysis the indicators identified above are applied. Moreover, several issues which can be seen as obstacles to Chinese companies achieving even higher levels of maturity and product sophistication in the future and becoming environmentally sustainable and socially responsible businesses are discussed. Also discussed are some current policy frameworks which have enabled Chinese companies to develop rapidly, with a particular focus on innovation and R&D policy. The section will conclude with several case studies of business to business cooperation and a discussion of

the role of foreign businesses and bilateral cooperation programmes in supporting innovation capacity among China's renewable energy technology companies.

6.1 China's wind energy companies and market development

The Chinese wind industry has experienced, and continues to experience, rapid development in its manufacturing capabilities. Many domestic manufacturers have emerged within a short period of time, particularly in the turbine and components manufacturing sector, and have accomplished in a few years what has taken western companies between two or three decades to achieve. According to several experts consulted during the research, this constitutes a technological leapfrog, although Chinese turbine manufacturers have not leapfrogged ahead of leading international companies.

There are approximately 70 domestic wind turbine manufacturers with an expected production capacity of over 30,000 MW per year by 2010 (Li and Ma 2009). Cooperation with foreign wind power companies through licensing agreements and joint ventures was important to gain access to technical knowledge and skills to achieve these capabilities and product quality.

In terms of domestic market share Chinese wind turbine and equipment manufacturers have already overtaken foreign competitors. Back in 2005, domestic companies accounted for only 23 percent of China's cumulative installed turbines. The largest part of the Chinese domestic market was then dominated by foreign wind turbine giants, including Spain's Gamesa, Denmark's Vestas, and Germany's Nordex. Since the 1990s, major European turbine manufacturers had gradually expanded their market share of the Chinese market with the support of low-interest loans and incentives from their governments. In 2005 the typical mainstream Chinese wind turbine had a capacity of 750 kilowatts (kW), while most European products generate more than 2,000 kW (Liu 2006).

The situation had changed dramatically by 2010. While in 2004, foreign-made equipment

still accounted for about 75 percent of the Chinese wind turbine market, at the end of 2007 domestic turbine makers accounted for 61.8 percent of China's market share (Chan 2009), surpassing overseas producers for the first time. Of the 3.4GW of wind capacity (the third largest addition behind Spain and the USA) China added in 2008, 1.4GW of this was produced by two domestic companies, Goldwind and Sinovel (Global Wind Energy Council, 2008). In 2009, the market share of domestic wind energy companies increased further to 86 percent (see Fig. 17). In 2010 foreign-owned manufacturers are estimated to again have won only 14.5% of the orders for turbines in China in 2010 (UNEP and Bloomberg New Energy Finance 2011). It is expected that Chinese manufacturers are set to expand their domestic market share even further in the coming years.

Figure 17: Increase of domestic market share of Chinese wind power companies from 2004-2009. (Data Sources: Chan 2009; ResearchInChina 2009; China Wind Energy Association 2009; Scott 2010)

The main reason for the expansion of Chinese companies' market shares is not better quality, but lower prices, which give domestic companies an edge over their foreign competitors. Other important reasons for the fast development of the Chinese wind industry and the increase

in manufacturing capabilities and domestic market shares are “buy Chinese” policies on the part of wind farm developers, the Chinese government’s economic stimulus package in 2008/9 and government-required bidding criteria for wind farm developments, which have given Chinese wind turbine manufacturers strong advantages (Scott 2010). While this strong government support is perceived as unfair by many foreign experts and businesses, it is perceived as necessary by Chinese wind energy experts and policymakers, as providing infant niche industry protection against the big international players.³¹

While many media reports complain about the Chinese wind market getting 'tough' for foreign companies (Reuters 2009), it is important to keep in mind that despite the decrease in market share, international companies overall have *increased* the number of wind turbines sold every year in China's rapidly growing market. For instance, Vestas, the top foreign wind turbine maker in China, as the end of 2009 had an accumulated installed turbine capacity of more than 2,000 MW in China (People's Daily Online 2010) of which 620 MW were sold in 2009 alone (Scott 2010).

Similarly, the Spanish wind turbine company Gamesa has increased its sales in China. According to Spanish renewable energy experts³², the business for Gamesa in China is going extremely well, despite shrinking market shares and the price of the company’s machines being about third higher than Chinese models. The company's wind turbine sales in China in 2008 accounted for 15 percent of its total global sales, up from 11 percent in 2006. New production facilities have been opened in Tianjin, and a fifth production facility will start operation in Jilin in 2011. According to the company's website, as of 2010 the company has already installed a total of about 2,000 of its Gamesa G5X-850 kW turbines in China in over 60 locations. In the pipeline are wind farm projects totalling 2,400 MW at varying stages of development (Gamesa website, 2010).

These examples show that the expansion of Chinese domestic companies' market share is

³¹ These positions were repeatedly stated by most wind power experts during interviews and communications.

³² Personal communication with Spanish energy expert of the Spanish Chamber of Commerce in Tianjin, June 2010.

therefore a positive sign that companies are maturing and does not impact the business of foreign companies. Win-win situations are possible and the development of wind power in China appears to be benefiting both domestic and international companies. One could also argue that Chinese domestic companies should naturally benefit more from the Chinese domestic market than their foreign competitors, because of advantages such as proximity. To expect that the Chinese wind energy system would continue to depend largely on foreign suppliers and expertise is quite unrealistic. Furthermore, it is questionable whether the Chinese government would have set renewable energy targets as high as they are now if it solely relied on deploying foreign made technologies.

The wind power value chain in China also keeps expanding and now includes not only components manufacturing, but also companies focusing on project development, wind farm installation, operation and management, technical services within the quality warranty period, equipment repair and professional cleaning and maintenance services. In terms of components, China has a production system of major parts including blades, gearboxes, generators and pylons. However, the domestic supply chain still remains dependent on imports for key components, such as precision bearings, electrical and control systems, and inverters (Schwartz 2009). This aspect can be expected to change over the next few years as Chinese companies are undertaking strong efforts to manufacture these key components domestically and reduce the dependency on foreign suppliers such as ABB, Emerson or Vacon, which are still leading suppliers for variable-frequency drives in China's wind energy sector.

China's wind power industry will continue to maintain its relatively high growth rate. However, rather than seeing new companies emerging, as has been the case in the first decade of the 21st century, the industry is expected to consolidate. With an increasing emphasis on producing high-quality equipment, some of the smaller companies can be expected to go out of business over the next few years.³³ Already several companies have emerged as key players in the industry and

³³ Presentation by James Liang, James Liang, AES Corporation, at the Beijing Energy and Environment Roundtable 4th March 2009.

achieved some elements of technological leapfrogging in their production capabilities, large through the acquisition of foreign know-how (see sections 6.1.1 and 6.5). About ten companies are now capable of manufacturing megawatt class turbines, with the three main companies Goldwind, Sinovel and Dongfeng leading the way. These three companies are expected to capture about 60% of China's wind market by 2010 (Windpower Monthly 2008) and are the potential candidates for successfully expanding their market overseas.

6.1.1 Wind turbine company profiles – Goldwind and Sinovel

The one primary domestic manufacturer is **Goldwind**³⁴ (*Jin Feng*) from Xinjiang province. Goldwind was born in 1986 as part of a small research project collaborating with the Dutch Government importing small 150 kW turbines to test in China.³⁵ By 1995, the company was also receiving loans from the German Government to develop 600kW turbines under a license agreement with the German firm Jacobs Energie (Windpower Monthly 2008). In 1999 the Chinese Ministry of Science and Technology began directly supporting Goldwind with the goal of building up a domestic wind power market leader. Since then Goldwind has been aggressively developing new technology and expanding its market share. The company's sales recorded a compound annual growth rate of over 100 percent for nine consecutive years since 2000. By the end of 2009, Goldwind cumulatively had installed over 5,500 units of wind turbines, mainly 1.5 MW turbines. In 2009, Goldwind was ranked the fifth largest wind turbine manufacturer globally in terms of newly installed capacity (PRNewswire-Asia 2010).

As a 55% state-owned company Goldwind has been a primary beneficiary of government policies that protected the niche market and preferentially supported utilisation of domestically manufactured wind turbines. Goldwind has managed to reach a technological turbine manufacturing capability level in about five years that took European manufacturers more than a

³⁴ <http://en.goldwind.cn/> Jin Feng Ke Ji Gu Fen You Xian Gong Si (金风科技股份有限公司)

³⁵ Interview with William Sun, energy expert of the Dutch embassy Beijing, June 2009.

decade to achieve.³⁶ Initially Goldwind had entered into a licensing arrangement with the German companies REpower and Vensys. This arrangement is an example of how energy technology leapfrogging has been facilitated, initially through purchasing licenses from overseas companies. The German turbine manufacturer REpower provided licences for 750kW turbines, and Vensys Energiesysteme GmbH licensed its gearless 1.2 MW and 1.5 MW turbines. Goldwind has also cooperated with Vensys to produce 2 MW and 2.5 MW turbines with a view toward offshore applications (Lewis 2007).

Other strategies included improving technical capacity by sending employees abroad to obtain advanced training. The licensing agreement prohibited Goldwind initially from marketing their turbines on the international market, a real barrier for further expansion. In a move to shake off this restriction and expand its business overseas, Goldwind acquired 70% of the German company Vensys in 2008 for Euro 41.2 million, the capital raised through the company's IPO at the Shenzhen stock exchange (Windpower Monthly 2008). In October 2010, Xinjiang Goldwind Science & Technology floated \$1.1bn worth of shares in the Hong Kong stock exchange. This revenue will likely be used to acquire further technical know-how from foreign companies.

In a similar approach, the company **Sinovel** (*Hua Rui*)³⁷, only established in 2004, initially licensed German technology from the small wind turbine maker Fuhrlander. Using and adapting this technology, Sinovel became the first Chinese firm to produce multi-MW sized turbines. The company then developed this acquired technology further, achieving some form of technological leapfrogging and exceeding the technical capabilities of their former German licensor.³⁸ Another form of technical support to develop 3MW wind turbines was provided through the UNDP China Renewable Energy Scale-up Programme (CRESP). Sinovel is now the largest supplier of 1.5 MW turbines in China, meeting about 60% of Chinese demand in 2007 (Windpower Monthly 2008).

³⁶ Interview with Vestas management staff in Beijing, March 2009

³⁷ www.sinovel.com/Companyoverview2.html

³⁸ Personal communication with renewable energy researcher from Institute for Environmental Policy at Tsinghua University, November 2009

The company has also begun to move from acquiring technology to developing their own equipment by setting up a wind turbine R&D centre with more than 200 technology staff members. The SL1500 and SL3000 series wind turbines have been researched and developed independently by Sinovel and the company has full IPRs for these technologies. Currently, Sinovel is undertaking R&D on a 5 MW offshore wind turbine system.

In 2008 Sinovel produced 935 wind turbine units with a total capacity of 1,400 MW, accounting for 22.5 percent of the total new installed capacity for the whole of 2008 throughout China. In 2009 the total capacity of Sinovel wind turbines had more than doubled to 3,523 GW (Scott 2010) and overtook Goldwind to become the largest Chinese manufacturer. Also during 2009, Sinovel turbines were used for China's first offshore wind farm, part of the Shanghai East Sea Bridge wind farm project. Sinovel is also providing technology for the Gansu 10GW turbine project, China's biggest planned wind farm. In addition to becoming a major player in the domestic market, Sinovel has developed a diversified market strategy, establishing links with key companies active in the global wind power sector on a global basis. The company's overseas sales revenue is expected to provide between 30-40 percent of the company's total income in future (Guo and Yang 2009).

Both companies Goldwind and Sinovel have achieved leapfrogging in terms of manufacturing capabilities, product quality and domestic market shares. The leading Chinese wind power companies have now reached a stage where they need to make the step to be able to compete on equal terms with foreign manufacturers, especially where they want to be able to compete in the international market. To be able to survive without the protection of Chinese government policy, these companies also would need to make stronger efforts to improve their innovative capacity, to close the technology gap with foreign players. Having reached this stage of development, Chinese companies cannot expect to gain more technology support from their international competitors. Instead, they are being supported by the government through export financing. For example, in November 2009 China's Export-Import Bank finalised a US\$2.9 billion

deal to finance clean energy technology exports of the China Energy Conservation Investment Corporation, a major energy-efficiency and renewable energy project developer (Borofsky 2009b). Chinese companies certainly have the advantage of cost-competitiveness which will help in entering markets in other developing countries. In order to establish themselves in western countries' high-end markets, improvements in technology quality are still required.

A first example of Chinese turbines being installed in western countries is a Chinese-US consortium building a 600 MW wind farm in Texas costing \$1.5 billion. The Chinese partner is A-Power Energy Generation Systems, a mainland company and the majority investor in Shenyang Power Consortium located in Shenyang; it will provide 240 turbines manufactured in China (Balfour 2009). In 2009 Goldwind, together with two local US American partners, invested to develop a wind farm in Pipestone, Minnesota, and installed three 1.5 MW wind turbines there as a pilot demonstration project. The company already has a production base in Germany and a wholly owned subsidiary in Australia in late 2009. How successful the Chinese companies will be in overseas markets is difficult to judge at this stage of development. It will certainly be difficult to gain significant market shares, particularly in the US and Europe, where there are still doubts about turbine quality and a heightened sense of alertness towards competitors from China. It seems unlikely that Chinese companies will be able to dominate western markets in the way that foreign companies dominated the Chinese market in 2005. However, in other developing country markets with fast wind power developments, such as Mexico or Turkey, Chinese companies will have good opportunities due to their advantage in price.

6.1.2 Future innovation potential for sustainable wind power

Wind power is a low-carbon technology to produce electricity; however, the manufacture and disposal of turbines and components still generates some environmental impacts. An example is blades. Most conventional wind turbine blades are made from glass fibre and epoxy or polyester

resin. The glass can be recovered, but only by burning off the resin - a waste of valuable material derived from fossil fuels. There are predictions that by 2015, given the continued growth of the global wind turbine market, one 15 tonne blade will need to be scrapped and replaced every three minutes (Butcher 2009).

Achieving a higher degree of product quality and value where wind energy companies produce wind turbines and equipment in an environmentally sustainable way is beginning to occur through the use of bamboo. Although replacement rates would be higher, using bamboo as blade material is suitable due to the high-strength fibres, and production is less energy intensive and polluting than commonly used materials such as fiberglass, polymers or resins. Bamboo strands can be processed in a similar way to glass fibre. Because the bamboo fibres are bound together by their own natural resin, blades made by this method contain only 10% by weight of synthetic resin, compared to 40% for glass composites (Butcher 2009). Furthermore, once the high-tech fatigue life of the blades have been exhausted, the bamboo is still good enough for other uses such as furniture and building materials. Bamboo blades of a length up to 20-30 metres do not require reinforcement of glass fibre (Risø DTU 2008). Bamboo blades made entirely with natural resins derived from plants would be fully biodegradable and could be used to fertilise the next crops of bamboo or composted at the end of their service lifetime.

Increased use of bamboo as a resource can also bring new forms of income to populations in rural areas - China has about 2.8 million hectares of Mao bamboo, much of which grows on mountainous areas unusable for farming (Research Horizons 2007). The use of bamboo in this way clearly adds another dimension to wind energy as an attractive sustainable electricity generation technology, especially if energy prices rise dramatically in future. This technology, however, still occupies a very small niche in China. The Centre for Bamboo and Rattan in China and Denmark's national laboratory Risø DTU are conducting research and developing blades made of bamboo for small and medium-sized wind turbines up to 1 MW. Bamboo blades are a promising idea for China, where the plant grows in profusion in most areas of the country. The

Chinese wind turbine market has yet to make a shift towards using sustainable materials for blade manufacturing on a large scale.

Should Chinese companies be able to further sophisticate bamboo turbine blades technology and make these commercially viable, this would constitute a technological leapfrog, possibly ahead of the established international leading turbine manufacturers which are not actively engaged in this kind of eco-innovation.

6.2 China's solar PV companies

It can be argued that leapfrogging is occurring not only among companies in the wind energy sector, but also among solar PV companies. Interestingly, solar PV companies have developed quite differently than companies in the wind energy sector. Although large-scale deployment and use of solar PV has not happened in China yet, some solar PV companies have leapfrogged in terms of their manufacturing capabilities, innovative capacity and market shares, both domestic and international. In the areas of silicon-ingot/silicon-rod manufacturing, major domestic producers now have mature technology. In battery manufacturing for energy storage associated with PV (among other technologies such as electric vehicles), the majority of Chinese PV companies are already at an internationally advanced level. In the manufacture of monocrystalline solar cells, which are the key part of solar panels, Chinese companies have achieved a position where they now rival the leading global companies such as First Solar Inc from the US or Germany's Solarworld.

In contrast to the Chinese wind energy sector, in the Chinese solar PV market international companies do not have any prospect of establishing themselves as important actors. In contrast, on the global market Chinese solar PV companies have begun transforming global competition through their low-cost 'disruptive' innovations in this sector. According to the PRTM Photovoltaic Sustainable Growth Index 2010, already four Chinese solar PV companies are among the global

top ten (PRTM 2010). In 2010, Suntech, Yingli and Trina Solar became GW producers and most of them doubled their shipments from 2009. German companies in particular have lost global market shares as they were not able to compensate for the fall in module prices and reductions in production costs during the economic crisis 2008/2009.

It has been countries like Germany with strong solar PV feed-in tariffs which have strongly contributed to the development of Chinese solar PV companies, effectively subsidising the Chinese solar PV industry. According to a market study by the German consulting company Roland Berger (2010), it is estimated that in 2009 every third solar crystalline module installed in Europe was produced in Asia (mainly in China) and the number is likely to increase to about two thirds by 2012. The study also concludes that several of Germany's solar companies are potentially at risk of going out of business as the German industry consolidates and global production will increasingly move to low-cost production regions such as China.

Likewise, the feed-in tariff in California has enabled the Chinese PV solar company Trina Solar to make strong inroads into the U.S. market. Trina is also making its way into the Eastern European market. In 2009, Trina Solar achieved a total net revenue of US\$845.1 million, an increase of 1.6% from 2008; gross profit of US\$237.2 million, a substantial jump of 44.2% from 2008; and gross margin of 28.1%, compared to 19.8% in 2008 (PRTM, 2010). According to one expert, the cost of Trina panels is about one third less than comparable products of European competitors, with quality being at least equal, in some cases apparently even better.³⁹

Overseas markets have, however, not benefited all Chinese solar PV manufacturers. It has been mainly the large players such as Suntech, Trina Solar or Yingli which are benefitting from overseas markets, whereas many small and medium sized solar PV companies are struggling due to the lack of long-term policy support frameworks. Even contracts for projects funded through the Renewable Energy Development Fund (see section 4.3.2) in China are in most cases only possible for large state-owned companies to acquire. Innovative capacity of SMEs is still low

³⁹ Personal communication with Binu Parthu, REEEP Deputy Director General , May 2010

and government support to build innovation capacity of SMEs is so far insufficient.⁴⁰

Furthermore, not in all areas of the solar PV sector are Chinese companies as advanced as in monocrystalline cell and module production. There are still large parts of the PV value chain where the global centers are not in China, such as polysilicon production, inverters and PV manufacturing equipment.

6.2.1 Company profile: Suntech Power Ltd

The company Suntech Power Ltd. is currently the unrivaled market leader in China. Suntech Power was founded in May 2002 and by March 2008 it had become the third largest player in the global solar industry. As of end 2009 it was about to surpass Q-Cells of Germany in terms of volume, and is steadily gaining ground on the world's largest, Arizona's First Solar (Queenie *et al.*, 2009). In 2010, Suntech became the largest PV module maker in the world among silicon or thin-film technologies, with respect to shipments. The PV module shipments of Suntech in 2010 were around 1.5 GW.⁴¹

Suntech started off with the design and manufacture of intelligent controller PV systems in 2003 and received certification from the International Energy Commission which opened entry to then lucrative export markets in Europe and the USA. To generate the capital it needed to grow further, Suntech floated on the New York Stock Exchange in December 2005. With the capital, Suntech made investments in technology development and opened new production facilities in China, and acquired national competitor companies to build Suntech's technical expertise.

By the end of 2008 Suntech had reached manufacturing capacity of 1 GW, and 50 MW of thin film solar cell production capacity in 2009. It is expected that Suntech will reach production capacity of 2 GW in 2010 (Osborne 2008). Suntech has achieved technological leapfrogging in

⁴⁰ Personal communication with Chris Lin, Manager of Tianwei Ltd, Beijing, between May 2009 and September 2010 and Rocky Cao, Sunosis Energy Ltd, Beijing, June 2008 and October 2009.

⁴¹ PVinsights announces worldwide 2010 top 10 ranking of PV module makers.
<http://pvinsights.com/Report/ReportPMM04A.php>

terms of production capacity and at the time of writing is the world's leading solar energy company as measured by production output of crystalline silicon solar modules. Suntech has a clear business goal, to be the world's lowest-cost solar producer. This has so far not only driven the company's growth, but also the continuing increase in solar electric applications around the world. However, to become a global leader in low-cost production will not be sufficient for long-term success; continued innovation and quality improvements will be needed. In addition to price competitiveness, conversion efficiency of Suntech products will be a key parameter in defining whether the company can leapfrog in terms of product innovation. Suntech therefore is putting efforts into developing solar panels that are increasingly efficient. Its current line of products has a conversion efficiency of up to 19%, which is a significant improvement on its early products with 14% efficiency.

In terms of innovative capacity, Suntech's founder and CEO Shi Zhengrong, a PhD graduate in electrical engineering of the University of New South Wales in Sydney, acquired knowledge and experience at the Australian company Pacific Solar where he developed new technologies that dramatically reduced the cost to produce solar energy by significantly reducing the amount of silicon needed in solar cells. After six years at Pacific Solar developing thin film technology, he became one of the inventors on the key patents for this technology. He brought several patents with him back to China and started his company. Advanced know-how and technology was one of the ingredients for successful business development.

Suntech has also developed its own 'Pluto technology' for crystalline silicon solar cells, which is advertised to improve power output by up to 12 percent compared to conventional production methods. At the time of writing, Suntech was awaiting receipt of the patent and licensing rights for the technology. According to the company's website, ongoing improvements of Pluto technology will achieve 20 percent conversion efficiency on monocrystalline PV cells and 18 percent on polycrystalline PV cells within the next two years. One of Suntech's latest product innovations targeting utility-scale, ground-mounted solar farm project developers, is its new

Suntech Reliathon package. For these Reliathon solar panels Suntech provides a 12-year workmanship warranty instead of the standard five years, and a 25-year performance warranty that guarantees a minimum power output for each year of the 25-year period (Wang, 2009). These warranties can be seen as signs of improving quality and confidence in product performance. That the company is beginning to take responsibility for its products and customers is a development moving towards extended producer responsibility which will become relevant in the next decades for setting up recycling schemes for solar PV products which have reached their end of life stage.

Suntech is not only improving its products, but also improving production processes. With the recent acquisition of KSL-Kuttler, a German company specializing in equipment automation in the printed circuit board industry, Suntech has been able to accelerate innovation in this area, aiming for significantly greater automation in PV cell and module production lines over the next years. Suntech's R&D division is increasing conversion efficiency while simultaneously lowering manufacturing costs in China. These are preconditions for making moves to expand production and sales in overseas markets. The plan for 2010 was to set up its first U.S. factory in the area of greater Phoenix, Arizona, central to the US solar market. The plant will have an initial production capacity of 30 MW and is expected to begin production in the third quarter of 2010 (Renewable Energy Focus 2009). In this respect the solar PV companies are moving ahead of their counterparts in the wind energy sector. If Suntech successfully establishes itself in the North American market, it would be a strong indication of that the company and technology are reaching high levels of sophistication.

In terms of international competitiveness, Chinese solar PV manufacturers are ahead of their wind energy peers. Cost competitiveness is their most important advantage as Chinese manufacturers undercut their European peers' prices between 30 and 40 percent (Kovalyova, Bryan and Dinkloh 2010). The main reason for this significantly lower cost is that Chinese manufacturers have the advantage over overseas companies in that they buy polysilicon, the key

material to make solar cells, from local manufacturers with lower electricity and labour costs, and transport costs are minimal. However, the push for low-cost polysilicon production in China has resulted in new types of environmental pollution. In this respect the Chinese solar PV industry is not different from other Chinese export-focused industries, focusing on fast returns on investment, rather than long-term sustainability of the industry.

6.2.2 Moving towards sustainable solar PV

The issue of environmental sustainability of PV companies' manufacturing operations along the value chain needs to be considered to make a holistic assessment about the contribution of solar PV to China's environmental leapfrogging potential. The solar PV industry in China has repeatedly been criticised for resulting in 'consumption abroad, pollution at home.' While the industry's development has occurred in rapid increases of manufacturing capabilities and product quality of many companies, environmental leapfrogging can only be said to occur if the overall environmental performance of a product over the whole life cycle has reduced impacts. It is clear that the majority of Chinese solar PV companies still need to tackle the challenge of reducing pollution resulting from production of solar PV products.

For example, the company Luoyang Zhonggui High-Technology Co. located in Henan Province near the Yellow River has received negative media attention in terms of being a green energy company, producing polysilicon destined for solar energy panels sold around the world, but being environmentally irresponsible by dumping the byproduct silicon tetrachloride on farmland of local peasant communities. Silicon tetrachloride is a highly toxic substance that poses environmental hazards and endangers human health. Exact figures how much waste is produced in total by Chinese solar PV companies and how much appropriate disposal increase production costs are not readily available. This uncompensated environmental damage can be seen as an 'environmental subsidy' to the Chinese PV sector.

Of the more than 500 PV enterprises and R&D units in China, it is highly likely that Luoyang Zhonggui High-Technology Co. is not the only company reducing production costs by avoiding appropriate treatment facilities for the waste products of PV polysilicon production. By mid 2008, more than 20 Chinese companies were starting to operate polysilicon manufacturing plants. The combined capacity of these new factories has been estimated at 80,000 to 100,000 tonnes -- more than double the 40,000 tonnes produced globally in 2008. Detailed information on these issues and the seriousness of the soil and water pollution are lacking (Cha 2008)⁴².

Looking 'downstream' towards the far end of the value chain, recovering and recycling of old solar panels is another emerging future challenge for the solar PV industry. The waste generated by PV products is in direct correlation with the growth of the global PV market. Recycling of end-of-life modules is necessary as PV panels often contain lead and cadmium which can pose health hazards if disposed of in a landfill (Gies 2010). Recycling is therefore an essential step on the way to a sustainable use of energy and materials in the PV industry. The recycling of PV modules is technically and economically feasible. PV modules contain materials that can be recovered and reused in either new PV modules or other new products. Industrial recycling processes exist for both thin-film and silicon modules. Materials such as glass, aluminium, as well as a variety of semiconductor materials, are valuable when recovered, but environmentally harmful when simply disposed of.

According to estimates by the German Ministry of the Environment (BMU), total solar PV waste in Europe amounted to 2,333 tonnes in 2007 (including production waste); this is estimated to increase to more than 35,000 tonnes by 2020 (Sander 2007). The study acknowledges that due to a large number of elements of uncertainty, exact quantification is difficult. For China, so far no comparable study exists. Given the estimated growth of the Chinese solar PV industry, the waste figures could be even higher than those from Europe.

In the current situation in China, where recycling and recovery for most waste products is

⁴² Presentation by Zou Xi, journalist for the Beijing Science and Technology Report, at the Beijing Energy and Environment Roundtable June 3rd, 2009.

not well regulated, the recycling of solar PV products and energy storage technologies, particularly lead acid batteries, will pose a challenge for enterprises and regulators. A recycling system solely based on the informal sector or voluntary commitments by industries is evidently not sufficient; a solution will very likely also require strong government regulations.

Another question is whether Chinese companies take responsibility for the PV products they are selling in other countries. There are already initiatives underway, initiated by European PV companies, to deal with this emerging issue, but increasingly also involving Chinese enterprises. In May 2009, Yingli became the first China-based company to join PV CYCLE⁴³, an organisation based in Brussels, that promotes voluntary take-back and recycling of end-of-life PV modules. PV CYCLE aims to define collection and recycling targets for the PV industry, and develop voluntary agreements among members.

Creating truly innovative and sustainable PV products will need to include a focus on environmentally conscious supply chain management and introduction of concepts and practices such as extended producer responsibility, take-back and recycling schemes for used solar PV systems, and a service orientation, to ensure that environmental impacts of products are addressed fully, from resource extraction to the end-of-life phase. So far this has not happened. While this is not yet an urgent problem, by 2020 the Chinese solar PV industry take-back schemes, collection points systems and recycling schemes and facilities will need to become operational.

6.3 Solar water heater companies

The Chinese solar water heating (SWH) industry often stands in the shadow of the Chinese solar PV sector, although it is by no means less advanced. Some Chinese SWH companies are already global leaders in solar thermal technology, a sector dominated as a whole by Chinese

⁴³ <http://www.pvcycle.org/index.php?id=3>

companies. China's largest SWH company, **Himin Solar Energy Group**, has in less than a decade become the world's leading manufacturer of SWHs. According to Himin's website, the company achieved growth from manual workshop production of solar products to large-scale industrial production system in a ten-year period, an expansion which has taken industrialised countries 60 years to achieve.⁴⁴ This development has largely been achieved without the technological support of foreign companies, but through the support of provincial and local government policies.

In contrast to the Chinese solar PV industry, the SWH market is largely domestic, the main product types being glass vacuum tube SWHs. Around 95 percent of the key technologies associated with SWH are generated and produced within China (Huang and Geng 2010). With sales of over 2 billion CNY (US\$280 million) in 2007, the Himin Group is an industry pioneer, and has helped to bring solar water heating into 40 million Chinese homes. Starting off as a small, independent business in the late 1980s, in 1992 the founder Huang Ming was encouraged by local government officials to set up a state-owned company.

However, the State took 70 percent of the profits, and Huang decided to start over again, founding Himin. By the year 2000, the company's sales had reached 500 million CNY (US\$60 million). Diversifying in 2003, the company started building higher quality units, with prices increasing from 1,500 CNY to 3,000 CNY (US\$219-430) for basic models. As of 2009, prices can be as high as 20,000 CNY (US\$2,900) for an installed SWH system, reflecting higher quality levels. The focus on quality, rather than low-cost production, is a clear sign of a maturing industry. Himin continues to be a domestic market leader, with over 14 percent market share.

In terms of innovative capacity, Himin Group has recently undertaken four national research projects under the '863 Programme" (see section 6.4.1). Himin now owns nearly 200 patents, established an independent intellectual property rights system, and entered into photovoltaic, energy-saving glass, solar energy integrated building and other cutting edge research fields. In recognition of the international significance of the company, in 2008 Goldman Sachs invested

⁴⁴ <http://himin.fuzing.com/>

nearly US\$100 million in Himin.⁴⁵

Himin's SWH systems have also reached international standards and gained international quality certification, opening access to the international market. While in domestic markets low prices are the main competitive advantage, in international markets, reliable quality and environmental performance are the main competitive advantages. According to Han, Mol and Lu (2010), for SWH companies like Himin to be successful internationally, they need to adjust their product structure since flat plate and heat pump SWH systems are mainstream in international higher-end markets, and have higher efficiency than the conventional Chinese vacuum tube collectors.

From an environmental leapfrogging perspective, Himin's SWHs have contributed strongly to saving power and thus reducing China's carbon emissions. The company's installed SWHs have so far saved energy equivalent to approximately 20 million metric tonnes of coal, or 55 MtCO₂ (The Climate Group 2008). According to the company's website information the SWH energy capacity of installed Himin products is equal to 4 GW of electricity.⁴⁶

It has been China's SWH technology and companies which have played a key role in helping several cities to achieve leapfrogging in reduction of residential electricity consumption and create city-level renewable energy technology development zones (see Chapter 7). In the case of Himin, the company has played a major role in creating 'China's Solar Valley' in Dezhou in Shandong Province (see section 7.1.2). Himin has also invested 1 billion CNY in the construction of an "International Environment-friendly Energy Conservation Demonstration Zone" and a "Chinese Solar Energy Demonstration Town".

6.4 Supportive policy frameworks for company innovation and R&D

From the examples above it can be seen that one of the features of China's renewable

⁴⁵ <http://www.forbes.com/feeds/afx/2008/12/12/afx5813430.html>

⁴⁶ <http://himin.fuzing.com/>

energy technology innovation is the role of foreign technology acquisition in the innovation chain. Furthermore, indigenous innovation capacity and R&D capacity are the crucial elements for companies to achieve the 'leap' from the Chinese market onto the international stage.

From the perspective of technology transfer it has been noted (e.g. Gallagher 2004) that developing recipient countries need to go through a process of developing the capabilities to produce or integrate advanced technologies by themselves, i.e. developing so-called absorptive capacity. Developing absorptive capacities in turn requires strategic policies to build the knowledge necessary for long-term technological innovation that can improve the quality of technology transferred and, potentially, the ability for technological leapfrogging.

As the examples above show, the innovation capacities of Chinese companies are undoubtedly improving. However, in comparison with international companies, there seems to be still a significant, if varying, gap. According to the UNDP Human Development Report 2010 (UNDP, 2010) referring to data from the China State Intellectual Property Office, most applicants for renewable energy-related patents are still foreign enterprise subsidiaries in China. For instance, as of 2009, China's top three applicants for wind power patents were all enterprises from developed countries – GE (155 patent applications), Vestas (51) and Wobben (40). Among the top ten companies, only three were Chinese – Huang Jinlong (34), Shanghai Electric (30) and Xinkai Tongyong (24). Although much wind power equipment is produced by Chinese enterprises, the real owners and innovators of new wind power technologies seem to be still foreign companies.

The early stages of all technology development in China traditionally included heavy reliance on foreign technologies which are absorbed, digested and re-innovated (Wong 2010). Competitiveness on price, little R&D, and less quality control will not be sufficient in the long term, especially not for survival in the competitive international market. Relying heavily on licensing of foreign clean energy technologies instead of innovating novel technologies at home is not an economically sustainable future option.

The following section discusses and assesses some the framework conditions which will enable or hinder further development of innovation capacity of Chinese renewable energy companies. The concept of the national system of innovation, one element of the theoretical framework for this research study, emphasises the importance of policy frameworks to support the innovative capacity of companies. While it is beyond the scope of this chapter section to discuss China's national system of innovation in detail, it will describe key relevant policy elements that have enabled Chinese renewable energy companies to achieve their current state of development, the future direction of innovation and R&D policy and challenges still lying ahead.

6.4.1 Energy innovation and R&D policies– current status and future direction

One of the main macro-level innovation policy frameworks, also relevant for Chinese renewable energy companies, is the major policy goal of becoming an innovation-based economy by 2020 and promoting “indigenous innovation” (*zizhu chuangxin*). The focus on innovation is an important element of the “Scientific Development” concept (*kexue fazhan guan*). It is generally acknowledged by most experts that domestic technology innovation and R&D have not been, and by many measures are still not, traditional strengths of modern Chinese industry (Wong 2010). This includes the renewable energy sector, for which science and technology research will play a central role in achieving further leapfrogging of China's energy sector. Several programmes that aim to increase China's innovation capacity have been initiated, including the Key Technology R&D Program, 863 Program, 973 Program, Torch Program and Spark Program.

The Medium and Long-Term Development Plan for Renewable Energy (see section 4.3) emphasises the specific objective of actively promoting the development of renewable energy technologies and industries, particularly by building up a renewable energy technology innovation system. In the Plan, 2010 is set as the target year for China to have achieved the basic ability to produce domestically the main renewable energy equipment it uses. By 2020, local

manufacturing capability is envisioned to be based mainly on home-grown Intellectual Property Rights (IPR), rather than on licensing agreements with foreign companies. Although Chinese renewable energy companies have made strong advances in manufacturing and innovative capacity, and most equipment can now be produced by Chinese companies, the goal for 2010 has not quite been met as quality issues are still a concern. Furthermore, several key components for wind turbines still need to be supplied by international companies.

The Medium- and Long-Term Science and Technology National Development Plan⁴⁷, or S&T Plan, unveiled in 2006, establishes the Chinese government's strategic role in innovation activities through to 2020. The S&T Plan calls for an increase in government R&D funding as a percentage of gross domestic product to reach 2.5 percent by 2020, compared to just over 1.5 percent in 2010 (and 3 percent in the United States and 4 percent in Japan in 2010) (Gordon, Wong and McLain, 2010). Renewable energy technologies are a designated priority area, in particular large wind turbine technology for both onshore and offshore applications, energy battery storage technologies for solar PV applications, concentrated solar power (CSP), building integrated solar PV and biomass. A main goal is to reduce the costs of these technologies and support scaling up. Most of China's renewable energy technology research has been focused on applied research and experimental development. In the S&T Plan, basic research for renewable energy technology is also emphasised.

Some other noteworthy government-funded clean-energy R&D initiatives include the Key Technology R&D Program, the '863 Programme' and the '973 Programme'. All of these programmes allocate a large amount of funds to R&D for clean energy technology development. How much of this will go towards renewable energies is, however, not clear. Renewables being only one of the 'new energy' technologies, it can be assumed that clean coal, nuclear and hydrogen research will each receive a major share.

Generally, China's approach to innovation is heavily focused on hardware solutions and the

⁴⁷ Guo jia zhong chang qi ke xue he ji shu fa zhan gui hua (国家中长期科学和技术发展规划)
http://www.gov.cn/jrzq/2006-02/09/content_183787.htm

development of human resources for innovation appears to be relatively neglected. Shortages of specialised human resources could be a major obstacle to the development of greater sophistication in Chinese innovation in the long term. According to Martinot (2010) tens of thousands—if not hundreds of thousands—of skilled engineers and technicians will be needed over the next decade. To address these issues many Chinese renewable energy companies, project developers and grid developers are beginning to attract highly qualified international experts to work in China, but there are obviously limits as to how much foreign experts can contribute to overcoming the skills shortage.

An idiosyncratic characteristic of China's governance system for science and technology innovation governance system gives the IPR issue an interesting spin. Despite the economic reforms, many environmental and renewable energy technology developers continue to be state-owned enterprises. In the early cases of technology acquisition from foreign companies, the purchases or licensing agreements were first made by a Chinese government agency which then passed the technology to several state-owned companies (Ala-Kurikka 2010). According to Western business practices this type of technology sharing is not acceptable, however, in the Chinese context it is a fully legitimate way of promoting technological know-how. It can be assumed that licenses bought by state-owned companies like Goldwind have also been shared among a range of other wind turbine companies. This would also explain the emergence of such a large number of wind power companies in a very short time.

One of the most important policy measures to strengthen the innovative capacity of China's renewable energy enterprises is to ensure an effective IPR protection system. Although the government has introduced a variety of measures, China's research and business community is still characterised by a systemic failure to protect IPRs, adversely affecting scientific integrity and effective cooperation between businesses. Improving the IPR protection system is an often stated recommendation for the promotion of innovation capacity of companies, and potentially technological leapfrogging.

6.4.2 Next steps for driving innovation in China's renewable energy sectors

The main focus of the government's innovation policy has been the promotion of large, state-owned enterprises with one of the main goals being achieving international competitiveness. Although small and medium sized enterprises (SMEs) make up more than 99% of all enterprises in China (Ho 2005), the innovative capacity of SMEs is so far lacking significantly behind that of the large companies and their counterparts in OECD countries. Still, many renewable energy and energy efficiency technologies are mostly developed and installed by local SMEs, and SME products are readily available in China in a range of sectors. Examples are household biogas, biomass pellets, SWH, geothermal equipment and heat pumps. As Chinese SMEs' survival mostly depends on competitiveness based on low prices rather than quality, improvement in SMEs' quality management and innovation capacity are important to achieve not only development of a few large companies, but of the whole sector.

Furthermore, manufacturing facilities and processes often do not consider environmental impacts and pollutants, as the example of the solar PV industry shows (see section 6.2.2). Many of the problems are not directly related to technology, but are related to management practices and awareness of the workforce. Organisational innovation should be a strong focus and could be easily solved through adequate skills training and capacity development. The challenge is the large number of these newly emerging companies in the renewable energy sector. At the time of writing there was no systematic assessment of the capacities and needs of the SMEs in the various sectors available.

Furthermore, many SMEs have been involved in the innovation of 'low-tech' technologies such as SWH, biomass pellets or household biogas. Developing hi-tech innovation capacity is a matter of earnest concern for Chinese policymakers, due to its connection with the pre-eminent national priority of socio-economic development and the high esteem for any kind of high-tech

solution. As a result, the current system of public support for R&D and innovation is heavily skewed towards industries classified as belonging to the high-tech sector. In the context of innovation of renewable energy companies, policy support for improving innovation of 'low tech' renewables is rather weak. For example, SWH companies are not considered a priority and barely make it on to the political agenda, often because policymakers and the public tend to view it as low in 'technological content' as compared to solar PV. Another reason is that the products on the market are already quite mature (see section 6.3), but there is still much potential for improvements in SWH technology.

There is concern among SWH companies that the main share of government industry support for innovation to achieve the 2020 targets will go to solar PV, and SHW companies will miss out. To bring about a low carbon systems transition, focusing only on hi-tech areas such as solar PV, while itself crucial, will not be enough. SWH is likely to be much more relevant for reducing electricity demand and reducing carbon emissions – and at a significantly lower cost than solar PV. Preferential tax policies, including exemptions from or reduction of value added tax (VAT), income tax and tariffs, could allow SWH companies to devote more resources to technological improvements, R&D and quality upgrades. Increased commitment and attention to developing and implementing SWH on a scale that rivals current policy support for solar PV would likely achieve significant results and support further development of SWH companies, especially SMEs, and further sophistication in SWH technology.

6.5 Business-to-business cooperation and competition between foreign and Chinese companies

In theory, cooperation between foreign and Chinese businesses would play a fundamental role in enabling Chinese companies to achieve leapfrogging. The low-carbon technology solutions and technology transfer would mainly occur within the private sector. The transfer of technology, including both hardware and soft skills, would indeed be of great value for Chinese companies. Business to business exchanges and cooperation are considered particularly important because

environmental and clean energy technologies are by and large not owned by governments, but belong to private companies.

The OECD's (2007) recommendations for China, in its review of innovation policy, therefore include to "develop partnerships with foreign enterprises to contribute to environmental progress through provision of training, technical support and cleaner technology".

In reality, however, there are multiple barriers to cooperation and win-win arrangements between Chinese and foreign companies. OECD-based companies continue to dominate intellectual property ownership of major low-carbon technologies and do not seem willing, sometimes for good reasons, to freely share these with Chinese competitors. On the one hand, the foreign private sector has indeed emerged as an important actor regarding investment, diffusion and innovation of renewable energy technology in China. On the other hand, sharing of technological know-how has been limited, with concerns about competitiveness and protection of IPRs being dominant.

The private sector can contribute to the development of a low-carbon energy sector in China not only through participation in government initiated programmes, but also through improvement of business-to-business relations between international and Chinese companies. This will be an important component in any technology innovation strategy to achieve emissions reduction, not only for China, but other developing countries. Foreign direct investment, collaborative R&D, technology licensing and joint ventures in the renewable energy sector in China have already played some role in the transfer of technology, especially in the wind (Lewis 2007) and solar PV sectors.

International renewable energy companies, particularly those operating in the wind energy sector, are already well established in China. For instance, Gamesa's north coast turbine manufacturing plant in Tianjin is the company's second largest foreign investment, surpassed only by its plant in the US. Germany's Nordex has located two of its three manufacturing centres in China and has established its Asian headquarters in Beijing. Nordex expects to invest an

additional CNY 500 million (US\$60 million) to grow its business in China four-fold in the next three years (Schwartz 2009). Vestas opened a R&D centre in China in October 2010.⁴⁸ (However, for new foreign companies trying to enter the market, the situation is rather difficult, due to the strong competition from both foreign and Chinese players.

Regarding licensing arrangements in the wind energy sector, foreign companies which have sold licenses, were the companies that did not have the capacity to establish themselves in the Chinese market. In selling their licenses they did not have much to lose, in the sense that they were not competing directly on the ground in China. The strategy has been to use the profits from licensing to move on and rapidly innovate new technologies and products. But, they still face risks as they are creating competitors in a key market in the coming years. All of China's leading turbine manufacturers started to build their manufacturing capabilities by technology transfer with western companies. The main technology transfer mechanisms have been licensing and joint development, and in the case of Goldwind and Vensys the acquisition of the whole company. Particularly German companies have been an important source for Chinese companies' technology and know-how acquisition (see Table 4).

Table 4: Company-to-company wind technology transfer mechanisms in China (Sources: Li & Hu 2007, Müller, Robinson, and Zhang 2010, Statistics on China's Wind Energy Installation 2008)

Chinese manufacturer	Technology specification	Year of cooperation	Foreign partner	Technology transfer mechanism	Stage of Production or Development
Goldwind	Gold Wind 660 kW	1997	Jacobs (Germany)	Licensing	Batch Production
	Gold Wind 50 750 kW	2001	REpower (Germany)	Licensing	Batch Production
	GoldWind 70/77 1.5 MW	2005	Vensys (Germany)	Joint development	Batch production for markets abroad
	2.5MW, 3MW, 5MW turbines	2008	Vensys (Germany)	Acquisition of Vensys by Goldwind	Design & Testing
	70/77 FL	2003	Fuhrländer	Joint Development	Batch production for

⁴⁸ <http://www.vestas.com/en/media/news/news-display.aspx?action=3&NewsID=2412>

Sinovel	1500 kW		(Germany)		markets abroad
	3MW and 5 MW turbines	2007	Windtec (Austria)	Joint Development	Design
Dongfang Electric	FD70B/77FL B 1500 kW	2004	REpower (Germany)	Licensing	Batch production for markets abroad
	2.5MW turbines	2005	Aerodyn (Germany)	Joint Development	Design & Testing
Shanghai Electric	SEC82 2 MW		Aerodyn (Germany)	Joint Development	Design
Minyang Wind Technology	83/MY1.5se		Aerodyn (Germany)	Joint Development	Testing
Hanwei Energy Services	aeroBlade 1.5 (rotors for 1.5MW turbines)	2008	Aerodyn (Germany)	Licensing	Batch production

The companies directly involved in the Chinese market try to protect their technologies to remain competitive. Real 'partnership' between Chinese and overseas renewable energy companies only exists in very few cases. The relationship between Chinese and foreign renewable energy companies, especially in the wind energy sector, is increasingly characterised by competition and concerns about IPRs. Joint ventures and licensing agreements have in the past been an important source of rapid technological innovation of Chinese companies, especially in the area of wind power and PV sectors. Two early solar PV joint ventures were dissolved, and since 2003 China's PV companies have been entirely domestic. Two Sino-foreign joint ventures, Xi'an-Nordex and Yitou-MADE, set up in the late 1990s to manufacture wind turbines in China only had limited success (Tan 2010).

The most prominent example of a Chinese company acquiring foreign technology and using it to leapfrog is Goldwind through its licensing agreement and later purchase of the German company Vensys. Most foreign companies have established China-based manufacturing facilities and are choosing not to partner directly with Chinese-owned companies in a way that involves core technologies, technical know-how or IPRs delivered and transferred beyond the company (Lewis 2007).

The Chinese government has tried a range of different policy measures to enable sharing of technologies and know-how. In the case of China's wind sector, a policy instrument to facilitate technology transfer was the 70% 'domestic content' regulation in terms of the value of incorporated materials and components, introduced in 2004 when most of wind turbines in the then very small Chinese market were imported. However, this regulation was eliminated in early 2010. According to Martinot and Li the requirement was dropped as no longer necessary, as virtually all turbine installations were Chinese-produced products (Martinot and Li 2010). Another reason for elimination of the regulation is the goal to move to larger turbine sizes, particularly for off-shore developments. These turbine technologies cannot yet be manufactured in China under the 70% local content requirement.

The regulatory environment is being perceived by foreign players as restrictive, unfair and impacting negatively on their business. However, as noted above, the annual turbine sales of foreign companies have been *increasing*, despite *reduction* in market shares. All foreign wind turbine companies in China face the same situation; therefore contacts and cooperation between the international companies is very close. They are organized through the European Commission Chamber of Commerce and have established a lobbying group under the energy forum of the EUCCC. The European companies try to voice their opinion about the wind power market through this organisation, as a collective body. To be able to influence the market conditions and protect their IPRs, foreign companies work collectively. Foreign players also have good working relations and close dialogue with the main industry bodies, the China Renewable Energy Industry Association (CREIA) and Chinese Wind Energy Association (CWEA). These two organisations are by no means independent industry associations as they exist in OECD countries, but are closely intertwined with government agencies. Nevertheless, these two associations are to some degree supportive of international players in the market. They are some of the few bodies in China that realize the benefits that foreign companies bring to the market in terms of market consolidation and equipment quality improvement. CREIA and CWEA have in some cases

advocated the foreign companies' position to the Chinese government and are seen as important support organisations by foreign industry players.⁴⁹

6.5.1 'Delivering exactly what is desired' -- company profile aerodyn

The German company aerodyn Energiesysteme GmbH⁵⁰ has been developing wind turbines and their components since 1983. The company specialises in research and engineering dedicated to the ongoing development and technological improvements of wind power systems. Initially aerodyn supported mainly small wind turbine and equipment manufacturers in Germany and Europe which did have manufacturing capabilities, but not have the necessary technological know-how and in-house research resources. After wind power market consolidation in Germany and Europe during the 1990s, many smaller companies disappeared and the large companies had by then developed their own engineering and R&D departments. Since the year 2000 the European demand for design and development services for wind turbines is characterized by a declining number of projects with roughly constant market volume. At the same time the global interest in wind energy has been constantly increasing, which lead to a growth of aerodyn in non-European markets.

As a result of these developments in Europe and growing demand from overseas, aerodyn started exploring market opportunities in other regions in which wind power is developing. The company's business concept has basically remained the same: aerodyn develops wind energy systems for companies which will mass manufacture these machines. The only difference is that these companies are now mainly in China and other Asian developing countries. In the last ten years aerodyn has been actively engaging in wind power technology transfer with Asian manufacturers, first with Korean and Japanese customers, and since the end of 2005 to a greater

⁴⁹ Personal communication with foreign wind energy experts who wanted to remain anonymous.

⁵⁰ Information about aerodyn was provided by Lars Klett, company representative in Shanghai, interviewed on 16 August 2010.

extent with Chinese customers.

For the company's market entry into China the support by a German regional government agency, the Economical Development and Technology Schleswig-Holstein (WTSH), was crucial. This agency had already supported other German wind energy businesses with their market entry to China. A second important aspect was thorough legal advice from a law firm with extensive experience in China. Through support of both partners a successful and timely market entry was secured and errors in contract arrangements were largely avoided. Especially keeping control over payment requirements has proven important success factor for aerodyn. The proper time of market entry was critical to secure a strong position in the Chinese wind energy market. aerodyn first set up a representative office in Shanghai, and not soon afterwards registered as independent company in China.

The company differs by nature substantially from other international established wind energy manufacturers operating in China, such as Vestas. In contrast to foreign manufacturers in China, aerodyn is not suffering from increasing competition from domestic Chinese companies. Crucial for the success of aerodyn in China is the fact that the company delivers against appropriate payment just that what is requested by Chinese companies - complete blueprints and construction documents of wind energy systems, either as a licensed product or as a customised product development. Generally, a first step in cooperation is a concept study, considering the customers' needs and technical capabilities. Following this concept study, aerodyn goes on to develop the wind energy system required by the customer and supports the technical realisation of a prototype.

According to Lars Klett, China representative of aerodyn in Shanghai, "essentially nothing has changed over the last twenty-five years in terms of how our company operates – we develop wind energy systems for customers who will then manufacture these systems. Traditionally aerodyn has been designing and developing customer specific wind energy systems. In the last few years in China aerodyn has had a large number of customer requests so that from a business

perspective it seemed more appropriate to have a license model. Because there are not many companies in China providing the services aerodyn offers, this has been accepted by the Chinese market and licensed wind energy systems have become important business for aerodyn in China.”⁵¹

In terms of aerodyn's contribution to the development of Chinese companies technical know-how, it essentially depends on the Chinese customers how they use the blueprint documents and other technical information they receive from aerodyn. Customers of aerodyn will receive blueprints for advanced and technologically sophisticated wind energy systems which basically enable the companies to produce these systems without the need to have extensive prior technological know-how and expertise in wind turbine systems. This basically enables new companies the market entry. Prerequisites are good management structures, a technically literate workforce and adequate technological manufacturing capabilities.

In most cases the delivery of technical design information only means the company can build these machines, in how far companies digest or absorb the technological information, how much they understand the technology, and if they can develop it any further depends on a range of factors. On the one hand, in some cases Chinese customers have already optimised and changed technical elements of the licensed systems. On the other hand, one issue that aerodyn has observed is that in some cases not all the technological advice they provide is followed by their customers. In order to reduce costs, Chinese customers compare the blueprints with the system specifications of domestic competitors and in many cases select cheaper components which then often results in lower quality and reduced performance. To achieve lower prices of turbines of 20 to 30 percent below international market prices, the use of domestically produced components is mostly necessary. It is therefore to some degree unavoidable for Chinese companies to make the tradeoff between quality and cost to be able to have a place in the Chinese market.

Regarding the innovative capacity of Chinese companies, based on aerodyn's experience

⁵¹ Ibid

with their customer companies, Lars Klett still sees that there are issues which hold back Chinese companies to develop their full technological potential and innovative capacity. This impacts the ability of companies to optimise the systems. Lack of critical thinking and hierarchical management structures are some of the obstacles to further enhance innovative capacity on company level. The hierarchical management structures of SOEs where employees are not able to question decisions by superiors are a case in point. The situation is quite different for private sector companies, which are generally less hierarchical, more innovative and show more understanding of engineering knowledge. The issue of innovative capacity will play an important role when Chinese companies will make the move towards manufacturing larger MW turbines. Whilst developing a 1.5 MW turbine into a 2.5 MW turbine based on the same technological knowhow is still possible, developing 5 MW or larger turbines for off-shore application requires many new skills as the large-sized turbines are a different category of technology. Developers and manufacturers need to incorporate a range of new concepts in order for the equipment to be reliable and economical for the specific offshore situations they are developed for.

In terms of cooperation and technology transfer, aerodyn does not consider it problematic to transfer know-how to Chinese companies – rather, aerodyn sees its involvement in the Chinese wind energy market as positive. The company contributes to increasing the quality of wind energy systems manufactured by domestic turbine companies and thereby the wider deployment and use of wind power in China. According to Klett: *“Are we building competitors for the international market? Yes, we are doing this, and we do this without having a bad conscious. We think that wind power technology is a very important alternative to coal-fired power stations in China and the current wind energy boom in China would certainly not have happened relying solely on technology imports from Europe or the US. We therefore do not see it as a problem to create competition. If we contribute to increasing turbine quality of Chinese manufacturers, in my opinion this is a good result.”*⁵²

⁵² Ibid

Government regulations have not impacted on aerodyn's business in China, in contrast to the large foreign manufacturers such as Vestas, GE or Gamesa. One reason is that aerodyn delivers exactly what is desired by the Chinese government – know-how and technology specifications which are needed by Chinese wind turbine companies and cannot be supplied by domestic technology developers or research laboratories.

So far, cooperation with Chinese customers has generally been very good and the overall experience of aerodyn in China has been very positive. At the time of writing the Chinese market is by far the single most important market for aerodyn and the company plans on staying in China for the next years, if framework conditions will not change significantly. The company assumes that for the medium to long term Chinese wind manufacturers will continue requiring aerodyn's services and that through constant technological advancement aerodyn will be able to stay ahead in terms of technology development. The example of aerodyn shows that technology transfer can be a win-win situation for both technology suppliers and buyers - western companies developing technologies and those Chinese companies manufacturing turbines.

6.5.2 The world's leading wind turbine manufacturer in China – Vestas

The world's largest wind turbine manufacturer, Vestas, is also one of the main foreign actors in China's wind energy sector.⁵³ Vestas started selling wind turbines in China in 1985 through Danish government-sponsored programmes to electrify rural communities. These programmes lasted for a number of years and in 2005 Vestas set up its first factory in China. Next to the United States, China is the most important growth market for Vestas and it will continue to be so for the foreseeable future. Beginning in 2007, Vestas had a rapid increase in sales in China, about 60 to 70 percent per year, which can be directly related to the Renewable Energy Law. The

⁵³ Information about Vestas based on an interview with Andrew Knight, Director Communications, and Morton Dyrholm, Government Relations, from Vestas China, Beijing, March 2009.

specification that the grid companies were required to buy a specified amount of wind-generated electricity was very important as well as quota regulations for the power companies to add three percent of wind power to their energy portfolios.

Vestas has not been, and is still not, engaged in a joint venture or other kind of technology sharing cooperation with any Chinese company, nor has Vestas licensed any kind of technology to Chinese firms. The main reason is the protection of the company's intellectual property rights. This is a critical and sensitive issue relating to technology transfer and support of the domestic wind industry. Clearly, the Chinese wind power companies have achieved fast and significant leapfrogging, on the technology side – Chinese competitors have done in five years what Vestas took 30 years to accomplish. Vestas China spokespeople interviewed as part of this research were not able to comment on whether there been a case where a Chinese company tried to copy Vestas turbine technologies, nor what Vestas China does to protect the company's IPRs in China.⁵⁴

Even though the company does not share core technologies, such as central computer software that runs turbine systems, Vestas is engaged in partnerships of other types with Chinese organisations, including businesses. Vestas' partnerships with customers include capacity building knowledge sharing and practical experience of which Vestas has much to offer through being an industry leader. For Vestas, cooperation on capacity development issues such as how to manage projects, troubleshooting and delivering within time is valuable, realistic and involves more concrete action, than focusing just on the narrow definition of technology transfer. According to senior Vestas executive Andrew Knight: *"We also have partnerships with our customers to do their training. Partnerships are moving more and more towards partnerships outside projects and contracts. It's often about sitting together for a few days and talking about things people might need to learn more about. Chinese companies in the long term will benefit a lot from this."*

Vestas has stated the goal of being a positive agent for low-carbon development in China, rather than just being another provider and supplier of turbines. This includes a CSR strategy

⁵⁴ *Ibid.*

which is currently still under development and will be linked to Vestas' core value propositions and will include environmental education, environmental awareness, and resources for sustainable development, to enable small-scale sustainability projects. As part of this CSR strategy, Vestas plans to cooperate with research and education institutions such as Tsinghua University as well as environmental NGOs.

For foreign wind energy companies in China such as Vestas, a positive working relationship with the government is crucial. The Chinese government has the expectation that foreign companies should provide something in return for their access to the growing Chinese market, such as technology transfer or cooperation with domestic companies. In the words of a senior Vestas manager Morton Dyrholm: *"We have to show the government what we are doing besides selling turbines, we have to show that we have value in a number of ways that can help China to develop, and that is the expectation."*⁵⁵

Moreover, Vestas participates actively in a series of Sino-Danish bilateral activities. Vestas is in the position that it needs to associate itself positively with both the Danish government and the Chinese government. Vestas does not rule out to advocate for the Chinese government in times of political crisis or in the context of the UNFCCC post-2012 negotiating process on a selective basis. A good bilateral relationship between Denmark and China is extremely important for Vestas; a worsening of the relationship would have very negative impacts on the company's business operations in China. One reason among others is that more and more wind power developments are decided through a public procurement process rather than through the open market. While the company cannot directly act as an intermediary between the two governments, the company is trying to play a role in improving the general overall relationship. This includes participation in the Danish government's climate focus discussions and other programmes to show the Chinese government that Vestas is making an effort and is willing to deliver in terms of technology transfer, at least in the 'soft' skills such as capacity building and energy infrastructure related issues, e.g. grid connection problems. In the context of climate change and the technology transfer

⁵⁵ Morton Dyrholm, pers. comm.

negotiations under the UNFCCC, a Vestas executive comments that, “the technology questions always come up, of course, and that’s where it becomes tricky... we are dealing with some very, very difficult questions here that Vestas needs to be aware of.”⁵⁶

Through its relationship with the Chinese government, Vestas is also trying to influence policy including regulation of the wind power industry, supporting the development of a competitive market-based system, which is considered to be more advantageous for foreign wind turbine manufacturers. However, Vestas as a sole player has very limited direct influence on the regulatory decision making processes. Nevertheless, Vestas considers that it has some positive influence on the political framework through working with regulators and explaining how wind turbine technology works as part of an integrated and renewable energy system. Its influence and impact is difficult to quantify; Vestas executive Morton Dyrholm states: *“We’re doing anything we can to support the Chinese government solving these problems. We are in the heart of this industry....we shouldn’t just be here to make money, we should be here to help, this is also my fundamental belief. That’s one of our goals, one of our roles we should take on. We are No. One, we are the leader of this industry, that also has some responsibilities.”*⁵⁷

6.5.3 Sino-Dutch Bilateral cooperation - facilitating business cooperation through PPPs

The number of macro-level bilateral energy and climate cooperation programmes between foreign governments and the Chinese government has significantly increased in recent years. Some of these have been described in the previous chapter. These cooperation agreements increasingly have the goal facilitating business-to-business cooperation which would otherwise be difficult to establish. Bilateral cooperation can potentially also facilitate technology transfer to Chinese companies and protect foreign company IPRs. Examples of bilateral cooperation

⁵⁶ *Ibid*

⁵⁷ Morton Dyrholm, pers. comm.

programmes for renewable energy that aim for business and research cooperation are the U.S.-China Renewable Energy Partnership and the U.S.-China Energy Cooperation Program, both initiated in November 2009. How far the Program will be successful in supporting leapfrogging through renewable energy or increasing innovative capacity of Chinese companies remains to be seen.

In contrast to the US, many European countries have already many years' experience in energy cooperation with China. While no official cooperation programme has been initiated between China and the Netherlands, Sino-Dutch cooperation on energy and environment⁵⁸ issues is very strong and is of several years' standing. As early as 1986 the Dutch Government supported the wind turbine company Goldwind as part of a small research project, importing and testing small 150 kW turbines in China (The Climate Group 2008).

The Dutch embassy in Beijing plays an important role as facilitator of cooperation between Dutch organisations and businesses and Chinese companies, government agencies and research bodies. In the embassy there are two departments working on energy cooperation issues. The first is the Aid Programme which directs aid funds towards projects which are energy and poverty related. One early example was a rural electrification project undertaken by the Dutch Aid programme in 2002 providing PV electric power to remote villages in Xinjiang. The project installed 78,000 solar PV and SWH systems in schools, public bathhouses and residential buildings. The manufacture and installation of the systems was carried out jointly by Xinjiang Sunoasis and Shell. For the project, Sunoasis took responsibility for installing and maintaining the systems, while Shell was responsible for supplying the systems and providing technical and management assistance.⁵⁹

The second department in the embassy dealing with energy issues is the economic cooperation department. This department has two main responsibilities: some 60 percent of the

⁵⁸ William Sun, Energy and Environment Officer, at the Dutch Embassy in Beijing, provided the main body of information about the Sino-Dutch cooperation.

⁵⁹ 'PV in China's rural areas' <http://www.enf.cn/magazine/issue1/pv.html>

responsibility consists of working with Chinese governmental agencies, providing advice on energy issues. In this field the embassy does not provide policy advice or try to influence what the Chinese government should do. The embassy is also very careful not to give the impression that the Netherlands is trying to interfere in domestic decision-making processes. The other 40% consists of helping companies to develop their business in China. The embassy provides support in the form of information about policies and regulations, and developments in the Chinese energy and power sector. Some companies have very close ties with the embassy and receive strong support which is crucial for successful wind power business operations in China – despite the size of the market and its fast growth, the market is extremely competitive. Other EU countries and their wind companies, particularly Spain and Denmark, are also competing with each other to strengthen their influence in China and increase their market share.

The cooperation between China and the Netherlands is perceived as having mutual benefits. Dutch technologies and innovations in the environmental and energy related field are valuable as China addresses sustainable energy development. Dutch energy companies, such as Eneco, and their clean energy technologies have potentially a very large market in China and are therefore very active in exploring the Chinese market. There is also a political benefit as this cooperation also strengthens the bilateral relationship between China and the Netherlands. Inside the EU the Netherlands is the second largest trade partner with China, with energy and environmental technologies having an important and growing share of this trade.

The relationship is currently entering a new phase with a strong focus on wind power. The Dutch wind power community is very active in expanding its business worldwide. China, with its large market and economy underpinned by the Chinese government ambition to develop sustainable energy, is very attractive for Dutch businesses. Many Dutch renewable energy companies entered the Chinese market as early as 2000 with new companies emerging just in recent years. An example of a large Dutch player in the Chinese wind power sector is the company CTC-Energy, a blade engineering company.

Due to the strong business focus the issues of technology transfer and IPRs are ongoing important issues for Sino-Dutch cooperation. Dutch companies are leading innovations in many fields of environmental and energy technologies, and are careful to protect their IPRs. Currently technology cooperation and transfer is very limited between Dutch and Chinese companies. An example is the Dutch company CTC which offered technical support to Chinese companies with wind blade development and received a share of the profits when the product was sold by the Chinese company. According to William Sun, Energy and Environment Officer at the Dutch Embassy in Beijing, technology transfer is an important issue. His comments are offered here in some detail, as they provide insight into a key aspect of technology transfer between companies.⁶⁰

“Actually, I have checked and every party seems to be quite sensitive about the issue of knowledge transfer.... I cannot confirm there is some technology transfer between enterprises.”

Regarding the potential of leapfrogging supported through Dutch-Sino cooperation the current status is not too positive:

“I actually hear more talk on this, and see less action. It’s a very nice idea, even the Chinese Premier on many occasion called on this, but most of these technologies [which enable leapfrogging] are owned by business companies. It is not always easy to make them share, or let China acquire that technology easily. So the actions for promoting leapfrogging until now are quite limited between Netherlands and China, I think this is true for most cooperation with what we call developed countries.”

Despite the lack of technological cooperation and transfer of know-how, William Sun is positive about the influence of Dutch companies on China’s energy development:

“Dutch companies will play a big role in innovation in the Chinese energy sector. China has abundant capital and Chinese people closely follow new technological developments. Through long-term cooperation and business benefits, the Dutch business community will play a positive role.”

⁶⁰ Quotations by William Sun, Interview February 2009, Dutch Embassy, Beijing.

Not only Dutch businesses, but also research partnerships play an important role in this cooperation. The Dutch national governmental research agency ECN (Energy Centre Netherlands) which has expansive research facilities for wind energy in the Netherlands is very actively involved in research cooperation. Another institute is WMC, a research institute under ECN, with a focus on the wind power sector.

One recent new development is the Sino-Dutch Wind Energy Research Centre in Baoding. In early 2007 the Chinese Academy of Sciences (CAS) and ECN⁶¹ initiated a plan to set up a joint-research centre. This research centre has the goal to perform research for Chinese wind turbine manufacturers and will include a large test facility for wind turbine blades as well as a test field for testing wind turbine prototypes. One major goal of the centre is also to assist Chinese companies to make progress towards developing larger wind turbines with more generation capacity. An agreement was signed as a first joint-project, and a feasibility study for a Joint Research Centre was produced. The conclusion of the feasibility study is that the establishment of such a centre would be beneficial for both parties. This report was finalized in mid-2008 and was submitted to both the Dutch government and Chinese authorities, in this case NDRC and related government ministries. On the Chinese side NDRC has given an oral confirmation and promise that the CAS will be the leading party in setting up the research institute. Both CAS and ECN are applying for governmental funding support, from the NDRC and the Dutch government respectively. The approval for financial support has not yet been granted and is expected to be a long-term procedure. From the Dutch side the project will be financed in part by the Ministry of Economic Affairs in the context of the Dutch Programme Economic Cooperation Projects. There will also be companies involved in the project. An example is the company Huayi⁶² which has a close relationship with CAS and has the role of technical advisor and supplies the intelligence and research support. This company also plays the role of pioneer to carry out tests, development and commercialization of the CAS research results.

⁶¹ "Co-operation between ECN and Chinese Academy of Sciences"
<http://www.ecn.nl/en/wind/news/item/article/191/558/>

⁶² 华翼 <http://www.hywind.cn/>

Another government supported research partnership will be established between Tsinghua University and TU Delft University. An inauguration event was held in October 2008 with participation of high-level political leaders from both countries, showing the political importance of such a partnership. Workshops on a range of different clean energy technologies including solar, wind, clean coal, biomass and efficient building were held. Both universities are very actively involved in this cooperation based on mutual interest. The long-term plan of the Dutch government is to set up a joint education and energy research centre located at Tsinghua University. This project is still under exploration with the establishment of the centre planned for 2010. The centre's field of activities will include student exchange programmes and a joint research platform. The intention is to promote this research cooperation nation-wide, with other universities joining at a later stage. The centre name is likely to be Sino-Dutch Education and Energy Research Centre.

6.5.4 Failed Cooperation - Wuxi Ryle Zhufeng Technology Co. Ltd

It is also important to note that many potentially mutual beneficial business partnerships in the renewable energy sector have been unsuccessful. An example of a failed renewable energy technology cooperation joint venture in the wind blade sector is that between the UK-based technology company Ryle Technology, specialising in wind turbine blades from the renewable resource bamboo, and the Chinese company Miracle Logistics.⁶³ The two companies had formed the Wuxi Ryle Zhufeng Technology Co. Ltd. Joint venture in August 2006 for the operation, development, and production of bamboo-made vanes for wind power generators. After only two years of cooperation in early 2008, Ryle Technology and Miracle Logistics separated and in due course ended the joint venture because of divergent ideas on operation and management, which

⁶³ Information about the experiences of the Wuxi Ryle Zhufeng Technology Co., Ltd. Joint-venture provided by Dr. Jim Platts, personal communication, March 2010.

made further cooperation difficult.

The joint venture Wuxi Ryle Zhufeng Technology initially set out to manufacture bamboo-made wind turbine blades for 800kW turbines. However, in the two years of cooperation the joint venture failed to produce any blades for trial operations on Windey turbines or even for load testing. After the split, Miracle Logistics had the right to use and share the blade technology of Wuxi Ryle Zhufeng Technology and to develop it further, which they did, supplying 100 sets of blades to Windey. However, these showed serious defects within weeks of beginning operation and are in the process of being replaced. It is questionable whether Miracle Logistics will be able to develop the technology and achieve successful commercial manufacture of the bamboo-made turbines.

According to Jim Platts from Ryle Technology, who brought the technical know-how and engineering expertise to the joint venture, a broad range of issues were responsible for the failure in cooperation and in producing functional blades. On the one hand, there were many technical issues, such as the lack of technical ability of the workforce, which made the manufacture of high-quality products impossible and cooperation difficult.

According to Platts *“in our factory in China we had many workmen...who would begin doing something and within minutes they would be doing it differently (i.e. there was no ability to keep doing something the same) and even if you pointed it out to them, they could not see that they were doing it differently (i.e. they were unable to notice the difference). There was an underlying inability to repeat, and to be consistent, and to know the difference between consistent and inconsistent.”*

Many faults appeared with the manufactured blades, e.g. the blades' trailing edges cracked and carbon fingers broke, which could have been avoided if the technical advice had been followed correctly. However, a deep unwillingness to cooperate and make decisions according to technical data and engineering requirements proved to be the major obstacle to developing functional blades, although the basic technology is completely sound and has much to offer.

On the other hand, this failure cannot only be attributed to the technical capacity of the workforce, but also on management failures. Many decisions of the senior Chinese company management were not made based on available technical data and engineering knowledge. The cultural aspects of 'saving face' and 'loyalty' to the Chinese director, important elements of traditional management structures, made it difficult to point out things that were going wrong, even when technical and engineering expertise clearly pointed to the issues that needed to be addressed and corrected. Even if decisions by Chinese senior company directors proved wrong, mistakes were not corrected. When the errors during trial phases occurred, responsibility was not taken by the persons responsible for the poor decisions; the blade failures were blamed on other factors.

It can be assumed that these issues are not only a single case experience, but rather widely spread among Chinese small and medium sized companies. This example strongly points to a range of underlying issues that are likely to make it very difficult for many Chinese companies to achieve leapfrogging of any kind. According to Platts, creating a technically literate workforce might take several decades rather than years. Changing the existing business culture and management structures is likely to be an even harder challenge. Also, in a culture that values outward appearance over inner reality, which also permeates the engineering and manufacturing sectors, the results are likely to be a technology that has outwardly the right appearance but is in effect dysfunctional.

6.6 Summary and Discussion

The rapid development and emergence of Chinese renewable energy companies has been widely acknowledged. The questions investigated in this section were whether Chinese renewable electricity companies in the wind power, solar PV and SWH sectors have *leapfrogged* in development, by what means they have achieved their leapfrogging, and what the future

potential for further leapfrogging is.

The findings suggest that some levels of technological leapfrogging occurred, at least among the leading Chinese companies, especially over the last five years. Two main aspects have been most important for Chinese companies to achieve this leapfrogging. The first is the acquisition of foreign know-how, in many cases through licensing of technologies from foreign companies, in the case of wind power particularly German companies, to gain more advanced manufacturing capabilities. While the conditions of these initial licensing arrangements have not always been the most favourable for Chinese companies, they have enabled Chinese companies to pass through early development stages in a relatively short number of years - something that has taken foreign companies decades to achieve. These developments can be classified as leapfrogging, although Chinese companies are still catching up with western market leaders. As Chinese companies show themselves to be emerging as competitors on the international market, foreign companies have become increasingly reluctant to even license their technologies, not to speak of entering into joint ventures. If Chinese companies want to leapfrog ahead of their western competitors, reach the top level of the global markets in terms of product quality, they cannot continue to rely on acquisition of technological know-how from overseas companies, but need to develop their innovative capacity.

The second driver has been government policies which strongly support and protect Chinese domestic companies and enable them to increase their domestic market shares. Various policy frameworks supporting development of Chinese companies have already been put in place, especially for those in the renewable electricity sector. Although low-carbon innovators, including SMEs, are considered key national assets, they are still in need of significantly greater support from policy, particularly to increase their innovative capacity. The challenge for China's innovation policy is to promote innovation in small and medium sized enterprises, as well as to support research into renewable and indigenous materials and technologies that are not considered 'high tech'.

An example here is wind turbine blades from bamboo which, as indicated, has significant potential to reduce environmental impacts from wind blade production, but in some cases have been held back by quality control risks and technical capacity constraints. Policies that effectively supported the existing competitive strengths of businesses driving disruptive low-carbon innovations would expedite a low carbon systems transition in China.

Governments, through bilateral cooperation agreements and public-private partnerships involving companies and research institutes, have in some cases taken the role as brokers between the different sectors of the Chinese economy and western companies. This has to some degree improved the situation regarding IPR protection and providing a basis for joint R&D programmes. Especially EU countries have been engaged in this cooperation for quite a number of years already.

7 Renewable electricity developments in China's cities

Cities in China will be crucial in deciding the direction of China's energy transition and play a key role in China's sustainable future. Already over 170 cities in China have populations of over 1 million people, and the world's first mega-city, comprising Hong Kong, Shenzhen and Guangzhou, is home to about 120 million (UN Habitat 2008). Over the next two decades over 325 million people will migrate to the cities and by 2030 China's cities are expected to house about 1 billion people (McKinsey Global Institute 2009). In 2005 about 40 percent of the country's population was classified as urban – by 2050 it is expected that China's urbanisation rate will be about 70 percent (UN Habitat 2008). To accommodate for this large number of people, over the next two decades China will add some 40 billion square metres of floor space, which means doubling the existing floor space – adding the equivalent of ten cities the size of New York (McKinsey Global Institute 2009)

China's provincial capitals and large municipalities are often viewed as cities that set urban development trends for new technology and policies. These cities also take the lead in the implementation of key policy measures in urban building energy efficiency and climate change mitigation. A study by the Global Carbon Project (Dhakal 2009) shows that the 35 largest cities in China represent less than one-fifth of China's population but produced about 40% of the nation's GDP, consume 40% of the total commercial energy of the nation and emit CO₂ at similar levels. The wide disparity between these cities and the rest of the country in per capita GDP, per capita energy consumption, and per capita CO₂ emissions shows the influence of large cities to shape national energy and carbon profiles. The study also looked specifically at of the four mega-cities of China: Beijing, Shanghai, Tianjin, and Chongqing. It revealed that energy use and CO₂ emissions have increased several-fold, with the growth of the tertiary sector contributing to the most in the last two decades. While the average per capita urban energy use and CO₂ emissions

in many of China's cities is still relatively low, as in the case of Chongqing (3.3 tons/person), in the case of key cities such as Beijing (11.9 tons/registered person), Shanghai (16.7 tons/registered person), and Tianjin (12.4 tons/registered person), emission levels have already reached or even exceeded those in developed country cities. These cities represent rapid urbanisation trends, the accelerated changes in technology, lifestyle, and societal transformation and demonstrate that urban development will increasingly determine China's energy uses and CO₂ emissions for the next few decades.

To counter unsustainable urban development trends many Chinese cities have begun taking action, including in the area of renewable electricity. Although most regulatory frameworks for national renewable electricity development and emission reduction targets are set by the central government, it is largely up to local mayors to design effective policy instruments to achieve low-carbon urban development. The move towards creating low-carbon cities has become a new slogan not only among cities worldwide but also in China. However, most mayors and city planners generally lack access to the knowledge, experience and financial resources to implement such changes. Yet there are some inspiring examples that show how Chinese cities have begun leapfrogging in terms of renewable electricity. Many municipalities are setting targets for future shares of renewable energy in government energy consumption or total city consumption, often in the 10–20 percent range. Many cities are enacting policies to promote solar PV and SWH in particular. Others are promoting industrial development zones for renewable energy businesses or are conducting urban planning that incorporates renewable electricity technologies and building codes for energy efficient housing.

The rapid expansion of renewable energy generation technologies in China is to some extent due to policy flexibility at city level. Some local municipal actors have demonstrated the ability to realise an energy transition on a local level in a relatively short time through innovative policy and regulation, much faster than provincial governments or China as a whole. At the end of 2009 a first inter-city energy conservation and emission reduction manifesto was jointly signed by

mayors of 40 Chinese cities, proposing to take joint action to support achieving the national emission intensity target of reducing carbon dioxide emissions per unit GDP by 40%-45% based on 2005 levels, particularly through renewable energy development (China CSR 2009).

In most cases fulfilling these targets will be accomplished through a variety of policy strategies, e.g. by providing incentive frameworks for renewable energy companies or promoting the installation and diffusion of renewables. Another development that would contribute to renewable energy development in cities is a plan involving major Chinese cities in emission trading schemes (McGarrrity 2010). In the following section several short case studies of cities are presented, which have either already managed a relatively fast diffusion of renewables and/or created renewable energy industry zones, or are in the process of setting up policies to enable an energy transition. A shift to renewable electricity supply for cities will be an important aspect of creating sustainable cities; however, other sectors need to be considered additionally to achieve the creation of sustainable eco-cities.

This chapter will also discuss some developments for vehicle electrification of urban transport sectors and the interdependency with renewable electricity technology deployment.. The last part of the chapter focuses on some of the international partnerships and initiatives which have formed in recent years trying to support the creation of eco-cities in China.

7.1 City renewable energy development – case studies

7.1.1 Rizhao - Shandong Province

The probably most cited example (e.g. ChinaGate 2007; Worldwatch Institute 2007; Fan *et al.* 2009; Bai *et al.* 2009; Kwan 2009) of city best practice in renewable electricity and electricity saving technology is the prefecture-level city of Rizhao in Shandong province. Rizhao received international recognition as one of the winner of the World Clean Energy Award in 2007. The reason for this focus on Rizhao is that municipal government has successfully started a transition

towards becoming a low-carbon city. Rizhao used a combination of incentives and funding for the city's solar industry to promote research and innovation. Legislative tools for integrating SWH into building codes and standards and educational campaigns further encouraged the uptake of renewables. These different policies helped lower the cost of SWH to the level of an ordinary electric heater (about \$190). As a result, SWHs are now installed in 99 percent of all buildings in Rizhao's urban area and in more than 30 percent of residences in its surrounding area.

With the utilization of solar energy in agriculture, construction, street lighting and heating, 3.8 billion kWh of electricity are being saved every year, displacing approximately 1.44 million tons of coal. This shift to renewable electricity has already resulted in a halving of the cities CO₂ emissions. In addition, more than 15,000 residential units in Rizhao use marsh gas generated from agricultural waste water. The city capitalised on this development with policies to promote SWH take-up among the public. From 2001 to 2005, GDP growth rate for Rizhao averaged 15 percent per year – implying almost a doubling of income levels in only five years. All new buildings are required to include SWHs, and the government oversees construction to ensure that this regulation is enforced and the panels are properly installed. The government has run educational campaigns to encourage people to install solar in their homes, and some government bodies and businesses have provided solar installations to their employees for free. Partly due to the widespread use of solar energy, Rizhao is consistently among the top 10 cities in China in terms of air quality.

Looking beyond the city's energy supply infrastructure and industry, Wang et al. (2009) carried out an ecosystem service assessment for Rizhao. The study shows that as a newly developed port city of China, Rizhao started rapid urban development when it was upgraded from a county-level into a prefectural-level city in 1989. In the early years of the 1990s, Rizhao experienced strong growth in population and heavy industry, this led to significant loss of arable land, forests and wetlands. This trend was changed in 1996 with the Rizhao's ninth Five-year Plan and a new direction in urban development was initiated in 2001 with the promulgation of a

long-term plan by the city government to *Build Rizhao City as an Eco-city (2001–2020)*.⁶⁴ The plan specifically states the goals of protecting and improving urban ecological quality, preventing and controlling environmental pollution and protecting residents' health.

Wang et al. (2009) conclude that implementation of more eco-environmentally friendly urban development policies in recent years have contributed to the protection and maintenance of the city's ecosystems. To maintain the quality of Rizhao's ecosystems and environment, current policies might need to be complemented by additional measures such as promotion of eco-agriculture and eco-forestry, sustainable tourism, stricter land-use policies, more financial support for ecosystem protection and the full integration of environmental impact assessments into urban development strategies.

The data show that Rizhao is an example of a city leapfrogging in terms of renewable electricity technology deployment and the development of renewables industries. If the city is successful in realising the goals set out in the eco-city development plan, by 2020 Rizhao would have achieved environmental leapfrogging by significantly reducing environmental impacts of urban development and reversing some of the ecological damages from earlier phases of development in the 1980s and 1990s.

7.1.2 China's 'solar valley': Dezhou – Shandong Province

Possibly drawing on the positive experience of Rizhao, the provincial government of Shandong has set up an ongoing policy programme to support research and development in the solar industry and replicate the experience of Rizhao in other parts of the province. This has encouraged other cities in the province, such as Dezhou, with 5.5 million people a third tier city in China, to follow similar developments. Dezhou has already been named 'China's solar valley' (*zhong guo tai yang gu*). Similarly to Rizhao, SWH application is very advanced with coverage of

⁶⁴ Guan yu jia qiang huan jing bao hu tui jin sheng tai shi jian she de jue ding 《关于加强环境保护推进生态市建设的决定》
http://www.mep.gov.cn/hjyw/200108/t20010822_79084.htm

about 60 percent of all buildings having SWH installations (Huang 2007). Public street lighting is powered almost solely by solar PV. Moreover, solar energy is not only used in home application, but also in industries such as paper making, machinery and textiles.

Solar energy also has become an integral part of Dezhou's economy. The Himin Group (see section 6.3), the world's largest SWH manufacturer, is based in Dezhou which has significantly contributed to the wide deployment of SWH throughout the city. Not only Himin, but a large number of around 100 other companies related to the solar PV and SHW industry value chains have developed in Dezhou and its economic development zone. According to the environmental group Greenpeace, by 2020 about 150,000 people in Dezhou will be employed in the solar energy sector⁶⁵.

The government continues to offer substantial support for the further development of the solar industry in Dezhou, including preferential tax benefits and other supporting policies. A variety of solar products are manufactured in Dezhou ranging from simple flat plate collectors to high end vacuum pipe collectors and high tech solar collectors. The local PV industry manufactures many products for different applications worldwide. Furthermore, company-lead R&D is thriving in Dezhou, particularly in the building sector with many demonstration applications on how to integrate solar PV and SWH into building design. This has created an architecture and building design industry focusing on how to fit and integrate solar heaters and solar PV aesthetically into building design. An example is a new congress center especially contracted for the 4th World Solar Cities Conference, which took place in Dezhou in September 2010. The 75,000 square meter center is a showcase of solar design and solar desalination technology featuring about 50,000 square-feet of solar PV panels on the exterior (Koerner 2009).

7.1.3 Baoding - Hebei Province

⁶⁵<http://www.greenpeace.org/china/en/campaigns/countdown-to-copenhagen/dezhou-solar-story>

Another example of a city which has made strong advances in promoting a renewable energy industry through creating city-level high tech renewable energy development zones is the city of Baoding in Hebei Province. Renewable energy development zones can be regarded as an appropriate unit of analysis for understanding China's innovation system as regional and local innovation clusters are increasingly becoming significant forces in shaping China's development. Analysis treating China's economy as a monolithic entity often misses the nuances in how China innovates (Chen and Kenny 2007). Local governments have been important contributors of investment in infrastructure and supporting institutions for new high-tech industry zones that have become incubation bases for new technology enterprise startups (Gu and Lundvall 2006) and high-tech industry zones which have played crucial roles in developing China's renewable energy technology.

Baoding is a city of 10 million people in Hebei province, located approximately 140 km south of Beijing. The city has undergone an economic transition from relying on energy intensive automobile and textile industries into the fastest-growing national hub of wind, solar and biomass energy-equipment makers in China. Since 2002 the Baoding High-Tech Development Zone has a particular focus on supporting the emerging renewable energy industry. In 2003 Baoding was designated as the main industrial base for development of China's new energy sector. Industries related to renewable electricity (wind, solar) and energy efficiency are important in Baoding's economic structure. Baoding now has the highest economic growth rate of any city in Hebei Province: in 2007, Baoding's GDP grew by 17 percent, with the renewables sector contributing 12 percent of this rise, a factor that is expected to increase to 40% by 2050 (Gang *et al.* 2009).

Baoding's economic shift was enabled by a combination of factors. Its growth as a hub for the renewable energy sector was supported by municipal government policies that included targeted tax benefits for companies and investors. Nearly 200 renewable energy companies have emerged in Baoding, some of which are now among China's biggest manufacturers in their fields. In the period 2002-2007 PV products with a capacity of 436 MW were produced in Baoding. In

2006 the Baoding municipal government committed itself to the concept of Baoding as China's "Electricity Valley" and decided that the further development of renewables should be the nucleus of Baoding's further development. Despite the recent success, Baoding faces many obstacles and challenges. Renewable energy industries in Baoding report practical challenges related to access to and security of supply of necessary raw materials, lack of skilled personnel, room for improvement of necessary public services, intellectual property, market access, and conditions for innovation. At a policy level, there is room for improvement of goals and framework conditions, particularly with regard to solar PV and wind. One of the overall challenges is to link the availability and potential for mass-production of low-cost renewable energy products in Baoding, to recognised needs and emerging consumption patterns in China and beyond (Reinvang *et al.*, 2008).

7.1.4 Kunming - Yunnan Province

Another city which aspires to become the "solar capital" of China is Kunming in Yunnan Province. In 2008, Kunming adopted a renewable energy policy framework "Advice on renewable energy development and use" which calls for 50% of all buildings in the city to have SWH and solar PV by 2010. The framework also established a designated development zone within the city, with buildings there to reach a 70% share, and for new construction to reach a 90% share. Further targets for 2015 include 6 million m² of solar panels city-wide (both hot water and PV), and solar PV capacity of 100 MW. Measures to promote renewable energy include low-interest loans, tax exemptions, and a special fund to encourage private investment. The city has also incorporated solar investments into its own procurement. And the city is providing support for R&D, industry development, university education, and a SWH equipment testing center. Outside the city, construction of the 166-MW Kunming Shilin solar PV power plant began in late 2008 and will become the largest such plant in China, at an investment cost of almost \$1.5 billion.

7.1.5 Shenyang - Liaoning Province

The city of Shenyang in Liaoning Province was chosen as China's geothermal heat pump (GHP) technology pilot promotion city in September 2006. The reason for this choice is the relatively rich geothermal potential in Liaoning Province. In response to being designated as pilot city, the Shenyang municipal government introduced guiding regulations and as a result Shenyang's GHP installations increased from 3.12 million m² in 2006 to 35.85 million m² GHP heating floor area in 2008 – about 18% of the total heating space area of the city, equivalent to a heating power capacity of 1,790 MW (Zheng 2010). The city has plans to increase GHP to at least 65 million m² by the end of 2010. GHP will then account for 32.5% of the entire city's heat supply (The Climate Group 2009). Local industry has developed at the same time. In 2005 there were only about one dozen related companies in Shenyang in 2005, by 2007 there more than 70 specialised companies (Zheng 2010).

7.1.6 Beijing - capital city

The 2008 Olympic Games boosted renewable energy development with a number of projects in the city of Beijing – during the games, one-quarter of all energy consumed at event venues was renewable. Beijing is also supporting renewable energy development in surrounding rural districts. However, in 2008 Beijing still received only 2% of its total energy consumption from renewables. The city had 3.8 million m² of SWH and 1.2 MW of grid-tied solar PV installed. There were also biogas digesters in use by 50,000 households, and 113 small hydro power plants. The 358 'Green Olympic' projects certainly gave the development of renewable energy a strong boost, but renewables growth was off a relatively low base, below the national average. This rather slow development does not constitute leapfrogging in energy development, but it suggests that the transition towards cleaner energy systems can possibly be achieved in a decadal time frame, if

the right framework conditions are implemented. Beijing's 11th Five-Year Plan (2006-2010)⁶⁶ targets a 4% share of electric power capacity from renewable energy by 2010, up from 1% in 2005, and a 6% share of heating capacity by 2010. To achieve these goals, the city allocated 13 billion CNY (\$2 billion) over the five-year period. The city is promoting GHP and provides subsidies of 35 CNY/m² for water-source pumps and 50 CNY/m² for ground-source pumps. The city had more than 500 GHP projects by the end of 2007, using shallow ground geothermal units that cover the urban area and extend beyond the suburbs. Beijing plans to enlarge the 2008 capacity of 10 million m² of heating capacity from water-source geothermal heat pump facilities to 30 million m² by 2010, increasing annually at a rate of about 6 million m². The city offers a one-time subsidy of 35-55 CNY (US\$ 5-8) per m² of floor area for heat supply projects using GHP (The Climate Group 2009). The city has also been installing renewable energy in municipal infrastructure, including 57,000 solar street lamps.

In October 2009 Beijing adopted an updated three-year solar development plan⁶⁷ which was implemented at the beginning of 2010. By 2012, Beijing aims to have established seven million m² of SWH, 70 MW of solar power generation, solar manufacturing output with a value of 20 billion CNY, and the formation of testing centers for PV and solar thermal heating applications. As a medium term goal for 2020 Beijing plans SWH to achieve installation of 11 million m², to install 300 MW of solar PV, and to achieve national leadership in the solar value chain. To achieve these goals Beijing is allocating a total of 1.44 billion CNY (about \$210 million), consisting of 160 million CNY of central government money, 980 million CNY of municipal money, and 300 million CNY in district and county money in investments across its various municipal departments.

A central element of the development plan are the six "Golden Sunshine" solar demonstration projects⁶⁸ which consist of a 20 MW solar PV roof-top project through which Beijing will supplement projects that qualify for the national solar roofs programme with additional

⁶⁶ Personal communication with researchers from Beijing Energy and Environment Research Centre, December 2008.

⁶⁷ 《北京市加快太阳能开发利用促进产业发展指导意见》
<http://www.china5e.com/show.php?contentid=67188>

⁶⁸ 六大太阳能工程 <http://www.china5e.com/show.php?contentid=67070>

financial incentives of 1CNY/watt per year until 2013. Also, a 50 MW solar PV power generation project is planned. Sustainability issues such as land use will be a major consideration, with an emphasis on the use of otherwise degraded land as well as large-scale agricultural facilities to strategically deploy solar installations. Solar campus projects will involve solar installations in 50% of all primary and secondary schools, using SWH, solar-powered lights, grid-connected PV, solar energy science classrooms and other projects, which also have the aim of educating students on the value of renewables. A SWH promotion project will provide a subsidy of 200 CNY per square meter (about 10% of the average capital cost) for the installation of SWH systems. Without specifying details, solar energy use will be promoted in rural communities. Finally, all Beijing city parks and 30 percent of district parks will be equipped with solar lights by 2012.⁶⁹

7.1.7 Wuxi city – Jiangsu Province

Wuxi in Jiangsu Province, population 6.3 million,⁷⁰ has the target to establish a basic industrial system in line with low-carbon economy concepts by 2015. The goal is to slow down carbon emission increases and decrease the carbon intensity of the industry sector by 35 percent compared to the year 2005 (for 2020, the target is 50 percent). 15 percent of the overall energy consumption is generated from renewable energy sources by 2015, and 20 percent by 2020.

Specific policy goals for the promotion and up-scaled implementation of renewable energy technologies on buildings include demonstrating the implementation of hydro-thermo pump and soil-thermo pump systems. Regarding solar power, research and demonstration of BIPV (building integrated Photovoltaic) technology will be promoted with the goal of developing efficient, reliable and safe on-grid solar PV systems. By 2015, 100 MW of on-grid solar roof projects and 10 MW of on-grid BIPV projects will be installed. As in other Chinese cities, the promotion of building

⁶⁹ See also: <http://greenleapforward.com/2010/01/21/solar-hops-us-china-cooperation-provinces-get-going-suntech-shining-strong/>

⁷⁰ Information about Wuxi's renewable energy development plan was provided by Liang Xu, researcher at Wuppertal Institute, Germany.

integrated solar thermal heating technology is another priority. By 2015, the building area with renewable energy applications will have a share of 15 percent of the total new built area, by 2020 this figure will increase to 25 percent.

7.1.8 Xianyang – Shaanxi Province

Xianyang, a city of five million located in Shaanxi Province, has been designated as China's official geothermal city. The Xianyang municipality submitted the application for the name of "China Geothermal Town" in 2005 and in February 2006, the Ministry of Land Resources and the China Meteorological Administration awarded Xianyang City as the first "China Geothermal City".

According to the municipal government's website⁷¹, the proved reserves of underground thermal water in Xianyang are approximately 25 billion cubic metres. The reserve within the wider municipal area of 177square kilometers considered for development stands even higher at 37.3 billion cubic meters, equivalent to 197billion tonnes of standard coal (5.77 million PJ) .The geothermal resources are endowed with high pressure which enables a natural flow up to 120 metres in height.

Xianyang started exploring and utilizing thermal energy as early as 1993. In 2005, before the city had gained the geothermal city status, only 23 geothermal wells existed and were mainly used for physical therapy, public bathing and swimming pools and household heating, According to Xian Yang government, the use of geothermal heating substituted approximately 100,000 tonnes of coal (2.9 PJ) each year.

According to Li (2010), at the time of writing in 2010, 40 wells had been drilled in Xianyang with depths ranging from 1500 – 3500 m, water temperatures ranging from 60 – 130°C, and well production ranging from 55.34 – 350 m³/h. The main use for geothermal energy is now household space heating in winter, but the resources are starting to be used more

⁷¹ Xian Yang Municipal Government website on the city's geothermal development plans:
http://www.xys.gov.cn/channel_1158/2006/0529/63723.html

comprehensively. In 2008, geothermal heating area was 2,100,000 m² and annual production 4 million cubic meter (Li 2010).

According to Icelandic company Verkis, engaged in cooperation Xianyang to further develop geothermal energy, targets for 2020 are 9,000,000 m² floor space heated through geothermal energy.⁷² Under a new joint venture between Shaanxi Geothermal Energy Development and Enx China, Shaanxi Green Energy will contribute to keep Chinese households heated through geothermal energy. The first phase of the project included the construction and operation of a geothermal district heating system, which services three colleges in the city of Xianyang, consisting of a total of 170,000 square meters that burned fossil fuels for heating. The next phase, a 47 million Euro investment, is a substantial expansion of the district heating system to include a new residential area. The project is recognized to have the potential to become the largest of its kind in the world.⁷³

7.2 Renewable electricity and urban transportation systems of Chinese cities

Renewable electricity is an important aspect in achieving low-carbon cities, particularly is the broad-based transitions include strategies for vehicle electrification. Urban transport systems need to be considered in particular. The evolution of the transport sector is complex and the issues of vehicle electrification increase this complexity. In the future renewable electricity systems and urban transport systems will be increasingly interlinked, one of the major innovative ideas being the use of electric vehicles acting as distributed energy storage devices which can feed energy back into the grid at peak times (Andersen et al. 2009). In the following section some of the issues relevant to urban development, renewable electricity and vehicle electrification in

⁷² Verkis company Xianyang project website: <http://www.verkis.com/projects/energy/geothermal/nr/1420>

⁷³ World Clean Energy Awards: <http://www.cleanenergyawards.com/top-navigation/nominees-projects/nominee-detail/project/16/?cHash=72699abae7>

China's cities are discussed. Biofuels and public transport are beyond the scope of this section.

International car manufacturers have been viewing the growth of the Chinese automobile market and the increasing affluence of Chinese consumers as an important opportunity for the industry's future development. However, there are many questions about the feasibility and sustainability of simply replicating the individual mobility patterns of western countries. Several issues have already gained the attention of Chinese policymakers and the Chinese environmental community, including local urban air pollution and health impacts, energy security and increasing oil dependency. Studies show that pollutants from motor vehicle emissions already contribute about 60% of total urban air pollution in Chinese cities (Zhou and Szyliowicz 2005). It is further estimated that the annual economic losses caused by air pollution are in the magnitude of about 5% of China's GDP (Feng 2006). Emissions of the current vehicle fleet are already impacting the health of hundreds of millions of urban residents in China. Despite improved vehicle emission and fuel economy standards closely following European standards, air pollution related illnesses continue to increase.

7.2.1 Vehicle electrification

Vehicle electrification offers a potential opportunity to avoid the replication of fossil-fuel based urban transport systems. There are already signs that technological leapfrogging is currently occurring in the development of China's electric vehicle (EV) industry. In particular, the development of battery technology for electric two-wheelers (E2Ws) or e-bikes is very advanced.⁷⁴ E2Ws are a category of vehicles that includes two-wheel bikes propelled by human pedaling supplemented by electrical power from a storage battery, and scooters propelled almost solely by electricity. These two types of EV bikes have made strong advances in quality, and the diffusion and commercialization has accelerated dramatically since the early 2000s.

⁷⁴ Information and data on E2Ws was provided by Feng Liguang, China Urban Sustainable Transport Research Centre, Beijing, March 2009.

E2Ws emerged from virtual non-existence in the 1990s. Then, in 2000 about 300,000 electric bikes were sold. It can be said that since then leapfrogging occurred in terms of the technological development, deployment and use of E2Ws: the number of E2Ws sold increased to 10 million in 2005 and 20 million in 2006 (Weinert *et al.* 2008). In 2007 an estimated 40 million to 50 million E2Ws were on the roads of China's cities (Asian Development Bank 2009) and, according to a report in the New York Times, by end of 2009 the number increased to 120 million (Goodman 2010). The average E2W has a range of 30 to 40 km with one charge and is quickly becoming one of the dominant travel modes in China's cities – they have proven to be one of the most convenient and fastest travel options for inner city transport.

E2W have significantly reduced environmental impacts compared to other urban private travel options such as cars or motorcycles. The average medium-sized e-bike uses between 3.8 and 7.6 kW/h per kilometer, the use-phase emissions are in the range of 15-27 grammes of CO₂ per kilometer (Asian Development Bank 2009), depending on the emissions factor of the local electricity grid. In contrast, a passenger car in urban city traffic in China uses the equivalent of 47 to 140 kW/h emitting 100 to 300 grammes of CO₂ per kilometer (Asian Development Bank 2009). Even compared to buses (between 8 to 26 kW/h/km; 24-96 g/CO₂/km) and motorcycles (between 21 to 42 kW/h/km; 64-128 g/CO₂/km) (Asian Development Bank, 2009), the environmental impact reduction is considerable, even if electricity is generated through coal; if electricity is generated solely through renewables, the environmental impacts would be even less. Aside from the environmental benefit, it is a more cost effective mobility option. In the case of Beijing, electricity for residential use in Beijing was 0.49 CNY per kilowatt hour in 2009. Given 10,000 km traveled per year, the total electricity cost would be between 186 CNY to 372 CNY. Compared to other options the cost is significantly lower. For instance, 10,000 km travelled by car with an average fuel consumption of ten litres/km at a pump price of about 4.5 CNY in Beijing would incur a total cost of about 4,500 CNY, between 12-24 times more expensive than traveling by e-bike.

To assess the innovation potential of e-bikes it is necessary to look not only at the impacts

generated during the use-phase, but consider the full life-cycle environmental impacts of e-bikes. Approximately 95% of e-bikes in the PRC are powered by lead acid batteries (Jamerson and Benjamin 2007), although lithium-ion batteries are coming into the market. The high life-cycle lead emission rates of e-bikes are about 10–20 times as high as tailpipe emissions from leaded fuel of motor vehicles (Asian Development Bank 2009), and the public health impacts are probably significant, although detailed studies are not available. Here lead pollution from industrial manufacturing processes of batteries stands out as a clear challenge to the environmental sustainability of this mode. Because the large batteries are replaced every 1–2 years, a medium-sized e-bike introduces 420 milligrams/km of lead into the environment during mining, smelting, and recycling stages (Asian Development Bank 2009).

Lead emissions from the disposal stage of batteries could be reduced through appropriate recycling systems. The official recycling rate of lead in China's lead acid battery industry is currently only around 30% (Mao, Lu, et al. 2006). However, the actual recycling rate is likely to be higher, due to the informal recycling sector, some estimates are as high as 85%–100% (Asian Development Bank 2009). Nevertheless, the situation is less than ideal with no formal incentives or take-back schemes for used batteries being so far established. Most people do not return their old batteries to the shop when purchasing new ones, but dispose of them through conventional household waste disposal⁷⁵.

Based on the technological developments and successful experiences of the E2W and battery industry, Chinese companies are now making strong efforts to develop fully electric passenger cars. While producing automobiles clearly requires much greater technological capability and resources than producing two wheelers, several of the top E2W firms have already made the 'leapfrog' from production of E2Ws to manufacturing and selling electric three- and four-wheel fully enclosed EVs (Weinert *et al.* 2008).

There are currently several main companies in China leading the market in electric cars: Build Your Dreams (BYD) Automotive, Wanxiang Group, Wuhan Dongfeng, Tianjin Qingquan and

⁷⁵ Informal personal communication with several e-bike shop owners in Beijing, May 2010.

Anhui Qirui. Build Your Dreams (BYD) Automotive leads the industry and has in recent years received international attention due to their presentation of plug-in hybrid vehicles and all-electrics at international car exhibitions. Most recently, BYD received international media attention through the announcement that US investor Warren Buffet bought a 10% share of BYD Auto for \$230 million. The firm was created only in 2003 and in October 2007, BYD announced the production of a plug-in hybrid electric vehicle sedan in China. In January 2009 the company announced plans to enter the US and European markets in 2011 with a range of electric and plug-in hybrid vehicles. BYD Automotive is also developing all-electric cars with a claimed range of 200 km, these vehicles have, however, not yet hit the market. In addition, BYD is also actively engaged in developing charging stations and infrastructure-related technologies (Schwartz 2008). Having started as a mobile phone battery manufacturer, BYD's strength still lies in lithium-ion battery technology. The battery packs can be used in plug-in vehicles and all electric vehicles as well as be installed in garages where they can be connected to solar panels. The energy produced by the solar panels during the peak time is stored in the battery system and can be used later at night for the home or to recharge vehicles. BYD has already begun showcasing solar homes, complete with batteries storage systems (Balchunas 2010).

Regarding the reduction of emissions of electric cars compared to other passenger car technologies, Gao, Wang and Wu (2008) compared the potential of powertrain technology improvements for private passenger vehicles to reduce carbon emissions of China's transport system. According to the study efficiency improvements of petrol and diesel vehicles could reduce carbon emissions in the magnitude of about 50 percent, moving towards vehicles using compressed natural gas or gasoline hybrids would even result in emission reductions of 55 percent. In contrast, PHEVs and EVs would only result in emissions reduction of less than 20% compared to current vehicles. Only if China's electricity mix consisted of *at least* 50 percent renewable electricity, the carbon abatement potential of PHEVs and EVs would be equal to the carbon emissions reductions of other technologies. Therefore, if the electricity mix remains coal-

based, electric vehicles in China will not offer the same potentials as improvements of the internal combustion engine. While the adoption of electric vehicles in Chinese cities would reduce local air pollution, the effect of vehicle electrification on overall carbon emissions reductions would not be significant. Simply replacing conventional automobiles with electric cars will not result in the emission reductions necessary for climate change stabilisation. The introduction of EVs would certainly be a technological leapfrog, but in terms of environmental improvement, EVs will not have climate benefits over gasoline vehicles.

This shows that an electric vehicle is not a complete solution in itself. Apart from setting up infrastructure charging stations, it is necessary to consider the whole electricity generation system. The fast innovations in China's EV market and renewable electricity sector seem somewhat encouraging, but is it a sustainable solution to private mobility issues in China? While the uptake of E2Ws seems to offer a sustainable transport solution, the development and uptake of fully electric cars is a different story. One factor is sheer congestion: the rapid spread of EVs would create detrimental effects on traffic as fast as would the spread of internal combustion engine vehicles. Creating a zero-carbon car for China's cities will very likely not solve the much bigger problems of urban congestion, traffic fatalities, urban sprawl, and the paving over of arable land.

While there are currently many constraints for China's cities to leapfrog in the urban transport sector, the potential of leapfrogging to small low-impact vehicles, especially e-bikes, exists and has merit, especially in view of the rapidly growing urban populations and automobile demand in China. To achieve significant environmental improvements a strong focus would be needed on radical innovations, rather than incrementally cleaner technologies and efficiency improvements. This does not only mean radical technological innovations, but also social innovation. It would not entail a process of skipping to the most efficient, cost-effective, low-polluting commercially viable technologies available, including E2Ws. Moreover, it would require smart urban design that avoids cities being further locked-in into car dependent urban environments. It would also require public mass transport systems and encouraging bicycle-

based transport modes.

7.3 International cooperation for low-carbon and eco-city developments

In recent years a number of international partnerships have been initiated to support the sustainable transition of China's urbanisation and to develop eco-cities, using China as testing ground and laboratory for low-carbon sustainability projects. In the following section several partnerships which have formed to support various aspects of eco-city development are discussed. It first outlines two examples of failed partnerships which had received significant amount of media attention and had been widely hailed as by both international and Chinese media and environmentalists. Then, other partnerships which might prove to be more realistic and effective in supporting sustainable urban transitions in China, maybe even leapfrogging of cities, will follow.

In 2005 it was announced that **Dongtan, the “the world's first eco-city”**, was going to be built on Chongming Island of the coast near Shanghai. Dongtan was meant to become a model of sustainable eco-city design for other Chinese cities to follow in the future. The original plan foresaw the transformation of the grassy island situated in the Yangtse river delta near the metropolis of Shanghai into an eco-city, housing first about 50,000, and by 2050 more than 500,000 people living in energy-efficient buildings of the highest international standards and using zero-emission public transport systems powered by renewables. The city has been designed to be self-sufficient in energy, meeting all its requirements with renewable sources such as solar, wind, and biomass. Waste was to be recycled as fuel and the waterfronts were to be lined with micro-windmills. The original timetable called for the first phase of construction to be completed as show case for the Shanghai Expo in 2010 and Dongtan was supposed to be connected to Shanghai by a 19 km bridge-tunnel in early 2010 (Cheng and Hu 2010).

Creating such an eco-city from scratch would indeed have been a major leapfrog in urban development. However, at the time of writing, none of the planned constructions of Dongtan were even started.

The Dongtan project was being developed by the Shanghai Industrial Investment Corporation (SIIC), an investment holdings company owned by the Shanghai Municipal Government, one of China's largest property developers. The vision for Dongtan eco-city was first hatched by the international consulting firm McKinsey & Company, the UK-based design, engineering and planning firm Arup was later taken under contract by SIIC in 2005 to design the "master plan" for Dongtan. The project soon after even became an important cornerstone in the UK–China relationship.

In an interview with the magazine *Architectural Design* (Castle 2008), Arup Director Peter Head emphasised that "the dynamism of the area is so extraordinary that things can change within two to three months." Several major changes did subsequently occur which put the construction plans on hold. There are several factors why the project has not yet been implemented including changes in leadership of Shanghai's municipal government and, maybe most importantly, lack of funding.

Should the project be taken up again eventually, some of the underlying problems of which might be hindering successful implementation is the top-down project design scheme which does not include consultation or involvement of the general public. For instance, farmers with fields near the project site had not been informed, let alone consulted, about intentions to transform the area. Some of the prior inhabitants have also already been 'cleared' off the site and moved to Shanghai city (Larson 2009).

Cheng and Hu (2010) note that one of the main characteristics of the conventional urban planning processes in China is a top-down approach in decision-making and lack of public participation, and this has also been the case with Dongtan. However, sustainable planning as a bottom-up process should be based on the involvement of all stakeholders from the beginning

and throughout the planning process, this has not happened in the case of Dongtan.

According to Cheng and Hu (2010, p.125) “Dongtan eco-city project may offer little on improving the sustainability of the developed cities, where 43% of China’s population currently lives”. Currently, a cluster of five villages near Dongtan already exist on Chongmin Island and these have been designated as eco-villages. While these villages are not powered by renewables, they showcase the realities of everyday sustainability in a rural area. According to Cheng and Hu (2010) these eco-villages and other types of sustainable communities, might prove to be more significant than high-tech eco-cities, as they are more relevant for the majority of Chinese people and closer to the China’s realities of rural life. Nevertheless, the Dongtan project, although not realised, has had some positive results as it has inspired other cities and generated significant enthusiasm for green buildings and influenced plans for other sustainable urban development projects in China (Cheng and Hu, 2010).

But even on smaller scale, such as rural eco-village development, international cooperation is not easy. A lesser known project, which also seems to have run into troubles, is the **eco-village of Huangbaiyu** which sought to transform a small village in northeast China’s Liaoning province into an energy-efficient modern community with buildings constructed from locally sourced renewable materials. The China-US Center for Sustainable Development intended to construct Huangbaiyu as a demonstration sustainable village based on cradle-to-cradle design principles as a scalable model. Chinese partner organisation for this project was China’s Administrative Center for Agenda 21. Part of this vision was to use special hay and pressed-earth bricks for housing construction. The eco-village project had been initiated in 2005 by environmental architect and author of *Cradle to Cradle*⁷⁶, Bill McDonough.

According to Larson (2009), local commentators pointed out that to clear the construction site, productive arable land was bulldozed, resulting in no harvest for four years. Cost overruns made the homes unaffordable to many villagers. In other instances, the farmers refused to live in them as the new yards were not large enough to raise animals and sustain a livelihood. Only little

⁷⁶ Cradle to Cradle: Remaking the Way we Make Things, http://www.mcdonough.com/cradle_to_cradle.htm

consideration for the needs of local residents and future inhabitants of the village seems to have been applied in the whole process. At the end, the Huangbaiyu houses ended up as empty uninhabited shells.

According to anthropologist Shannon May who accompanied and observed the process a wide range of factors including “conflicts of interest, desire for rapid scale, personal aggrandizement, a persistently global perspective, technical inexperience, faulty materials, lack of oversight, and poor communication, amongst other things, ensured that the promise of a model ecological development in Huangbaiyu never came to pass” (May 2009).

Both examples of Dongtan and Huangbaiyu, despite their difference in scale, show similarities. The failure of both projects shows the need for more locally guided processes and more community consultation. It seems somewhat incongruous that Chinese urban planning and development practices are often criticised by Western observers for their top-down approach, but that these joint-projects suffered from the same problem. A lack of sound oversight seems to be another major issue that occurred as no one effectively ensured that plans on paper were consistently translated into projects on the ground.

7.3.1 Sino-Singapore Eco-City Project (SSTECP)

A more promising cooperation is the Sino-Singapore Eco-City Project (SSTECP)⁷⁷ in Tianjin Municipality in the country’s north-east. The SSTECP is the first official bi-lateral project that has the goal to establish an eco-city. GEF and World Bank are additional cooperation partners. Rather than directly financing the cities construction projects, with a grant of \$6.16 million from the GEF, the World Bank will assist the local authorities to create the policy, regulatory, institutional, financial and monitoring mechanisms for the “eco-city” which is expected to be home to 350,000

⁷⁷ <http://www.eco-city.gov.cn/eco/shouye/zoujinshengtaicheng/shengtaichengjianjie/en/en.html>

people by 2020. It will be located in the Tianjin Binhai New Area in the Bohai Rim, some 40 km away from Tianjin city center. The eco-city will be constructed on an area of wasteland which has been degraded by years of salt-farming. The wastelands represent a huge opportunity for development and no valuable farmland or ecosystems will be destroyed through urban developments.

On 18 November 2007, China and Singapore signed a framework agreement for the development the project in Tianjin. In contrast to Dongtan ecocity, the Tianjin project has already broken ground. The project moved from concept development in April 2007, to partnership signing and groundbreaking in September 2008 in fast succession. The project seems promising in part because of strong government support and because money is coming from both governments' sources. Furthermore, the project is a PPP with strong participation of the private sector, therefore very much a profit-driven venture. The structure of the PPP includes a consortium of investment and development corporations from both Tianjin and Singapore (The Green Leap Forward, 2008). According to Goh Chye Boon, CEO of the Sino-Singapore Tianjin Eco-City Investment and Development Co., Ltd, one of the consortium partners, the project is not about creating a show case eco-city:

...[Rather,] it is about building not so sexy, but green buildings, [and looking at] how people live inside them. It's about [creating an] eco-lifestyle." (The Green Leap Forward 2008)

The indicators include a number of sustainable consumption indicators which are classified as Good Lifestyle Habits and include indicators such as "the daily water consumption per day each person should not exceed 120 litres by 2013" and "the amount of domestic waste generated by each person should not exceed 0.8 kg by 2013". One of the most ambitious indicators of the project is the proportion of green trips (i.e. mass transit, cycling or walking) used in the city at 90% by 2020. Although the SSTECP does not seem to consult with local communities or environmental groups, so far, this project seems to be on the right track. Whether it will achieve its targets and create an environmentally, socially and economically sustainable city will be seen in

the next few years when the first inhabitants will move into Tianjin Eco-city. The strengths and weaknesses of the cooperation are summarised in Table 5.

Table 5: SWOT Analysis: Sino-Singapore Eco-City Project	
Strengths:	Strong government support through bilateral agreement; low danger of cultural misunderstandings between partners
Weaknesses:	Low level of local stakeholder consultations;
Opportunities:	Innovative ambitious approach that could serve as pilot for scaling up
Threats:	Going the same direction as other high-profile projects (e.g. Dongtan) with maybe expectations set too high; strong reliance of private financing

7.3.2 WWF's Low Carbon City Initiative

Compared to the other sustainable urban projects discussed above, the World Wildlife Fund (WWF) is taking a slightly different approach to low-carbon city development as it does not try to create new eco-cities from scratch, but work with municipal governments on the low-carbon transition of existing cities. In addition to a wide range of environmental protection programmes in China, WWF has set up a Climate Change and Energy Programme to facilitate the development and implementation of Chinese national policies to follow a development path that decouples economic development from energy consumption.

As an important element of the Climate Change and Energy Programme, in 2007 WWF-China initiated the Low Carbon City Initiative (LCCI)⁷⁸ and works with the municipal governments of Baoding and Shanghai. In Baoding, WWF cooperates closely with the National renewable energy Industrial Production Base and the Administration of Baoding National Hi-tech Industry Development Zone supporting the design and implementation of sustainable development projects such as a Solar Energy Demonstration City and a production base of RE. One of the goals for Baoding is to achieve a 50% reduction in energy intensity by 2020 over 2005 levels.

In addition to working with the pilot cities Baoding and Shanghai, WWF has also initiated

⁷⁸ Information about WWF's LCCI through personal communication with Lei Hongpeng, LCCI Project Manager, Mai 2010.

partnerships with other local governments to promote development of RE. WWF supports the establishment of a nation-wide network for information exchange on municipal low-carbon policies and technology cooperation in the renewable energy field, and promotion of investment in and export of renewable energy products. Focus of the LCCI is energy efficiency in buildings, renewable energy and manufacturing of efficiency products. WWF and the city's municipal governments aim to show how economic growth and energy consumption can be decoupled, in order to reduce the environmental impacts from CO₂ emissions and growing energy consumption (Reinvang 2008).

In the context of the LCCI there are now about 50 cities in communication with WWF and each other about how to facilitate the low-carbon transition on municipal level. The goal is to scale up successful pilots and spread best practice experiences among Chinese municipal governments. WWF supports cities mainly in the attempts to develop a systematic approach to low-carbon development. It recommends a six step procedure which includes creation of emission inventories, conceptualization of low-carbon development scenarios, target setting, action plan development, implementation and monitoring. WWF is also providing technical assistance, networking, and bringing together experts with municipal governments. Through the LCCI WWF is taking a facilitating role, it provides recommendations, but cannot request or enforce any of the recommendations. It also tries to involve business stakeholders, which is a cross-cutting issue, connecting LCCI to other WWF projects and stakeholder processes.

WWF has the best reputation of international environmental NGOs among Chinese society and maintains good working relationships with the Chinese government. The influence through the LCCI on municipal development has some potential. It also enables local NGOs to get involved in this project as WWF advocates for more public participation. For instance, WWF set up an NGO consortium including more than 50 influential environmental local NGOs in China to cooperate on low-carbon development.

This initiative and others that might follow this approach will potentially be important to

enable sustainability transitions of cities in China. However, there are clear limits of what LCCI can achieve enabling leapfrogging of cities might not be possible. For instance, although Baoding is a successful example of how a city can transform its economic structure and become a hub for renewable energy development, not every city will be able to follow this example as local conditions of many other cities are less favourable. Furthermore, WWF's facilitating role limited to providing recommendations might not have direct impact on policy making processes and implementation of low-carbon development plans. The strengths and weaknesses of the WWF LCCI are summarised in Table 6.

Table 6: SWOT Analysis WWF China Low Carbon City Initiative	
Strengths:	Extensive international best practice experience; good working relationship with Chinese government
Weaknesses:	Limited influence as international NGO; dependence on foreign funding; not all pilots can be replicated (e.g. Baoding renewable energy hub)
Opportunities:	Creating information sharing through city networks; up-scaling and replication of pilot projects
Threats:	Government restrictions on international NGO activities

7.4 Summary and Discussion

In this chapter several case studies of Chinese cities which have made some significant achievements in the diffusion and application of renewable energy technologies have been described and analysed. These case studies show that there is potential for leapfrogging of Chinese cities and that is achievable in a relatively short number of years, as in the case of Rizhao. The Rizhao example further shows that a combination of factors, including long-term vision and knowledge, strong political will, good policy and management measures, and enforcement of implementation by government agencies are necessary, to achieve such transitions. It might take a decade or longer to see the results of a successful transition management strategy once it has been put in place.

The examples also show that it might be easier for small or medium-sized cities to leapfrog in renewable electricity technology, for the large metropolises like Beijing and Shanghai renewables

installations are rather additional to current electricity supply, rather than replacing conventional energy generation. In terms of technology, it is safe to say that particularly the promotion of SWH technologies and fostering of local industries has proven to be the most effective approach in several cities to achieve significant reductions in electricity use and achieve a shift in the industrial structure of cities.

Whilst these are examples of how some Chinese cities have strongly increased the use of renewable energy and encouraged the growth of renewable energy industries in their cities, so far no city seems to have yet made a real leapfrog towards becoming a sustainable eco-city. To achieve a true transition towards low-carbon and sustainable eco-cities not renewable energy will be a crucial component of any eco-city, but other innovative urban planning strategies and ecosystem protection policies need to be adopted.

An integrated systems perspective demonstrates the connection between renewable electricity, vehicle electrification and sustainable transport. Vehicle electrification is often proposed as a solution for sustainable urban transport. The case of Chinese cities shows that this only makes environmental sense if the electricity is based largely on renewables.

Several international initiatives have attempted to contribute to the development of eco-cities. The two most prominent examples, Dongtan and Huangbaiyu, have unfortunately not (yet) delivered what they promised. The cases show that solutions to achieve eco-city development cannot only rely on top-down processes planned on drawing boards by expert teams. The example of Dongtan shows that many mega-projects that might look good on drawing boards often cannot be realised in practice. These high-profile, visionary projects, after an initial phase of enthusiasm, have failed as actual implementation and oversight of regulations and plans could not be realised. The current bilateral Sino-Singapore public-private partnership for the creation of an eco-city near Tianjin might be on the right track, but also still needs to deliver.

Furthermore, eco-city solutions require public participation. There is a general tendency in China to approach sustainable urban development as a technological problem which can only be

solved by technical and scientific experts. However, creating low-carbon and eco-cities does not require only high-tech solutions such as renewable energy technologies. Equally important are creating a long-term vision, organisational structures and inclusive administrative processes allowing public consultation to implement a long-term low carbon strategy for urban development. It is highly important that in the processes the full engagement, strengths and interests of all stakeholders are considered. These stakeholders include, but are not limited to, property developers, renewable energy technology developers, R&D institutions, green businesses (and those that want to become green), the media, environmental groups and general public.

8 Large-scale deployment and use of renewable electricity technologies

China watchers in both the popular press and the technical/academic media have remarked on the impressive rate of growth of renewable and clean energy in China in the years since the introduction of China's Renewable Energy Law in particular (e.g. Gordon, Wong and McLain 2010; Tyfeld, Jin and Rooker 2010). The following section examines the situation in greater detail, focusing on renewable electricity technology deployment and use, by first outlining the current status of three major renewable electricity technologies in China – small hydro, wind, and solar PV, and two energy saving renewable technologies – geothermal heat pumps and solar water heaters (SWHs) – and assessing whether it is appropriate to speak of leapfrogging development. In addition, specific policy frameworks and their effectiveness which have led to the diffusion of these technologies will be discussed.

Following this, several case studies of the most relevant existing international partnerships and cooperation initiatives for renewables will be discussed and analysed in how far they have contributed to the large-scale diffusion and use of the technologies described above.

8.1 China's small hydro power development

At the time of writing China's hydro power is going through a phase of high-speed development. Hydro power is already a mature technology and industry and accounts for the largest share of renewable energy. While large hydro power, due to its often significant negative environmental and social impacts, is in the context of sustainable development cannot be considered a sustainable form of electricity generation, small hydro power (SHP) is a renewable energy technology option that can enable low-carbon development as it generally causes no

migration or land submersion. The definition and classification of SHP varies from country to country. In China, SHP was in the early stages of development defined as dam constructions under 25 MW capacity. The continuing growth of the national economy and increase in rural energy consumption has likewise resulted in an increase in the definition of SHP capacity range. Now, hydro power plants with installed capacity of up to 50 MW are referred to as SHP (Zhou et al. 2009), which is large compared to other countries' standards such as 25 MW in Canada or 30 MW in the US. 'Small' hydro towards the top of this range can have some adverse environmental impacts, even if these are limited. Small hydro installations below 20 MW are therefore more in line with sustainable energy development.

During the last 50 years of China's development, small hydro power played an important role in electrification in remote rural areas. SHP technology is already fully commercialised and has currently entered a period of rapid growth. In 2004, China's total installed capacity of SHP was 34.66 GW and generated 97.79 TWh of electricity (Zhou et al. 2009). This was already the largest installed capacity of SHP worldwide. However, compared to large dam development, SMP now plays a secondary role in hydro power development. In 2007 the installed capacity and energy generation of hydro power in China totaled 145.26 GW and 486.7 TWh, most of which was large hydro power (Huang and Yan 2009).

In China, SHP mainly supplies electricity for rural markets through county or prefecture grids which often are not connected to the national grid. A county grid ranges normally from around 20 to 50 MW in general. Even on the local level, grid integration is problematic with presently only about 64.4% of the SHP installed capacity and 66.9% of SHP generation being integrated into the county or prefecture grids (Tong 2009).

Local grids and counties are able to set up an independent tariff system of their own. The tariffs for electricity generated from SHP are comparatively low. According to Zhou et al. (2009), the tariff per kWh in 2004 was around 0.27 CNY, compared to 0.36 CNY/kWh for fossil generation, which makes SHP less attractive. Therefore, the growth rate of SHP over the last two decades

has been much lower than that of electricity from coal. In 2004 the share of SHP in rural electricity demand only accounted for 24.8%, a drop from 49.5% in 1990 (Zhou *et al.* 2009).

According to many commentators and experts, developing small hydro power in rural areas is still the most viable option for increasing sustainable rural electricity supply (Pan *et al.* 2006; Tong 2009; Zhou *et al.* 2009) while at the same time reducing the environmental and social impacts associated with large-scale hydro power developments. By 2010, the total hydro power installation capacity reached 213 GW (REN21 2011), of which large hydro power accounted for about 65 -70 percent, small hydro power 20 percent and pump-storage generation for about 10 percent (Chang *et al.* 2009). The national development target for SHP is 75GW by 2020, which is just above half of the exploitable potential which is estimated to be about 128 GW (Zhou *et al.* 2009). In western China the total small hydro power utilization currently accounts for only about 12% of the technologically exploitable potential in the region (Pan *et al.* 2006). This still leaves a significant amount of total exploitable potential.

However, SHP has some disadvantages. For example, most of the unexploited potential lies in rather remote mountainous counties in the western region, where the cost for construction is high. While the exploitation of the remaining potential is technologically feasible, the costs are likely to be higher than current costs. In contrast to other renewable electricity technologies, such as wind and solar PV where costs continue to decline, the exploitation of SHP cost is gradually beginning to increase due to the reduction in easily accessible available resources. Furthermore, the scale of electricity production from SHP is small, compared to large hydro, and it has higher per unit investment cost and lacks economies of scale. Finally, seasonal and yearly variation is unavoidable while demand and consumption are more constant over time.

Despite these drawbacks, if the large unused potential for SHP were to be fully utilised it would contribute to China's low-carbon development, particularly if SHP can substitute for large hydro dam constructions to reduce the latter's negative social and environmental impacts such as forced migration and re-settlement, submergence of agricultural plantations, water resources

reallocation or geological changes. Some SHP projects, mostly micro-hydro, could have social benefits, contributing to local economic development. Besides electricity generation, SHP plants can be part of irrigation and water supply projects to ensure water provision for agriculture.

8.2 Wind power development

China's installed wind power capacity has experienced unprecedented growth rates over the period from 2004 to 2009. According to the New and Renewable Energy Bureau of the NEA the total wind power installation in China increased from 764 MW in 2004 to 42.2 GW by the end of 2010 (Li and Ma 2009; GWEC 2011). The annual growth rate of wind power is over 100 percent, on average 113 percent (Li and Ma 2009) (see Table 7).

Table 7: Wind power installed capacity, electricity generation outputs and capacity factors, 2004-2010 (sources: Li and Ma 2009; EIA International Energy Statistics (accessed 2011); GWEC 2011; China Daily 2011)

	2004	2005	2006	2007	2008	2009	2010
Capacity (MW)	764	1,260	2,597	5,912	12,170	25,805	44,781
Electricity Production (GW/h)	1,265	1,927	3,675	5,425	12,425	26,000 (apprx)	42,000 (apprx)
Capacity factor (%)	18.9	17.4	16.1	10.4	11.6	11.5	11.3

One frequent criticism by both Chinese and foreign wind energy experts is that analyses and planning generally focus only on MW capacity of wind turbines installed, rather than counting electricity actually generated by wind energy installations. In China there is a significant gap between capacity installed and the actual electricity generated as the low capacity factors show (see Table 7).

In 2004, although just 1,265 GWh of electricity were generated from wind in China, accounting for only 0.01 percent of the country's total electricity generation (Li 2005), the capacity factor of almost 19 percent was significantly higher than 11.3 percent capacity factor in 2010. The electricity produced by wind during 2010 reached approximately 42,000 GWh of electricity (China

Daily 2011). While installed capacity and electricity output are increasing, capacity factors are declining. Overall, wind power still accounts for only about 2 percent of total installed electricity capacity and 0.4 percent of China's total energy supply (Kwok 2009).

One reason for low capacity factors is the issue of inadequate grid connection, which has somewhat overshadowed the huge achievement of wind capacity installation. At the end of 2009, of the 25 GW installed capacity, only just over 16GW were grid connected (Neng Yuan Ping Lun 2010). The rapid expansion and scale of wind energy generation, a number of problems with integrating this renewable energy into the national grid are becoming more prominent. One main problem for grid integration is not so much technical, but the fractured organizational and administrative structure of transmission and distribution between national and local levels makes it difficult for grid connections to be made.⁷⁹

Other reasons for low capacity factors are the lack of management experience for effective wind farm construction and wind farm operation, with some installations being poorly constructed and not generating electricity even if grid connectivity is available. These factors also impact the life time of domestically produced turbines, which, even though exact data are not available, is estimated to about 20-30% lower than that of foreign turbines.⁸⁰ Given the persistent difficulties of effective on-shore wind farm management in China, the management of off-shore wind farms will pose additional challenges. Taking into account the actual electricity generated from wind power and the unsolved problems relating to grid connectivity and wind farm management, it is not possible to say that environmental leapfrogging in wind power technology *use* has been achieved.

Despite these challenges, China has since the passing of the Renewable Energy Law emerged as the world's biggest market for turbines and as the locomotive of the international wind industry. and added 13,800 MW in 2009 alone (WWEA 2010), which accounted for more

⁷⁹ Interview with Sebastian Meyer, research director of Beijing-based energy consultant Azure International, June 2009.

⁸⁰ Personal communication with foreign and Chinese wind energy experts.

than 10 percent of the total power capacity installed in that year (REN21 2009). In 2010 the newly installed wind capacity reached about 18.9 GW (BP 2011). The increase in capacity from less than one GW in 2004 to more than 44GW by the end of 2010 clearly shows that wind power in China certainly has moved beyond the status of a niche level technology.

The development already achieved is complemented by high ambition for planned wind power capacity for 2020. China first announced its 30 GW wind power target for 2020 in 2007, and then revised the numbers up to 100 GW by 2020 in May 2009 (Mo 2009). An alternative energy development stimulus plan draft is currently under development, which would see installed wind power capacity increase to 150 GW by 2020, of which 30 GW would come from offshore wind farms (Zheng and Mao 2009). Should China's wind power capacity indeed reach 150 GW by 2020, wind power would certainly begin to re-shaped the technological electricity system and established itself as a crucial element of the energy system, reducing the reliance on coal to some degree.

Over the next decades, however, fossil fuel generation is also likely to have expanded, from about 650 GW at the end of 2009 to about 950-1000 GW by 2020. Thus, the huge development of wind would still not be sufficient to achieve a change on the macro landscape level in terms of wind energy supplying most or even a substantial proportion of China's electricity, as deemed possible by various wind potential assessment studies (e.g., McElroy et al. 2009). If full grid integration of wind power could be achieved over the next decade and if the ambitious (still unofficial) target of 150 GW of wind power were to be installed in China by 2020, as currently predicted by planners and experts, the annual power generation from wind could reach about 250 TWh. In terms of reduction of environmental impacts the avoided annual CO₂ emissions would be about 150 MtCO₂.⁸¹

Taking the increase in numbers and size of wind farm development projects as indicators, China does show signs of leapfrogging. By the end of 2005 there were over 60 wind farms

⁸¹ 1 GWh of wind power can save about 600 tonnes of CO₂ emissions in China, depending on regional emissions factors.

distributed across 15 provinces in China, which increased to over 100 in 22 provinces by 2009 (Schwartz 2009). In terms of the size of wind farm projects, some leapfrogging will likely occur in the period from 2010-2020. China is now constructing some of the world's largest wind power bases of which the six largest wind farm 'bases' include 12 GW in Gansu Province; 20 GW in Hami, in Xinjiang Province; 20 GW in Western Inner Mongolia; 30 GW in Eastern Inner Mongolia; 10 GW in Hebei Province; and 10 GW in Jiangsu Province (Schwartz 2009). The development of wind power bases at this scale and speed is something no other country has undertaken so far.

In 2010 China started the construction of a 120 billion CNY (\$17.6 billion) wind power project in Gansu province. The project, named 'The Three Gorges Dam of the Land', would be China's biggest single wind power station with an installed capacity of 20GW by 2020. During the 11th and 12th Five-Year Plan period, it aims to construct 10 GW and below of wind-power generation. Plans will see around 5 GW of capacity in place by the end of 2010 and around 13 GW by 2015, with total static investment of more than 120 billion CNY (Lu 2010).

On the one hand, the development of such mega wind projects brings socio-economic development opportunities to remote areas and offers employment opportunities for constructing wind farms, monitoring and maintaining wind turbines and other facilities. On the other hand they raise questions about the social sustainability of such projects, e.g. what are the impacts on local communities living in the vicinity of such mega wind farms? Top-down approaches in project planning are characterised by lack of communication between developers and local residents. According to Han *et al.* (2009), local governments and communities do not have enough influence on the establishment of wind farms in their territory, and have no influence on the way wind farms are operated. Han *et al.* (2009) also foresee potential conflicts between local economic interests and wind farm developments in the future, since a large area of land could be taken up without sufficient compensation to local people.

The development of off-shore wind farms might constitute future leapfrogging in the industry. In August 2005, Guohua Energy Investment Company began construction of China's first offshore

wind power plant, Shanghai's East Sea Bridge project, with an installed capacity of 102 MW. The first turbines were put into operation in September 2009; the project will be completed in early 2010. The electricity is fed into Shanghai's municipal power grid. This 'small-scale' demonstration project will have 34 wind turbines, each with 3 MW capacity, at an estimated cost of 2.1 billion CNY (US\$ 307 million), with all turbines and equipment developed by domestic Chinese companies. The East China Sea Bridge wind farm location is estimated to have more than 8,000 annual hours of generation-adequate wind resources: generating efficiency is therefore estimated to be more than 30% higher than that of land-based wind farms (People's Daily Online 2009). Six additional larger off-shore projects are being planned in the Shanghai area over the next few years. They have the advantages of not taking up land, freedom from topographical problems, higher wind speeds, higher capacity turbine units and more annual hours in operation, but disadvantages and challenges in terms of maintenance and operating costs, e.g. corrosion management, grid connectivity and wind farm operation. Furthermore, the frequency of taifuns poses additional risks to investors, technological challenges and even limitations to the exploitation of off-shore wind resources in the East China Sea.

8.2.1 Wind power support policies

The main policy framework for wind power promotion is a FIT system which was updated in July 2009⁸² and which applies for the entire operational period of a wind farm (set at 20 years). Prior to the introduction of the FIT, a dual track system existed in China. The first track was a project-by-project "government approval" process for projects of over 50 MW, which needed to be approved by the NDRC and were given a fixed tariff. Projects of less than 50 MW were selected and approved by provincial governments through a concession tendering process, but prices for those projects were still checked and approved by the NDRC. Five rounds of concession tendering took place between 2003 and 2009. In 2008, tariffs were approved through concession

⁸² Guo jia fa gai wei gong bu feng dian biao qian shang wang dian jia 国家发改委公布风电标杆上网电价 <http://www.creia.net/html/2009727101918320.html>

tendering for more than 72 projects (GWEC 2010).

The initial aim of the concession scheme was to encourage a reduction in the price of wind power in China. However, the strategy partly backfired and tariffs offered by winning concessions were in some cases less than 0.4 CNY/kWh – much too low to be commercially viable. The electricity prices offered were too low for developers to cover their costs and make a reasonable profit, thereby directly affecting the quality of installed equipment and performance of installations. According to most experts consulted during this research, the tendering processes were extremely intransparent and ineffective, and are one of the main reasons for a large number of poorly installed and unconnected turbines.

The new FIT regulation has replaced the previous selection processes. There are now four different categories of tariff, depending on a region's wind resources: 0.51, 0.54, 0.58 and 0.61 CNY/kWh (GWEC 2010). These are considerably higher than the tariffs that resulted from the early concession tendering processes and those currently paid for coal-fired electricity, which average between 0.25-0.4 CNY/kWh (Fu 2009). The level of the new FIT is comparable to that of the government approved tariffs over the past several years in most regions, and it is substantially higher than the concession tariff. It gives investors a much clearer idea of the long-term framework for the sector. The four current tariff levels were still determined in a non-market manner and based largely based on national and regional 'government approved' tariffs developed between 2006 and 2008. Whether the new tariffs are 'right' remains to be seen (GWEC 2010) and future adjustments are likely. Two unresolved questions related to China's wind power pricing remain: First, whether the tariffs will prove to be high enough to ensure installation of high quality equipment. If they are not, financial constraints potentially will hold back the entire industry, but this is not something the government would like to see.

The second question is whether the Chinese government indeed keeps tariffs for wind power projects intentionally low in order to attract international financial support through the flexible mechanisms of the Kyoto Protocol. This second issue is directly related to CDM projects

for wind farm development (see also section 8.7.1).⁸³

8.3 Solar photovoltaic development

The large-scale application and usage of solar photovoltaic (PV) for electricity generation has until 2009 not occurred, except for show case projects. Solar PV has for many years only been an export-focused industry in China. Until 2009 about 98% of the solar PV components and products manufactured in China were exported (The Climate Group 2009). Basically, the solar PV feed-in tariffs in several western markets, particularly Germany and Spain, have subsidised the development of a Chinese PV manufacturing industry.

However, following the collapse of international markets in the wake of the 2008-9 global financial crisis and economic downturn in most countries, China's solar PV industry has been refocusing. Supported by government subsidies to overcome price barriers, the government is trying to absorb in the domestic market the excess capacity of domestically manufactured PV modules by stimulating the internal domestic market and increase demand for solar PV products. However, this is not likely to be easy given the much higher costs of PV per kW than most other electricity generation technologies.

At the time of writing solar PV deployment and power generation is still at a very early stage of development in China. At the end of 2008 the cumulative installed capacity of solar PV was still below the 100MW mark. By the end of 2009, according to the China Renewable Energy Society, the installed capacity of PV plants has climbed to about 300MW (Huang and Gong 2010) (see Figure 18). However, China has great potential for expansion of solar PV in both off-grid applications and PV power stations to supply the grid. Two-thirds of China's land area, particularly in the northwest and southwest, enjoys over 2,200 radiation hours annually and has solar resources in excess of 500 KJ/cm²/year (by comparison, Germany and Japan average only 400 and 450 KJ/cm²/year respectively) (China Greentech Initiative 2009).

⁸³ Personal Communication with experts from the GWEC, June 2010.

Figure 18: Annual Installation of Solar PV in China (sources: The Climate Group, 2009; Huang, 2009; Huang and Gong, 2010)

Unlike Europe and the United States, where the photovoltaic products are mainly used as roof-top PV applications, in China PV stations will be the backbone in the development of the PV industry. A range of large-scale solar projects is currently being planned, some already under development. The currently largest grid-connected solar PV station is located in Shilin, near Kunming city in Yunnan Province. The first stage of the 66MW station was completed and started generating electricity at the end of 2009, while the 20MW second phase and 36 MW third phase are still under construction. Bigger projects are planned. An example is a 2 GW solar power project in Ordos, Inner Mongolia, to be built by the US-based company First Solar. This construction will be the world's largest solar power plant, sufficient to power about three million Chinese households. Another example is ReneSola's 150 MW on-grid solar project in the Taiyangshan Development Zone in Wuzhong, Ningxia Hui Autonomous Region. A third project is the Chinese Government's Dahan solar project, a 1.5 MW solar thermal power plant near Beijing, which will be increased to 5 to 10 MW by 2015 (Queenie *et al.* 2009). Should these large-scale

projects and more of this kind go ahead as planned, China might be able to leapfrog in the large-scale application of solar PV as it has with the construction of large wind power bases. Furthermore, favourable government subsidies and programmes are being initiated and may well support leapfrogging in this sector (see section 4.3).

The main factor which will determine whether solar PV application will experience faster development in the next years is price competitiveness, which comprises the two elements of conversion efficiency and production plus installation efficiency. At present, solar PV is not yet competitive with other energy sources, even though solar electricity cost in China is estimated to have declined by 50% from 2006 to 2008. According to business reports, the cost of polycrystalline silicon PV systems in China decreased to 31 CNY per Wp in December 2008, 50% down from October 2006, due to cheaper polycrystalline silicon, better processing and higher cell efficiency. The projected price for the year 2010 and beyond is closer to around 20 CNY per Wp (Wong 2009).

In China, the installed cost solar PV electricity has declined from around 4 CNY per KWh down to 2-2.5 CNY per KWh (or around 30-40 US cents per kWh) for large-scale solar PV farms, depending on the region. The price for roof-top PV and building integrated PV continues to be high, even in provinces such as Jiangsu, the home of about 160 solar PV companies, at around 3.7 to 4.3 CNY per KWh (Ariel 2009).

According to estimates by Suntech, China's leading solar PV manufacturer, the Chinese solar PV industry could reach a solar energy generation cost of one CNY/kWh (15 cents US) or below for large scale concentrated solar power stations by 2012, approaching the cost of conventional power generation (China Greentech Initiative 2009). Assuming this grid parity is achieved, even if later than 2012, a strong development in the application of solar PV can be expected to take place in China. Market projections in 2009 have suggested China will exceed its original 2020 target of 1.8 GW installed solar PV capacity, and industry reports now indicate the government is proposing a new target of 2 GW for 2011 and 20 GW for 2020 with new policy

support (China Greentech Initiative 2009). However, despite the significant decrease in price of PV and increase in domestic demand through government support, the high current cost of PV and continuous government subsidies for coal are still working against the process of large-scale solar PV application in the short term.

8.3.1 Solar PV support policies

According to Huang and Gong (2010) the National Energy Administration (NEA) calculated that meeting the 2020 target for solar energy, set out under Renewable Energy Development Plan, will require investments of 530 billion CNY in solar technologies, mostly solar PV. This would be approximately 17 percent of the clean energy development budget earmarked by the government for renewable energy development. There is concern among stakeholders in the SWH sector that most of these investments will be directed towards creating a domestic market for solar PV, while SWH support would be neglected.

A strong sign supporting this prediction are two government solar PV support policies issued in 2009. To support the implementation of the Renewable Energy Law, the Chinese government issued the “Solar Roofs Programme” PV subsidy policy, issued in March 2009, followed by the “Golden Sun” policy, issued in July 2009. The “Solar Roofs Programme” was developed and launched jointly by the Ministry of Finance and the Ministry of Housing and Urban-Rural Development. The new regulations are laid out under “Application of Building-mounted Solar Photovoltaic Financial Assistance Fund Management Interim Measures”⁸⁴ to jump-start the domestic solar market.

The most relevant part of the *Interim Measures* is Article Six, which guarantees financial incentives of up to 20 CNY/Wp of installed PV capacity, depending on the complexity of technology used (e.g. degree of integration with building materials) and other factors. The subsidy

⁸⁴ Tai yang neng guang dian jian zhu ying yong cai zheng bu zhu zi jin guan li zan xing ban fa 《太阳能光电建筑应用财政补助资金管理暂行办法》 Full Chinese text: http://www.cin.gov.cn/zcfg/xgbwgz/200903/t20090326_187941.htm

is only applicable for projects that meet a set of specific criteria: The project needs to be a single engineering application of solar PV installed capacity that is not less than 50kWp and applications should achieve advanced efficiency standards, over 16% for monocrystalline, 14% for multicrystalline and 6% for amorphous silicon (thin-film) applications. Priority will be given to building-integrated PV applications, grid-connected building PV applications and schools, hospitals, government agencies and other public building PV projects will receive priority support. These project requirements show that the subsidy programme is different from previous PV support programmes in the past supporting rural electrification through PV development (as discussed in section 5.2). A 50 kW system is not small for a distributed roof top system. The programme aims to promote projects of reasonable scale supporting applications mainly for public buildings in urban areas.

The Solar Roofs Programme is a substantial subsidy plan: given the current decline in costs CNY 20/Wp corresponds to projected average retail costs of roof-top mounted solar PV panels. According to Wong (2009), a solar developer of a roof-top system making use of the subsidy would just have had to pay for the price of installation (which amounts to 60-100% of the price of the solar panels), and get the solar panels effectively free. In other words, the price of installed roof-top solar would have more than halved as a result of receiving the full subsidy.

However, the *Interim Measures* and the CNY 20/Wp incentive level were only valid for the year 2009 and the subsidy rate is subject to revision for future years. Therefore the initial high subsidy can be seen as an interim support measure for solar PV companies which faced overproduction resulting from loss of overseas export markets. The flexibility of the *Interim Measures* allows the government to reduce the subsidy over time as the costs of solar declines with further technological improvement. Nevertheless, the subsidy is a clear signal that the Chinese government encourages the use of solar PV and support will likely continue.

Furthermore, the programme includes promotion of supportive solar policies at the provincial levels (including FIT programmes) and promotion of technical standards. Policies such as FITs

would fall within the jurisdiction of provinces reflecting the understanding that different regions have different solar endowments and different existing electricity tariff structures, thus requiring a more tailored approach that is best left to the provinces. This is similar to current existing FIT arrangements for wind power.

The second major policy to support solar PV development issued in July 2009 is the 'Golden Sun' policy⁸⁵ which complements the Solar Roofs Programme. It targets larger utility-scale projects of more than 300 kWp and is to be seen as a demonstration programme to promote renewable electricity generation and create a domestic market for its solar cell and panel manufacturers. The Golden Sun policy explicitly excludes projects which fall under the Solar Roofs Programme from benefiting under the Golden Sun programme.

The policy stipulates that the government will subsidise 50 percent of the investment for solar power projects as well as relevant power transmission and distribution systems that connect to grid networks. For independent photovoltaic power generating systems in remote regions without power supply, the subsidy will rise to 70 percent. The policy also emphasises grid-connectivity of projects. Grid companies are required to buy all surplus electricity output from solar power projects at similar rates to benchmark on-grid tariffs set for coal-fired power generators. To qualify for the subsidy each project must have a generating capacity of at least 300 kWp, construction will have to be completed in one year and operations will have to have a minimum 20-year lifetime (Bai and Walet 2009). Under the programme the government planned to install 500 MW of solar power pilot projects in two to three years. To guarantee an equal share of projects among the provinces, the total generating capacity of such pilot projects in each province in principle should not exceed 20 MW.

By November 2009 the Ministry of Finance had selected 294 projects totaling 642 MW which require total construction costs of roughly CNY 20 billion. About half the cost for the project's

⁸⁵ Jin tai yang shi fan gong cheng cai zheng bu zhu zi jin guan li zan xing ban fa 《金太阳示范工程财政补助资金管理暂行办法》 Full Chinese text: http://www.china.com.cn/policy/txt/2009-07/23/content_18186602.htm

installation and related transmission costs will be subsidized under the Golden Sun Programme. Technology and pricing requirements for these projects are defined. Prices to be paid for crystalline silicon panels should be no higher than CNY 14 (\$2) per Wp. The ceiling for amorphous silicon panels is CNY 9 (\$1.32) per Wp. Monocrystalline silicon panels must have at least 15 percent conversion efficiency. The minimum efficiency for multicrystalline panels would be 14 percent and 6 percent for amorphous silicon thin films (Wang 2009).

One of the potential drawbacks of both solar programmes is that they reward installed capacity (by providing subsidies on a per Wp basis) and not actual solar power generation (on a KWh basis). Likewise, in the Chinese wind industry the pursuit of installed capacity targets came at the expense of actual electricity generation and turbine quality. Furthermore, many wind farms were left unconnected to the grid. A FIT for solar PV would therefore be preferable, rewarding actual solar power generation. Both programmes mention the creation of FITs for solar PV, which would allow solar power plant operators to sell electricity at government-set, premium prices. Both programmes have sent a strong signal that China is serious about developing its domestic solar PV market, and will undoubtedly stimulate more activity in domestic deployment and further support policies are expected.

The latest policy development to support solar PV is a feed-in tariff for large solar PV plants.⁸⁶ The FIT includes CNY 1.15/kWh on-grid tariff (including tax) will be applicable to solar PV projects approved before July 1 2011 and completed before December 31 2011. Furthermore, CNY 1/kWh on-grid tariff will be applicable to solar PV projects (CNY1.15/kWh for projects in Tibet Autonomous Region) approved after July 1 2011, or approved before July 1 2011 but completed after Dec 31 2011. The NDRC will adjust on-grid tariff in the future according to investment cost variation, technology development, and other factors. According to experts from Chinese solar PV sector consulted during the field research, the policy is not sufficient security for

⁸⁶ Guo jia fa gai wei guan yu wan shan tai yang neng guang fu da dian shang wang dian jia zheng ce de tong zhi
《国家发展改革委关于完善太阳能光伏发电上网电价政策的通知》 http://www.gov.cn/jwqk/2011-08/01/content_1917358.htm

small and medium sized solar PV companies to make long-term investment decisions and business planning.

8.4 Solar Water Heating

In contrast to the solar PV market, China's solar water heater (SWH) market is already mature, although not saturated, and has been growing at approximately 20% per year over the last decade. While SWHs have not been very successful in many other countries, more than 200 million Chinese people already use SWH and the market in China has grown rapidly, accounting for about 60 percent of global installed capacity (Huang and Gong 2010). While solar water heating does not contribute to electricity capacity, it is important in avoiding an increase in demand for electricity. Moreover, it is an example, even if modest (in terms of overall significance in the energy sector), of China leapfrogging ahead of other countries in technology application with about 64 percent of global installed capacity in 2010 (REN21 2011).

Currently there are approximately 5000 SWH manufacturers in China (Han, Mol and Lu 2010). The SWH industry and market in China have been especially strong in the eastern provinces of Shandong, Jiangsu and Zhejiang, the latter being the main centres with about 20% of all SWH companies and with sales reaching 5.76 billion CNY in 2007 (Han, Mol and Lu 2010).

However, the diffusion of this technology has not yet taken off in western provinces and poorer rural areas. The main reason is that the current market price of 1500 to 3000 CNY is significantly higher than that of an electric water heater (average about 800 CNY) and a fuel gas water heater (average 500 CNY) (Han, Mol and Lu 2010). Despite the relatively rapid payback of a SWH, the higher price still makes SWH unaffordable for cash-short families in the poorer regions of China. Governmental subsidies, or some means of overcoming the capital market problem, such as loans from local authorities recouped through local property taxes, would be required for the effective further promotion of the use of SWHs in these areas.

The industry has already created employment for over 600,000 people. In 2006 the domestic market had a turnover of over 20 billion CNY (US\$2.6 billion). China had an estimated installed capacity of 80 million square metres in 2005 (NDRC 2007), and 108 million square metres in 2007 (Han, Mol and Lu 2010). The installed capacity grew to over 114 million square meters by end of 2008 (Brown 2010) and 168 million square metres or 118 GW by end of 2010 (REN21 2011).

The success of the technology is largely due to its relatively low overall cost (even though a higher upfront cost) and higher safety compared to gas or electricity. The designed life expectancy of most SWH products varies from 10 to 15 years. The payback rate on investment can range from 8 months to 7 years (Han, Mol and Lu 2010), depending on a range of factors such as household water use, product performance, additional electricity use for water heating, etc. SWHs are now installed in 10% of all Chinese homes and the market continues to grow. The government target is to increase the number of households with installed water heaters to 30% by 2030 (The Climate Group 2008).

Despite the positive development and official government support, many obstacles still continue to exist which impede the wider diffusion of SWHs. For example, local regulators in urban areas, such as property managers of apartment complexes, often do not permit the installation of SWHs, based on the perception and experience that SWHs often cause significant water leakage which can damage and destroy roofs and homes. This negative reputation of SWHs is due lack of standardization for SWHs which has created a black market for uncertified (and thus cheaper) systems and has left a stigma on SWH technologies among building inspectors and property managers (Feng, Sovacool and Vu 2010).

Quantifying the positive environmental impact of SWH through the electricity saved is difficult. The main difficulty is to determine how much top-up electric heating is used on average to complement SWHs. One estimate is that a one square metre installation of SWH can reduce electricity consumption by 0.12 tonnes of coal equivalent (TCE) per year, which translates roughly

into one MWh electricity per year. In terms of CO₂ emissions this would be about 200 kg per year per square meter of SWH installation (Li and Hu 2005). In 2008, China's total stock of 114 million square metres of SWH would therefore have saved overall approximately 114 TWh of electricity that year – the equivalent of the annual electricity output of about 50 coal-fired power stations (Brown 2010) - thereby significantly reducing the need for conventional electric power generation at the margin.

Other environmental benefits include the reduction of ambient air pollutants SO₂, NO_x and PM emissions. China's households have a growing demand for hot water; according to a survey in 2004, only 10% of the water used by Chinese residents is hot water. More than 90% of the survey respondents indicated that they need more hot water in daily life (Han, Mol and Lu 2010). SWH is therefore a suitable and necessary technology to address this growing hot water demand while reducing the amount of electricity needed for water heating.

8.5 Geothermal energy & heat pumps

Another important technology which is reducing the growth in electricity consumption is geothermal ground source heat pump (GHP) technology. This technology has not received the same amount of attention as other renewable energy sources. Important data have often not been available and different sources provide different data about the sector's development. What can be said about geothermal energy is that after about ten years of development in China, GHP technologies have evolved to include air conditioning and heating (of space and water).

According to a report by The Climate Group (The Climate Group 2009), the sector has developed rapidly in China, with installed heating capacity in 2007 at 1,900 MW. This equals about 80 million square meters of floor area in buildings. According to Xu (2008) the installation of GHP technology experienced a jump from 2006 to 2007 when the amount of floor area supplied by heat pumps more than tripled from 25 million to 80 million square meters. However, compared to the currently existing total building floor space of about 40 billion square meters, this still only

amounts to about 0.2%.

In contrast, according to the data from the BP database, installed capacity of geothermal even has declined in the time from 2005 to 2010 from 27.8 MW to 24 MW (see Table 8)

Table 8: Geothermal installed capacity from 2005 to 2010 (source BP 2011)

	2005	2006	2007	2008	2009	2010
Geothermal capacity (MW)	27.8	27.8	27.8	24.0	24.0	24.0

What is significant, however, is the future potential for GHP technology to reduce energy consumption in the building sector as it is expected that over the next two decades China is expected to add another 40 *billion* square meters of floor space.

China's official GHP development programme has been maturing over the last few years. In particular, local city pilot projects have stimulated local governments to support their own GHP. Challenges to enable accelerated application of the technologies include, foremost, reducing installation costs, which are still high compared with conventional heating systems. The operating costs are on average about 25-50% lower than conventional space heating systems. Although many new residential buildings in northern China have under floor heating and would be suited for heat pumps, this energy saving technology is still considered a high-tech option mostly only installed in top-end luxury apartment blocks.⁸⁷

Groundwater heat pump systems have become the most wildly used type of GHP in China. However, a number of factors seriously restrict wider application of groundwater heat pumps, particularly limited availability of groundwater and a range legal issues concerning ground-water withdrawal (Yang *et al.* 2010). This restriction might also be one factor why so far GHP has not taken off as fast as other renewable energy technologies.

⁸⁷ Personal communication with Beijing real estate developer, March 2009.

8.6 Further potentials – moving to full commercialisation

The potential for further leapfrogging of renewable energy technology sectors certainly exists. Only a few renewables technologies have already reached full commercialization status in China. To achieve further leapfrogging in deployment will depend on how fast China can bring other renewable technologies from R&D and demonstration project stages into full commercialisation. As argued above, increasing the innovative capacity of Chinese companies, particularly SMEs, will play a crucial role in this. Those technologies still in the early stages of commercialization can possibly achieve further diffusion in the next few years (see Table 9).

Table 9: State of development of selected renewable energy technologies in China (source: author's assessment based on Zhang et al. 2009 and expert consultations)

Technologies	Stage of technology development			
	R & D	Demonstration	Early commercialisation	Commercialised
Small hydro power				X
Solar water heater				X
Concentrated Solar Power (CSP)	X			
Passive solar house			X	
Building-integrated PV		X		
Solar stove			X	
Solar drier		X		
Solar PV system				X
Grid-connected wind turbine				X
Off-grid small wind turbine				X
Geothermal power (heat pumps)			X	
Geothermal space heating			X	
Biomass cook stove				X

Technologies	Stage of technology development			
	R & D	Demonstration	Early commercialisation	Commercialised
Household biogas				X
Biogas plants			X	
Biomass gasification		X		
Biomass pellets			X	
Biodiesel			X	
Bio-ethanol				X
2 nd generation biofuels		X		
Wave power generation	X			
Tidal power		X		
Ocean thermal energy conversion	X			

8.7 International partnerships supporting large scale deployment of renewable energy in China

A wide range of international cooperation initiatives have focused on supporting China's renewable energy development. The following section describes some of the most significant mechanisms which are currently the main vehicles for international cooperation with China and assess in which ways they have contributed to large-scale deployment of these technologies.

8.7.1 Clean Development Mechanism in China

One of the main international technology transfer mechanisms to promote low-carbon technology applications and use in developing countries under the Kyoto Protocol, which has in recent years been highly relevant for China, includes the Clean Development Mechanism (CDM). This project-based flexible market instrument is currently the main vehicle under the UNFCCC's Kyoto Protocol giving developing countries improved access to clean low-carbon technologies.

Now linked to the European Emissions Trading System (EU ETS), the CDM has also become an important component of how European governments intend to comply with their Kyoto commitments. The CDM has so far to some degree succeeded in engaging buyers and sellers and reducing emissions of the GHGs covered under the Kyoto Protocol, although as a mechanism it is not without criticism.

Even though China was initially skeptical towards the CDM as a carbon market-based approach, it has quickly emerged as the world's number one host country for CDM projects with a share of more than 60% of global certified emissions reductions (CERs). The reason for this is that CDM projects provide additional financial support for the deployment of renewable energy technologies in China and brings foreign investment into China. Furthermore, it provides tax revenue to the Chinese government who takes a share of 65% of the CER revenue from HFC and PFC projects, and 30% of N₂O projects.

At the end of 2009, 652 Chinese CDM projects were approved by the UNFCCC CDM Executive Board, 2,232 CDM projects were approved by the Chinese Designated National Authority (DNA), and another 2,354 projects were at after the validations stage ("in the pipeline"). Of the 652 projects already approved by the EB a large number were renewable energy projects, mostly small hydro (324 projects) and wind power (196 projects) as well as 14 biomass projects and four biogas. From the approved projects at the end of 2009 China will be issued 936,994 k-tCO₂ equivalent of CERs until 2012. The largest buyers of China's CERs are the UK government (39%), followed by Japan (15%) and the Netherlands (10%) (IGES 2009).

Table 10: Status of CDM in China (as of Nov 2009) (Source: IGES 2009; UNFCCC database)

Project Status	Number of Projects
CDM projects registered at CDM executive board	652
CDM projects approved by Chinese DNA	2232
CDM projects at or after the validation stage	2354

The institutional structure of China's CDM decision making and the project application and approval procedures are relatively complex. The National Coordination Committee on Climate

Change (NCCCC) which is chaired by the Chairman of the NDRC is the main body to set and review China's national policies, regulations and standards for CDM project activities. The NCCCC also nominates and approves the members of the National CDM Board which consists of representatives from seven ministries, chaired by NDRC and MOST. The Board reviews CDM project activities, reports to the Committee on overall progress and makes recommendations on the amendment of the current measures for the operation and management of CDM projects. Finally, the Designated National Authority (DNA), hosted by NDRC, deals with the day-to-day CDM project application procedures, approves or rejects CDM project activities on the basis of the conclusions by the Board and supervises the implementation of CDM project activities (Zhu and Pan 2006; IGES 2009) (see Figure 19)..

Figure 19: Chinese DNA project approval procedure (source: IGES, 2009)

Opinions about the effectiveness of the CDM in providing a solution to support developing countries, including China, are strongly divided. Was and will the CDM be a suitable vehicle to enable fast access to cutting-edge environmental technologies for a leapfrog transition to a sustainable low-carbon energy future for China and other developing countries? According to Berrah et al. (2007) the potential for obtaining and deploying these technologies in this way can be enhanced by exploiting the possibilities offered by the CDM. They consider the CDM an effective mechanism for the deployment and long-term support of renewable energy technologies, more effective than other means of financial support, for example, capital subsidies.

One criticism of the CDM concerns inefficiencies and market distortions with inflated abatement costs that were created through reduction of industrial waste gases in the refrigerant, nylon and fertilizer industries, particularly via HFC-23 destruction projects, accounting for about one quarter of global CERs until 2012 (IGES 2009). Globally, HFC-23 projects will generate more than 500 million CERs by 2012 – in the case of China eleven HFC-23 projects with a total amount of about 365 million tCO₂ reduction by 2012 (IGES 2009). According to critics such as de Sepibus (2009) the CDM has created perverse incentives to continue the production of these highly potent GHGs and even to protract, rather than strengthen, the implementation of national climate policies, including the phase out of industrial gases such as HFC-23. The normal costs for abating HFC-23 emissions are estimated to be about US\$ 0.20 per ton of CO₂ equivalent, however, revenues from selling CER credits exceed the costs for producing the HCFC-22 significantly. The current amount being paid to destroy HFC-23 exceeds the actual cost of destruction by up to 70 times. According to the NGO CDM-Watch, plant operators have artificially increased HCFC-22 production and the rate at which the waste product HFC-23 is generated (CDM Watch 2010).⁸⁸

Another criticism has been the dearth of projects in the energy sector, approximately one third of the total, of which the emissions reductions generated through renewable energy projects (mainly wind, hydro and biomass) account for only 19% of the total. The CDM as a market-instrument which principally rewards short-term abatement fails to incentivise effectively

⁸⁸ Personal communication with Eva Filzmoser, CDM-Watch, Bonn, June 2010.

innovation and structural changes that allow the large-scale deployment of renewable energy (de Sepibus 2009). This seems to hold true also for China. Despite the relatively large number of renewable energy CDM projects, the emission reduction is low, compared to those generated through destruction of industrial gases. Low revenues from a large number of renewable energy projects demonstrate a major shortcoming of the CDM for the deployment of renewables. Compared to other CDM project types, renewable energy projects are not the most profitable ones (Schroeder 2009). To increase the share of low-carbon and renewable energy projects in the energy sector it has been suggested to focus CDM projects only on CO₂ reduction and address other GHGs, particularly industrial waste gases, separately (Wara 2007).

Similarly, Sugiyama and Ohshita's (2006) early criticism of the CDM is that in its current form it does not offer enough capital and resources to realize the leapfrogging potential through renewable energy diffusion and bringing about major energy efficiency improvements in China and other developing countries. In terms of FDI, the total potential CDM opportunities in the period up till 2012 are estimated only at 0.2 – 0.3% of inward bound FDI (Li *et al.* 2008). Regarding wind power, in 2010 total investment in Chinese wind power projects reached 130 billion CNY, with CDM funds contributing only about 1 billion CNY (He and Morse 2010). In the words of Fan *et al.* (2010, p.34) "while China is significant for the CDM, the CDM is insignificant for China."

Therefore, in order to make a difference to China's energy development through flexible mechanisms under a global climate change regime, the future global architecture post-2012 will need to involve a significant improvement of the current CDM structure. Specific opportunities to this end are, for example, the introduction of programmatic CDM to reduce the transaction costs for small and diffused individual projects, such as household biogas. The normal project-by-project approval process is simplified by aggregation into a broader programme that can include many individual activities including, for example, end-use efficiency projects in sectors such as transport, street lighting or buildings for which there is great potential in China (Hinostroza *et al.*

2007).

Furthermore, the issue of additionality is quite vexed. It requires the existence of barriers such as insufficient investment, technology or policy barriers, so that the project without the additional support through the CDM would not have been implemented. In other words, the CDM does not intend to finance projects that would have happened anyway under business as usual scenarios, but only projects which are additional to the baseline development scenarios. According to He and Morse (2010), the CDM has to some degree trapped climate and energy policymakers, not only those in China, in the following way: "On the one hand, ignoring domestic subsidies for low-carbon energy investments results in CDM crediting for BAU domestic activity. On the other hand, incorporating emissions-reducing domestic policies into the baseline against which CDM projects are compared might create a perverse incentive against implementing such policies, as they would jeopardize CDM revenues" (He and Morse 2010, p.4).

For example, CDM has been used to fund many wind power projects in China. Compared to commercial fossil fuel power generation projects, wind power projects still have the risks of high investment costs per unit and low financial return rates, which make it hard for project developers to get loans from commercial banks. Wind farm developments registered under the CDM can help to improve wind power projects' financial benefits and reduce the financial risks. If CERs can be earned, bank loans can be obtained much easier as project risks would be partially compensated by the potential CER revenues. About one third of the wind energy projects currently developed in China are registered under the Kyoto Protocol as CDM projects and sell CERs on the international carbon markets. However, according to many experts it is questionable whether these projects would *not* have been developed anyway without CDM financing. From the investment perspective, the revenue generated by the CERs has contributed generally only to a marginal part to the profitability of the projects (Schneider 2007).

Furthermore, with the policy support of the Renewable Energy Law, the FIT and requirements of the government that large national power companies include wind energy in their

portfolios, experts claim that most of the wind farm developments would have been developed without additional financing through CDM.⁸⁹

The difficulty of applying the additionality criteria for wind farm developments has become visible in December 2009 and February 2010 when the CDM Executive Board rejected in total twelve wind farm projects from China on the grounds that the proposed projects were profitable and capable of cutting emissions without receiving the offsets generated through the CDM (Szabo and Chestney 2010). The rejection of the wind farm development projects under the CDM is also directly related to discussions regarding the subsidised tariffs for wind power electricity in China. The Executive Board further claims China intentionally keeps electricity prices and tariffs for wind energy low to be able to qualify for CDM funding (Zhang 2010). In contrast, the Global Wind Energy Council claims that tariffs for wind power have either remained stable or have even risen, as has been well documented in studies and records from the concession tendering processes (GWEC 2010) and that wind power still requires the additional funding support through the CDM. This decision by the EB has sent a wrong signal for wind energy developers in China and other developing countries that can make use of the flexible mechanisms (GWEC and IETA 2009). At the time of writing the issue has not been resolved and will continue to be discussed in the context of ongoing CDM reforms.

Similar issues have emerged with hydro electricity projects. While SHP projects are eligible and generally encouraged as CDM projects, there are differing views as to whether large hydro projects with water storage should be included, or at least be subject to a set of international criteria set by non-governmental environmental organisations, such as those developed by the World Commission on Dams (WCD). The environmental and social sustainability of CDM hydro power projects are sometimes questionable. For example, the organisation International Rivers found out that 7,500 people had been evicted to make way for the CDM Xiaoxi hydro dam project in Hunan Province without proper compensation. Xiaoxi is one of at least eleven Chinese large hydropower projects from which the German electricity utility RWE was purchasing offset credits

⁸⁹ Personal communications with several foreign and Chinese renewable energy experts

(Shih 2010).

Based on the recommendations from the WCD (2000), in 2010 the European Climate Exchange decided that carbon emission offsets generated by large hydroelectric dams of more than 20 MW in capacity will not be eligible anymore to be traded under the EU-ETS. Similar to the 'business as usual' debate of Chinese wind power CDM projects, at a meeting of the CDM executive board in February 2010, 38 dams from China failed to get carbon credits. This decision is likely to have a positive impact on hydro power CDM projects in China and promote the development of SHP electricity, rather than large dam constructions.

Another point of critique towards the CDM is that currently many projects do not sufficiently consider other aspects and criteria of sustainable development in the host country and are in some cases not implemented without causing any other negative environmental impacts. There seems to be a tradeoff between the mechanism's two main objectives—cost-effective emission reductions and sustainable development in the host country. The CDM's market logic is on the one hand expected to reduce the overall costs of global climate change mitigation efforts, a negative side effect is that it draws attention away from small-scale community based projects with additional social and environmental benefits (Löwbrand et al. 2009). The concept of environmental leapfrogging requires taking these issues into account.

Furthermore, most Chinese CDM projects do not have to any significant extent consulted with local community stakeholders. There have been reports that in some cases the PDD sections on local stakeholder communications have been filled in without having gone through proper processes including stakeholder meetings and feedback rounds. The limited voice of the Chinese communities, potentially directly affected by CDM projects, during project development is commonly acknowledged by CDM project developers and international observers of China's CDM market.⁹⁰ Furthermore, the thirty-day commenting period is for many project developers only considered an unnecessary procedure which, in order to reduce transaction costs, is in many

⁹⁰ Personal communication with various CDM consultants and CDM experts both Chinese and foreign between October 2008 – June 2010

cases not carried out according to requirements (Lövbrand et al., 2009).

It has been recommended that increased citizen participation is needed to guarantee the social and environmental sustainable development of CDM projects (Boyd et al. 2007). However, the capacity of NGOs in China to act as 'watchdogs' requires capacity development before this can happen. The requirements of international CER buyers for local NGO participation in the creation, management and evaluation of regional development efforts could be examples how to improve NGO engagement in CDM project development.

As the CDM involves complicated international modalities and procedures several **initiatives providing CDM support and capacity building** have been established by some of the Annex I countries which are Parties to the Kyoto Protocol. Initially, China's and other country's domestic regulatory authorities and institutions in the first two years of the CDM (from 2005) were not sufficiently equipped to carry out extensive capacity building activities to improve awareness among enterprises. Therefore cooperation between international development institutions, consulting agencies, financial institutions, and investors as well as foreign and local government authorities have been necessary for the planning, application and implementing of CDM project activities (Zhu and Pan, 2006).

Some of the partnerships that were initiated to build CDM capacity in China include projects by the Asian Development Bank and World Bank which try to provide information about the potential of CDM in China, financing channels, methodologies, and successful case studies. The UNDP, in cooperation with the Norwegian and Italian governments, funded capacity building projects including pilot CDM projects. Bi-lateral cooperation between China and the UK and Canada also had similar capacity building goals. It is difficult to assess the effectiveness of these initiatives on a case by case basis, but looking at the number of CDM projects that were registered with the UNFCCC CDM Executive Board particularly since 2007 and have subsequently been implemented in China, it is clear that capacity for CDM projects increased significantly within a very short time in China. The combined efforts of cooperative arrangements

mentioned above have certainly played an important part in building capacity.

The CDM has created a complex bureaucratic system through which transaction costs for project development are getting so high that projects generating reductions of less than 20,000 tonnes CO₂ are not profitable any longer. Current project registration time is now approximately one year. The initial idea behind the CDM, that projects which are not economically viable in developing countries are made possible through the CDM, holds true only in very few cases. The increasingly complex bureaucratic requirements have resulted in another negative effectively contributed to reduced trust between donor countries and recipients. Despite its multiple shortcomings, the CDM so far has enabled the largest transfer of climate finance in history. According to CDM project development and consulting experts working in China, one of the most important challenges for making the CDM more effective in the post-2012 framework, is to create better communication and transparency based on trust, rather than increase regulations that make the procedures even more protracted and difficult.⁹¹ Many experts working in the field of renewable energy are, however, not convinced that in the future the CDM will continue to play an important role in China's energy development or enable a large-scale shift towards. To achieve a large and faster shift towards renewable energy application and use in China, other mechanisms of international cooperation, particularly for capacity building, will need to be explored in addition to CDM.⁹²

8.7.2 IGES Sino-Japan CDM Collaboration Programme

One international initiative for improving CDM cooperation is the Institute for Global Environmental Strategies' (IGES) *Sino-Japan CDM Collaboration Programme*⁹³ initiated in 2006 after discussions between Japan's Ministry of the Environment (MoE) and NDRC. IGES and

⁹¹ Personal Communication with Henning Huenteler, CDM project developer in Beijing.

⁹² Participation in Chinese CDM energy project expert discussion at GTZ Office Beijing, October 2009

⁹³ Programme website: <http://www.iges.or.jp/en/cdm/china.html>

Additional information was provided by Keisuke Iyadomi and Jane Romero from IGES, Japan, January 2009

Tsinghua University under supervision of Japan's MoE and NEDR were contracted to implement these cooperative activities. Initially envisioned as a three-year programme, it has been extended and is at the time of writing still running. As the other initiatives mentioned above, this programme is not directly taking part in CDM activities, but offers capacity building, research support to identify barriers, facilitates implementation and advises how to improve the existing CDM structure. It is funded by the Ministry of the Environment (MoE) Japan and has the goal to support CDM development in Asian-Pacific countries so that the Japanese government can acquire CERs from projects in these countries. The constellation of partners in this project is unusual as normally NDRC does not cooperate with environmental Ministries of other countries. This shows that through the CDM the divide between government agencies working in the field of industrial development and environmental protection can be bridged (see Fig. 20)

Figure 20: Programme structure of IGES Sino-Japan CDM collaboration programme
(source: author's assessment)

Under the capacity building component of the project training workshops are held for developers as well as government officials to explain what the CDM is, how to get involved in

CDM projects and how to develop CDM projects. IGES also provides assistance in calculating emission reductions of potential project ideas and supports the application process for CDM projects under the UNFCCC. Through the project about 50,000 CERs are generated annually for the Japanese government. This provides a double benefit for both governments: Japan's MoE is going to have CERs from this programme for off-setting Japan's emissions, and NDRC sells the credits from this programme. The Japanese private sector was not involved under this programme, because the Japanese government and private companies are in a competitive relationship to acquire CER credits. While the programme does not involve the Japanese private sector, it assisted the Chinese private sector in developing CDM projects or providing technology for CDM project implementation.

In terms of renewable energy technology transfer through CDM, no Japanese technologies transferred to China. As a result of China's wind energy policies, for most of the wind power CDM projects Chinese domestic technologies and equipment are being used and the Chinese wind industry is much more mature than that of Japan. Regarding solar PV, Japanese technology is not competitive in the context of the CDM, due to high costs. In addition to capacity building for CDM project development and implementation, the MoE of Japan is also promoting the co-benefits approach through the programme, to transfer to experiences and technologies from environmental pollution and environmental management from Japan to China. The co-benefits approach is like a package solution, potentially also applicable for the CDM. It addresses the sustainability aspects of CDM projects, which is currently not monetized. The sustainability benefits have been referred to as the auxiliary benefits or co-benefits.

The co-benefit approach could be particularly useful for CDM projects for promotion of public urban transport systems. Innovative solutions such as Bus Rapid Transit (BRT), which have proven quite successful in many Asian cities including Beijing, could be promoted through CDM which include co-benefit criteria. While the CER revenues these projects would be generating are not large compared to those of other projects, so not really an incentive for private companies to

invest, it has proven to be a good solution addressing basic problems of urban congestion, local air pollution and public health. A BRT system does not require mayor infrastructure developments, and can deliver the results in a relatively short amount of time, with less cost. However, in the current system this kind of project will not be prioritised, but the inclusion of co-benefit criteria would highlight those additional sustainability aspects.

Furthermore, the programme supports research on CDM and the development of the CDM in a post-2012 climate regime. The research outcomes of the programme are not solely used by the Japanese government to be more effective in the implementation of CDM projects, but also provide advice to the UNFCCC on improvements for post-2012 CDM developments. The MoE expects the programme to provide inputs from the programmes experiences and lessons learned to provide proposals for the CDM under the future climate regime. One of the recent research outputs submitted by IGES to the UNFCCC CDM Executive Board is a study on the transaction costs of CDM project developments, showing that the increasingly complex methodologies strongly impact on the CERs generated through the project lifetime.

Table 11: SWOT Analysis Clean Development Mechanism in China (author's assessment)

Table 6: SWOT Analysis Clean Development Mechanism in China:	
Strengths:	Good institutional framework and technological capacity in China to develop and carry out CDM projects; renewable energy projects are being favoured and supported by the government and DNA
Weaknesses:	Difficult and time consuming project application procedures; increasingly high transaction costs; most CERs generated through HFC-23 destruction; low public participation in project development processes; social and environmental sustainability criteria often not considered in project development and implementation; renewable energy projects not the most profitable projects for developers
Opportunities:	Programmatic or sectoral CDM to promote small-scale projects; inclusion of co-benefit criteria into CDM project development methodologies; increased NGO participation in CDM project development (e.g. Gold Standard projects)
Threats:	Uncertainty regarding international carbon market for CERs beyond 2012; decreasing trust between donors and recipients; future conflicts about additionality criteria for wind and hydro projects;

8.7.3 China Renewable Energy Scale-up Program (CRESP)

The most relevant inter-governmental cooperation partnership for promotion of renewable energy in China is the China Renewable Energy Scale-up Program (CRESP)⁹⁴ which was developed by the Government of China in cooperation with the World Bank (WB) and the Global Environment Facility (GEF). The programme management office is located at the ERI under oversight of the NDRC. CRESP provides assistance with the implementation of a renewable energy policy development and investment programme. It has been an important high-level international cooperation programme to push renewable energy development in China. CRESP is a comprehensive 10 to 12 year programme, implemented in three phases. An institutional development and capacity building component was designed to meet national priorities and the needs of the pilot provinces to initiate the scale-up of renewables, and will include the following: Mandated Market Policy (MMP) research and implementation support; technology improvement for wind and biomass; and long-term capacity building.

It aims to study the current renewable energy resources status, learn from the experiences of developed countries in the development of renewables, study and formulate renewable energy development policy in China, implement renewable energy scale-up development, provide cost-effective and commercial renewable energy electricity to the electric power market with the overall goal to replace coal-fired generation and reduce the local and global negative environmental impacts of energy generation. CRESP aims to create a legal, regulatory, and institutional environment conducive to large-scale renewable energy generation, and to demonstrate early success in large-scale, renewable energy development with participating local developers. It is likely that CRESP through the MMP component has contributed to the implementation of a mandated market share regulation under the Medium and Long Term renewable energy Development Plan discussed above. Some of the main outputs and publications of CRESP concern the development of methodologies for off-shore wind farm development and promotion of

⁹⁴ CRESP programme website: <http://www.cresp.org.cn/english/index.asp>

tidal energy pilot projects.

8.7.4 Renewable Energy & Energy Efficiency Partnership (REEEP)

Another global high-profile multi-stakeholder partnership that is also very active in China, is the Renewable Energy & Energy Efficiency Partnership (REEEP)⁹⁵ which was first officially presented at the Johannesburg World Summit on Sustainable Development (WSSD) in August 2002 as one of the 'Type II' outcomes. REEEP was then formally launched at in London on 23 October 2003. Now, with more than 250 partners, and almost 50 governments involved, \$16,450,000 of available funds and an annual budget of around \$8,000,000, REEEP has emerged as one of the largest networks of stakeholders registered with the Commission on Sustainable Development (CSD). It has the goal to accelerate the global market for sustainable and renewable energy by acting as an international and regional enabler, multiplier and catalyst to change and develop sustainable energy systems. REEEP works with governments, businesses, industry, financiers and civil society across the world. The REEEP Programme has, at the time of writing, so far offered support to 84 projects spread over 50 countries.

In a study by Pattberg et al. (2009) REEEP has been found, in comparison with other partnerships registered under the CSD, to be a relatively successful partnership. The conclusions of this study suggest that REEEP is a rare case among Type II partnerships, not only due to its large number of over 250 partners and comparatively high budget, but also because it is a "partnership that delivers" with low project failure rate. Some criticism has been raised regarding REEEP's focus on emerging renewable energy and energy efficiency markets, while neglecting smaller, poorer developing countries, especially in Sub-Saharan Africa. The relative success of REEEP seems to be based on the partnership's bottom-up approach and visible regionalisation, despite having a business/state bias, thereby being able to provide what is needed on the ground

⁹⁵ REEEP website: <http://www.reeep.org>

and effectively connecting donors with recipients and facilitating efficient allocation of resources. The study concludes that “its current scale suggests that with such high levels of output, it definitely can have a considerable impact in the area of sustainable energy policy.” (Pattberg *et al.* 2009)

Regarding the impact of REEEP projects in China, no detailed analyses exist so far. REEEP has been working in China since 2003. The East Asia Regional Secretariat and Steering Committee is one of eight REEEP regional secretariats worldwide. It based in Beijing at the Chinese Renewable Energy Industry Association (CREIA)⁹⁶ while connecting the international industries of renewable energy by partnering with associations abroad, institutes, academics, etc. The East Asia Regional Secretariat has close connection with government authorities through which to influence policy making and implementation. The East Asia RS has been hosted by CREIA since its formulation in 2004 and coordinates REEEP activities not only for China, but also in other Asian priority countries. In October 2008, REEEP established an official partnership with the Energy Research Institute. This means that REEEP, and potentially the projects funded through REEEP, have now stronger support by the central government and potentially more influence on government policy.⁹⁷

To date, REEEP has implemented 16 projects in China covering a wide range of activities, including capacity building for policymakers to implement the renewable energy Law, rural biogas, wind power roadmaps, and harmonisation of efficiency standards. None of the projects of the previous project rounds has been classified as failed. The total funding for these projects is around €3.5 million. The largest project with €625,000 is the “Capacity Building Support for the Implementation of the Renewable Energy Law in China”. The project includes co-funding from The Energy Foundation, World Bank CRES Project and the Australian Greenhouse Office. The main activities include training workshops for government officials and energy enterprise leaders as well as monitoring of the renewable energy Law with particular emphasis on pricing

⁹⁶ <http://www.creia.net>

⁹⁷ Participation in the partnership MoU signing ceremony between REEEP and Energy Research Institute.

mechanisms. The expected impacts are enhanced understanding of the renewable energy Law on the part of 300 central government and provincial officials and enterprise leaders, to facilitate implementation. Feedback in the form of policy advice was given to the NDRC to adjust the regulations in response to market conditions.

In the seventh REEEP programme cycle which started in 2009, 49 clean energy and efficiency projects using funds of over €4.3 million available from the governments of United Kingdom, Norway, Australia, Ireland and Italy were funded. 16 projects averaging €100,000 were funded in the emerging economies of China, Brazil, India, South Africa and Mexico by the United Kingdom and Norway. In China, nine projects received funding under this new project cycle. China is also part of five further multi-country international projects which also include partners from other countries.

As can be seen from the list of projects, priority was given to projects that will be carried out with support by the government and the financial sector. REEEP prefers to fund projects that have the explicit support of a Chinese government agency. This is different to the REEEP approach in India, where project implementing agencies from the private sector or independent research organisations are preferred. REEEP has already established strong networks with potential partners in China.

According to Binu Parthan⁹⁸ the performance and effectiveness of Chinese projects has been good in both absolute and relative terms. The REEEP Secretariat is generally satisfied with project outcomes. REEEP projects have high visibility and generate a lot of activity towards making substantive progress in supporting energy transitions in developing countries. The general opinion of Chinese and foreign energy experts is generally very positive, however, some have questioned the effectiveness and impacts of some of the projects.⁹⁹ Nevertheless, so far all projects have delivered the expected outputs and have been successful in bringing together international and Chinese researchers and organisations to conduct joint-research activities.

⁹⁸ Personal communication with Binu Parthan, REEEP Deputy Director General, July 2010

⁹⁹ Personal communication with Chinese and foreign experts who have worked on REEEP projects in China.

Regarding their contribution to large-scale adoption and use of renewable energy technologies, REEEP projects have indirectly contributed. While the projects do not directly facilitate technology hardware transfer or provide finance for projects, they do address macro level issues and generate policy advice to improve the policy framework conditions that can further pave the way for renewable energy development.

In the long run, REEEP will continue to promote renewables projects in China. According to REEEP Secretariat¹⁰⁰ there are significant needs geographically and sectorally (e.g. for small wind development) where REEEP sees opportunities for more work. Also, energy regulation is regarded as an important area to mainstream both renewables and energy efficiency. China is not a member of the newly International Renewable Energy Agency (IRENA), this justifies more work on renewable energy in China by REEEP. In the future the issue of grid integration could also be an option for the new project rounds.

Table 12: SWOT Analysis Renewable energy and energy efficiency programme (REEEP)	
Strengths:	High profile and visibility, attracting a large number of proposals; official government support of NDRC's Energy Research Institute; close working relationship with China's Renewable Energy Industry Association; projects awarded to a variety of stakeholders including government agencies, NGOs, and research institutes
Weaknesses:	Dependent on limited European government funding for projects;
Opportunities:	Policy recommendations for renewable energy development to enable improved policy environment; potential high-level policy impacts; support for innovative international cooperation approaches
Threats:	Potentially no future funding for renewable energy projects in China as industry matures

8.7.5 EU-China Energy and Environment Programme (EU-China EEP)¹⁰¹

Several bi-lateral initiatives for renewable energy cooperation between China and (mostly) European countries have been initiated over the last few years. These bi-lateral initiatives focus on a variety of aspects relating to renewable energy and technology transfer, including capacity

¹⁰⁰ Personal Communication with Binu Parthan, REEEP Deputy Director General, July 2010

¹⁰¹ Interview with former programme Co-director Dr. Kurt Wiesegart, Beijing, July 2008

building, training, joint R&D activities and policy advice. Bilateral partnerships are highly important from a political perspective and have in the past been the main vehicles for the introduction of new technologies to China. The achievements, difficulties, contribution to large-scale technology application, China's energy transition and future developments of current bi-lateral initiatives are described and assessed below.

An example that illustrates the issues is the EU-China Energy and Environment Programme (EU-China EEP) which was completed end of 2009.¹⁰² The total funding was relatively high compared to other bilateral initiatives and other EU funded cooperation programmes, amounting to €42.9 million with the EU providing €20 million and €22.9 million coming from the Chinese government, mostly in the form of in-kind contributions. There were four major programme components: energy policy development, energy efficiency, renewable energy and natural gas. The renewable energy component has received total funding of €12.08 million, with the EU contributing €4.68 million and the Chinese government €7.4 million. The programme was coordinated by the Ministry of Commerce, while the NDRC, ERI the Ministry of Science and Technology (MOST), and China National Petroleum Corporation were involved in implementation of the programme. It involved technical assistance, technology development, capacity building, and market development. The EU-China EEP also involved assistance for policy development at the central state and local levels.

Under the EU-China EEP, projects were awarded through a tender system and calls for proposals. Most projects were feasibility studies on a range of issues relevant for China's energy transition. The EU-China EEP supported projects in 16 provinces in China. The funding for each project was in the order of around €500,000 – 800,000. Projects were awarded to consultant organisations or consortiums that consisted of up to six partners, both Chinese and European. Under the renewable energy component the two thematic focus areas were 'Biomass Conversion Technologies for Rural Energy Provision' and 'Off-shore Wind Energy Technologies'. Under the biomass focus area, priority was given to projects which focused on pelletising technologies for

¹⁰² Project website: <http://www.eep.org.cn/>

rural energy provision, gasification/biogas for power generation technologies and direct combustion for heat and power generation technologies. Under the off-shore wind energy focus the localisation of development and production of large turbine technology and off-shore wind farm development technology in Chinese companies was supported.

The EU-EEP suffered from severe delays in implementation of concrete projects. Some projects had to be cancelled, such as the Training Support for the Dissemination of the Chinese Renewable Energy Law. While originally intended to run until end of 2008, the programme was extended until end of 2009. The initial programme design and how grants and projects were to be awarded limited the flexibility of programme management directors during implementation. This led to internal management problems between European and Chinese directors who had to manage different expectations from the EU donor and Chinese government agencies. Main points of disagreement have been the selection and award process for tenders and proposals for either European or Chinese organisations and companies for project implementation.¹⁰³ In addition, the bureaucracies of both the EU and the NDRC are highly formalised and have different institutional procedures that can often not be understood by the other side.

Through communications with both foreign and Chinese energy experts involved in the programme or EEP projects and experts from other energy related organisations, several recommendations on how to improve future collaboration emerged. While China and the EU were equal partners in the management structure of the programme, regarding the overall design and intention, the programme had the goal to facilitate technology transfer from Europe to China through PPPs. By the Chinese side it was, however, perceived as an indirect mechanism to facilitate market entry for European technology companies and businesses. Furthermore, the project was not perceived to be contributing to the improvement of China's own technology innovation capacity. Replacing hardware technology transfer activities with joint-research and technology development activities would help to increase the innovative capacity of Chinese

¹⁰³ Personal informal communication with several Chinese energy experts and former programme staff in Beijing during 2008

enterprises and renewable energy sectors.¹⁰⁴

Table 13: SWOT Analysis EU-China Energy and Environment Programme	
Strengths:	Large funding sources available; clean and renewable energy collaboration priority for both governments
Weaknesses:	Bureaucratic structures and procedures of EU and NDRC often obstruct project implementation; EU requirements on transparency of how funds are spent
Opportunities:	Improvement in innovative capacity of Chinese companies if joint research can be facilitated through EU-Chinese cooperation
Threats:	High-level political disagreements and tensions between EU and China can impact on project implementation and future funding of programmes.

8.7.6 Sino-Danish Wind Energy Development Programme (WED)/ Sino-Danish Renewable Energy Development Programme (RED)

Other bilateral programmes between smaller European countries and China also exist, such as the Sino-Danish Wind Energy Development Programme (WED), which had a relatively small budget and focus on very specific issues, in this case wind energy technology. This three year programme ended in mid 2010. The WED was designed to enhance the use wind energy through knowledge transfer and capacity building of policymakers at central and provincial government level. The WED consisted of four main components: The “Wind Resource Assessment” component established numerical models and a wind atlas for the provinces of Liaoning, Jilin and Heilongjiang. Other project components included the “Wind Project Planning and Evaluation Component” to develop feasibility study templates for large scale wind farms in China and suggestions for performance improvement of existing wind farms. The third component focused on “Studies on Grid Integration of Wind Power in China” on the issue of grid absorption capacities and training in wind resource assessment software applications. Finally, the fourth training component consisted of a series of trainings on the topics of large scale wind farm finance and insurance, wind farm operation and maintenance.¹⁰⁵

¹⁰⁴ Personal communication with programme staff in Beijing, Mai 2008

¹⁰⁵ Information from WED programme website: www.dwed.org.cn

The programme has proven to be of mutual benefit for both countries. Indirect programme goals and outcomes included enhanced market opportunities for Danish companies involved in wind energy development. For example, through the translation of and training provided in the use of software applications, Danish companies gained market access to China. The Chinese partner organisations participating in the training were in return given preferential prices for software purchases.¹⁰⁶ The Danish wind turbine manufacturer Vestas has also been involved to deliver training for Chinese developers on micro-siting. These efforts by the Danish government and companies are highly appreciated by the Chinese government and the Sino-Danish partnership enjoyed high-level support by the NDRC which considers cooperation with Denmark crucial to solving some of the infrastructure problems in the wind power sector.

The follow-up programme of the WED is the Sino-Danish Renewable Energy Development Programme (RED)¹⁰⁷, a five-year programme (2009-2013), jointly developed by the Chinese and Danish governments in 2008 and kicked-off in February 2010¹⁰⁸. The programme is on the Danish side coordinated by DANIDA and the implementing agency on the Chinese side is the Energy Research Institute (ERI) which also hosts the programme management office (see figure 21). Compared to other bilateral cooperation partnerships in China the RED has relatively small funding (about 10 million Euros co-financing from the Chinese side), but for country like Denmark it is a substantial international development project.

¹⁰⁶ Informal communication with Chinese and Danish programme staff during China Wind Power Expo, Beijing, October 2008

¹⁰⁷RED website:
<http://www.cnred.org.cn/english/webSite/index.jsp;jsessionid=9E8F3BAFA547E2C2ADFA0EC9B7C3D3D0>

¹⁰⁸ Information about the RED was provided by Dr. Uwe Weber, International Advisor to the REC Programme, interviewed in Beijing, March 2010.

Figure 21: Organisational structure of the Sino-Danish Renewable Energy Development Programme (RED) (Source: Sino-Danish Renewable Energy Development Programme promotion materials)

The RED programme aims at institutional capacity building and technology innovation for renewable energy development. The two main components are an organizational capacity building component, the second component to support and co-finance technology promotion partnerships between Danish and Chinese organisations from the public and private sector. RED focuses on the renewable energy sectors of wind power, solar PV and biomass (including biofuels) as well as cross-sectoral issues for renewable energy development such as smart grid development.

The main intended outcome from RED is the creation of a national renewable energy centre. The initial plan was to create a national level policy centre for renewable energy policy development. However, due to the extreme institutional fragmentation of the Chinese energy decision making system, creating a centre for renewable energy in China which would play a major role in renewable energy policymaking proves an extremely difficult task. Many of the

Chinese organisations involved in energy policy making are not entirely favourable to renewable energy development, other organisations already involved in renewable energy would not like to give up the influence they have on policy development processes at the current stage.

Therefore it appears a preference of the programme management to focus such a centre on renewable energy technologies, which is less controversial and has more potential for achieving a successful outcome. Such a centre would eventually including technology testing laboratories. The design of the Chinese centre hence draws on examples from EU and US. One department of this centre would act as a renewable energy information dissemination centre. One goal is to produce national renewable energy technology roadmaps, taking the IEA roadmap publications as models. The project already secured co-financing by the IEA to produce a China technology roadmap. The establishment of a joint-research department with the Riso Centre in Denmark is also envisioned.

There are nevertheless some uncertainties and challenges for the success of a new, national level renewable energy technology centre. For instance, there already exist a range of technological laboratories for wind and solar PV in China. Challenges are to find synergies and avoid overlaps which could cause competition with existing centres. Another challenge is the institutional set-up of the renewable energy technology centre. Currently two potential options exist: the first is to attach it directly to the NEA, which would give the centre political influence. The second option would be attaching it to another sub-ordinated institution, which would reduce conflict potential with current institutional heavyweights involved in renewable energy development.

According the international advisor Dr. Uwe Weber there are several reason why the Danish government supports renewable energy development in China through this type of bilateral cooperation and the facilitation of public private partnerships: *“The RED has to been in the context of the question that many countries and companies ask themselves: How can one cooperate with China with mutual benefit for both sides? One answer is to move away from a*

single project-to-project approach to build long-term strategic bilateral technology cooperation.”

Similarly to the WED, the main goals are to bring Danish experiences into the Chinese renewable energy sector development, positively contribute to the development of a domestic renewable energy market and thereby provide opportunities for Danish companies to profit from the domestic Chinese market. It also reflects the strategic importance of the renewable energy sector and industry in Denmark’s future development strategy. For instance, the Danish onshore wind energy market appears almost saturated, although the country has to achieve a 30 percent share of renewable under the EU Renewable Energy Directive, Denmark’s renewable energy companies are therefore looking for new markets abroad and have identified China as one of the most important future growth markets.

Although Danish companies are highly interested in the Chinese market, they are also apprehensive about protecting their IPRs. In the context of a CDM project, a biomass facility was supplied by a Danish company. Following this project the facility was reverse engineered and another three CDM projects were implemented and registered using the same technology – but without Danish involvement nor royalty payments to the Danish company, although the project development documents state that Danish technology was utilised.

The Danish government is also using the renewable energy technology cooperation partnerships to promote climate change mitigation policies. By using Danish companies such as Vestas as a key benchmark, the Danish government is provides examples that disprove the common belief that climate protection has negative consequences for economic development and that there is no trade-off between emission reductions and economic GDP growth.

The transition of China’s energy system towards a higher non-fossil fuel and renewable energy penetration appears according to Weber, *“a way too complicated issue as to be solved it with the current institutional fragmentation. The current policy development path still operates according to the principle of trial and error. Sooner or later it will be necessary to re-establish a*

ministry of energy to develop a more strategic, consistent and enforced approach.”

Table 14: SWOT Sino-Danish Renewable Energy Development Programme (RED)	
Strengths:	Specific focus on three types of renewable energy technology; Denmark has strong experience in the development of renewable energy policies, technology expertise and R&D; relative flexibility about spending of allocated funding; strategic focus and strong partnerships with Chinese government and research institutes
Weaknesses:	Limited amount of funding & resources in relation to the targets set
Opportunities :	Vehicle for promotion of Danish companies for turbine technology, wind resource assessment software, second generation biofuels, large-scale biomass applications; creation of a national renewable energy technology centre has potentially strong long-term influence on institutional renewable energy landscape
Threats:	Institutional fragmentation & rivalries between different governmental agencies might impact on programme outcomes.

8.8 Summary and Discussion

Has China experienced leapfrogging in terms of large-scale deployment and use of renewables? The research shows that one needs to separate the issues of deployment and actual use of technologies and consider renewable electricity installations in relationship to overall energy technology development. It is also necessary to differentiate between the different sectors as in each sector the situation is distinctive.

In terms of large-scale deployment, several renewable energy technology sectors have experienced different degrees of development in recent years. The most prominent example is the wind power sector which has shown annual growth rates of more than 100 percent since the introduction of the Renewable Energy Law. While the large-scale deployment of wind turbines through construction of large wind power bases could be considered a leapfrog in technology deployment, in the use of wind power, many issues including undersupplied grid integration, sometimes poor turbine quality and misguided planning by project developers have so far prevented effective use of available wind resources. It is therefore not appropriate to speak of leapfrogging as wind power utilisation rates are much lower than the potential given through

installed capacity.

The only technology that seems to have achieved leapfrogging in both aspects of deployment and use are SWH technologies for households and industrial applications. Disruptive innovative technologies that are relatively low-tech, such as the SHW, seem to have the most environmental benefits as they can achieve significant reduction in electricity consumption without generating other significant environmental problems. China's SWH leapfrog is a case in point. The 300 million square meter target for 2020 would result in annual electricity savings of about 300 TWh, with ongoing improvements in technology potentially even more.

Large and small hydro power has also experienced rapid growth rates in recent years. Looking solely at reductions in coal use and CO₂ achieved by hydro power is not sufficient to make an assessment about the contribution of this technology to environmental leapfrogging. Even small hydro power remains controversial as social and other environmental impacts are significant. Only the use of micro hydro power is an environmentally sound application which also can have co-benefits for rural socio-economic development. However, micro-hydro in China plays only a marginal role.

In the case of solar PV, technological leapfrogging occurred in the manufacturing output of solar PV panels. More than 90 percent are exported to Europe and other markets, therefore no large-scale deployment of solar PV has yet occurred in China. The continued high costs of solar PV make large scale diffusion a challenge. It is too early to speak of leapfrogging in the case of solar PV, only over the next decade will leapfrogging in terms of deployment and use will occur. Once solar PV reaches grid parity, a strong leapfrog can be expected to take place. Government goal is to have 20MW installed by 2020. From an environmental perspective, the displacement of coal-fired electricity generation through solar PV will, however, still be marginal.

In contrast to the first area of renewables in rural areas where international partnerships and development aid cooperation has been more or less directly involved in installation of renewable energy technologies, in the large scale deployment of renewable energy technologies,

international partnerships have not played a direct role. The main work here has been done by Chinese and foreign project developers and companies. International actors such as governments, inter-governmental organisations, research institutes or non-governmental organisations in cooperation and partnership with Chinese organisations have nevertheless contributed to the large scale deployment in indirect ways. The research shows that the CDM, the main mechanisms of multilateral climate cooperation, has not significantly contributed to renewable energy technology deployment and use – despite the fact that China is the largest CDM market worldwide. European governments continue to be the most relevant international actors through their bilateral cooperation projects most of which include technical training and capacity development components. A number of projects also aim at providing policy recommendations and advice to the Chinese government how to establish the right institutional frameworks necessary to guide a transition towards a sustainable decentralized energy system powered by renewables. The policy transfer of a feed-in-tariff is related to European-Chinese cooperation. The experience of REEEP shows that multi-stakeholder partnerships involving non-state actors can be useful to promote policy advice and recommendations for institutional change as non-state actors can work around political sensitivities which often limit the possibilities of bilateral cooperation.

9 Renewable energy developments in the context of China's overall energy sector development strategy

As demonstrated in the previous chapters, several types of renewable energy development are occurring in China. So far these developments have not yet shifted China's dependence on fossil fuels. This final chapter centering on shifting energy paradigms will focus on a comparison of China with other countries regarding progress towards transition of energy systems looking at installed capacity of renewable energy technology, Chinese companies' expansion in global markets and the construction of a national smart electricity grid. Regarding the concept of leapfrogging, this chapter in particular considers the definition of leapfrogging as national development strategy and policy device (see section 3.1.2) and the definition of environmental leapfrogging (see section 3.1.3) through achieving a fast transition to an energy system centred on renewable energy technologies, potentially even ahead of the so-called developed countries.

9.1 China's renewable energy sectors – moving to first position?

China's total installed capacity of renewable energy, production capacity of Chinese renewable energy companies, and increasing market shares were to some extent covered in the previous sections. In this section China's renewable energy and energy sector development will be compared with those of other countries, drawing on the definition of leapfrogging as national development strategy which aims to surpass other countries,

China's renewable energy development in the period from 2005 to 2010 has certainly happened much faster than in other large emerging economies such as India, Brazil or South Africa. In 2007, Martinot and Li (2007) considered that with continued policy support at the national and local levels, China renewable energy development could even surpass industrialised countries in the near future. There were clear signs of this with SWH technologies, a sector in

which China already back in 2007 was worldwide market leader. In 2008 China's share of installed SWH made up about 70.5 percent of global share, followed by the EU with about 12.3 percent (REN21 2010).

By 2010 China had surpassed some industrialised countries in other important renewable energy technology sectors. In 2010 China's total renewable power capacity (not including hydro) reached 50 GW, only second behind the United States. Counting hydro power total renewable power capacity reached 263 GW, more than any other country in the world (REN 2011). Of this some 18,928 MW were increases in wind power capacity, accounting for almost half (49.5 percent) of global installed wind capacity in 2010 and making China clear leader in this category (GWEC 2011). By the end of 2010 China had reached 226 GW of total renewables capacity (including large and small hydro), the largest renewable energy capacity worldwide (REN21 2011).

Table 15: Existing renewable energy capacity of leading countries as of end-2010 (source: REN21 2011)

	#1	#2	#3	#4	#5
Renewables power capacity (not including hydro)	United States	China	Germany	Spain	India
Renewables power capacity (including all hydro)	China	United States	Canada	Brazil	Germany/India
Wind power	China	United States	Germany	Spain	India
Biomass power	United States	Brazil	Germany	China	Sweden
Geothermal power	United States	Philippines	Indonesia	Mexico	Italy
Solar PV (grid-connected)	Germany	Spain	Japan	Italy	United States
Solar water heating	China	Turkey	Germany	Japan	Greece

For the wind energy sector China's Mid- and Long-term Development Plan for renewable energy initially set the goal of reaching 30 GW by 2020. According to commentators and wind

energy industry experts from the Global Wind Energy Council¹⁰⁹ consulted in 2009, a capacity of 35 GW was considered possible in China by the end of 2011. This would have put China ten years ahead of its own schedule. In fact, by the end of 2010 China already had constructed 44 GW of wind power, leapfrogging ahead not only of the national target but also surpass the installed capacity of current leader the United States.

Furthermore, the original 2007 goal of having 30 GW of installed wind capacity in China as of 2020 has been increased to 150 GW. At the time of writing US wind developments were defined by drop in the project development pipeline, due to the lack of stable policy and new power purchase agreements (American Wind Energy Association 2010). If China's current growth rates in the wind power sector continue as in the years since the introduction of the Renewable Energy Law, while other countries' development slows, the country can be expected to remain the world's No1 country in terms of installed wind power capacity.

Not only in the cumulative installation of renewable energy technologies, also in terms of manufacturing capacity, product output and sales of renewable energy technology did China make fast progress and surpassed many developed countries. Particularly mainland China's PV production has boomed in recent years and supplied about 30% of global demand in 2008. If 'Greater China', including Taiwan, is considered, the figure is even higher - closer to 40% (The Climate Group 2009). Within just one decade China became the world's leading producer – in 1999 China manufactured only about 1% of the world's solar panels, by 2008 it was the world's leading producer with a 32% market share (UNEP, SEFI & Bloomberg NEF 2010).

In the first two financial quarters of 2010, Suntech Power surpassed previous industry leader First Solar Inc. from the US in sales to become the world's largest solar PV manufacturer by revenue (SolarServer 2011). In 2009, Chinese manufacturers produced 3.84GW of PV cells and 3.60GW of PV modules during the year, representing roughly 20 percent of the roughly 10 GW of PV cells and the 8 GW of PV modules produced that year (SolarServer 2011). The over-supply that was experienced already in 2009 has led to drastic price cuts, making Chinese PV products

¹⁰⁹ Personal communication with Chinese experts from the Global Wind Energy Council, June 2010.

even more competitive internationally. Recent developments in European markets, such as the feed-in tariff in the UK introduced in 2009, will potentially further stimulate demand for Chinese PV products. Regarding the quality of Chinese PV products, in comparison with the products of companies from the US, Europe and Japan these are still on average of better quality, higher conversion efficiency and longer lifetime..

These examples above show that China has already emerged as one of the world's renewable energy powerhouses. Another measure to assess China's development in comparison to other countries is to look at the investment attracted by renewable energy sectors. China surpassed the US in 2009 as the country with the greatest investment in clean energy. China invested a total of \$34.6 billion and took the top spot for overall clean energy finance and investment, pushing the United States with \$18.6 billion into second place (Pew Charitable Trusts 2010). In terms of asset finance of wind farms, solar parks and other projects, China also leads with investments totaling \$29.2 billion, compared to about \$10.7 billion in the US (UNEP, SEFI & Bloomberg NEF 2010).

Another field in which China could potentially "leap ahead" of industrialised countries is the exploration of renewable energy markets in other developing countries. Chinese renewable energy technology companies have already started moved into other developing country markets, particularly Africa. Examples are Chinese government cooperation projects with African governments in the area of science and technology aiming to promote solar PV and providing capacity development and technical training (Jia 2004). However, these developments are still rather slow. An investment project by the Chinese company Tianpu for solar PV manufacturing in Kenya was put on hold in 2009 as a result of the financial crisis (Patton 2009). In the wind energy sector, it might prove harder than expected for many Chinese companies to get a firm foothold in the renewable energy markets in Europe and the US and compete with the established global leaders in wind technology. There are also patent issues which are not relevant for the companies operating in the Chinese domestic market, but will likely be an issue if they go to the US – which

is the main area in which Chinese wind energy companies would like to enter into. Chinese wind turbines might not yet be able to compete with western turbines in the US or Europe, but emerging markets in developing countries can give Chinese wind turbine manufacturers opportunities. For example, Russian wind farm developers have been investigating the purchase of Chinese turbines for wind farm developments in Siberia, mainly due to the geographic proximity closeness of the Chinese suppliers, lower costs and the suitability of Chinese turbines for extremely cold winter conditions.¹¹⁰ Through emerging markets Chinese companies can get onto a virtuous cycle of greater sales, more experience, lower costs, more sophisticated design, they then might get the capacity to successfully enter western markets.

9.2 Leapfrogging as national strategic policy device

As has been remarked and demonstrated throughout this thesis, it has been mainly Chinese consistent policies that have driven the renewable energy development. To some lesser degree international partnerships have also played a supporting role. So far China has not declared energy leapfrogging officially as explicit development goal. Nevertheless, recent development demonstrate that China's leadership and industries have the ambition to achieve leapfrogging of the energy sector, mainly for reasons of energy security and economic competitiveness. However, while current policy frameworks are supportive of rapid development of renewables, to achieve leapfrogging additional policy measures beyond the energy sector would be required.

A recent example for new policy frameworks giving new incentives for renewable energy policy development was the 40-45% emission intensity target by 2020 that was announced in November 2009 just before the UN climate conference in Copenhagen and officially submitted under the Copenhagen Accord. There have been many discussions whether the Chinese targets can be seen as additional new effort addressing the issue of climate change. According to some

¹¹⁰ Personal communication with Russian wind farm developer at China 2008 Wind Power Exhibition in Beijing, October 2008.

commentators they do not represent a deviation from existing Chinese energy policy goals, thereby they are consistent with what can be called business-as-usual. Here one has to distinguish between commentators who are mainly concerned about the environmental impacts of ongoing rapid industrialisation (Rogelj et al. 2010), and those whose focus is the political and foreign policy aspects of climate and economic development, particularly in view of ongoing climate negotiations (Levi 2009).

Energy policy would include innovative energy pricing reforms to enable leapfrogging beyond the fast development one has observed to date. In addition to setting rational prices for energy, which has been on the agenda of Chinese energy policy for years, the integration of the environmental externalities of coal-fired power stations or large-scale hydro power developments into the price for electricity would be a major achievement. The introduction of a domestic Chinese carbon market and emission trading system (ETS), which has been announced in July 2010 by the NDRC (Li 2010), would be an important step into this direction.

Through this policy development China would leapfrog ahead the US and other industrialised countries which at the time of writing have put the introduction of domestic ETS on hold. China in contrast is set to begin domestic carbon trading programs during its 12th Five-Year Plan period (2011-2015) to help it meet its 2020 carbon intensity target. The Chinese government has announced they are certain that putting a price on carbon is a crucial step for the country to employ the market to reduce its carbon emissions and genuinely shift to a low-carbon economy. The introduction of a Chinese ETS would also be a change in the government's policy approach which has predominantly relied on regulatory and administrative tools instead of market mechanisms to address energy efficiency and emissions reductions.

9.3 Grid extensions and smart grids

As noted above (see sections 4.2 and 8.2), China's policy is setting targets based on capacity installed, rather than setting targets for electricity generated or energy consumed from

renewable sources. In this case China is not doing as well as other countries. For instance, approximately one third of total installed wind power capacity are said not to be grid-connected (Schwartz 2010).

Grid development currently is the bottleneck for China's renewable electricity development. The development of a highly efficient electric power infrastructure and particularly **smart grid development** would be essential for increasing the use of renewable and enable nationwide leapfrogging in the electricity sector. Smart grids will be important component of renewable energy leapfrogging strategies in China and one potential area where China could leapfrog ahead of other countries¹¹¹.

The grid connectivity issues for renewable energy sources, particularly wind, currently causes a significant portion of energy generated from renewable sources not being utilized. China's grid companies often state technical reasons for not being able to comply with their grid connection obligations stipulated by legislation, as transmission networks are not technically able to support large-scale renewable energy facilities and grid operators are not trained to manage of this new type of electricity generation. According to Schwartz (2009), in 2007 the State Grid distributed only one tenth (5 TWh) of the potential energy of wind farms which were theoretically able to produce at a close to 100% load factor.

Another reason is that because electricity generated cannot easily be traded and dispatched effectively between local, regional and national grids. Part of this is due to the intermittent nature of electricity generated by renewable sources such as solar and wind, which is difficult for the current over-burdened electric power infrastructure to handle. Furthermore, the current regulatory structure of the electricity system does not allow efficient power dispatching and trading.¹¹² These issues can be solved only through changing regulatory and institutional structures and making the grid smarter.

In China, as elsewhere, smart grid is still only an emerging concept and technology. The

¹¹¹ Presentation by Yang Fuqiang, WWF-China, at a UNFCCC Conference of Parties 15 side event in Copenhagen, December 2009.

¹¹² Interview with Uwe Weber, international advisor Sino-Danish RED Programme, January 2010.

development of power grids in China is lagging, which has caused difficulties in connecting and distributing power generated from wind farm developments. While the government has provided support for the growth of the renewable energy sector, the lack of a fully developed grid is now the major limit to further renewable energy development. To enable renewable energy leapfrogging the development of a national smart grid is necessary. Smart grids would further increase the ability to recover from frequent power disturbance events and breakdowns, enable interconnections between large utilities and small-scale, independent power generators, local grids and users, along with the capability to enable active participation by consumers on the demand side to improve energy efficiency through the introduction and facilitation of smart metering.

The Chinese government has serious intention to foster the construction of power grids and to connect the remote centres of wind power generation in the north-west with electricity demand and energy consumption centres in the coastal regions. A ten year government programme to build a smart grid to move power transmission into the digital age, securing electricity supplies and boosting energy conservation was announced end 2009 with about \$US 7.3 billion to be spent in 2010 (Fu 2009). This amount of investment in grids is higher than investments in the US (\$US 7.1 billion) and the EU, estimated to invest about 5 billion EUR or \$US 6.7 billion annually (Coppa 2010). Measures of the Chinese smart grid programme include the standardisation of grid construction and the design of a five-year technical renovation plan for the present grid to increase its transmission capacity, enhance its operational performance and reduce line losses.

9.4 Is China leapfrogging its environmental degradation through renewable energy?

In theory, environmental leapfrogging (see section 3.1.3) can be achieved by adopting international advanced practices and most efficient technologies, promoting domestic technical innovations, and achieving sustainable urban planning and infrastructure development. China has

the technical capacity, the market, and the relatively minor obstacles of stranded costs and vested interests which are often ignored in political process, to deploy these technologies. Another supportive factor is China's ability through strong government finance to doggedly increase production in industries and niche sectors which are not initially cost-competitive, in the case of renewable energy an example is solar PV, and drive down costs because of sheer economies of scale, which then could enable rapid diffusion. Despite its advantageous position of not yet being fully locked-in, although heavily reliant on fossil fuels, China's economic growth has so far largely followed a resource-intensive path similar to that of many developed countries which has incurred significant environmental degradation.

The years since the introduction of the Renewable Energy Law saw a rapid increase in renewable energy technology development and diffusion. Although during the six years from 2005 to 2010 energy consumption from other renewable energies (excluding hydro) increased by more than 1115 percent from 15 840 TJ in 2005 to 192 600 TJ in 2010, this has so far not significantly changed the development paradigm with coal still being the main type of energy consumed. In the six years from 2005 to 2010 China consumed 366374 PJ of energy produced from coal and compared to 1122 PJ of energy produced by other renewables (see Fig. 22).

Figure 22: China's cumulative final energy consumption by energy type from 2005-2010.

(data source: BP Statistical View of World Energy 2011)

There are a number of practical difficulties and underlying issues which need to be considered for environmental leapfrogging of China as a country through renewable energy. To make an assessment about the ability of China as a whole country to achieve national environmental leapfrogging, it is obviously too narrow to focus only on the energy sector, renewable energy technology and climate policy. To achieve a fast transition towards a low-carbon and green economy, the goal of mainstreaming renewable energy is certainly central concern. In addition, many other factors and sectors need to be considered such as buildings, transport, China's future industrial development and social aspects of energy consumption require attention. The magnitude of China's energy and environmental challenges remains enormous, despite the significant increase in renewable energy capacity. To create a sustainable economy it is necessary to further scale up renewables and look beyond energy.

While China's emissions will continue to grow under the current government's emission intensity target, it is nevertheless an important target given China's current status of development. Furthermore, it is certainly comparable in ambition to the goals of western industrialised countries, particularly if measured in absolute reduction in emissions. If one assumes an average annual GDP growth of 8% in China, it is expected to achieve emissions reductions of 2.5 GtCO₂ in 2020 under the target. While this is certainly not adequate to ensure limiting planetary temperature increase to below 2 degrees, comparing it to the emissions reduction pledges of the United States, 17% reductions over 2005 levels by 2020 will result only in 0.8 GtCO₂ (Athanasίου 2010). From this perspective one could argue that China has leapfrogged the United States in ambition and reduction targets from now until 2020. However, it is not sufficient to enable environmental leapfrogging for climate change mitigation.

In the implementation of cleaner production processes, looking at environmental

leapfrogging and the greening of industry through cleaner production, Ho (2008) concludes that there are strong structural factors at work that impede macro-level leapfrogging. These barriers include political and institutional constraints, market imperfections, and the nature of the developmental state. Another constraint for leapfrogging is the time dimension, often called the 'window of opportunity' (Berrah et al 2007), which is closing fast.

The introduction of the concept of "Green GDP", was initially suggested and elaborated by the Chinese Ministry of Environment, back then still the State Environmental Protection Agency (SEPA), in 2004 together with the National Bureau of Statistics would have been a truly strategic policy direction for sustainable development. For Green GDP accounting, the economic costs of environmental impact and ecological destruction were subtracted from traditional GDP. The estimated costs of environmental pollution amounted to U.S.\$64 billion, or ~3% of China's GDP in 2004 (Liu and Diamond 2008). However, the work on the Green GDP approach was not continued, the official reason is the inaccuracy of estimation methods. The introduction of Green GDP measurement would have constituted a significant leapfrog in environmental and economic policy development. In developing a Green GDP concept and accounting methodologies, China was in advance of most other countries. However, as it was not realised, no leapfrogging happened. A similar innovative approach has not yet been realised by neither western industrialised countries nor other developing countries. The continuous improvement of the methodologies, including placing monetary value on ecosystem services, would be an important element of enabling China's development towards sustainability.

9.5 Summary and Discussion

This chapter introduced and compared China with other countries regarding progress towards transition of energy systems looking at installed capacity of renewable energy technology, Chinese companies' expansion in global markets and the construction of a national smart

electricity grid, Regarding the concept of leapfrogging, the remaining two definitions of leapfrogging as national development policy strategy and environmental leapfrogging through achieving a fast transition to an energy system centred on renewable energy technologies were looked at.

Regarding overall installed renewable energy capacity China has leapfrogged in some technology areas within a short time ahead of many other countries, including the United States. Specifically the area of SWH technology stands out where China is unrivalled leader in terms of installed capacity. Since the introduction of the Renewable Energy Law, wind power has also taken off significantly and China became world leader in 2010. In the solar PV sector, China has developed the largest manufacturing capacity with world leading manufacturers in terms of production output and sales volumes. To continue this development and move ahead of other countries in other sectors will require a concerted and sustained effort at technology education, training, R&D, business development and international technology transfer.

In terms of strategic policy development, the research does not provide evidence to support the idea that Chinese energy and climate policies and legislation are yet sufficiently ambitious to be classified as strategic policy devices to enable China's renewable energy companies to make China world leader in renewables. Regarding absolute reduction of China's environmental impacts through renewable energy development, this has so far not happened either, environmental leapfrogging has not been achieved. For example, given its current state of development, China's emission intensity reduction target of 40-45 percent by 2020 compared to 2005 levels is advanced, however, not adequate to constitute a significant reduction in environmental impacts. This would require moving to a Green Economy based on life cycle thinking and eco-innovation principles, strengthening overall environmental governance and mainstreaming the concept of 'ecological civilisation'.

10 Discussion and Conclusion

The overall purpose of this research was to identify and analyse cases where China's energy system shows signs of leapfrogging through renewable electricity technologies. Furthermore, the objective was to analyse the relationship between Chinese government development plans and energy policies implemented since 2005, China's national innovation systems and international partnerships, and how the interlinkage between these elements has contributed to the development of renewables. The research focused primarily on renewable electricity, but non-electrical renewable energy technologies such as solar water heating and geothermal were also considered. Vehicle electrification in China's cities, because of its connection to the electricity sector and future electricity systems, was also discussed.

10.1 Leapfrogging in China's renewable electricity sector?

On a conceptual level, the research identified that the current concept of technological leapfrogging has not been sufficiently refined and no systematic definitions exist to use the leapfrogging concept as a practical analytical research tool. Three definitions of leapfrogging were used for analysis. First, technological leapfrogging in industrial innovation, second leapfrogging as national development strategy and policy device and, third, environmental leapfrogging through achieving a fast transition to an energy system centred on renewable energy technologies. Furthermore, the research shows that it is useful to differentiate three elements of technological leapfrogging: skipping steps in technology development, rapid passing through of technological development stages and the rapid adoption of technologies.

The overall research results show that leapfrogging in China's renewable electricity sector has only occurred in a few selected cases. A summary of the different areas and developments that are classified as leapfrogging in this thesis is provided below (Table 16).

Table 16: Identified leapfrogging developments in China's electricity sector (author's assessment) Note: 'X' indicates that no evidence for leapfrogging was found in this area or sector.

	Technological leapfrogging			Leapfrogging as development strategy and policy device	Environmental leapfrogging
	Skipping steps in technology development.	Rapid passing through of manufacturing stages	Rapid adoption of technologies		
Rural areas	Solar PV home systems (skipping grid-based electricity system)	X	X	X	X
Renewable electricity companies	X	Wind and solar PV companies developed manufacturing capacities within a few years which took western market leaders decades	X	Strong government support with the goal to create global industry leaders (only partly successful as innovation capacity of Chinese enterprises still low)	X
Renewable electricity in cities	X	X	Diffusion of electric bikes in Chinese cities (140 million in 2010)	Municipal policy frameworks and building codes for integration of SWH into building design (in selected cities)	X
Large-scale application and use	X	X	Construction of large-scale mega wind farm bases; wide adoption and use of SWH technologies (118 GW by end of 2010)	Renewable electricity development targets ambitious, but not yet high enough to be classified as national leapfrogging strategy	X
China's national energy sector development	X	Solar PV sector global market leader in monocrystalline panels (measured by production output and revenue)	World leader in SWH technologies manufacturing and application (64 percent of global installed capacity)	X	X (Renewable electricity technology has not yet displaced conventional fossil fuel electricity generation)

The results of this research show that technological leapfrogging in China has occurred only in selected cases. In rural areas electrification of villages through off-grid small-scale renewable energy technologies such as solar PV home systems has enabled rural communities to leapfrog conventional grid based electricity supply and guaranteed energy independence from centralised

power generation. However, costs per unit of energy remain relatively high with solutions such as solar PV. While solar PV home systems have been a costly leapfrogging option, more low-tech solutions such as rural household biogas digestors and improved biomass cooking stoves seem to offer more opportunities for satisfying rural energy needs in a fairly low-cost, environmentally sustainable way in the short and medium term.

While some Chinese companies have significantly improved manufacturing capabilities and increased their market shares in China and overseas, product quality and innovative capacity remain in many cases an issue to be addressed. Absorption of overseas technology and strong advances in innovative capacity have allowed some Chinese solar PV companies to develop into global brands through low-cost production of monocrystalline PV cells and modules.

In the wind energy sector, entry into international markets of leading companies has not yet been achieved. In terms of leapfrogging, particularly through licensing foreign technology Chinese companies have, within a period of five to ten years, been able to mature and develop to a level which took western market leaders decades to achieve. This development can be considered leapfrogging. However, identifying whether stages of technology development were skipped or just passed through in rapid succession was beyond the scope of this research and would require in-depth research and investigation at a company level. Despite their rapid development, Chinese renewable energy companies also still have some way to go to improve their innovative capacity, and their performance in terms of environmental sustainability and social responsibility.

This research has also described and analysed several case studies of Chinese cities which are very active in the diffusion and application of renewable electricity and electricity saving technologies. Rizhao city is a rather successful example that indicates the potential for moving fast towards low-carbon development through electricity saving technologies such as solar water heaters. Other examples from cities like Dezhou, Baoding or Shenyang show that no urban development experience is the same and strategies to create leapfrogging pathways need to consider local conditions. The examples also show that it might be easier for some smaller cities

which are still in early stages of urban development to achieve a low-carbon transition. Mega cities such as Beijing or Shanghai are mostly already locked-in: it will be difficult to transform these cities into low-carbon cities, and even promoting the wide use of energy saving technologies in buildings is proving difficult. Whilst these are examples of how some Chinese cities have strongly increased the use of renewable energy and encouraged the growth of renewable energy industries in their cities, so far no city seems to have yet made a real leapfrog towards becoming a sustainable eco-city.

It was beyond the scope of the research to examine the role of renewable energy in the Chinese transport sector. Nevertheless, the research considered vehicle electrification in Chinese cities and sustainable transport and mobility patterns. The wide adoption of e-bikes, which can be observed in most Chinese cities, does constitute a socio-technical sustainability transition and technical leapfrogging through rapid adoption of new technologies to some degree. Nonetheless, a life-cycle perspective shows that the use of e-bikes has not necessarily resulted in a reduction of impacts, but rather a shifting from local air pollution to high lead emissions during production and recycling stages of e-bike batteries. Moreover, e-bikes are not replacing car trips in cities, but appear in most cases to be replacing bicycles.

Regarding large-scale deployment and use of renewable electricity technologies, the research shows that it is necessary to separate the issues of deployment and actual use of technologies. In terms of large-scale deployment, several renewable energy technologies in some sectors have indeed experienced significant degrees of development in the period 2005 - 2010. The most prominent example is the wind power sector which has shown annual growth rates of more than 100 percent since the introduction of the Renewable Energy Law. However, in the use of wind power, developments are not encouraging as the wind power utilisation rate is much lower than the potential given through installed capacity. This is due to many different factors, most of all deficiencies in grid integration, sometimes poor turbine quality, and misguided planning by project developers.

In the case of solar PV, no large-scale deployment of solar PV has yet occurred in China. The continued high costs of solar PV make large scale diffusion in China a challenge. It is too early to speak of leapfrogging in the case of solar PV, since it is only over the next one or two decades that widespread deployment and use of this technology is likely to occur in China. The only energy technology which has achieved leapfrogging in both aspects of deployment and use is SWH for households and industrial applications. This technology has demonstrated remarkable growth rates and resulted in significant electricity savings at a competitive cost.

In terms of China's national energy sector transition, and making a comparison to those of industrialised countries, the research revealed that overall installed capacity of wind power and SWH in China has leapfrogged within a short time ahead of many other countries, including the US. Specifically, the area of SWH technology stands out where China is now an unrivalled leader in terms of installed capacity. Since the introduction of the Renewable Energy Law, wind power has also taken off significantly and China has been the world leader since the end of 2010. To achieve leapfrogging development in other sectors and move ahead of other countries will require a concerted and sustained effort at technology education, training, R&D, business development and international technology transfer. According to experts interviewed, the renewable energy race will increasingly focus on the issues relating to smart grid developments; at the same time this will also be an area for international cooperation, and smart grid development and management will become a major area of cooperation between governments and private sector in the decade.

Considering the ultimate challenge, environmental leapfrogging, the comparison of renewable electricity to the growth of conventional coal-fired electricity generation capacity shows that, so far, renewables are essentially only additional to existing capacity, only replacing some conventional coal-fired electricity generation at the margin, and not having yet altered China's electricity and energy supply and demand structure. Even in 2020 the situation will not have changed significantly under current development targets. Absolute reduction of China's

environmental impacts through renewables below environmental safety thresholds levels has so far not happened.

10.2 Institutional support for renewable energy development

The research further analysed how far Chinese national domestic energy policy making has contributed to renewable electricity development. The evidence suggests that government support programmes and policies for renewable electricity technologies were crucial in initiating the growth of industry sectors and the deployment of technologies. Rural renewable energy development is facilitated through financial subsidy programmes promoting the uptake and installation of PV solar homes and household biogas digesters. Additional government support could further focus on the training of a skilled renewable energy workforce in rural areas and support institutional development, e.g. small county-level rural energy offices are mostly understaffed and employees are often unable to adapt to the rapid developments taking place.

The Renewable Energy Law was a major institutional milestone that kick-started the large scale deployment of renewable energy technologies in China, particularly spurring wind sector development. The Chinese Renewable Energy Law has, however, due to its general nature, not been a complete piece of legislation; therefore a range of additions and adjustments, complementing the initial legislation, which was too weak to be effective, were necessary. In terms of facilitating the use of renewable energy, particularly wind power, Chinese renewable energy policy still has some way to develop if a paradigm shift in the energy system is to be achieved. It is possible to talk of leapfrogging meaningfully in the electricity sector only if both capacity *and* output (use) demonstrate leapfrogging. Despite its shortcomings, the Renewable Energy Law has so far given huge momentum to the development of renewable energy and clearly contributed to leapfrogging in installed capacity, although less so for leapfrogging in use of RE.

Regarding national target setting for renewables, due to target's cautious nature, although it has proved to be main incentive and had encouraging effect on company investments and renewable energy plant installations, the targets are not sufficient to be called a national leapfrogging strategy. National policy making and regulations are currently lagging behind the 'real world' development in renewable energy deployment, especially wind farm installations and market development. It is likely that the current unofficial target of 150 GW for wind power by 2020 will be revised and increased. China has not yet officially announced the amendment of its 2020 wind power target, but already renewable energy experts and government officials predict that domestic installed wind-power capacity could be as high as 150 GW by that year.

The research also shows that China's institutional structure for energy policy making is highly fragmented and its current form will probably not be able to support a leapfrogging transition of the energy sector. Currently at least 57 institutions have in some way or another influence on energy policymaking. Due to the complexity of the institutional set-up, it is often difficult even for experts to fully understand the exact roles, responsibilities and decision making processes of the different institutions. The fragmentation has had negative impacts on general renewable energy policy development, and particularly on designing an integrated strategy for the deployment of renewable energy and grid extension. The Chinese case shows that highly fragmented decision-making processes can hamper fast and effective transition processes.

Although low-carbon innovators, including SMEs, are officially considered key national assets, they are still in need of significantly greater support through government policy, particularly to increase their innovative capacity. The challenge for China's innovation policy is to promote SME development, as well as to support research into renewable and indigenous materials and technologies that are not considered 'high tech'. Policies that effectively support the existing competitive strengths of businesses driving disruptive renewable energy innovations would expedite the energy system transition in China. A strengthened IPR protection system would also resolve complicated issues of scientific integrity and IPR protection among Chinese

companies. Without measures of strengthened IPR protection and R&D support it is likely to be difficult for China's companies to continue leapfrogging.

For cities, municipal government policy initiatives to support local renewable energy industries and regulations such as building codes have been most relevant in enabling the transition through uptake of electricity saving renewable energy technologies, most importantly SWHs. Furthermore, the research results suggest that eco-city solutions benefit from public participation. There is a general tendency in China to approach sustainable urban development as a technological problem which can be solved by technical and scientific experts. Several international initiatives have attempted to contribute to this development. The two most prominent examples, Dongtan and Huangbaiyu, have unfortunately not (yet) delivered what they promised. These cases show that solutions to achieve eco-city development cannot rely only on top-down processes planned on drawing boards by expert teams – an indication that transition processes require both coordinated steering processes and channels for stakeholder participation.

Moreover, creating low-carbon eco-cities would require not only high-tech solutions such as renewable energy technologies. More important are creating a long-term vision, organisational structures and inclusive administrative processes to implement a long-term low-carbon strategy for urban development. It is important that, in the processes of full engagement and coordination, the strengths and interests of all stakeholders are considered. An eco-city is not self-sustaining if it is built merely with 'eco-hardware'. Equally important is 'eco-software', i.e. social values, belief systems and social practices consistent with sustainability, equity and public participation – practices that must be instilled rather than installed.

In terms of policy development, the research does not provide evidence that shows Chinese macro-level energy and climate policies and legislation are advanced enough to enable leapfrogging of the renewable sector ahead of industrialised countries, a transition of the energy sector or even environmental leapfrogging. However, given its current state of development, China's carbon emission intensity reduction target of 40-45 percent by 2020 compared to 2005

levels is a significant target, the current study suggests.. Another policy development which is at the time of writing being discussed by policymakers in China is the introduction of a domestic emissions trading system and the introduction of caps on provincial energy consumption. Such a policy has now been foreshadowed for 2012.

10.3 The role of international partnerships and cooperation

Regarding international partnerships and initiatives, the research results show that international cooperation has been and will continue to be an important element contributing to China's development of renewable energy. However, the factual evidence for the effectiveness and direct influence of partnerships and future potential for partnerships with China is rather limited. The collection of partnership case studies helps to give a wider picture of the various types of partnerships and enables reflection on their success or failure and an assessment of how far partnerships have contributed to leapfrogging in the renewable energy sector.

In the area of electrification in rural China, a number of bilateral partnerships were important in the early stages. International partnerships and development aid cooperation have in some cases directly facilitated installation of solar PV and household biogas technologies in rural China. However, international organisations seem to have limited their engagement in this area, which indicates that it is not considered a priority area any longer and that Chinese domestic policy and government departments are expected to be able to solve these challenges without further international support. This traditional area of official development assistance seems no longer to be a priority for international donors and cooperation initiatives in China.

One of the main findings from the research about company cooperation is that the rapid rise of China's wind and solar PV companies was in many cases initiated through the introduction of technological know-how from industrialised countries. For example, the licensing of patents and purchase of German wind power companies by Goldwind was crucial for China's wind industry

development. In the short term, licensing arrangements with international companies might prove to be effective methods in supporting the first stages of company development. However, early indications are that, if Chinese companies start emerging as competitors on the international market, foreign companies will be increasingly reluctant to license their technologies. If Chinese companies wish to reach the top level of global markets in terms of product quality, they will not be able to continue relying on acquisition of technological know-how from international companies, but need to develop their innovative capacity. Several companies have achieved this already, an example being the solar PV company Suntech, which has not only expanded on the international market through low-cost products, but also through innovation of new solar PV products and applications. However, companies based in OECD countries still continue to dominate intellectual property ownership of major low carbon technologies.

In the large scale deployment of renewable energy technologies, international partnerships have not played a direct role. The main work here has been done by Chinese and sometimes foreign project developers and companies. Nevertheless, international actors such as governments, inter-governmental organisations, research institutes or non-governmental organisations in cooperation and partnership with Chinese organisations have contributed to large scale deployment in many indirect ways. The research shows that the CDM, the main mechanism of multilateral climate cooperation, has not significantly contributed to the development of renewable energy in terms of large-scale deployment and use – despite the fact that China is the largest CDM market worldwide.

Governments continue to be relevant international actors through their bilateral cooperation projects, most of which include technical training and capacity development components. Governments, through bilateral cooperation agreements and public-private partnerships involving companies and research institutes, are also taking a facilitating role between the different sectors of the Chinese economy, and this has to some degree improved the situation. EU countries in particular have been engaged in partnerships already for a number of years. Bilateral cooperation

involving the private sector can take many forms other than sharing of core technologies: capacity building, innovation in management practices and project operation are fields where cooperation is possible.

A number of bilateral programmes also aim at providing policy recommendations and advice to the Chinese government on how to establish the right institutional frameworks necessary to guide a transition towards a sustainable decentralised energy system powered by renewables. However, these areas of policy work for foreign governments are sensitive as they can easily be perceived as interfering in China's domestic affairs. Therefore, technical cooperation is preferred as it can also support business-to-business cooperation. However, the increasing competitiveness of Chinese enterprises makes it increasingly difficult to justify technical support for Chinese renewable energy development domestically as it can be seen as building up competition for western renewable energy companies.

Cooperation partnerships involving foreign NGOs and think tanks seem to have proven useful in promoting policy advice and recommendations for institutional change, partly because NGOs can work around political sensitivities which often limit the possibilities of official bilateral cooperation. However, the reality is that NGOs, even well funded international ones, have only limited influence on Chinese energy policy making and only in very few selected cases can even indirect influence be exerted. Overall, China's institutional changes and renewable energy policy developments are difficult to attribute to international initiatives, and even less so to one specific partnership or project. What can be said with some certainty is that international exemplars have been important in creating models for China's energy policy. An example is the FIT for wind power which has proven successful, although with the qualifications noted above, in promotion of wind power.

In terms of environmental leapfrogging, many partnerships contribute to renewable energy development and environmental protection in China; however, there is not yet any partnership with the declared objective to enable China's environmental leapfrogging. From the perspective of

many western observers the realisation that China might leapfrog ahead of other countries in renewable energy technology development is often accompanied by perception of China as an emerging threat. Whilst on the one hand, the reduction of every single tonne of CO₂ emissions which is avoided through renewable energy technology is an achievement welcomed by the international community, on the other hand, as China rapidly installs more renewable electricity capacity and the country's renewable energy companies become more mature, they are viewed increasingly as potential competitors on the international level, particularly by the United States. This contributes to the use of the leapfrogging concept in political rhetoric.

10.4 Conclusions

The main aim of this thesis has been to analyse the specific pathways of China's renewable electricity sector development and what potentials and opportunities for, and barriers to, accelerating this transition process exist. It also aimed to identify the role of China's energy and climate policies and institutional frameworks in contributing to leapfrogging in renewable electricity technologies and assessed the role of international cooperation in the form of partnerships between Chinese and international stakeholder groups.

At the broadest level, the research findings show that leapfrogging in renewable electricity development is possible, but has so far only occurred to a limited extent in China. It is fair to say that technological leapfrogging of China's renewable electricity sector and companies, particularly over the period from 2005 to 2010 in the sectors wind, solar PV and solar water heating, has been quite remarkable in terms of developing manufacturing capabilities (monocrystalline solar PV products) and large-scale diffusion of some technologies (wind power, SWH and e-bikes). However, technological leapfrogging in the strict sense of skipping stages of technology development were only identified in the case of rural solar PV home systems for rural electrification, a case not specific to China. Renewable electricity development resulted in some

reduction of environmental impacts through electricity savings and emission reductions. However, it has not occurred to the extent that it has significantly changed the existing development pathway and energy structure.

In terms of contribution to theoretical knowledge, the research found that the current concept and use of the term leapfrogging requires much more differentiation and refinement. The identification and classification of different elements of leapfrogging proved useful to assess where China is headed in terms of transitioning to a low-carbon sustainable energy system and green economy. The application of the leapfrogging typology was helpful as a framework for analysis of what has been achieved, what else could be done and what needs to be done. At the same time, it does have limitations which should be acknowledged. Leapfrogging as a concept is still too vague and limited and there is scope for future research to establish more refined definitions of leapfrogging more suitable as an assessment framework for renewable energy development to be used in other large developing country settings, such as India, South Africa or Brazil. It would ideally also contribute to the development of specific indicators to measure leapfrogging in more detail.

The other central question of this thesis concerned the role of China's energy policy. China has proven to be a quick learner of international best practices for the promotion of renewables. It has adapted to the Chinese situation effective policies from Europe, such as feed-in tariffs for wind power, while creating unique policies of its own to support industry development, particularly at city and local levels. In terms of institutional development, the re-establishment of a Ministry of Energy would be a possible option to solve issues of institutional fragmentation, which certainly represents a significant problem. Such reform would likely also be helpful to support a faster transition and potential leapfrogging of the country's energy system. An energy system based on renewable energy integrated with a smart grid will be largely a decentralised system, but to facilitate the transition a strong coordinating body appears desirable, to put in place the necessary supporting policies and frameworks and oversee implementation of the policies on micro, meso

and national levels.

System innovation in the sense of a paradigm shift of the energy sector is still elusive. Technological leapfrogging of the renewable electricity sector alone will not be sufficient to achieve such environment outcomes; it requires a national leapfrogging policy strategy. China's policy target for renewable energy development, namely the current overall target of 15 percent renewable energy supply (including large hydro power-generation) by 2020, is in its current form not an ambitious environmental leapfrogging target. According to the research, the 15% target could probably be reached with new renewables alone. To increase the environmental integrity of the target, large hydro power could be excluded. If wind power capacity including both onshore and offshore were to increase to about 300 GW by 2020, which according to many experts is within the country's technical potential, then the CO₂ reductions would become material – more than 10% of the estimated Chinese CO₂ emissions from power in 2020. Future renewable energy deployment will likely also occur through off-shore wind energy development, requiring a new set of policies, as well as actions to meet the requirements of this technology. To avoid the current problem of deficient grid integration, future targets would, in addition to installed capacity, need to stipulate targets for electricity generated. China might then succeed in significantly increasing the proportion of renewable electricity in its electricity output mix, not just in terms of capacity installed. This in turn may presage the beginning of a steady and statistically meaningful decline in energy output from coal-fired plants and reductions of associated GHG emissions.

Chinese renewable energy companies have in a number of cases experienced technological leapfrogging, mainly in terms of rapid development of manufacturing abilities. However, detailed analysis of in-firm technology developments was beyond the scope of this research. The details of technological in-firm developments since the introduction of the Renewable Energy Law and other policies would require further in-depth research. While the developments of Chinese companies has been positively welcomed as a contribution to the transition to a global low carbon economy, the emergence of Chinese companies is sometimes noted with concern as western and

Japanese companies are alarmed by the growing competitiveness of Chinese renewable energy companies and their own loss of market shares.

The research findings do not support these concerns as healthy competition between Chinese and foreign companies have positive effects on the global diffusion of renewable energy technologies. Chinese companies are already beginning to transform global competition through their low-cost disruptive innovations. In addition, increased cooperation will have positive effects in further bringing down costs and increasing the quality of low carbon technologies, and this will further support diffusion, in other developing countries also. Chinese renewable energy technologies, as they fall in price, are becoming more affordable for low-income populations in other developing countries. Many Chinese renewable energy companies are already expanding their markets in developing countries, potentially enabling these countries to achieve leapfrogging in the deployment of renewable energy technologies, especially rural renewable solutions. Such impacts were not part of this research, but they certainly warrant further investigation. From a global perspective and in view of the need to achieve a fast transition to a global low-carbon economy, it is a very positive development that a number of Chinese renewable energy companies are emerging as global players.

International cooperation will continue to be important for China's renewables development. Foreign enterprises, moreover, can contribute to strengthening Chinese companies' ability to provide innovative solutions to problems of a global nature such as climate change, while still expanding sales in the growing Chinese market. Furthermore, China's renewable energy companies can potentially make a significant contribution to the world's knowledge pool and help to solve the major global problems of energy security and climate change. China and OECD member countries have a shared interest in solving these problems. An important challenge is to create win-win solutions for both Chinese and foreign companies, without weakening the competitive pressures for innovation, an ideal outcome which has in most cases not yet been realised.

Despite the achievements of China's government and companies in achieving some degree of leapfrogging in deployment of renewable energy technologies, and companies becoming global players competing head to head with established international companies, China is still far from leapfrogging its environmental problems. Creating a sustainable Chinese energy sector will require much more radical changes in its development pathway.

The research on the currently existing types of partnerships shows that the current level of cooperation is quite insufficient given the challenges posed by climate change. According to the IEA, any energy infrastructure constructed after 2017 will have to be zero carbon if the 2 degree target is to be achieved (IEA 2011). To enable leapfrogging resulting in an absolute reduction of environmental impacts, an increased focus should be placed on partnerships which would need to move beyond partnerships for industrial energy efficiency, the current focus. Future partnerships and fields of cooperation will likely shift more towards supporting leapfrogging of cities. Future partnership models could increasingly focus on city-to-city cooperation. Existing sister city partnerships could take up sustainable urban development as a new field of cooperation and exchanges through which best practices can be exchanged and shared.

As part of the research on China's leapfrogging potential western media discussions were followed. From the perspective of many western observers, particularly those from the United States, the realisation that China appears to be leapfrogging ahead of other countries in renewable energy technology development is often accompanied by a perception of China as an emerging threat. On the one hand, China's increased emissions from thermal electricity generations mean that China is accused of doing *too little*. On the other hand, as China rapidly installs more renewable energy capacity and the country's renewable energy companies become more mature, they are viewed increasingly as potential competitors on the international level, and China seems to be doing *too well*.

These highly politicised issues often make partnerships and cooperation difficult. Due to the politically significant nature of the leapfrogging of China as a country, and the perceived political

and economic risk of China's development to richer industrialised countries, it might become increasingly difficult to convince constituencies in those countries that increasing cooperation is necessary. It is helpful to recall that the race to a clean and renewable energy future is not a zero-sum game. Cooperation can help the US, Europe, China and other countries to achieve their energy, climate and development goals. European countries like Germany, through multiple partnerships including technology transfer, are profiting from China's move towards a green economy and low-carbon energy system. To achieve environmental leapfrogging through renewable energies, much more cooperation would be required to speed up technological change.

The findings associated with this research are of particular importance for increased global cooperation on climate change as the country's actions show that China has the intention to realise low-carbon development. Many Chinese people are ready to move along a different socio-economic development pathway that does not replicate the western development model, aware of the environmental and other downsides of unbalanced growth. Could China do it alone? The answer is probably yes, but with both international support in the form of technology cooperation and capacity building, and stronger signals from industrialised countries that Western countries are serious about fast emission reductions, the transition could be more effective and faster.

To conclude this thesis, the hypothesis posed that leapfrogging in China's electricity sector is a possible development pathway has only been partly confirmed. Only a few selected cases of leapfrogging in electricity sector development could be identified. Potentials for future leapfrogging still exist; however, their realisation would require the government to implement even stronger policy frameworks and target setting. Regarding partnerships, it is probably fair to say that only *if* China as a country achieves a transition to a low-carbon energy sector will the whole planet avoid dangerous climate change and successfully address other global environmental challenges. The same can be said about the United States and Europe: these countries have demonstrable potential for rapid carbon emission reductions vital to contain climate change. This emphasises the need for much closer cooperation in the important energy-related areas

discussed in this thesis. Healthy competition will be an important driver of the clean energy race. However, putting narrow national or commercial interests first is counter-productive when there is so much at stake. Cooperation on all levels needs to be further developed and promoted.

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12 Annex One: Interviewee lists and interview schedules

Semi-structured interviews

Interview with Han Wei, project manager of GEF Efficient Lighting Initiative, Beijing, 22 May 2008
(provided information on international cooperation and building energy efficiency)

Interview with former EU EEP programme Co-director Dr. Kurt Wiesegeart, Beijing, 24 June 2008
(provided information on EU-China cooperation, energy institutions and energy policy development)

Interview with two environmental experts from Japan's Ministry of the Environment who wished to remain anonymous, Tokyo, January 2009 (provided information on Japan-China environmental cooperation and CDM)

Interview with Keisuke Iyadomi and Jane Romero, researcher at IGES, Japan, January 2009
(provided information on renewable energy policy, Japan-China cooperation and CDM)

Interview with Andrew Knight, Director Communications, and Morton Dyrholm, Government Relations, from Vestas China, Beijing, 17 March 2009 (provided information about industry cooperation, China's wind power sector and China's renewable energy policy)

Interview with Dr. Wang Yu, Institute for Energy and Environment Economics, Tsinghua University, 26 March 2009 (provided information on China's energy policy)

Interview with Rick Weston, Regulatory Assistance Project, Beijing, 11 May 2009 (provided information about US-China cooperation on energy policy)

Interview with Dr. Liu Zhen, School of Environment, Tsinghua University, 4 June 2009 (provided information about China's energy policy)

Interview with Sebastian Meyer, research director of Beijing-based energy consultant Azure International, Beijing, 15 June 2009 (provided information about renewable energy sector, investment environment and CDM)

Interview with William Sun, energy expert, Dutch embassy Beijing, 23 June 2009 (provided information on Dutch-Chinese energy cooperation and joint energy research initiatives)

Information about the RED was provided by Dr. Uwe Weber, International Advisor to the REC Programme, interviewed in Beijing, 2 March 2010 (provided information on Danish-Chinese renewable energy cooperation, China's wind power sector, renewable energy policies and energy institutions)

Information about aerodyn was provided by Lars Klett, company representative in Shanghai, interviewed by phone on 16 August 2010 (provided information on German-Chinese wind

industry cooperation and China's wind energy sector)

Personal communications

Personal communication with Tim Tennigkeit, German bio-energy expert working in Yunnan Province, 11 September 2008 (provided information on rural bio energy and German-Chinese cooperation)

Personal communication with Deng Wen, environmental expert from the NGO Sichuan Green River, 5 December 2009 (provided information on rural biogas developments)

Personal communication with Spanish energy expert of the Spanish Chamber of Commerce in Tianjin, 16 June 2010 (provided information on Spanish-Chinese wind energy cooperation)

Personal email communication with Binu Parthu, REEEP Deputy Director General, Beijing, May 2010 (provided information on REEEP cooperation and projects in China)

Personal communication and email exchanges with Chris Lin, Manager of Tianwei Ltd, Beijing, between May 2009 and September 2010 (provided information on China's solar PV industry development and policies)

Personal communication and email exchanges with Rocky Cao, Oasis Energy Company, Beijing, between June 2008 and June 2010 (provided information on China's solar PV industry development and policies).

Personal email communication with Dr. Jim Platts, Cambridge University, March 2010 (Provided information about the experiences of the Wuxi Ryle Zhufeng Technology Co., Ltd. Joint-venture and innovation in China's wind power sector)

Personal communication and email exchange with Liu An, researcher at Beijing's Energy and Environment Research Centre, December 2008 (provided information on Beijing's energy policies)

Personal communication and email exchange with Liang Xu, researcher at Wuppertal Institute, Germany (provided information on Wuxi city renewable energy development targets)

Personal communication and email exchange with Feng Liguang, China Urban Sustainable Transport Research Centre, Beijing, March 2009 (Provided information on urban development and transport, electric vehicles)

Personal communication with Qiao Liming, expert from the Global Wind Energy Council, Bonn, June 2010 (provided information on wind power projects and CDM)

Personal communication with Eva Filzmoser, Director CDM-Watch, Bonn and Beijing, June and October 2010 (provided information on CDM in China)

Personal communication with Henning Huenteler, CDM project developer at UPS, Beijing, February & April 2010 (provided information on CDM in China and German-Chinese cooperation)

Personal communication with Lei Hongpeng, WWF LCCI Project Manager, Mai 2010 (provided

information on WWF's Low-carbon city initiative).

In addition, personal communications with several experts and stakeholders served as background information. The communication partners either wished to remain anonymous or in the communication were not informed that the information would be used for this research, therefore mentioning of names and/or organisational affiliation would be inappropriate.

Personal communication with Chinese and Danish programme staff during China Wind Power Expo, Beijing, October 2008

Personal communication with Russian wind farm developer at China 2008 Wind Power Exhibition in Beijing, October 2008

Personal communication with international and Chinese wind energy experts (who did not wish to be identified by name), Beijing, May 2009 & February 2010

Informal personal communications with several e-bike shop owners in Beijing, May 2010 (provided information on recycling of e-bike batteries)

Personal communication with various CDM consultants and CDM experts both Chinese and foreign between October 2008 – June 2010

Personal communication with Chinese and foreign experts who have worked on REEEP projects in China

Personal informal communication with several Chinese energy experts and former international cooperation programme staff in Beijing during 2008 (wished to remain anonymous)

Some information was taken from presentations given at public events:

Presentation by James Liang, James Liang, AES Corporation, at the Beijing Energy and Environment Roundtable 4 March 2009.

Presentation by Zou Xi, journalist for the Beijing Science and Technology Report, at the Beijing Energy and Environment Roundtable 3 June 2009.

Presentation by Dr. Yang Fuqiang, WWF-China at a UNFCCC Conference of Parties 15 side event in Copenhagen, December 2009.

Participant observation events:

Participation in Chinese CDM energy project expert discussion at GTZ Office Beijing, October 2009

Participation in the partnership MoU signing ceremony between REEEP and Energy Research Institute, Beijing, October 2008

Participation in REEEP project preparation consultations and project workshops, June 2008 at China Standard Certification Centre and September 2008 at Energy Research Institute and October 2009 at Beijing Energy and Environment Research Institute.

13 Annex Two: Interview/personal communication guiding questions

Interviews and personal communications were structured according to the following guiding questions. Depending on the professional expertise and organizational background of interviewee, more specific questions were raised either on renewable energy cooperation, policy frameworks, industry sectors or assessments on leapfrogging potentials.

What is the history of your organizations involvement in China renewable energy sector, what is the current status, what are future targets? (please provide a short overview)

What are experiences in cooperation with Chinese/foreign organizations/government agencies for renewable energy development?

What are the current institutional, policy or regulatory issues in China that impact (positively/negatively) on the development of renewable energy technologies such as wind/solarPV/geothermal etc.?

Which areas of China's renewable energy sector have already achieved leapfrogging development and how do you assess the potential for leapfrogging in the future?

What are main opportunities and/or barriers (technical/institutional/organizational) to achieve faster growth and/or leapfrogging of renewable energy in China?

What are the main issues China's renewable energy companies are facing for further industry development and technological innovation?