Renewable energy projects in rural China: a systemic capacity development approach

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Renewable Energy Projects in Rural China: A Systemic Capacity Approach

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Renewable energy can provide sustainable energy services in rural areas. However, ensuring the continued functioning of the technology in remote locations has been a major challenge. The aim of this study is to identify strategies that have been most successful in enabling access to sustainable energy services in rural areas of developing countries. This thesis draws on literature from the fields of capacity development, technology studies, and renewable energy project implementation. The strategies were identified by comparing existing frameworks with empirical data from three case studies of renewable energy projects in the Inner Mongolia Autonomous Region, China. Data for the case studies were collected via literature search, project document collection, site visits and interviews with a wide variety of stakeholders. The key findings of this thesis are that expanding energy access in developing countries will require significant capacity development efforts. Delivering energy services using decentralised renewable energy systems require the involvement of a diverse range of actors, including governments, program planners, equipment manufacturers, system designers, service networks and end-users. The most suitable delivery mechanism for sustainable energy services will vary from one location to another because of differences in the actors involved, their existing capacity and the history of their interaction. Assessing and building upon existing capacity is essential for delivering energy services in rural areas effectively. A major contribution of this thesis is the development of the “renewable energy capacity pyramid”, an analytical framework that explains how rural electrification projects can enhance local capacity in a systemic way. The framework includes tools; skills and knowledge; organisational structures; sectoral networks; and • the institutional environment. This study found that the provision of sustainable energy services in rural areas of developing countries is most successful when each project contributes to the evolution of these interrelated elements over a long timeframe. The capacity pyramid can be used to guide the design and assessment of renewable energy rural electrification projects within China and in other developing countries. The framework also contributes to a deeper understanding of capacity development in other sectors, especially where infrastructure is central to the challenge of service provision.

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Abstract

Renewable energy can provide sustainable energy services in rural areas. However, ensuring the continued functioning of the technology in remote locations has been a major challenge.

The aim of this study is to identify strategies that have been most successful in enabling access to sustainable energy services in rural areas of developing countries. This thesis draws on literature from the fields of capacity development, technology studies, and renewable energy project implementation. The strategies were identified by comparing existing frameworks with empirical data from three case studies of renewable energy projects in the Inner Mongolia Autonomous Region, China. Data for the case studies were collected via literature search, project document collection, site visits and interviews with a wide variety of stakeholders.

The key findings of this thesis are that expanding energy access in developing countries will require significant capacity development efforts. Delivering energy services using decentralised renewable energy systems require the involvement of a diverse range of actors, including governments, program planners, equipment manufacturers, system designers, service networks and end-users. The most suitable delivery mechanism for sustainable energy services will vary from one location to another because of differences in the actors involved, their existing capacity and the history of their interaction. Assessing and building upon existing capacity is essential for delivering energy services in rural areas effectively.

A major contribution of this thesis is the development of the "renewable energy capacity pyramid", an analytical framework that explains how rural electrification projects can enhance local capacity in a systemic way. The framework includes

- tools;
- skills and knowledge;

- organisational structures;
- sectoral networks; and
- the institutional environment.

This study found that the provision of sustainable energy services in rural areas of developing countries is most successful when each project contributes to the evolution of these interrelated elements over a long timeframe. The capacity pyramid can be used to guide the design and assessment of renewable energy rural electrification projects within China and in other developing countries. The framework also contributes to a deeper understanding of capacity development in other sectors, especially where infrastructure is central to the challenge of service provision.

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Many of the insights in this thesis were drawn from my previous experience working in renewable energy in remote areas. Many thanks to the staff at Bushlight (Australia and India), Rural Integrated Development Services (Nepal), Engineers Without Borders (Australia) and Grupo Fenix (Nicaragua). Your dedication to helping others inspires me every day.

On a more personal note, to my wonderful family and friends, I am so lucky to have such an amazing cheer squad. Thank you for feeding me cups of tea during the writing process and for putting a smile in my heart. Finally, thank you to my parents for your constant love and support. I would like to dedicate this thesis to you.

Relevant Publications

Some of the research reported in this thesis was originally published elsewhere. A list of relevant publications arising from this PhD thesis appears below.

1. To, L.S. (2007), Approaches to Using Renewable Energy in Rural Areas of China, *International Solar Energy Society Solar World Congress*, Beijing, China, 18-21 September. (full paper refereed)

2. To, L. S. (2008) Monitoring and Evaluation of PV Programs in Rural Areas in the Asia-Pacific Region. *3rd International Solar Energy Society Conference, Asia Pacific Region/ 43rd ANZSES Annual Conference*. Sydney, Australia. (abstract refereed)

3. To, L.S., Alex Zahnd, and Renate Riek (2012). "Building Capacity for Solar Photovoltaics in Rural Nepal." *World Renewable Energy Forum.* Colorado, USA. (abstract refereed)

Relevant Presentations

A list of relevant presentations arising from this PhD thesis appears below.

1. Guest lecture, Capacity Development: Case Studies of PV Projects in China & Nepal, Sustainable Energy in Developing Countries course, University of New South Wales, 8 October 2013

2. Presentation, Capacity Development for Renewable Energy Projects in Rural China, Joan Waugh Scholarship Celebratory Lunch, 4 August 2013

3. Presentation, Discussion Panel on Rural Electrification, Engaging Women in Clean Energy Solutions Workshop, World Renewable Energy Forum, Denver, 13 May 2012

4. Guest lecture, Humanitarian Engineering: Engineers Without Borders, Sustainable Energy course, University of New South Wales, 28 September 2010

5. Guest lecture, Humanitarian Engineering: Engineers Without Borders, Strategic Leadership and Ethics course, University of New South Wales, 15 September 2010

6. Presentation, Supporting Solar Energy in Rural Nepal, Women in Engineering & IT Hands On Day, University of Technology Sydney, 19 May 2010

7. Presentation, Social and Institutional Aspects of Photovoltaic Projects in Western China, Tara Old Girls Association, 31 March 2010

8. Presentation, Social and Institutional Aspects of Photovoltaic Projects in Western China, Sustainable Energy Discussion Group, University of New South Wales, 26 March 2010

9. Presentation, Social and Institutional Aspects of Photovoltaic Projects in Western China, Climate: Science + Humanities Symposium, The Faculty Club, Harvard University, 4 March 2010

10. Presentation, Solar Photovoltaic Projects in Remote Areas of China, Asia Pacific Week, Australian National University, 11 February 2010

11. Presentation, Institutional and Policy Support Structures for PV Projects in Developing Countries, Institute for Sustainable Futures, University of Technology Sydney, 27 January 2010

12. Presentation, Experiences with Photovoltaic Systems in Remote Areas, Kathmandu University, 2 March 2009

13. Poster, Implementing Photovoltaic Systems in Remote Communities of China, Energy Showcase, University of New South Wales, 5 December 2008

14. Presentation, Photovoltaic Systems in Remote Areas in China and Nepal, Centre for Energy and Environmental Markets, 21 November 2008

15. Poster, Implementing Photovoltaic Systems in Remote Communities of China, Centre for Energy Research and Policy Analysis Launch, University of New South Wales, 12 August 2008

16. Presentation, Evaluation of PV Lighting Systems at a Health Outpost in Nepal, Sustainable Energy Discussion Group, University of New South Wales, 18 March 2008

17. Presentation, Photovoltaics in Remote Areas of China, Institute for Sustainable Futures, University of Technology Sydney, 16 January 2008

List of Acronyms & Abbreviations

CPC Communist Party of China

GDP Gross Domestic Product

GW Giga Watts

IBRD International Bank for Reconstruction and Development

ICT Information and communication technology

IEC International Electrotechnical Commission

IMAR Inner Mongolia Autonomous Region

ISO International Organisation for Standardisation

kW Kilo Watts

kWh Kilo Watt hours

LED Light-emitting diode

MW Mega Watts

OECD Organisation for Economic Co-operation and Development

PV Photovoltaics

REDP Renewable Energy Development Project

RMB *Renmenbi* or Chinese Yuan (the legal tender in China)

SETC State Economic and Trade Commission

USD United States dollar (the legal tender in the United States of America)

W Watts

Note on Chinese Language

Chinese words appearing in this thesis have been transcribed into the Roman alphabet using the standard *pinyin* system, and have been *italicised* in the text.

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1 Introduction

1.1 Problem Statement

Modern energy services are essential for socio-economic development. However, 1.3 billion people lack access to electricity, mainly in the rural areas of developing countries (IEA, 2013, p. 23). Improving access to modern energy services is a top priority for sustainable development. The United Nations has declared 2014-2024 to be the international decade of Energy for All, which includes the aim of providing universal access to modern energy services (UN, 2013).

Renewable energy systems can make an important contribution to rural electrification because of their decentralised nature. It is often uneconomical to extend conventional electricity grids to rural areas which have low population density, low demand for electricity and low ability to pay. Renewable energy can generate electricity where it is consumed, eliminating the cost of transmitting electricity over long wires in the grid. This often makes delivering modern energy services to rural areas using renewable energy more cost effective than grid extension (Anderson, 1997, p. 192). Renewable energy systems are flexible and modular, so systems can be adjusted to account for changes in energy demand and the geographical layout of settlements. Renewable energy systems can be configured as mini-grids to supply power to a group of households, or as stand-alone systems to supply power to individual households. The use of renewable energy systems in rural areas will continue to accelerate due to the significant reduction in system costs in recent years.

There has been some success in realising these benefits in rural areas, especially in Kenya, China, Bangladesh, India, Sri Lanka and Mexico (Urmee et al., 2009). However, many renewable energy projects have struggled to contribute significantly to fulfilling the local energy needs of rural communities in developing countries. For example, an analysis of solar home systems surveys in six developing countries found that only 55% of systems were functioning (Nieuwenhout et al., 2000, p. 9). The literature review presented in Chapter 3 found the following common issues across a range of contexts:

- lack of appropriate financial arrangements,
- poor alignment with institutional structures, existing policies and regulations,
- poor acculturation and social acceptance,
- inappropriate hardware design and low quality hardware, leading to poor technical performance.

This thesis addresses these challenges by investigating appropriate socio-technical configurations for renewable energy in order for the technology to fulfil the energy and development needs of rural communities.

1.2 Aim & Scope

> The aim of this study is to identify strategies that have been most successful in enabling access to sustainable energy services in the rural areas of developing countries.

Energy services include lighting, heating, cooling and communications. Sustainability in this context refers to environmental, economic and social sustainability of the energy services. This thesis will focus on renewable energy technologies because they have the potential to provide energy services in a sustainable way.

This aim will be fulfilled through developing an analytical framework using a systems approach to capacity development. This involves considering all contextual elements and how they are linked together in a multi-level whole. Systems approaches focus on the inter-relationship between the different component of capacity within a system boundary and accommodates multiple perspectives. The analytical framework will be developed through examining three case studies of renewable energy projects in rural China, as well as relevant literature.

1.3 Thesis Overview

Chapter 2 discusses the research methods used in this thesis. It includes details of the case studies, data collection strategies, data analysis and development of the analytical framework.

Chapter 3 reviews the literature. It establishes the role of renewable energy in international development and summarises the lessons learnt from implementing renewable energy use in developing countries thus far. It then reviews relevant literature on capacity development and technology studies, with an emphasis on systems perspectives.

Chapter 4 draws on the literature reviewed in Chapter 3 and develops a multi-layer framework for capacity development for renewable energy electrification in developing countries.

Chapter 5 frames the three case studies of renewable energy projects in IMAR by analysing the national and provincial contexts. This chapter focuses on key developments in political structure, ideology, renewable energy policy and rural electrification policy.

Chapters 6 to 8 analyse the three case studies of renewable energy projects implemented in IMAR using the analytical framework developed in Chapter 4.

Chapter 9 syntheses the results from all three case studies and identifies strategies for capacity development. It discusses the case studies in relation to the literature; the national and provincial contexts; and the capacity development framework developed in Chapter 4.

This thesis concludes in Chapter 10 with a summary of strategies for enabling sustainable energy services in rural areas, a discussion of the policy and theoretical contributions of the thesis, the limitations of the study and avenues for further research.

2 Research Methods

2.1 Introduction

This chapter describes the research methods used in this thesis to identify strategies that have been most successful in enabling access to sustainable energy services in the rural areas of developing countries. The research design consisted of multiple case studies and an inductive approach was used to build the analytical framework. Section 2.2 outlines this inductive case study approach, and introduces the case studies. Section 2.3 describes the data collection strategy used and the fieldwork undertaken. Section 2.4 describes how the data was analysed and how the analytical framework was developed. The resulting analytical framework will be presented in Chapter 4.

2.2 Case Studies

A case study is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (Yin, 1989). This thesis aimed to identify strategies that have been the most effective in enabling access to sustainable energy services in rural areas of developing countries. Case studies were chosen as the research design because case studies are most appropriate for answering "how" and "why" research questions which focus on contemporary events (Yin, 2014, p. 14). Case studies are also appropriate for in-depth descriptions of complex situations, such as sustainable energy in developing countries (Yin, 2014, p. 4).

This thesis uses case studies to build theory in an inductive way. The method used integrates procedures from both grounded theory and case study research (Eisenhardt, 1989). Grounded theory was first articulated by Glaser and Strauss (1967) and was elaborated on

Table 2.1: Process of Building Theory from Case Study Research
This table has been removed due to Copyright restrictions.
Source: p. 533, Eisenhardt, 1989

in later works (Glaser, 1978; Strauss, 1987; Strauss and Corbin, 1990). Grounded theory is a "general method of constant comparative analysis" (Strauss and Corbin, 1998, p. 158), where data analysis is done alongside data collection. It is an inductive method where theory emerges from the data itself. Inducing the theory from empirical data in this way ensures that the resulting theory is relevant, testable and valid. The type of theory which emerges from case study research can be described as middle-range typological theories. In contrast to general explanatory theory, these theories give a rich and differentiated understanding of a phenomenon, and provide nuanced policy recommendations appropriate for the context (George and Bennett, 2005, p. 235). Therefore, this research design is particularly appropriate for identifying useful strategies for providing sustainable energy services in developing countries.

An overview of the process of building theory from case study research is given in Table 2.1. The research began by carefully defining the research question in order to focus efforts. A priori constructs were identified through examining existing renewable energy project implementation frameworks and past project experiences. However, theoretical flexibility was retained throughout the research process. Case studies were selected to focus on theoretically useful cases where renewable energy systems had been implemented at a large scale. Data collection instruments were then designed using a systems approach to build a complex, rich picture of the case studies. Data analysis overlapped with data collection in the form of field notes and allowed for adjustments to the data collection protocol as needed. The data analysis consisted of within-case analysis to identify the most salient features of each case study, as well as cross-case pattern searching. A draft framework was constructed from this analysis and refined through iterations between the literature and the empirical case studies. This processes ended once theoretical saturation was reached when improvements to the framework became marginal. The remainder of this chapter will describe these processes in more detail.

The unit of analysis for this thesis is the renewable energy project. This is a useful unit of analysis because projects embody different strategies to providing sustainable energy services in developing countries. A project is also a useful unit of analysis because many case studies of renewable energy projects in developing countries already exist, so comparisons to existing literature can be made.

Three Chinese renewable energy projects between 2000 and 2008 were chosen as case studies for this thesis. The projects were the Brightness Program Pilot Phase, the Renewable Energy Development Project (REDP) and the Township Electrification Program. These case studies were selected because they were the largest renewable energy rural electrification projects in China at the time. Other projects implemented in China were smaller pilot projects aimed at testing technical viability (Wang (2004) provides a comprehensive list of other renewable energy projects implemented in China). The three projects selected for this thesis cover a period where China transitioned from pilot projects to full-scale implementation of renewable energy in rural areas. As there are few instances of this kind of scale-up around the world, these Chinese case studies hold valuable lessons for other countries that are looking to scale up the use of renewable energy in rural areas.

Sustainable energy access can be achieved using a variety of implementation approaches and technologies. The projects were selected to cover a variety of technologies and implementation structures in order to maximise the generalisability of the findings (see Table 2.2 on the following page). The Brightness Program Pilot Phase and Township Electrification Program were both led by a large Chinese government agency. However, the the Township Electrification Program was much larger than the Brightness Program Pilot Phase. The Renewable Energy Development Project was led by an international organisation, the World Bank, with a long-standing relationship with different Chinese government departments. The Brightness Program Pilot Phase and Renewable Energy Development Project deployed small hybrid wind/PV systems, each large enough to supply one household. The Township Electrification Program took a different approach and installed mini-grids which were designed to supply a whole township from a central location.

The case studies focused on the experience in the Inner Mongolia Autonomous Region (IMAR) of China. China's governance is decentralised and the implementation of renewable energy projects differ substantially between provinces. Given the limited resources for the thesis, detailed analysis of the case studies focused on a single province. However, the implementation of projects in IMAR are significant in the national context, so this thesis also offered more general observations at the national level.

Table 2.2: Summary of Case Studies

	Brightness Program Pilot Phase	Renewable Energy Development Project	Township Electrification Program
Period	2000	2001-2008	2001-2005
Leading Agencies	State Development Planning Commission	World Bank, State Economic & Trade Commission/National Reform & Development Commission, Global Environment Facility	State Development Planning Commission/National Reform & Development Commission
Budget	20 million RMB	Total: US$40 million PV Component only: US$27 million (approx. 224 million RMB in 2001)	4.7 billion RMB
Number of systems in IMAR	approximately 4,000	4,700	42
Typical system in IMAR	300W wind/ $100W_p$ PV hybrid household system	300W wind/ $100W_p$ PV hybrid household system	7 - 57 kW PV or PV/wind hybrid centralised system

2.3 Data Collection

2.3.1 Fieldwork

Two trips to China were made in 2007 and 2010 to collect data for this thesis. These research trips focused on conducting interviews, making observations, examining wind/PV hybrid systems and collecting documents. The research sites included Beijing, Hohhot (the capital of the IMAR) and rural areas in IMAR to capture the national, provincial and local perspectives.

In Beijing, semi-structured interviews were conducted with project staff, researchers, policy-makers, industry groups and consultants. They offered a national perspective on renewable energy rural electrification and shared their experience from different provinces. This provided a broader context and points of comparison for the case studies in IMAR.

Documents were collected from project offices and the national library. Participation in international conferences and exhibitions in Beijing provided an insight into the operations of major renewable energy manufacturers.

In Hohhot, semi-structured interviews were conducted with component manufacturers, system integration companies and project administration organisations. Project documents were collected from companies that had been involved in each of the case study projects. Field visits to PV manufacturers in Qinghai Province were made as part of an international study tour which provided a point of comparison for IMAR.

Fieldwork was conducted in two *banners* and a *sumu*[1] in IMAR. Data at the local level was collected by:

- conducting semi-structured interviews with shop owners, technicians, customers in the shops, households and local government officials, as well as taking photographs when appropriate,
- observing the operation of wind and wind/PV hybrid system shops, including assisting with the installation of a household wind/PV system and observing shop sales,
- conducting technical assessments of wind/PV hybrid systems, and
- collecting documents from local shops.

All data was collected using procedures approved by the University of New South Wales Human Research Ethics Advisory Panel. The panel provided guidance on minimising harm, transparent participant recruitment, informed consent, keeping records and maintaining confidentiality. Confidentiality has been maintained throughout this thesis by referring to sources by their stakeholder role and a letter as a unique identifier, for example, End-User A.

2.3.2 Data Collection Questions: A Systems Approach

The fieldwork in Beijing and IMAR was guided by the data collection questions presented in Appendix 2. The questions were developed using a systems approach which defined

[1] The administrative divisions in IMAR carry traditional Mongolian names, but are equivalent to administrative divisions in the rest of China. The administrative divisions from highest to lowest in IMAR and their conventional equivalents are: Autonomous Region/ Province, League/ Prefecture, Banner/County, Sumu/Township, and Gacha/Village.

renewable energy projects as systems consisting of multiple components working in concert towards a common goal, embedded within an operating environment (which may be a larger system).

Systems thinking was developed in the 1930's. Since then, the systems field has expanded to over a thousand distinct methodologies and has been applied to many different problems (Williams, 2009, p. 4). The diversity of approaches can be divided into two main categories - hard and soft traditions of systems thinking. The first wave of inquiry in the systems field focused on hard systems approaches which assumed that the models developed in systems thinking corresponded to systems in the real world. This phase tended to focus on finding solutions to problems where there is perceived unity of purpose amongst the stakeholders. In hard systems approaches, the metaphor of systems as a machine is often used (Reynolds and Holwell, 2010, pp. 9-11). The second wave of inquiry in the systems field consisted of the soft systems tradition which is based on the idea that systems are epistemological constructs. This second wave had a pluralist outlook which acknowledged that not all stakeholders agree on the problem definition. The approaches focused on people and their perspectives. In soft systems approaches, a guiding metaphor for a systems is a living organism (Reynolds and Holwell, 2010, pp. 9-11).

This thesis adopted a soft systems approach to capacity development because it is well suited to dealing with the complexity of energy provision in rural areas, and can provide multiple perspectives on the situation. In addition, the systems approach offers a contextual framework for capacity development and is well suited for examining national and sectoral conditions (Lusthaus et al., 1999, p . 7).

The guiding questions were developed around three key public policy evaluation questions of how, why and to what effect different governments pursue a particular course of action or inaction (Parsons, 1995). The guiding questions included the project case studies, as well as the institutional environment in which they operated. Within the project case studies, the following aspects were included:

- the project goals at the national, provincial and local levels;
- the technical, organisational and cultural aspects of the technology implementation;
- the outcomes for each major stakeholder group (end-users, renewable energy busi-

nesses, project facilitators, project sponsors and policy-makers.

The effect of the project on the renewable energy technological system and how this affected other projects was also considered.

2.3.3 Surveys & Interviews

Data collection from households included a survey to collect technical information on the state of the renewable energy system, maintenance and repair arrangements and electricity access in a consistent format (see Appendix 3). Interviews with all stakeholders were semi-structured using the guiding questions and recorded in written notes or audio recordings. Access to the key organisations was gained initially through introductions from the Chinese Academy of Sciences and the University of New South Wales. Subsequent interviews were secured through introductions from key interviewees (snowball sampling). In total, 43 interviews were conducted with the full spectrum of project stakeholders: end-users, technicians, managers at companies involved with project implementation, local government officials and project designers (see Appendix 1 for a full list of interviews).

2.3.4 Position of the Researcher

As this thesis uses qualitative methods to examine the social and political dimensions of renewable energy projects, the position and role of the researcher relative to the projects is important. Patton (1990) offers a useful spectrum for the role of the research which stretches from full participant to observation as a outsider. Most of the observations were made with the researcher as a project outsider and an outsider of the Chinese political system because the research was conducted by an Australian university. The researcher's position as an outsider allowed her to gain access to diverse perspectives once anonymity for the interviewees was assured.

At the same time, the researcher's Chinese cultural identity helped her to understand the context for the projects. She is a fluent speaker of Cantonese Chinese and English, and studied Mandarin Chinese for three years before embarking on the fieldwork. Interviews were conducted in Mandarin Chinese and English. While in rural areas of IMAR the research was greatly enhanced with the help of fluent Mandarin speakers who could also understand the local nuances of the language. Fluent Mandarin Chinese speakers helped with transcribing and translating key interviews to ensure accuracy.

2.4 Data Analysis & Development of the Framework

As mentioned previously, this study takes an inductive approach to building theory from case studies. One feature of this type of study is the data collection phase overlaps with the analysis phase through the use of field notes. Field notes are a running commentary on the fieldwork, preliminary analysis and observations written at the end of each day. The use of field notes provided opportunities for identifying key themes while in the field and adjusting the research design. During the fieldwork, capacity development emerged as the central theme and questions were refined to cover this area in more depth.

All materials were collated and coded using ATLAS.ti qualitative data analysis software. Codes were developed and used to tag data about each project and the variety of topics covered. This helped to separate out information relevant to different aspects of each case study, as sources often referred to more than one case study. Descriptive case studies were then constructed with careful reference to the coded materials. A technical assessment of the renewable energy systems for each case study were made using the data collected from the household survey, photographs and semi-structured interviews with end-users, technicians, engineering managers. This data was compared with national and international standards, and other technical assessments of the same projects. This within-case analysis identified the most salient elements in each case study. Cross-case patterns were identified by using tables comparing different dimensions of the case studies and drawing up a comprehensive timeline for policy and political events throughout the period.

From the within-case and cross-case analysis, capacity development emerged as the central factor in enabling access to sustainable energy services in rural China. At the same time, patterns and relationships between the different elements of capacity development emerged from the analysis. In particular, the context for the development of this capacity within China was apparent in all three case studies. Note that this thesis does impose a particular type of analysis, such as socio-technical analysis, on the case studies. Rather, the analytical framework was refined through a highly iterative process of (1) reference to the literature and (2) comparison to the empirical evidence in each case study. This ensured a high degree of validity in the framework. Literature from different disciplines were identified and contributed to constructing framework. Although literature was used in an iterative way throughout the analysis process, a review of the literature is presented in Chapter 3 of this thesis in order to establish a conceptual basis for the analytical framework in Chapter 4. The literature will also be referred to in the discussion and conclusions to draw out the implications of the case studies for existing theories around sustainable energy access, capacity development and technological change.

Reliability and validity were ensured with the use of multiple sources to triangulate the data. This involved constructing a case study database with all the materials collected and careful cross referencing of the material in compiling the case study reports. Each finding involved reference to more than one source of data (for example, interviews and archival documents, or multiple interviewees). Collecting data at the local level is essential to validate collated data at higher levels of government in China (Heimer and Thogersen, 2006). The data collected for each case study were broad in focus to improve understanding of the context.

2.4.1 Interdisciplinary Research

Interdisciplinary research involves using conceptual models that link or integrate theoretical frameworks from two or more disciplines. This requires using methodologies that are not limited to any one field and requires that the perspectives and skills of multiple disciplines to be used throughout the research process (Aboelela et al., 2007, p. 341). Interdisciplinary research often focuses on complex and multi-dimensional 'real world' problems. As such, the research aims to creates change by contributing practical solutions that can be applied in a social context (Wickson et al., 2006).

This thesis will use an interdisciplinary approach by deploying literature from the fields of capacity development and technology studies. Both bodies of literature provide useful perspectives on the problem of sustainable energy service provision in developing countries. The technology studies literature illuminates the technical and social dimensions of renewable energy systems and how technological change occurs. The capacity development literature offers a human-centred perspective to how endogenous capacity can be enhanced to achieve a community's self-determined development goals. A systems approach will be used to examine the complex set of interactions between the elements identified by these two bodies of literature. These concepts will be reviewed in Chapter 3.

Interdisciplinary research is related to, but differs from multidisciplinary and transdisciplinary research. Rosenfield (1992) defines multidisciplinary, interdisciplinary and transdisciplinary research along a spectrum with varying degrees of synthesis. Multidisciplinary research involves the different disciplines working in parallel on a common problem without interaction. Interdisciplinary research involves using different discipline-specific understandings to bring multiple perspectives to a common problem. Transdisciplinary research involves a fusion of discipline-specific theories, concepts and methods. This thesis draws upon two different literatures in understanding the case studies and developing the analytical framework. The literatures are compatible, but a fusion of the two is not sought in this thesis. Thus, this thesis constitutes interdisciplinary, rather than transdisciplinary research.

A particular challenge for interdisciplinary research is reconciling the divergent paradigms of inquiry that inform different disciplines. While not attempting to resolve these tensions, this thesis avoids the extremes of strong positivism and strong constructivism. While each discipline use a diversity of approaches, the physical and social sciences tend to employ a positivist or post-positivist paradigm that assume that an objective reality exists and is knowable. Positivist assumptions underpin the scientific method, which involves proposing and proving hypotheses via experiments to gain generalisable knowledge that is time and context-free. Post-positivists acknowledge that the knowledge, background and values can influence the observation process and pursue objectivity by acknowledging these possible biases. The humanities tend to employ a critical theory or constructivist paradigm which assumes that reality is subjective and that knowledge is socially or individually constructed (Guba and Lincoln, 1994). In this thesis, I take the stance that physical objects, such as renewable energy hardware, have an objective reality, but that their use by humans is informed by social and cultural conditions. Thus, the strategies for enabling access to sustainable energy services identified in this thesis are derived with a nuanced understanding of the context, and can ultimately create change in the 'real world'.

2.5 Conclusion

This chapter has outlined the research methods used to identify strategies that have been most successful in enabling access to sustainable energy services in the rural areas of developing countries. An inductive approach to building theory from multiple case studies has been used. The literature with was found to be most relevant to the case studies is presented in the next chapter, before the analytical framework is presented in Chapter 4.

3 Literature Review

3.1 Introduction

This chapter presents a review of the literature on sustainable energy access in developing countries, as well as the conceptual frameworks that were most relevant to the case studies. This literature will give the theoretical context for the analytical framework developed in Chapter 4. As this thesis draws on theories from diverse fields, this chapter will give a brief overview of each field before discussing the literature which was most relevant to the case studies in depth.

Section 3.2 reviews the literature on sustainable energy access in developing countries. This section explores the motivations behind renewable energy projects by examining the links between energy and development. It also examines current approaches to renewable energy project implementation and their limitations.

The first conceptual framework relevant to sustainable energy access in developing countries is capacity development. Capacity development grew out of the international development literature. It offers a human-centred perspective to how endogenous capacity for sustaining energy services in rural areas can be enhanced to achieve a community's development goals. Section 3.3 reviews the literature on capacity development. The section discusses definitions of capacity and reviews the literature on capacity development approaches, including organisational, institutional, participatory and systems approaches. This section also discusses the timeframes and sequencing for capacity development activities.

The second conceptual framework relevant to sustainable energy access in developing countries comes from the technology studies literature. The technology studies literature illuminates the technical and social dimensions of renewable energy systems and how technological systems can change over time. Section 3.4 reviews the relevant literature from the field of technology studies. The section defines technology as a socio-technical system and examines how technological changes occur.

3.2 Sustainable Energy Access

3.2.1 Energy & Sustainable Development

This section identifies the role of renewable energy in international development and the rationale behind funding renewable energy projects in developing countries.

Sustainable Development

Sustainable development emerged as an integrated analysis of poverty and environmental degradation on a global scale. The classic modern definition for sustainable development is given by Brundtland in 1980 in the World Conservation Strategy. In Brundtland's report, sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"(WCED, 1987). However, Brundtland's definition leaves a certain ambiguity as it attempts to bridge long-standing debates on the goals and means of development. The looseness of the concept and lack of theoretical underpinning has enabled the term 'sustainable development' to be used to justify a myriad of policies and practices, including the status quo (Hopwood et al., 2005).

The 1992 Rio conference was a major attempt at implementing a global sustainable development agenda. The conference (attended by governments, heads of state and NGOs) launched high-level convention processes on climate change, biodiversity and desertification. It also launched Agenda 21, a more local-level, community-led process of sustainable development. Implementation of sustainability initiatives became managerialised through bureaucracies with a plethora of planning tools, frameworks, indicators, audits and evaluation methodologies to help government, businesses and communities to meet sustainable development goals. With this focus on managerial approaches, the wider political economy of sustainable development were ignored (Leach et al., 2010, p. 39-40).

Current debates about sustainable development policy are more normative and refer to a set of social, environmental and economic values. These need to be defined for specific issues and contexts. Leach et al. (2010) argue that it is useful to recognise multiple sustainabilities which represent the views and interests of different groups. This examination, in turn, provides guidance on different 'pathways' towards sustainability.

Economic development is currently closely tied to use of fossil fuels which emit carbon dioxide into the atmosphere and contribute to climate change. Renewable energy technologies have emerged as an energy pathway for sustainable development. Renewable energy covers a range of technologies that tap into natural energy flows (such as solar radiation, hydro, wind, tidal and geothermal) and do not emit carbon dioxide. Sustainable development policy in the context of renewable energy in China will be discussed in Section 5.3 on page 78.

Energy & Development Outcomes

The link between economic growth and energy consumption is inconclusive due to different climate conditions, energy consumption patterns, economic structures between countries, as well as the different methodologies used (Payne, 2010). However, most studies at the country-level show that energy consumption causes economic growth, and is a limiting factor in economic growth (Ozturk, 2010). Kaygusuz (2012) proposes that energy is linked to human, social and economic development through a virtuous cycle (see Figure 3.1).

Figure 3.1: Links Between Energy Human, Economic and Social Development
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Source: *Kaygusuz, 2012, p. 1119*

Energy services include lighting, heating, cooling and communication. These are essential for development. Table 3.1 on the following page shows how access to modern energy, including electricity, was seen by the UN as integral to achieving the Millennium Development Goals by 2015[1] (see Table 3.1 on the next page).

Given the importance of modern energy to the development process, energy was recognised as a basic human need in its own right when it was included as one of eleven themes during the consultation process for the post-2015 development agenda (UN-Energy and

[1]The Millennium Development Goals are a set of measurable targets adopted by the United Nations General Assembly in 2000 which form a framework for international development activities.

Table 3.1: Energy and the Millennium Development Goals

Millennium Development Goal	Influence of Energy
1. Eradicate extreme poverty and hunger	Energy inputs such as electricity and fuels are essential to generate jobs, industrial activities, transportation, commerce, micro-enterprises and agriculture outputs. Most staple foods must be processed, conserved and cooked, requiring heat from various fuels.
2. Achieve universal primary education	To attract teachers to rural areas electricity is needed for homes and schools. After dusk study requires illumination. Many children, especially girls, do not attend primary schools in order to carry wood and water to meet family subsistence needs.
3. Promote gender equality and empower women	Lack of access to modern fuels and electricity contributes to gender inequality. Women are responsible for most household cooking and water boiling activities. This takes time away from other productive activities as well as from educational and social participation. Access to modern fuels eases women's domestic burden and allows them to pursue educational, economic and other opportunities.
4. Reduce child mortality	Diseases caused by unboiled water, and respiratory illness caused by the effects of indoor air pollution from traditional fuels and stoves, directly contribute to infant and child disease and mortality.
5. Improve maternal health	Women are disproportionately affected by indoor air pollution and water- and food-borne illnesses. Lack of electricity in health clinics, illumination for nighttime deliveries, and the daily drudgery and physical burden of fuel collection and transport all contribute to poor maternal health conditions, especially in rural areas.
6. Combat HIV/AIDS, malaria and other diseases	Electricity for communication such as radio and television can spread important public health information to combat deadly diseases. Health care facilities, doctors and nurses, all require electricity and the services that it provides (illumination, refrigeration, sterilisation, etc) to deliver effective health services.
7. Ensure environmental sustainability	Energy production, distribution and consumption has many adverse effects on the local, regional and global environment including indoor, local and regional air pollution, local particulates, land degradation, acidification of land and water, and climate change. Cleaner energy systems are needed to address all of these effects and to contribute to environmental sustainability.
8. Develop a global partnership for development	The World Summit for Sustainable Development called for partnerships between public entities, development agencies, civil society and the private sector to support sustainable development, including the delivery of affordable, reliable and environmentally sustainable energy services.

Source: UN-Energy 2005

Figure 3.2: The Quality of Energy Services and Household Income
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Source: IEA, 2010, p. 267

SE4ALL, 2013). The United Nations has also adopted a goal to "ensure universal access to modern energy services" by 2030 (Ban, 2011). It is estimated that an average of US$ 48 billion per year is needed to achieve this goal, more than five times the level of investment in extending energy services in 2009. However, the amount of additional funding required is equivalent to about 3% of global investments in energy infrastructure until 2030 (IEA, 2011, p. 3), so universal access is well within reach.

Rural Electrification

Electricity access is particularly important because it can fulfil the largest range of human needs, and is the only form of energy which can provide many modern energy services, such as communication. Electricity is also convenient, easily controlled and clean (unlike traditional fuels which take time and effort to collect, cause indoor air pollution and pose fire risks). For these reasons, electricity is highly valued by households and they tend to shift their energy consumption away from traditional fuels to electricity consumption as their income increases. Figure 3.2 shows that as household incomes increase, higher quality are chosen to provide a wider range of energy services. Households often use a combination of fuels and technologies as they transition to more modern fuels. The concept of a simple "energy ladder" where households move up from one fuel to another in distinct stages is inadequate for understanding the behaviour of households which choose a mix of fuels according to efficiency, affordability, social preferences and energy security (IEA, 2010, p. 267).

The issue of improving energy access is largely one of rural electrification in developing countries as 84% of people without access to modern energy services live in the rural areas of developing countries (IEA, 2011, p. 3). Most rural electrification projects in the 1970's and 80's involved extension of the grid. However, these projects tended not to help the poorest people in rural areas, but benefited wealthier people who could afford to buy appliances and pay electricity tariffs once the grid arrived in their area. In addition, it is often uneconomic to extend the grid to rural areas which are remote, with low population density, low demand for electricity and, low ability to pay connection and ongoing tariff costs. Thus, rural electrification via grid extension often added to the insolvency of state-run utilities (ISDS, 2003, p. 10).

Renewable energy technologies (such as micro-hydro, wind, biomass generators and PV) can make an important contribution to rural electrification. Renewable energy is decentralised, which means that electricity can be generated where it is consumed and eliminates transmission costs over the electricity grid. This often makes delivering modern energy services to rural areas using renewable energy cheaper than the grid (REN21, 2014, p. 93). In addition, renewable energy systems are flexible and modular, so systems can be adjusted to account for changing needs. Renewable energy systems can be configured as a mini-grid to supply power to a group of households, or as stand-alone systems to supply power to individual households.

3.2.2 Barriers to Renewable Energy Rural Electrification

Section 3.2.1 established the role of renewable energy in rural electrification and the rationale for renewable energy projects in developing countries. Early renewable energy projects for rural electrification in the 1970's and 1980's focused on demonstration of the technology. Most overseas development funding for renewable energy projects in the 1980's was directed towards meeting hardware costs. Many projects had poor technical performance, were not well suited to end-user needs or local circumstances (Martinot et al., 2002, p. 313) [2]. The conventional approach to addressing these issues seeks to identify barriers which prevent renewable energy from entering the market. A number of studies reviewing the experience from past renewable energy projects have identified common barriers and success factors. These factors are often interdependent and have been compiled into frameworks to aid the design and implementation of renewable energy projects in developing countries (for example, Bazilian et al., 2012; Boldt et al., 2012; Retnanestri and Outhred, 2011; Urmee et al., 2009). This section discusses the common barriers to renewable energy rural electrification identified in the literature.

[2] A review of solar home system project evaluations in rural areas showed that only 55% of previously installed systems were in good working order at the time that the evaluations were conducted (Nieuwenhout et al., 2000, p. 9). Martinot et al. (2002, p. 316) are more optimistic and estimate that 80-90% of solar home systems in the field are functioning.

Financial

Affordability Although the lifecycle cost[3] of renewable energy systems is often lower than fossil fuel systems in rural areas, renewable energy systems usually have a higher upfront cost. This makes renewable energy systems unaffordable for many people in developing countries who have low incomes and lack access to credit.

Several project models have been designed to overcome these financial barriers. These models include (Retnanestri et al., 2008; IEA-PVPS, 2003*c*; Nieuwenhout et al., 2001):

1. *Cash:* The end-user is able to pay for the full cost of the renewable energy system. Smaller renewable energy systems, often using low powered light-emitting diodes (LED) lighting, can make renewable energy systems more affordable by reducing the unit cost (Nath et al., 2010).

2. *Credit sales:* The end-user buys the renewable energy system using credit. These can be divided into three sub-categories:

    a) *Dealer credit:* The renewable energy system dealer enters into a credit arrangement with the end-user when they sell the renewable energy system. Grameen Shakti has been particularly successful with distributing renewable energy systems by offering end-users micro-finance in Bangladesh (Asif and Barua, 2011).

    b) *End-user credit:* The end-user obtains credit from a third-party financial institution when they purchase the system.

    c) *Lease/ Hire purchase:* The dealer leases the system to the end-user. In the case of a hire purchase agreement, the ownership of the system is transferred from the dealer to the end-user at the end of the lease period.

3. *Fee for service:* An energy service company provides energy services to the end-user for a periodic fee. The energy service company owns the system and is responsible for maintenance.

4. *Subsidies:* The government or a donor agency reimburses the partial or full cost of purchasing renewable energy systems to the end-user or the dealer.

[3]Lifecycle costs include initial capital, fuel, operation, maintenance and decommissioning costs.

The choice of model depends upon many factors, including the total cost, income level of the end-users, access to financial institutions, as well as social norms. In general, when there is a large gap between affordability and cost, full or partial subsidies can be used. As the gap between affordability and cost decreases, fee-for-service and credit models can be used. Finally, if there renewable energy systems are affordable in an area, then a cash model can be used in a self-sustaining market (Retnanestri et al., 2008). Local manufacture of renewable energy system components can also reduce costs (Bruce, 2007, p. 2).

Finance As mentioned in Section 3.2.1, large-scale mobilisation of finance from public and private sources is needed to make universal access to modern energy a reality. However, current financial arrangements do not meet this level of ambition. In addition, financial institutions may demand a premium for loans for renewable energy systems as they are perceived as high-risk (GNESD, 2007, p. 13), with more capital risked upfront than with fossil fuel projects (Beck and Martinot, 2004, p. 4). In order to attract and facilitate greater investment in renewable energy, Milford et al. (2011) recommends that countries:

- create tax and other investment incentives with reassurances that will attract funds from new and wider range of investors,
- explore the creation of green bonds to provide long-term, widespread capital for renewable energy infrastructure projects, and
- align investment reduced risk-to-reward ratio clean energy opportunities and appropriate returns.

A set of coherent institutional structures, policies and regulations for renewable energy rural electrification are also important for attracting finance. This will be discussed further in the next section.

Market Distortions There are several factors which make renewable energy more expensive than fossil fuels unnecessarily. Firstly, the price of fossil fuels do not account for its environmental impacts, so the cost to society is externalised. If these cost of combusting fossil fuels were included in the price of electricity, estimates show that many renewable energy technologies would be competitive with coal plants (Owen, 2006). Secondly, many countries provide implicit and explicit subsides for fossil fuels. These subsidies can take the form of direct budgetary transfers, tax concessions, research and development spending, liability insurance, leases, land rights, water disposal and guarantees to mitigate project financing or fuel price risks (Beck and Martinot, 2004, p. 4). The Group of Twenty (G-20) countries and the Asia-Pacific Economic Cooperation (APEC) forum have committed to phasing out fossil fuel subsidies. However, these subsidies are often not transparent and reforms have been difficult to achieve as there are strong political incentives to stay with the status quo (GSI and IISD, 2010). Thirdly, equipment used in renewable energy systems can be subject to higher import taxes and other trade barriers . Recently, renewable energy equipment have been ensnarled in trade disputes between China, the United States and the European Union. Tariffs on environmental goods such as solar PV panels can be as high as 35% of their value and World Trade Organisation is currently negotiating an end to these tariffs (Wingfield, 2014).

Institutional, Policy & Regulatory

The path dependence of existing policy frameworks, regulations and institutional arrangements, are barriers to renewable energy dissemination. Politics often favour conventional energy and protect existing arrangements (Ban, 2011, p. 5-6). Conversely, renewable energy technologies often lack coherent long-term policies (including a defined role for renewable energy), and lack regulations and institutions designed specifically to implement renewable energy policies (GNESD, 2007, p. 13). Barriers to enacting renewable energy support policies include a lack of technical information about renewable energy, a lack of understanding of policy options, difficulties with quantifying and internalising costs and benefits, and lock-in to existing technologies and policies. Where renewable energy policies exist, policy implementation may be hampered by poor management and administration of financial incentives (IPCC, 2011, p. 148-149).

In addition, instability in the macro-economic environment can derail renewable energy projects (Boldt et al., 2012, p. 11). For example, the World Bank/ Global Environment Facility Solar Home Systems Project implemented in Indonesia between 1997 and 2003 had to substantially reduce its goals at the onset of the Asian financial crisis. The devaluation of the Indonesian Rupiah against the US Dollar tripled the price of solar home systems used in the project and the crisis in the banking sector meant that credit was unavailable for solar home system dealers (Retnanestri, 2007, p. 127-144).

Technical

Low quality renewable energy hardware decreases the system lifetime and reliability, increases costs for end-users, and tarnishes the reputation of renewable energy in the marketplace. Minor technical issues are often the reason for stopping credit payments (Nieuwenhout et al., 2004, p. 7). Therefore, there is a need to balance hardware quality and reducing upfront costs (discussed in Section 3.2.2). The quality of renewable energy system components can be improved through product branding, component testing, minimum quality standards, certification and labelling. Improved management practices such as computerised management information systems can also help (Nieuwenhout et al., 2004, p. 14-16).

The technical performance of renewable energy systems is also affected by a lack of trained personnel for manufacturing, system design, installation and maintenance in rural areas (Watson et al., 2012, p. 46). Providing avenues for technical training and certification can help to boost the number of qualified personnel. Providing renewable energy system maintenance in rural areas remains a challenge as demand and the ability to pay for maintenance in these areas are low. Households in rural areas may be dispersed across rough terrain, increasing the cost of providing technical services.

The operation of the renewable energy system by end-users can have a dramatic impact on the lifetime of the system, especially the batteries. Thus, manuals and training for end-users is also important for the technical performance of renewable energy systems.

Information & Skills

Markets function well when all actors have low-cost access to information and skills. A lack of awareness and information about renewable energy, especially of their characteristics and advantages, means increased uncertainty about the technology and often blocks decisions. There is a need for more information for planners, developers, professionals, technicians, end-users and financial institutions (Beck and Martinot, 2004; GNESD, 2007, p. 14).

In addition to the need for technical skills discussed in Section 3.2.2, firms require commercial skills, such as finance and business development. Business support services are required to boost the skills of renewable energy firms, especially smaller companies in rural areas.

Social Acceptance

Social acceptance or renewable energy innovation has socio-political, community and market components (Wustenhagen et al., 2007). For renewable energy projects in rural areas of developing countries, community acceptance is key. Renewable energy systems must meet local requirements and are institutionalised into the local culture (Retnanestri, 2007, p. 98-104). This process can be enhanced by using participatory and gender-sensitive approaches. Resistance to renewable energy can occur when the livelihood of a household is very vulnerable as they do not have any contingencies if and when the technology does not perform well (McKay et al., 2007). This is linked with perceptions of the reliability of renewable energy systems. Resistance to renewable energy can also result when projects upset local hierarchies or change traditional roles.

3.2.3 Limitations of Current Approaches

Much international assistance for renewable energy projects in developing countries to date have focused on the macro-level benefits of renewable energy for sustainable development. That is, the provision of much needed energy for rural development without the emission of greenhouse gases. As a result, they have focused on identifying technical, social and policy 'barriers' to implementing renewable energy in developing countries. However, the barriers approach fails to address how renewable energy can contribute to fulfilling community needs and how the technology fits in with existing social and institutional structures.

In many ways, the problems with the barriers approach are parallel to much international development assistance to date. Conventional development projects have had limited impact due to a lack of capacity in developing countries to sustain the technological solutions supported by donor agencies. Alternative development approaches which focused on capacity development and ownership by developing countries have been proposed. Section 3.3 will explore these approaches further.

The 'barriers' approach is aligned with a 'technology-push' view of technological change[4].

[4] From the economics of innovation literature.

In this view, new technologies arise from advances in scientific and technical understanding, but barriers to the dissemination of new technologies can exist. The 'barriers' approach is technologically deterministic because it presumes that society must change to accommodate renewable energy technology. Recent literature has highlighted the social, cultural, political and economic aspects of renewable energy projects in developing countries (Watson et al., 2012). An alternative approach has emerged which acknowledges that hardware evolves with social institutions to fulfil needs. These themes will be explored further in Section 3.4.

The following sections will review the capacity development and technologies studies literature, which will help to illuminate how appropriate socio-technical configurations for renewable energy can evolve in a rural context.

3.3 Capacity Development

This section reviews the literature on capacity development. It offers a human-centred perspective to how endogenous capacity for sustaining energy services in rural areas can be enhanced to achieve a community's development goals.

3.3.1 Defining Capacity Development

Capacity Development

The concept of capacity development emerged in the late 1980's in response to shortcomings in the international aid sector over the previous decades. The dominant model of development was project-based and driven by donor agencies. This model lacked long-term impact as developing nations lacked the 'capacity' to sustain the technological and economic solutions to poverty. Capacity development was part of a new approach that focused on developing country ownership (Lusthaus et al., 1999; Bolger, 2000).

Since then, capacity development has been identified as essential for increasing the effectiveness of international assistance[5].Capacity development has become ubiquitous in international development and many programs have been implemented with the aim of

[5] It is at the heart of the Paris Declaration on Aid Effectiveness (2005) and the Accra Agenda for Action (which emerged from the Third High Level Forum on Aid Effectiveness in 2008).

increasing capacity. However, there are many definitions of the concept (see box on the following page for a sample of definitions). Although a variety of approaches to capacity development will be reviewed in section 3.3.2 this thesis adopts the following working definition of capacity development:

Capacity development is a process that enables individuals, organisations, networks and societies to be resilient and reach their own sustainable development objectives.

In this definition, capacity development is an endogenous and continuous process of change. However, deliberate efforts can be made to assist this process. This definition acknowledges that capacity is systemic and exists at different levels of human organisation - individuals, organisations, networks of actors and societies. The inclusion of sustainable development in the definition of capacity development is important because this thesis is interested in sustainable energy outcomes in the rural areas which meet the basic needs of the poor and acknowledges the limitations of the natural environment. Resilience is the ability to self-sustain in a constantly changing environment.

Some see capacity development as a process towards achieving development goals (a 'means'), and others see developing capacity as an objective in itself (an 'end') (Bolger, 2000). This definition incorporates both dimensions of capacity development. Capacity development is both a 'means' to help individuals, organisations and societies to reach their own sustainable development objectives and an 'end' state of resilience.

Some Definitions of Capacity Development

- Capacity development is "the process through which individuals, organisations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time" (UNDP, 2008, p. 4).
- Capacity development is understood as "the process whereby people, organisations and society as a whole unleash, strengthen, create, adapt and maintain capacity over time". Where capacity is "the ability of people, organisations and society as a whole to manage their affairs successfully" (OECD, 2006, p. 12).
- Capacity is "the ability of an organisation to function as a resilient, strategic and autonomous entity" (Kaplan, 1999, p. 8).
- "Capacity development is a locally driven process of learning by leaders, coalitions and other agents of change that brings about changes in sociopolitical, policy-related, and organizational factors to enhance local ownership for and the effectiveness and efficiency of efforts to achieve a development goal. Where capacity is "the availability of resources and the efficiency and effectiveness with which societies deploy those resources to identify and pursue their development goals on a sustainable basis" (Otoo et al., 2009, p. 3).
- "Capacity is the ability of a human system to perform, sustain itself and self-renew". Capacity development is "changes in capacity over time" (Ubels et al., 2010, p. 4).

Contrast with Capacity Building

Although the terms 'capacity building' and 'capacity development' are sometimes used interchangeably, this thesis will use 'capacity building' in a more limited sense than 'capacity development'. The UNDP (2009*b*) offers a useful differentiation between the two terms:

> Capacity development commonly refers to the process of creating and building capacities and their (subsequent) use, management and retention. This process is driven from the inside and starts from existing capacity assets. Capacity building commonly refers to a process that supports only the initial stages

> of building or creating capacities and is based on an assumption that there are no existing capacities to start from. It is therefore less comprehensive than capacity development. The OECD/DAC writes that capacity building 'suggests a process starting with a plain surface and involving the step-by-step erection of a new structure, based on a preconceived design. Experience suggests that capacity is not successfully enhanced in this way.' Capacity building can be relevant to crisis or immediate post-conflict situations where existing capacity has largely been lost due to capacity destruction or capacity flight.

Capacity building and capacity development differ in their underlying assumptions about the development process. Capacity building is aligned with the dominant development approach which assumes that knowledge and skills can be transferred from developed to developing countries in a linear way through development projects. Capacity development is aligned with an alternative approach to development which assumes that development is a complex process that must be locally driven. The two development approaches are compared in Table 3.2.

Table 3.2: Dominant and Alternative Development Approaches

Dominant Development Approach	Alternative Development Approach
Development can be created and engineered.	Development is a process which is already in motion.
Development is done on behalf of those in need.	Development is driven from within.
Development is linear, predictable, and has a beginning and an end.	Development is non-linear, complex and unpredictable. Not all needs and outcomes can be foreseen.
Development 'projects' (which are time-bound, with limited resources and set outcomes) are the main vehicle of development.	Development workers act as facilitators of growth and interventions remain flexible.
Development occurs when understanding and knowledge are transferred.	Development occurs when clients are empowered.
The culture, norms and values of the donors and development workers are privileged.	Multiple sets of culture, norms and values are equally respected.

Source: summarised from Kaplan, 1999.

Capacity building is often undertaken in the context of transferring renewable energy technology from a developed to a developing country (Metz et al., 2000). Through technology transfer, it is hoped that developing countries can 'leapfrog' or bypass some of the environmentally polluting technologies which developed countries have used in their own development process (Sauter and Watson, 2008). Capacity building, in this context, seeks to improve the 'absorptive capacity' of developing countries (Kaplan, 1999, p. 8). From this viewpoint, capacity is merely the ability to implement development projects conceived and funded from outside. Lack of absorptive capacity limits aid effectiveness and causes declining marginal returns (de Renzio, 2005, p. 2).

Capacity building activities emphasise quantifiable outcomes, such as technical training, in line with donor reporting needs. However, technical assistance of this type implies inequality and dependency because it assumes that developing countries are lacking in knowledge and skills (Fukuda-Parr et al., 2002, p. 3). Capacity building has been criticised for destroying existing capacity, using inappropriate methods, fixating on predetermined results, and ignoring the aspirations of those seeking to develop (Boyd, 2009, p. 18).

This thesis challenges this approach to renewable energy in developing countries by using capacity development as a starting point. Capacity development is aligned with the alternative development approach, which challenges existing power dynamics and practices within the development industry. Capacity development differs from capacity building in the following key ways (Boyd, 2009; Bolger, 2000):

1. capacity development is an endogenous process and based on locally driven agendas,
2. capacity development includes a reciprocal and respectful exchange of learning and accountability,
3. capacity development activities must adapt to a specific context and build on existing capacities, and
4. capacity development involves long-term investment, and ongoing adaptation.

3.3.2 Capacity Development Approaches

Having explored the various definitions of capacity development, this section examines *how* interventions can enhance capacity. Different capacity development approaches have different assumptions about change, entry points for interventions and intended results.

Lusthaus et al. (1999) offers a useful taxonomy of capacity development approaches. They categorise capacity development into the following approaches:

- organisational approaches which focus on individual organisations,
- institutional approaches which focus on the formal and informal rules that govern society,
- participatory process approaches which focus on meaningful inclusion of all stakeholders and,
- systems approaches which focus on the interactions between actors.

This section reviews capacity development approaches using these four broad categories.

Organisational Approaches

Organisational approaches see effective organisations as the key to development (Lusthaus et al., 1999, p. 4). Organisational capacity development involves "conscious and holistic interventions which aim to improve an organisation's effectiveness and sustainability in relation to its mission and context" (Hailey et al., 2005, p. 4). Organisations can include government agencies, non-government organisations, civil society and community groups.

The organisational approach to capacity development draws upon theory and methods from the well established field of organisational development. Organisational development can be divided into closed and open systems approaches (Richter, 2010; Lusthaus et al., 1999, p. 5-6). The closed systems approach assumes that organisations are regular and predictable. Capacity development approaches aligned with a closed systems view of organisations prescribe steps to increase the effectiveness and productivity of organisations.

The open systems approach assumes that organisations are irregular and unpredictable, with complex interactions with its institutional environment. Figure 3.3 shows an open systems view of organisations. Organisations constantly interact with its institutional environment to obtain inputs, uses the inputs to organise production, and produces outputs. Organisations need to be resilient and adapt to changes in the institutional environment, as well as produce outputs that are useful for stakeholders. This, in turn, allows the organisations to obtain inputs or resources. The institutional context provides incentives for organisations (Communities, 2005, p. 8). Organisational capacity depends upon leadership, reward systems, work structures, coordination mechanisms, control mechanisms and internal relationships (Communities, 2005, p. 16). Open systems approaches incorporate tools which help organisations to navigate complex external environments and create productive internal cultures.

Figure 3.3: Organisations as Open Systems
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Source: Communities, 2005

Sequencing of capacity development within organisations is important. An influential open systems approach to organisational capacity development was devised by Allan Kaplan and his colleagues at the Community Development Resource Association (Soal, 2010; Ubels et al., 2010). Kaplan (1999) identified the following elements of capacity for organisations to function effectively:

1. Context and conceptual framework: An understanding of the world in which the organisation operates and its place in the world. An organisational 'attitude' which give it the confidence to act in a way which it believes will be effective and acceptance of responsibility for social and physical conditions.

2. Vision: The ability to plan a focused program of action to achieve their vision based on their unique strengths and relationships with others.

3. Strategy: The ability to develop and refine methodologies and practices to achieve its vision.

4. Culture: Awareness of and conscious decisions about norms and values (or the 'way things are done') within the organisation.

5. Structure: Structuring functions, procedures, accountability, decision-making and lines of communication in line with its vision and strategy.

6. Skills: Individual skills, abilities and competencies.

7. Material resources: Sufficient and appropriate physical resources and space from which to operate.

The sequence in which these elements are developed is important - the provision of material resources, skills training and restructuring will not be effective if an organisation does not understand its context, is unclear about its vision and strategy. The intangible elements at the top of the hierarchy are more important than the tangible elements at the bottom of the hierarchy. Various strategies have been suggested for working on the intangible elements of capacity, including surfacing theories of change (Aragon, 2010) and appreciative inquiry (Postma, 1998).

In the field of renewable energy rural electrification, a closed systems view of organisations dominate. Organisational approaches to capacity development tend to focus on building the technical capacity of individuals within organisations involved in delivering sustainable energy services. For example, the International Energy Agency Photovoltaic Power Systems Programme recommends capacity development through "technical support activities, training, specific technical assistance and resource networking" for government bodies, the utility sector, the financial community, non-government organisations, the service delivery chain and training organisations (IEA-PVPS, 2003*a*). However, focusing on technical knowledge and skills ignores the more intangible elements of capacity, such as the conceptual framework and vision of an organisation.

The narrow focus of organisational approaches to capacity development is both a strength and weakness. A focus on organisations clearly defines the field of change and allows capacity development practitioners to draw upon well established tools and theories from organisational development. However, the narrow focus means that other important factors for development, such as supportive institutions, can be overlooked (Lusthaus et al., 1999; Grindle and Hilderbrand, 1995, p. 6).

Institutional Approaches

Institutions are the "rules of the game" in a society or "the humanly devised constraints that shape human interaction" (North, 1990, p. 3). Institutions can be formal or informal, and include laws, policies, culture, norms and values. Institutions influence the actions of individuals and organisations by creating incentives. In turn, the behaviour of individuals either reinforce or challenge the existing institutions. Thus, institutional change is a dynamic interaction between the behaviour of actors and the institutions themselves (Giddens, 1984; Woodhill, 2010). Institutions are important because capacity exists not only in the skills of individuals within organisations, but also in the rules that govern their interactions (Fukuda-Parr et al., 2002, p. 9). Organisations and individuals need opportunities and incentives to exercise their skills for capacity to be realised.

The institutional approach to capacity development involves identifying specific actors and institutions to be changed. The actors and institutions identified in this approach can be divided into three main categories (Otoo et al., 2009) :

1. Conductive socio-political environment: the social and political forces that identify and prioritise development goals,
2. Efficient policy instruments: the formal mechanisms such as rule, laws, regulations and standards,
3. Effectiveness of organisational arrangements: the systems, rules, processes and personnel within an organisation.

Examples of institutional approaches to capacity development include strengthening the civil service, ensuring good public financial management with parliamentary oversight, promoting participation of disadvantaged groups in decision-making, increasing transparency, undertaking judicial reforms and creating an enabling environment for the private sector and civil society to thrive (Hope, 2011, p. 61). Institutional approaches to capacity development increase the capacity to create, change, enforce and learn from institutions (Lusthaus et al., 1999, p. 6).

Institutional capacity development in practice is often a complex process which may include organisational capacity development. This is because institutions can exist within organisations and can affect their effectiveness. These organisational capacity development activities are expected to influence the institutional environment, but results may only emerge after a number of decades (for example, see Land, 2000).

Institutions have increasingly been recognised as critical for the success of renewable energy rural electrification projects. The institutions which are important for renewable energy projects include:

- long-term policies, regulations and organisations designed specifically to implement renewable energy policies,
- management structures for financial incentives, and

- the macro-economic environment.

Most renewable energy rural electrification projects which tackle institutional issues take a market-oriented approach (for example, Graham, 2001; Schellekens and Wongnapapisan, 2011; Martinot et al., 2002). These projects aim to build institutions that make renewable energy commercially viable and self-sustaining in the context of a free market (Acker and Kammen, 1996) or subsidised project (Dornan, 2011).

However, institutions have only recently been linked with capacity development in the literature on renewable energy for rural electrification. For PV component manufacture in developing countries, institutions strongly influence networks of actors by affecting market operation, facilitating connectivity and information flows, altering resource allocation, and providing incentives to invest and innovate (Bruce, 2007, p. 173). Clemens et al. (2010) identifies the following areas for institutional capacity development activities specific to renewable energy in developing countries:

- policies and regulations,
- situational analysis,
- stakeholder dialogue, communication and community mobilisation,
- setting up and enhancing organisations,
- training of community members and program implementers, and
- implementation and management.

Institutional approaches to capacity development adopt a macro perspective which is able to deal with the issues which underlie development problems (Lusthaus et al., 1999, p. 6-7) . However, the approach often relies on experts to identify the institutions which need to be changed. This is problematic because the assumptions and viewpoint of external development organisations are privileged over the ideas of local people and may act to undermine capacity development (Fukuda-Parr et al., 2002). Participatory approaches to capacity development are designed to overcome this problem.

Participatory Process Approach

Participatory approaches to capacity development focus on the *process* of development. This approach is based on the premise that capacity development can only occur when the intended beneficiaries are empowered through participatory processes and feel a high degree of ownership. Participatory process approaches address issues of unequal voice, conflicting values and contested interests between aid donors and recipients (Tandon, 2010). The approach builds on the strengths of existing local organisations, institutions and models rather than imposing foreign models. Participatory approaches are consistent with a vision of development that is people-centred, non-hierarchical and focused on social justice (Lusthaus et al., 1999, p. 8).

Ownership of development goals by the intended beneficiaries is widely acknowledged as a crucial factor for aid effectiveness (Declaration, 2005). A participatory process approach focuses on including organisations at all levels (such as parliaments, local authorities, civil society organisations and governments) and traditionally marginalised groups into decision-making processes (AAA, 2008). Ownership of development outcomes can be enhanced through participatory processes in capacity development activities. The following dimensions in capacity development activities could contribute to ownership (Vinadio et al., 2012):

1. commitment of social and political leaders to advancing the development process;
2. compatibility of social norms and values;
3. stakeholder participation in setting priorities;
4. stakeholder demand for accountability; and
5. transparency of information provided to stakeholders.

A participatory approach re-frames the relationship between donors, recipients and their intermediaries (such as non-governmental organisations in developing countries). The traditional relationship between donors and recipients of aid has involved a transfer of funds, expertise and technology from developed to developing countries. This has often acted to undermine rather than build the capacity of those in developing countries through displacement of local expertise, external control over the agenda and lack of accountability to the beneficiaries (Eade, 2007; Fukuda-Parr et al., 2002). Participatory approaches to capacity development reframes this relationship in terms of a partnership where responsibilities and decision-making are shared. Instead of a transfer of skills and technology, learning and self-reflection is expected from both the recipients and donors of aid.

However, there are limitations to participatory approaches that affect the design and implementation of capacity development activities. Participation may be limited if there is a tradition of dependency in the community, high work loads limiting the time available, tensions within the community, or resistance to government and non-government bureaucracies. Governance structures and unequal power dynamics can also limit the spaces in which participation can be used. Participation can be improved through developing strong knowledge of socio-cultural contexts; providing incentives and support for participation; building an active civil society; and critically examining the terms of partnership between donors and implementation organisations to address power differentials (Angeles and Gurstein, 2000). Participatory approaches to capacity development may include organisational and institutional capacity development activities to enable participation. Although participatory approaches seek to support the voices of the most marginalised, this is difficult to achieve in reality as power differentials and other differences cannot be completely eliminated within communities, or between donors and recipients.

In the field of renewable energy, participatory process approaches to capacity development have focused on including end-users in decision-making for rural electrification projects. The communities in which renewable energy rural electrification projects are implemented in developing countries often require knowledge and tools before they are able to participate in decision-making. Therefore, information and education activities for end-users need to be implemented at the beginning of the project cycle (for example, the Bushlight India Project in Tuckwell et al., 2011).

There has been substantial work in integrating gender perspectives in renewable energy rural electrification projects and enabling equal participation of both genders in the planning process. Sensitivity to gender issues is important as men and women have different roles within the household and thus different energy needs and priorities (ISDS, 2003, p. xi). Participatory approaches to capacity development for renewable energy projects must ensure that both women and men are able to attend meetings and voice their opinions. Helpful measures include having female meeting facilitators, making arrangements for childcare and transportation, and having women-only meetings (Hughes et al., 2013, p. 5).

Participatory process approaches to capacity development clearly define the scope of capacity development activities. However, participatory approaches tend to focus on the individual, without examining how empowerment of individuals leads to capacity development. The process focus can also lead to a lack of consideration of outcomes (Lusthaus et al., 1999, p. 8).

Systems Approaches

Systems approaches to capacity development are "multilevel, holistic and interrelated, in which each system and part is linked to another" and involves "consideration of all contextual elements as well as the linkages between them" (Lusthaus et al., 1999, p. 7). Systems approaches focus on the inter-relationship between the different parts of the system within a system boundary and accommodates multiple perspectives. Development practitioners use systems approaches to help them understand and navigate the complex social context of capacity interventions (Greijn, 2009).

A hard systems interpretation of capacity sees it as embedded in different levels of human organisation (Ubels et al., 2010, p. 9). Bolger (2000) divides these into four levels – individual, organisational, sector/network and enabling environment (as illustrated in Figure 3.4). The individual level refers to people and their skills and abilities. The organisational level refers to the structures, processes, resources and management of organisations. The sector/network level refers to a sector of the economy (e.g. the PV sector) or a development theme (e.g. poverty reduction). The enabling environment is the broad institutional context for a development activity (e.g. policies, laws and attitudes) which can affect capacity development activities. The arrows in Figure 3.4 indicate that the different levels of capacity interact with each other and are interdependent. It is important to examine all levels of capacity as well as the interaction between the levels (Bolger, 2000, p. 4). These divisions are common in systems approaches to capacity development. For example, the UNDP and the OECD both analyse capacity at the individual, organisational and enabling environment levels (UNDP, 2008; OECD, 2006).

Other ways of making division for analysing the capacity at multiple levels are possible. Capacity can be divided into different geographic or administrative units (villages/communities, provinces/states/districts, national and international levels) (Ubels et al., 2010, p. 42). Capacity associated around a project can be divided in terms of the macro-level institutional environment, the meso-level of the structures and systems of organisations involved, and the micro-level of the project (Angeles and Gurstein, 2000).

Figure 3.4: Levels of Capacity Development
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Source: Bolger, 2000

In the application of soft systems thinking to capacity development, the most common metaphor for capacity is a living organism (for example, Ubels et al., 2010; Land, 2009). Capacity is seen as an emergent property of a system under constant change and has properties not found in its constituent parts. That is, capacity is more than the sum of its parts. In this view, capacity is relational, rather than a static set of competencies. Capacity describes how well a system functions, its agency, and ability to respond and adapt. Where there is high capacity, a group of concerned people are able to act effectively, to sustain the activity and to adapt to change (Land et al., 2009; Ubels et al., 2010).

Using a soft systems thinking approach, Baser and Morgan (2008) identified five collective capabilities that are crucial to capacity as a system condition. These include:

- the capability to commit and engage;
- the capability to carry out technical service delivery and logistical tasks;
- the capability to relate and attract resources and support;
- the capability to balance diversity and coherence; and
- the capability to adapt and self-renew.

These elements of capacity interact in complex ways as capacity develops (Baser and Morgan, 2008).Capacity development is neither a linear nor predictable process (Kaplan, 1999, p. 5). Capacity development is often unpredictable because it emerges from complex interactions between actors and from multiple processes (Kaplan, 1999; Land et al., 2009).

Capacity development interventions need to account for this uncertainty by including a degree of flexibility (Kaplan, 1999; Land et al., 2009).

Systems approaches to capacity development incorporate organisational, institutional and participatory approaches. As discussed in Section 3.3.2, organisations can be viewed as closed or open systems. Similarly, institutions can be viewed as systems of actors and their interrelationships. Systems approaches can enable participation from multiple stakeholders because systems approaches encompass multiple viewpoints.

In the field of renewable energy, international organisations have begun to acknowledge multiple dimensions to capacity development through a hard systems view. The International Energy Agency acknowledges that capacity for renewable energy spans across the individual, organisational and enabling environment levels (IRENA, 2012). The Clean Energy Ministerial adds a network dimension to capacity, which spans across levels and includes communication and negotiation platforms for stakeholders to engage with each other (GIZ et al., 2012).

Time Element of Capacity Development

Since capacity development must occur from within, time is required for people and organisations to learn by doing (Lavergne and Saxby, 2001, p. 3). Changes on the institutional context and organisational levels need a long-term time frame and a sustained relationship between donor and partners in developing countries (Eade, 2007, p. 636). The time needed varies depending on the intended outcomes and the complexity of the situation (Communities, 2010; Greijn and Fowler, 2010). Donors may impose their own short-term time frames because of project-cycle and accountability concerns. This may act to undermine capacity development. Clearly, an approach that has a longer time frame than an individual project is required.

Realistically, there needs to be a balance between long-term approach and the need to demonstrate short-term results (Baser and Morgan, 2008, p. 82-83). One way of balancing these capacity development priorities is SNV Netherlands Development Organisation's AAA framework for managing results (Greijn and Fowler, 2010). AAA signifies a continuous project cycle of:

- Analysis and planning,
- Action and monitoring and
- Assessing results and evaluation.

The framework helps project managers to develop organisational capacity along three different time scales: strategy (3 years or more), client (1-3 years) and assignment (weeks/months). This framework highlights the importance of continuous learning by the development agency as well as the intended beneficiaries and acknowledges changes in context over time. However, the framework is still centred on SNV's internal processes and does not effectively address the issue of mismatch in time frame between donor and other actors. In the AAA framework, recipients of aid must work within the time table of donors.

As capacity develops over time, stages of development becomes important. Many capacity development activities lack appropriate sequencing of measures so that capacities can develop fully (Institute, 2006, p. 19). Organisations, institutions and systems may be capable of some changes and incapable of other types of changes at different stages. This means that the sequencing of capacity development interventions is important because different interventions may be required at different stages (Lusthaus et al., 1999, p. 10). This requires capacity development professionals to develop their own skills in careful observation, interpreting observations and selecting appropriate capacity development measures in response to the stage and circumstances of their clients (Soal, 2010, p. 132). However, frameworks for determining timing and sequencing are also needed.

Communities (2010) suggests that capacity development measures should proceed in small, incremental steps or stages, starting from the basics. For example, public sector reforms to increase their efficiency cannot be implemented until basic reforms to strengthen rule-based government and markets are undertaken (Schick, 1998). This implies that interventions to create an enabling environment need to proceed smaller scale interventions. However, the time needed to create change at the macro level may be impractical in terms of the short-term needs of donors for accountability and performance (Baser and Morgan, 2008, p. 80).

Kaplan (1999) suggests that capacity development for organisations should also follow a sequence of steps for developing the capacity of organisations (discussed in Section 3.3.2).

Capacity development should progress from intangible elements (such as the organisations conceptual understanding of its context and purpose) to more tangible elements (such as resources and skills). This contrasts with the approach taken in Communities (2010) as an organisation first needs to orientate itself within its institutional environment, but the creation of an ideal environment is not a prerequisite for capacity development.

The political dimensions of change cannot be ignored and these may limit or expand the possibilities for capacity development at a given time. Capacity development measures that directly threaten vested interests may be better tackled at later stages. On the other hand, the commitment of senior leaders could significantly speed up and increase the scale of change by putting the issue on the external and internal agenda, changing their own behaviour and creating space within the system (Baser and Morgan, 2008, p. 80). Communities (2010, p. 52) recommends that capacity development tasks which involve low complexity and a small number of people to make changes should be scheduled first as they are likely to encounter less resistance.

Capacity development is a non-linear process, so stages may need to be repeated (Soal, 2010) or may need to proceed in parallel (Communities, 2010, p. 50). Capacity development activities themselves "generates the next set of conditions that must be seen and worked with (and cannot necessarily be anticipated from the start)" (Soal, 2010, p. 6). Complexity theory is helpful for devising strategies to assess changing circumstances in the external environment and within the unit of change as capacity is developed. With reference to complexity theory, Baser and Morgan (2008) categorise capacity development approaches according to their degree of flexibility (see Figure 3.5). They describe capacity development approaches as planned, incremental and emergent.

Figure 3.5: Planned to Emergent Approaches
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Source: Land et al. 2009, p. 5

Planned approaches to capacity development have a low level of flexibility and are characterised by centralised control and the use of project management techniques. Planned approaches are unsuitable for complex situations, but may be appropriate where there is a strong consensus amongst stakeholders, where funding exists for support systems, and where results can be easily measured.

At the other end of the spectrum, emergent approaches offer a high degree of flexibility. Emergent approaches do not identify specific goals, but create a protected space that allows capacity to grow from complex, often ad hoc, interactions between actors. These interactions are facilitated by an agreed set of rules for conduct, a common set of values and a collective identity. Emergent approaches fully acknowledge the unpredictable nature of the capacity development process, but do not work well when there is major conflict, politicisation of the issue or where objectives need to be reached in a short time.

Incremental approaches sit between planned and emergent approaches and offer a practical way of combining formal project structure with the need for flexibility in implementation (Land et al., 2009, p.5). Incremental approaches do set overall objectives, but these can be adjusted as the project progresses. Incremental approaches are most suitable where the context is changing rapidly or where the method for intervention is initially unclear. Lindblom (1959, p. 81) describes decision-making in the policy arena as an incremental process of "successive limited comparisons" where policies are constantly revised by considering a limited set of new policies which differ marginally from current practice. The chain of previous policy choices shape and inform present policy choices.

Planned approaches have dominated for capacity development activities for renewable energy rural electrification even though they have sometimes been inappropriate for the context. Effective capacity development often involves a combination of planned, incremental and emergent approaches.

Time frames and sequencing are important aspects of capacity development, but these aspects are missing from current models for capacity development for renewable energy rural electrification.

3.4 Technology & Technological Change

The previous section reviewed the literature on capacity development as it provides a useful framework for addressing the problems encountered by renewable energy projects in developing countries. Renewable energy rural electrification involves the adoption of a new energy technology in rural areas. This section reviews the technology studies literature relevant to improving energy access. This literature provides an alternative to the techno-centric 'barriers' approach to scaling-up renewable energy. The technology studies literature offers insights on how hardware co-evolves with social institutions. This section will define technological systems and discuss how technology changes over time. The application of technological systems theories to energy systems will also be discussed.

3.4.1 Technological Systems

The term 'technology' is often used to refer to hardware and technical skills. This restricted definition of technology implies that technology is a neutral tool that can be used in different contexts without modification. However, technology is part of a pattern of human activity, so technology cannot be separated from the values and daily life of those who use it. Technology can be viewed as a socio-technical system with interconnected elements. These elements evolve together as technological change occurs.

Pacey (1983) uses the term 'technology practice' to include the technical, organisational and cultural aspects of technology. Technical aspects include physical artefacts and the knowledge, skills and techniques need to operate them.Organisational aspects include planning, finance, administration, policy and regulation. Cultural aspects include the values, ideology, beliefs and other influences on the creativity of the designers and inventors of the technology.

Technology practice refers to the general meaning of technology and differentiates it from the more restricted, conventional definition of technology which refers to the technical aspects only (see Figure 3.6). When a technology is established, these three aspects of technology work together as a system which fulfils a societal function, such as energy services (Geels, 2005).

Such an integrated view of technology is needed to avoid ineffective 'technical fixes' to problems. Technology designed for one context may require significant modification to suit the needs of those using the hardware for different purposes. Renewable energy hardware will not function well in developing countries if the cultural and organisation aspects of the technology have not been properly addressed. Addressing these issues will require detailed analysis of specific situations in which the technology is used.

Figure 3.6: Definition of technology practice
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Source: Pacey, 1983, p. 6

3.4.2 Stages of Technological Change

Schumpeter (1934) identified three stages of technological change - invention, innovation and diffusion. He defined invention as the demonstration of a new technology, innovation as the introduction of an invention to the market, and diffusion as the process of spreading the technology through the market.

The 'linear model of innovation' assumes that technologies move smoothly through each stage. The most widely used version of the linear model was put forward by Bush (1945). He argued that government supported basic research was essential for technological and economic progress (Godin, 2006). This typifies the supply-push view of technological change which argues that technology is an autonomous factor. The opposing view is that the demand-pull of market forces are the main driver of technological change. Demand-pull theories assert that technological change occurs with market or government induced demand (Gallagher et al., 2012, p. 239).

The stages of technological change have been elaborated into a technology life-cycle. In this model, technologies go through the stages of emergence, growth, maturity and decline. A technology emerges after a technological discontinuity which are innovations that change underlying processes or products. This is followed by an era for ferment where there is competition between a variety of designs until one of them is selected as the dominant configuration and becomes the industry standard. Incremental changes to the dominant design then become the focus of industry activity until the next technological discontinuity occurs and the cycle begins again with the new technology (Anderson and Tushman, 1990).

As a technology progresses through its life-cycle, the performance of a technology progresses slowly at first, then accelerates and then declines over time or engineering effort or funds invested (See 3.7). This variation in the rate of change over time forms the shape of an s-curve and can be described mathematically an a logistical function. These curves have been fit to historical data for renewable energy (Schilling and Esmundo, 2009).

Figure 3.7: Technology S-curve
This figure has been removed due to Copyright restrictions.
Source: Taylor and Taylor, 2012

As technical performance varies over time, diffusion of technologies also follows the shape of an S-curve. That is, adoption of a technology over time is initially low, then accelerates and then plateaus as market saturation approaches. S-curves have been used to forecast the diffusion rate of renewable energy technologies and future costs. However, S-curves have been mainly applied to commercial products and need refinement to use with renewable energy technologies because renewable energy technologies are driven by government policies (Rao and Kishore, 2010).

The shape of the S-curve also shows that different groups of consumers adopt the technology as it progresses through its life-cycle. Consumers can be divided into innovators, early adopters, early majority, late majority and laggards . As an innovation diffuses through a society[6], each group of consumers through a five- step process of knowledge, persuasion, decision, implementation and confirmation (Rogers, 1995). This process offers a very useful account of how technologies emerge and develop over time from the perspective of the end-user of renewable energy technologies (Retnanestri, 2007).

Interventions designed to develop capacity for renewable energy rural electrification must take into account the position of different technologies along these stages. Long-term support for renewable energy may be needed until the acceleration stage is reached. We must also take into account the position of renewable energy technologies relative to each other and to other energy technologies along the S-curves.

The linear model of technological change has been widely used, but it does not adequately reflect the complex interactions between the technical and other aspects of technology (Balconi et al., 2010). S-curves provide useful empirical models for the diffusion of new technologies and the rate of technical improvement. Other aspects, such as the emergence of technologies, user preferences, organisational and cultural aspects, and the interactions between these elements are ignored. Supply-push and demand-pull theories are both limited because they assume that technological change proceeds along a linear path-

[6]Diffusion of innovation is the "process by which an innovation is communicated through certain channels over time among members of a social system" where communication is a two-way process of creating a shared understanding (Rogers, 1995, p. 5).

way, with a single source of innovation. This ignores the fact that markets and technology development influence each other (Dosi, 1982). The systemic perspective on technological change addresses these inadequacies.

3.4.3 Systems Perspectives on Technological Change

Rather than a smooth transition between discrete stages, systemic approaches acknowledge that technological change is a complex and uncertain process. Change in technological systems involves the co-evolution of the cultural, organisational and technical elements of technology. This 'chain-linked' model of innovation recognises that there are interactions and feedback loops between each stage of the process (see Figure 3.8). Innovation activities proceed in parallel, rather than a set of discrete steps. From a systemic perspective, both demand-pull and technology-push factors are important drivers for technological change. Initial designs can arise from market demand or new scientific discoveries, and these designs are refined through continuous feedback over time (Kline and Rosenberg, 1986). This section will first examine the roots of these systemic perspectives in evolutionary theory and the implications for path dependency. This section will then review two key frameworks - innovation systems and technological transitions.

Figure 3.8: Chain Linked Model
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Source: Gallagher et al., 2012

Evolutionary Theory

The modern use of the term 'evolutionary economics' can be traced to Nelson and Winter's book, *An Evolutionary Theory of Economic Change*(1982). Evolutionary theories are concerned with "processes of long-term and progressive change" and are dynamic in nature (Nelson and Winter, 1982, p. 10). Nelson and Winter (1982) draw an analogy with biological evolution. 'Routines' which are the predictable behavioural patterns of a firm play the role of genes. The most successful routines will be selected in the market environment since the most profitable firms will grow and account for a larger share of the industry. 'Searches' are activities undertaken by firms to modify their routines. These activities include market analysis, operational research, and research and development. Searches are analogous to mutations in biological evolution. Searches are partially determined by existing routines of a firm and this is similar to biological mutation where mutations are variants of existing genetic patterns (Nelson and Winter, 1982, pp. 14-17).

Evolutionary economics has been most fruitfully applied to technological change (Hodgson, 1999, p. 129). Within Nelson and Winter's model, firms perform searches to generate technological innovations. A successful innovation generates profits for the firm making it. Thus, more profitable technologies will replace less profitable ones because firms with more profitable technologies expand and other firms will adopt the more profitable technology (Dosi and Nelson, 1994, p. 163). Evolutionary economics has had a major impact on the study of technology policy and innovation systems explored below.

Path Dependence and Lock-in

Another important concept for understanding systemic perspectives on technological change is path dependency. That is, the success of a technology depends partly on historical events and initial conditions. Small advantages gained by a technology at the beginning can accumulate into dominance of the technology over another in a market due to effect of increasing returns (Arthur, 1989). Increasing returns to scale form positive feedback loops that reduce costs as production increases. Arthur (1994) identifies four classes of increasing returns:

- Economies of scale occur as production volumes increase because fixed costs are spread across a larger number of units.
- Learning economies occur via 'learning-by-doing' as firms accumulate skills and knowledge with increasing production (Arrow, 1962). Learning and experience curves model this empirically.
- Adaptive expectations occur as increasing adoption reduces uncertainty about a technology's quality, performance and permanence.
- Network economies occur as more users adopt the technology, the more useful it becomes. One example of this is the telephone.

These increasing returns are reinforced by technological paradigms. A technological paradigm is an outlook or agreed definition of the 'problem'. Technological trajectories result from 'normal' problem solving within the prevailing technological paradigm. As the technological paradigm guides change, innovations along a particular technological trajectory tend to be incremental improvements on current technologies (Dosi, 1982).

Thus, "dynamic increasing returns tend to 'lock in' the processes of technical change into particular trajectories, entailing a mutual reinforcement (a positive feedback) between a certain pattern of learning and a pattern of allocation of resources into innovative activities where learning has already occurred in the past" (Dosi, 1988, p. 1148). As technologies gain increasing market share, technological lock-in can occur. The same mechanisms that accelerate the performance and adoption of a particular technology can create technological lock-in (Arthur, 1989). As the technical, organisational and cultural components of the technology link together, other (possibly superior) technologies are excluded from the market as they cannot compete economically with the existing technology.

For energy technologies, governing institutions have played a large role in creating technological lock-in. Unruh (2000) gives a detailed account of how developed countries have been locked into fossil-fuel based energy systems through co-evolution of technology and governing institutions. The resulting 'techno-institutional complex' has created persistent market and policy failures that inhibit the diffusion of low-carbon energy technologies.

Developing countries may also be subject to carbon lock-in as leapfrogging appears possible only when technology leaders, usually in developed countries, have already deployed the technology successfully. The bulk of energy technologies transferred from developed to developing countries are fossil fuel based because the major technology vendors, financial institutions, development banks and developing country governments have capabilities and preferences for large, fossil-fuel based energy projects (Unruh and Carrillo-Hermosilla, 2006).

Technological Capabilities

The innovation studies literature provides insights into the technological capabilities of firms to manage change. Technological capabilities can be divided into two categories (Bell, 2009, p. 11):

1. Production capability: the capability to continue producing goods and services using

existing product technology, processes and organisational configurations.

2. Innovation capability: the ability to create new configurations of products and process technology, or to implement improvements to existing technologies.

Innovation capabilities introduce technologies which are new to the firm, new to a particular market or new to the world (OECD, 2005).

It has increasingly been recognised that developing countries need to strengthen their own innovation capabilities in order to be be "adaptors, improvers and creators of technologies they use in their development" (Bell, 2009, p. 4). Technological capabilities can be acquired by developing countries through technology transfer from developed countries. However, these efforts need to focus on transferring the knowledge and expertise behind the technology, rather than the hardware only. Incremental and adaptive innovation are important in developing country contexts (Ockwell and Mallett, 2012, p. 6).

In recent years, theoretical understandings of technological capabilities have come to the forefront as transfer of low carbon technologies to developing countries is urgently required in global climate mitigation efforts (Ockwell and Mallett, 2012). China has been successful in developing its technological capabilities for low carbon technologies, especially in near-market technologies, driven by technological learning at the market-oriented level and through interaction with second-tier foreign firms (rather than being driven by research and development work). This has been supported by Chinese domestic policy to provide incentives for firms to engage with low carbon technologies, as well as strategic engagement with international climate mechanisms to provide funding and capability building opportunities (Watson et al., 2014).

Technological Innovation Systems

Building on the insights from evolutionary economics and path dependency, the innovation systems approach focuses on the drivers and barriers to the emergence of new innovations. This approach examines the structures and functions of the innovation system.

Innovation systems were first analysed within national borders. The concept of national innovation systems was introduced by Freeman (1988) who defined it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technology". Since then, studies of innovation systems have expanded to regional, sectorial and technological innovation systems (Carlsson et al., 2002).

For the purposes of this study, technological innovation systems are the most relevant. These are defined as "dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology" (Carlsson and Stankiewicz, 1991, p. 93). Technological innovation systems consist of:

- all actors (or organisations) in the supply chain,
- their network of interactions, and
- the institutions that govern them (Bruce, 2007; Jacobsson and Bergek, 2004) (see Figure 3.8 on page 47).

Technological innovation systems need to perform a number of function in order to work well. These inter-related functions include:

1. entrepreneurial activities,
2. knowledge development,
3. knowledge diffusion through networks,
4. guidance of the search,
5. market formation,
6. resource mobilisation, and
7. creation of legitimacy/counteract resistance to change (Hekkert et al., 2007).

Jacobsson and Bergek (2004) show that functions of innovation systems can be induced by government policies, firm entry or activity and feedback from market formation. Conversely, blocking mechanisms for functions include high uncertainty, lack of legitimacy, weak connectivity, ambiguous behaviour of established firms, and government policy.

Jacobsson and Bergek (2006) identified two types of networks that are important to fulfil system functions in developing countries. First, learning networks allow the transfer of tactic and explicit knowledge (knowledge diffusion through networks). Learning networks also influence expectations about the technology, perceptions about what is desirable, and guide investment decisions (guidance of the search). Second, advocacy coalitions seek to influence the political agenda. These networks have a profound influence on R&D funding (guidance of the search), support policies (market formation) and project funding (resource mobilisation). Advocacy coalitions also create legitimacy for a technological system.

Innovation systems approaches have been used to analyse the energy sector and examine the transition to sustainable energy systems at a macro-level (for example, see Foxon et al., 2007; Gallagher et al., 2012; Negro et al., 2012; Tsoutsos and Stamboulis, 2005; Jacobsson and Bergek, 2004). These studies have sought to identify the barriers to the diffusion of sustainable energy technologies and policies to overcome them. Individual renewable energy technologies have been analysed using technological innovation systems (Bruce et al., 2009) and functions of innovation systems approaches (Negro, 2007).

The technological innovation systems approach is associated with the 'barriers' approach to renewable energy deployment. The approach examines how innovations change within a market, but fail to factor in the broader context which can influence innovation systems. For example, demographics and economic outlook (Markard and Truffer, 2008, p. 601). The technological innovations systems and associated 'barriers' approach are insufficient by themselves.

Technological Transitions

Another systemic approach with roots in evolutionary economics and sociology of technology is the multi-level perspective. This approach provides a broader view of technological transitions that involve transformation of sectors. This involves multiple technologies that work together to fulfil whole societal functions (such as transportation). The multi-level perspectives locates technological innovations within an existing technological regimen. At the micro-level are the niche-innovations which fulfil a specific need. At the meso-level are a collection of socio-technical regimes (such as the electricity sector) and these include networks of actors and social groups; formal, normative and cognitive rules and; material and technical elements. At the macro-level is the socio-technical landscape which changes slowly and can influence the other levels, but is not easily affected by changes in the socio-technical regime (Geels, 2005).

This approach gives insights into how technological transitions within existing regimes take place. Innovations are initially restricted to niches (e.g. research and development projects) because existing regimens are firmly entrenched. Technological transitions occur when developments at the niche-innovation, socio-technical regime and the socio-technical landscape levels link up and strengthen each other (Verbong and Geels, 2007).

The multi-level perspective has been used to analyse energy transitions from fossil fuel-based to sustainable energy technologies (Verbong and Geels, 2007; Verbong et al., 2008; Rehman et al., 2010). The multi-level perspective highlights the importance of the existing socio-technical regimen and socio-technical landscape in the context of energy transitions in rural areas. Technological transitions have also been used to understand sustainable energy in developing countries where existing energy regimes are less stable (for example, Berkhout et al., 2010; Byrne et al., 2014). However, when applied in the context of a developing country, the multi-level perspective is limited by its lack of focus on the role of politics in technology transitions and everyday life (Smits, 2011). The technological transitions literature highlights the importance of user preferences and needs in developing new technological systems. Social practices in the context of the socio-technical landscape are also important.

There are many similarities between the technological innovation systems and multi-level perspectives. Both acknowledge the importance of networks, learning processes and institutions in technological change. Both draw on evolutionary economic theorising and describe the phenomena of path dependency, lock-in, non-linearity and interdependence (Markard and Truffer, 2008). The technological innovation systems approach focuses on renewable energy options and barriers. A multi-level perspective offers an analysis of renewable energy trends along with longer-term, structural trends in the energy sector. Both perspectives could be improved by analysis of the role of politics and the everyday use of technology.

3.5 Conclusion

This chapter presented an overview of the motivations for renewable energy projects and the current approaches to using the technology in developing countries. Access to sustainable energy services is intertwined with sustainable development, which combines the imperatives for development and environmental protection. Renewable energy can make a positive contribution to development goals, but has faced a number of financial, institutional, policy, technical and social challenges. Efforts to improve energy access using renewable energy have focused on overcoming barriers to deployment of the technology, but have been met with limited success. This approach is techno-centric and fails to address how the technology can address community needs within existing social and institutional structures.

A broader, more systematic understanding of how renewable energy technological systems can be developed and supported is essential. This chapter also reviewed two conceptual frameworks which offer insights into this and were most relevant to the case studies. The first concept was capacity development, which can be defined as a process that enables individuals, organisations, networks and societies to be resilient and reach their own sustainable development goals. Capacity development involves changes on many levels and approaches to capacity development include organisational, institutional, participatory process and systems approaches. A key lesson from the capacity development literature is that capacity for renewable energy must be developed over long timeframes with attention to multiple levels, stakeholders and changing contexts.

The second conceptual framework reviewed in this chapter was the literature from technology studies. This offered insights into the adoption of renewable energy technologies in rural areas. Technologies consist of technical, organisational and cultural components. Technological change can be described as progressing linearly from discovery to full adoption to decline. However, technological change is a complex and uncertain process, with feedbacks and interaction between each phase. One important implication is that historical events can create path dependence and technological lock-in through increasing returns to scale. Both technological innovation systems and technological transitions literature provide useful analytical frameworks for technological change from a systems perspective. These are useful for understanding the complex process at work at renewable energy technologies diffuse through rural areas in developing countries.

Chapter 4 will refer to the capacity development and technology studies literature and present the analytical framework developed from the case studies.

4 Analytical Framework: The Renewable Energy Capacity Pyramid

4.1 Introduction

The aim of this chapter is to set out the analytical framework for enabling access to sustainable energy services in rural areas of developing countries developed using the inductive case study approach discussed in Chapter 2. The framework builds on insights from capacity development and technology studies, as well as previous experience with renewable energy projects reviewed in Chapter 3. The framework was developed by iterating between analysing the case studies and reflecting on the literature.

A systems approach was be adopted in order to analyse the complex interactions involved in establishing a renewable energy in rural areas. The framework builds upon an existing framework called the ’capacity pyramid’ described in Section 4.2. Because the original capacity pyramid was not designed specifically for analysing renewable energy, additions to the framework was made during the course of the research. A new framework called the Renewable Energy Capacity Pyramid was developed. Each layer of the Renewable Energy Capacity Pyramid will then be described in detail in Sections 4.3 to 4.7. This framework will then be used to structure the analysis of the three case studies of renewable energy projects in the Inner Mongolia Autonomous Region in China in Chapters 6 to 8.

4.2 The Pyramid Structure

4.2.1 The Capacity Pyramid

This thesis will build on an existing systemic capacity development framework. The capacity pyramid was first developed by Potter and Brough (2004). With the aim of improving healthcare in India, they identified a four-tier hierarchy of capacity development needs:

1. *tools*, which include funds, equipment and consumables,
2. *skills*, which are the technical skills of individuals,
3. *staff and infrastructure*, which include sufficient staffing levels and effective supervision, as well as sufficient building facilities and support services, and
4. *structures, systems and roles*, which include organisational capabilities for decision-making, accountability, information flow and resource management.

Table 4.1 presents a more detailed view of the layers of capacity and their component elements.

Table 4.1: Component Elements of Capacity Pyramid

Capacity Layer	Component Element	Description of Component Element
Tools	Performance capacity	Are the tools, money, equipment, consumables, etc. available to do the job? A doctor, however well trained, without diagnostic instruments, drugs or therapeutic consumables is of very limited use.
Skills	Personal capacity	Are the staff sufficiently knowledgeable, skilled and confident to perform properly? Do they need training, experience, or motivation? Are they deficient in technical skills, managerial skills, interpersonal skills, gender-sensitivity skills, or specific role-related skills?
Staff & Infrastructure	Workload capacity	Are there enough staff with broad enough skills to cope with the workload? Are job descriptions practicable? Is skill mix appropriate?
	Supervisory capacity	Are there reporting and monitoring systems in place? Are there clear lines of accountability? Can supervisors physically monitor the staff under them? Are there effective incentives and sanctions available?

	Facility capacity	Are training centres big enough, with the right staff in sufficient numbers? Are clinics and hospitals of a size to cope with the patient workload? Are staff residences sufficiently large? Are there enough offices, workshops and warehouses to support the workload?
	Support service capacity	Are there laboratories, training institutions, bio-medical engineering services, supply organisations, building services, administrative staff, laundries, research facilities, quality control services? They may be provided by the private sector, but they are required.
Structures, Systems and Roles	Systems capacity	Do the flows of information, money and managerial decisions function in a timely and effective manner? Can purchases be made without lengthy delays for authorisation? Are proper filing and information systems in use? Are staff transferred without reference to local managers' wishes? Can private sector services be contracted as required? Is there good communication with the community? Are there sufficient links with NGOs?

	Structural capacity	Are there decision-making forums where inter-sectoral discussion may occur and corporate decisions made, records kept and individuals called to account for non-performance?
	Role capacity	This applies to individuals, to teams and to structure such as committees. Have they been given the authority and responsibility to make the decisions essential to effective performance, whether regarding schedules, money, staff appointments, etc?

These layers of capacity are interdependent. Although each layer interacts with other layers in complex ways, each layer requires its own strategic response. The layers of capacity can be organised in a hierarchy. The effectiveness of each layer depends upon the effectiveness of the layers below it. For example, the effective use of tools need skilled individuals. Figure 4.1 shows the layers of capacity arranged in a pyramid where the elements at the bottom of the hierarchy enable the effective use of elements above it.

Potter and Brough's definition of capacity development highlights the need to address different layers of social reality (Gelder, 2011, p. 37). The layers of capacity at the bottom of the hierarchy tend to be more socio-cultural and complex. Therefore, it often takes a longer time to effect change at the lower level. The layers of capacity at the top tend to be more technical and therefore quicker and easier to change (see Figure 4.1). Although this hierarchal structure implies that capacity development can be planned logically, the process is often iterative. However, the hierarchical structure of the capacity pyramid provides useful insights into the ways in which capacity can develop and points of intervention.

The broad categories and hierarchical structure of the capacity pyramid is a useful framework for analysising renewable energy rural electrification. It is consistent with an understanding of renewable energy technology as consisting of technical (tools and skills) and social dimensions. The capacity pyramid also recognises that capacity stretches across different levels of social organisation - from individual skills to organisational structures, systems and roles. Although the capacity development concept was first developed in the healthcare sector, it has been usefully applied (with appropriate modifications) to capacity development in fields as diverse as sanitation, environmental assessment and policing in developing countries (Kirchhoff, 2006; Harris, 2010; van Loon et al., 2010; Gelder, 2011).The capacity pyramid structure is appropriate for analysing renewable energy rural electrification because it addresses the capacity needs of developing countries in supporting services in rural areas (including energy services).

Figure 4.1: The Capacity Pyramid
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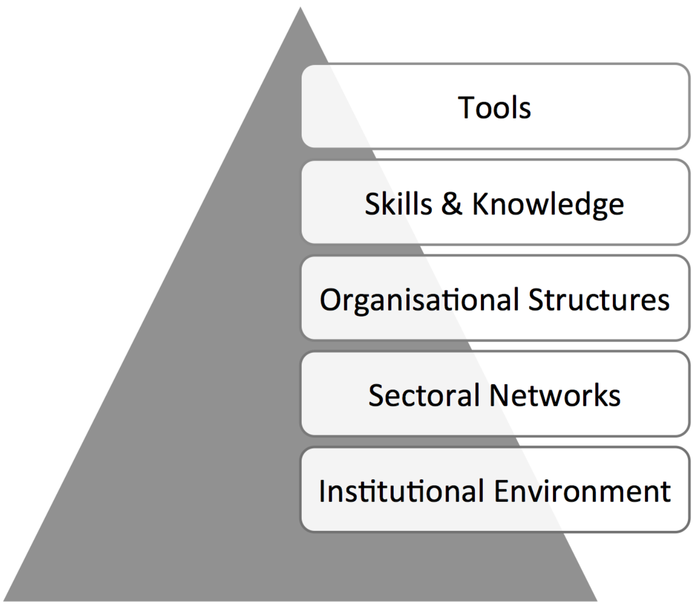
Source: Potter and Brough, 2004, p. 340

4.2.2 Extensions to the Capacity Pyramid

Potter and Brough's definition of capacity is limited to the level of the organisation. As such, it is a systems approach to organisational capacity development. The 'renewable energy capacity pyramid' proposed in this thesis extends Potter and Brough's concept of a capacity pyramid to include the sector level and the institutional environment level. These are important aspects of capacity that are included in many other systemic approaches discussed in Section 3.3.2 (for example, Bolger (2000)).

The remainder of this chapter will describe these additions to the capacity pyramid and operationalises the concept for sustainable energy service provision in rural areas. In particular, different components for each layer of capacity are proposed in response to lessons learned from past renewable energy projects. Literature from technology studies and capacity development will be used to illuminate the mechanisms that operate within each layer of capacity. The structure of the renewable energy capacity pyramid is given in Figure 4.2. The lower layers enable and support the layers that are above them. The hierarchy does not imply that the layers at the top are more important than the layers at the bottom. The arrows in Figure 4.2 indicate that the layers are interdependent.

Figure 4.2: The Renewable Energy Capacity Pyramid



4.3 Tools

The 'tools' layer of the renewable energy capacity pyramid relates to the hardware. Reliable hardware is important as renewable energy systems often operate in harsh conditions, in locations which are difficult to access should repairs be needed. Therefore, a key factor for enabling access to sustainable energy service is the reliability of hardware installed (see Table 4.2). Warranty, standards and testing have been used to improve the quality of renewable energy equipment in rural areas Nieuwenhout et al. (2004). However, the main determinate of how well a renewable energy system can be utilised is the existence of skilled and knowledgeable individuals.

Table 4.2: The Renewable Energy Capacity Pyramid: Tools

Capacity Layer	Component
Tools	reliable hardware

4.4 Skills and Knowledge

This layer of capacity consists of the skills and knowledge possessed by individuals. The main need in developing countries is to develop skills and knowledge in adapting technologies to local conditions or in supply chain management, and not necessarily innovating at the technological frontier (**?**). The International Labor Organisation identified a wide range of occupations that needed to be filled in equipment manufacture and distribution; project development; construction and installation; operation and maintenance; and cross-cutting or enabling activities (such as management). The key shortages are for technicians and engineers (ILO, 2011). Often, there are inadequate numbers of renewable energy technical personnel in rural areas and the required expertise is located far away or difficult to access. Commercial skills such as accounting, marketing and quality assurance are also important for the effective functioning of organisations involved in delivering energy services (IEA-PVPS, 2003*a*).

End-users of renewable energy systems in rural areas are involved in managing their energy usage, maintenance and repair. Therefore, a key part of capacity for renewable energy rural electrification is the technical capacity of individual end-users. Knowledge is also key to technology adoption. As discussed in Section 3.4.2, end-users go through a five-step process of knowledge, persuasion, decision, implementation and confirmation as they adopt new technology (Rogers, 1995). The response to technology may vary according to their perception of risk, socio-economic status, ability to extract resources from the local environment and relationship with political power holders (McKay et al., 2007).

Existing education and training channels can deliver many of the skills needed by the renewable energy sector through initial training or supplementary education specific to renewable energy (ILO, 2011). Improving the technical skills of individuals through awareness raising and training has been the main focus of many renewable energy capacity building efforts in the past. For example, the best practice guidelines for capacity building for rural electrification in developing countries developed by the International Energy Agency's Implementing Agreement on PV Power Systems concentrate purely on technical training. The capacity building measures include seminars, information booklets and training manuals (IEA-PVPS, 2003*a*). Certification of training according to international standards, such as the Institute for Sustainable Power, can ensure that training is of a consistent quality and up-to-date. However, technical training to improve the skills and knowledge of individuals is insufficient. Staffing levels may be insufficient as people trained in renewable energy may move on to more lucrative jobs, or their effectiveness may be undermined by the organisational structures imposed on them. Supportive organisational structures are needed. Table 4.3 summarises the skills and knowledge layer of the renewable energy capacity pyramid.

Table 4.3: The Renewable Energy Capacity Pyramid: Skills & Knowledge

Capacity Layer	Component
Skills & Knowledge	end-user awareness of renewable energy
	end-user technical skills
	end-user energy management skills
	supply chain technical skills
	supply chain commercial skills

4.5 Organisational Structures

Strong local organisations are vital for installing, operating and maintaining renewable energy systems in rural areas. An organisation consists of a network staff, facilities, structures and processes of supervision, decision-making, information sharing and financial flows

(Potter and Brough, 2004, p. 339). The 'organisational structures' layer of the renewable energy capacity pyramid combines the 'staff and infrastructure' and the 'structures, system and roles' layers in Potter and Brough's model as both layers relate to the functioning of organisations.

Sustainable financial arrangements are vital for enabling sustainable energy access in rural areas. Appropriate financial arrangements need to be made for the purchase, installation, operation and maintenance of renewable energy systems. As discussed in Section 3.2.2, a number of financial models have been used for renewable energy projects in the past. These models include cash sales, credit sales (dealer, end-user or hire purchase), fee for service and subsidy. The model should take into account the cost of the systems relative to income of end-users, as well as the availability of the necessary organisation structures, such as the existence of local micro-finance institutions.

Effective organisational structures are needed to support trained staff so that they are able to make use of their skills and knowledge. Individual skills and organisational capacity are interlinked (Otoo et al., 2009; Johnson and Thomas, 2007). Potter and Brough (2004) highlighted the following aspects of effective organisational structures:

- Workload capacity: appropriate staffing at sufficient levels.
- Supervisory capacity: appropriate reporting and monitoring systems, clear lines of accountability and, effective incentives and sanctions.
- Facility capacity: appropriate and sufficient facilities for work to be carried out, e.g. workshops.
- Support service capacity: access to support services, e.g. administrative staff, research facilities, quality control services.
- Systems capacity: Timely and effective flow of information, money and managerial decisions, information management system, communication with community.
- Structural capacity: effective and accountable decision-making forums.
- Role capacity: authority and responsibilities clearly defined for individuals, teams and committees.

Effective organisational structures need to remain flexible so as to meet the challenges of a changing institutional environment. Organisations interact with their environment in complex ways. Organisations obtain inputs from its institutional environment and organise production process to make outputs. Organisation need to be flexible and adapt to changes in the institutional environment, as well as produce outputs that are useful for stakeholders. This, in turn, allows the organisations to obtain inputs or resources. The institutional context provides incentives for organisations (Communities, 2005, p. 8).

Table 4.4 summarises the components of capacity that are required in the organisational structures layer in order to implement sustainable networks of operation and maintenance support for renewable energy in rural areas.

Table 4.4: The Renewable Energy Capacity Pyramid: Organisational Structures

Capacity Layer	Components
Organisational Structures	sustainable financial arrangements
	effectiveness
	flexibility

4.6 Sectoral Networks

This layer of the capacity pyramid refers to linkages between organisations involved in renewable energy rural electrification. The sector level was not included in Potter and Brough's model. However, the sector level is very important for ensuring access to sustainable energy in rural areas.

The literature on technological innovation systems (discussed in Section 3.4.3) offers useful insights into the renewable energy sector. A technological system can be defined as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology" (Carlsson and Stankiewicz, 1991, p. 93). Thus, a technological system consists of networks of organisations in the context of an institutional environment. A strong technological innovation system has the capacity to execute the following functions (as discussed in Section 3.4.3):

1. entrepreneurial activities - such as the entry of new businesses into the market or the diversification of activities of incumbent businesses,

2. knowledge development - such as R & D projects and patents,

3. knowledge diffusion through networks - such as workshops and conferences,

4. guidance of the search - such as government or industry targets,

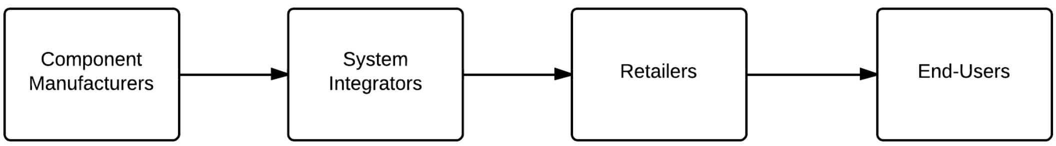
5. market formation - such as the formation of niche markets and tax regimes to benefit new technologies,

6. resources mobilisation - such as financial and human capital, and

7. creation of legitimacy or counteract resistance to change - such as activities undertaken by interest and lobby groups (Hekkert et al., 2007).

Practical Action describes the rural energy sector as an 'energy access ecosystem' which "comprises multiple inter-related systems, which collectively deliver energy supplies and appliances, using a mix of energy sources and a range of technologies" (Practical Action, 2012). A healthy energy access ecosystem will include a large number of diverse actors with strong linkages between them. The organisations involved in the renewable energy technological system can be thought of as a supply chain consisting of component suppliers; system integrators; retailers; and customers (see Figure 4.3). These actors may be part of the public or private sector, and some functions may be combined in the same organisation. Nonetheless, all of these actors need to be present and interact with one another.

Figure 4.3: Renewable Energy Supply Chain



Adapted from Cabraal, 2000.

Two types of networks that are important for fulfilling system functions in developing countries (Jacobsson and Bergek, 2006) . First, learning networks allow the transfer of tactic and explicit knowledge (knowledge diffusion through networks). Technical skills and knowledge may be passed from one actor to another, without going through each link in the supply chain. For example, installation and service personnel who encounter a problem while repairing a renewable energy system may contact the component manufacturer directly for detailed repair instructions. Organisations in the system can also collaborate on a more formal level, for example through strategic partnerships or industry associations. Learning networks also influence expectations about the technology, perceptions about what is desirable, and guide investment decisions (guidance of the search).

Second, advocacy coalitions can seek to influence the political agenda (Jacobsson and Bergek, 2006) . Advocacy coalitions can influence R&D funding (guidance of the search), support policies (market formation), project funding (resource mobilisation) and create legitimacy for a technological system.

One type of organisation that is important for creating linkages to form a strong renewable energy sector are system facilitators. Retnanestri (2007) highlights the importance of facilitators in linking end-users of renewable energy with renewable energy sponsors or donors. Facilitators bridge the socioeconomic and technical gaps between donors and end-users by facilitating the flow of innovations that match the needs of end-users. Martinot et al. (2002) elaborate on the role of 'market facilitation organisations'. These help the renewable energy sector to establish by providing networking, partner matching, information dissemination, market research, user education, business-deal identification and facilitation, technical assistance, consulting services, financing and policy advice or advocacy. These can be non-government organisations, government departments or private sector organisations.

Table 4.5 summarises the sectoral networks layer of the renewable energy capacity pyramid.

Table 4.5: The Renewable Energy Capacity Pyramid: Sectoral Networks

Capacity Layer	Components
Sectoral Networks	organisations along the whole supply chain
	learning networks
	advocacy coalitions

4.7 Institutional Environment

This layer of the capacity pyramid is another addition to Potter and Brough's model. An enabling institutional environment is widely acknowledged to be important for both capacity development and for innovation systems to develop (see Section 3.3.2 and Chapter 3). As defined in Section 3.3.2, institutions are the “rules of the game” in a society or “the humanly devised constraints that shape human interaction”(North, 1990, p. 3). In the field of technology studies, the Multi-Level Perspective (discussed in Section 3.4.3) defines this socio-technical landscape as the elements in the environment that influence the functioning of the of a socio-technical regime or sector, but are not easily affected by changes in the regime. Therefore, alignment of the renewable energy sector with the institutional environment is vital for the technology to succeed. The institutional environment can hinder renewable energy deployment due to carbon lock-in.

There are several elements which are important for renewable energy deployment. Firstly, a clear vision of the role of renewable energy expressed in high-level policies and a sector development plan are essential. Long-term, coherent policies that define a specific role for renewable energy and their application to to rural electrification forms a stable base for establishing the other layers of capacity (GNESD, 2007, p. 13). For example, a clear policy vision helps to create a favourable investment environment for the private sector to participate in the renewable energy sector.

Secondly, integrated planning and coordination between the renewable energy sector and other sectors such as rural development and electricity sector are important. Linkages at the planning level can ensure that plans in these sectors complement each other, rather than cause redundancy or interference. Supply and demand-side planning also need to be coordinated (Matheson and Giroux, 2010).

Thirdly, renewable energy projects must take values and norms into account. The norms or ’ways of doing things’ are important for how policies are implemented and determines the range from which strategies can be chosen. The norms for the end-user are also important because renewable energy systems must be acculturated into the local context in order for them to be sustainable (Retnanestri, 2007, p. 97). The success of a rural electrification project can be determined by how well matched the technology is to existing local culture. Norms are determined by a combination of experience, habits and traditions.

Fourthly, the macroeconomic environment can have a profound influence on the outcomes of renewable energy projects through currency fluctuations, the availability of labour, financing and investment in research and development. The type of economy is also important. China is an economy in transition that has experienced profound social and economic change since it's formation in 1949. In a study of opportunities and barriers to sustainable energy in Russia (another economy in transition), Martinot (1998) found that the country had strong technical skills and knowledge, but lacked sustainable markets for renewable energy. He recommended that capacity development activities be focused on forming institutions that would be in line with the new economic structure. He highlighted the importance of economic analysis, management and finance; information services; regulatory development; new market intermediation institutions; stronger legal and market institutions; and implementation mechanisms supporting independent power producers.

Lastly, policy learning processes are important as the renewable energy sector is established. Coordinated learning activities involving all stakeholders focused on understanding the context are needed prior to renewable energy project design and implementation (Tukunga and Outhred, 2012). This helps to address issues of unequal voice, conflicting values and contested interests between aid donors and recipients (see Section 3.3.2). Breukers and Wolsink (2007) argue that capacity includes the ability to "facilitate open-policy processes that provide access to relevant stakeholders and room from various types of knowledge resources". This type of capacity consists of:

- relational resources - which are "the bonds between people and organisations that are based on shared understandings and mutual trust" (the configuration of actors determines how knowledge resources can flow),
- knowledge resources - from the national or local level which can include technical, environmental, local, experiential and tactic knowledge,
- mobilisation resources - the degree to which the stakeholders are involved in decision-making processes (Breukers and Wolsink, 2007, p. 94).

Institutional approaches to capacity development (discussed in Section 3.3.2) offer insights into how this layer of capacity can be developed. In particular, the institutional capacity development activities identified by Clemens et al. (2010) cover a broad range of activities relevant to renewable energy projects in developing countries.

A summary of the factors in the institutional environment which enable sustainable energy services appears in Table 4.6.

Table 4.6: The Renewable Energy Capacity Pyramid: Institutional Environment

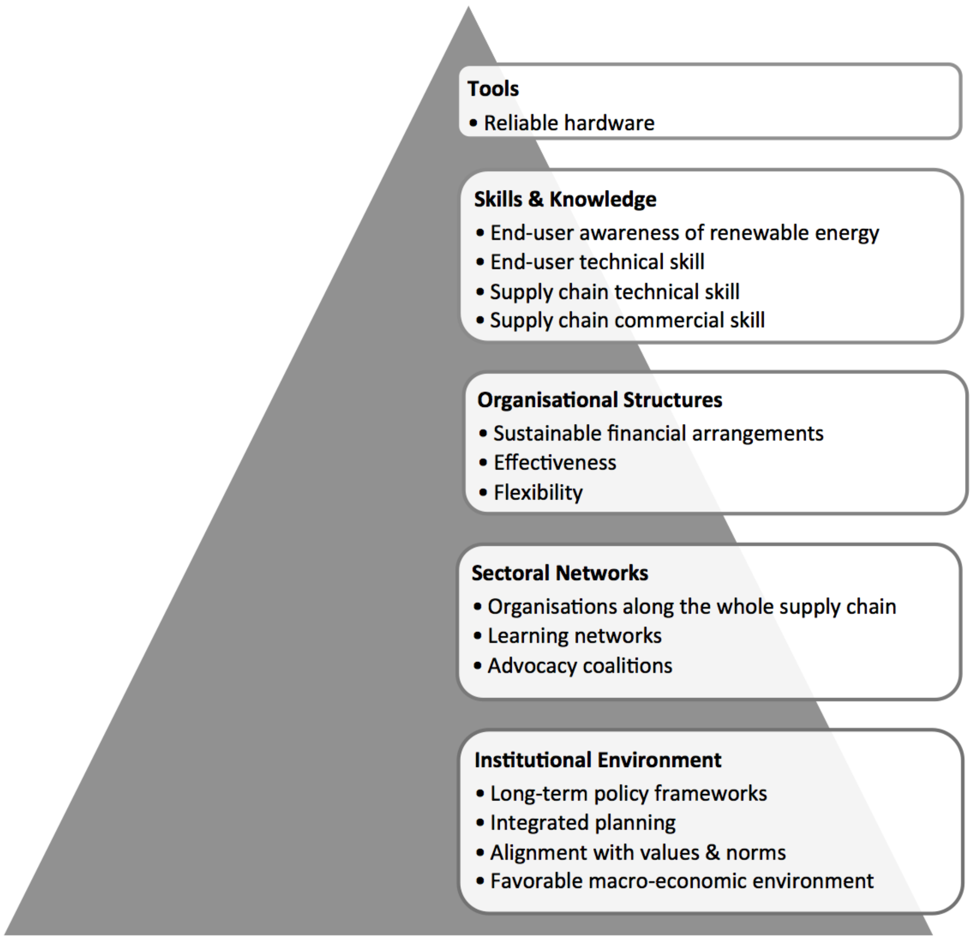
Capacity Layer	Components
Institutional Environment	long-term policy frameworks
	integrated planning
	alignment with values and norms
	favourable macro-economic environment
	policy learning processes

4.8 Conclusion

This chapter presented the Renewable Energy Capacity Pyramid developed from analysing the case studies. Figure 4.4 shows each of the components found to be important in each layer of capacity. Existing approaches to improving access to sustainable energy services in developing countries focus on overcoming barriers to renewable energy technologies. This techno-centric approach has been met with limited success because it fails to address how the technology can fulfil community needs within existing social and institutional structures. The renewable energy capacity pyramid addresses these problems and shows how capacity for renewable energy can be built up in a systematic way.

The framework presented in this section will be used to frame the analyse of three case studies in the Inner Mongolia Autonomous Region in China in Chapters 6 to 8. Before each project is analysed, the next chapter will give an overview of the institutional environment which pertains to all of the case studies.

Figure 4.4: Components of the Renewable Energy Capacity Pyramid



5 Mapping the Institutional Environment

5.1 Introduction

Chapter 4 developed the renewable energy capacity pyramid for delivering sustainable energy services to rural areas. The foundation of the renewable energy capacity pyramid is an enabling institutional environment. Institutions are the "rules of the game" for society, and can have a profound impact on energy services through policies, values and norms. This chapter will explore the institutional environment for renewable energy projects in China and IMAR in order to i) provide the background for understanding the case studies in the following chapters, and ii) to analyse the institutional environment in which the case studies are embedded. Sections 5.2 and 5.3 will provide background on China's policy context and policies relevant to renewable energy in rural areas. Section 5.4 will discuss the socioeconomic circumstances in IMAR and the history of renewable energy policies for the region.

5.2 National Policy Context

5.2.1 Political Context

China has a unique political system which has undergone radical reforms since the establishment of the People's Republic in 1949. This set of unique political institutions have a profound influence on all aspects of policy-making, including renewable energy projects. In particular, the relationship between the different levels of government and between agencies; the dominance of the Communist Party and its ideology; and contemporary policy concerns have profound impacts on how renewable energy projects are conceived and implemented. This section will give a brief overview of the Chinese political institutions relevant to the case studies.

The highest level of political authority in China rests with the National People's Congress. It has about 3,000 members who are elected every five years to represent the provinces, autonomous region and major cities. The National People's Congress meets annually for two weeks, and when it is not in session, a Standing Committee acts on its behalf. The State Council is the executive body of the government, with the ministries and commission reporting to it. The State Council meets monthly, but also has a Standing Committee which meets more regularly. The Chinese People's Political Consultative Conference includes ethnic minorities, religious groups, experts and approved non-Communist Party political organisations. It acts as an advisory body for government policies and meets annually around the same time as the National People's Congress (Dillion, 2008, pp. 137-140).

Away from the central government, the Chinese state is organised into four levels - province, prefecture, county and township. The organisation of the government at the centre is replicated at each of the other levels. Thus, each level of government has a people's congress, a people's government, ministries and so on[1] (Saich, 2011, pp. 179-182). Ministry units are simultaneously responsible to the ministry at the government level above it, as well as the local government which coordinates all activities within its geographical area at the same level (Saich, 2011, p. 144). The dominance of either one of these sources of authority can affect project implementation (this will be explored further in Section 5.2.2).

During the 1980's the central planning system was reformed to a contracted fiscal responsibility system. This increased investment and service provision by local governments. Under tax-sharing reforms implemented in 1994, the tax revenue of local governments decreased, while their expenditure responsibilities did not. This shortfall was partly offset by fiscal transfers from the central government to the provinces, which in turn, made transfers to lower levels of government. These transfers are largely calculated based on average revenues collected in previous years, so they did not reduce inequality between provinces. There are two important implications from this change in the relationship between the central and local governments for the case studies in this thesis. The first is that poorer

[1] Note that prefectures are administrative units only and are not a level of government.

areas suffer from inadequate basic services due to the decentralisation of expenditure responsibilities to local governments, their low level of tax revenue and insufficient fiscal transfers from central government (Mei and Wang, 2006, pp. 29-32). The second implication is that development outcomes are increasingly determined by local governments and their resources, especially the provincial level governments (Saich, 2011, pp. 199-207).

The Communist Party of China (CPC) is the main political force in China. It supervises the government through a parallel organisational structure with a large overlap in personnel between the government and Communist Party bodies (Dillion, 2008, p. 137). Therefore, the ideology of the Communist Party is the guiding principle for development in China. Each new generation of leaders make a contribution to the party canon based on Marxism-Leninism. These have included: Mao Zedong Thought, Deng Xiaoping Theory, the Three Represents (Jiang Zemin) and the Scientific Development Concept (Hu Jintao) (see Table 5.1).

Table 5.1: Summary of Communist Party of China Ideologies

Generation	Leaders	Period of influence[2]	Ideology
First	Mao Zedong, Liu Shaoqi, Peng Dehuai, Lin Biao & Zhou Enlai	1949 - 1976	Mao Zedong Thought
Second	Deng Xiaoping, Chen Yun, Hu Yaobang, Zhao Ziyang,	1978 - 1997	Deng Xiaoping Theory
Third	Jiang Zemin & Zhu Rongji	1997 - 2002	Three Represents
Fourth	Hu Jintao & Wen Jiabao	2002 - 2012	Scientific Development Concept
Fifth	Xi Jinping & Li Keqiang	2012 - present	-

Sources: Saich, 2011; Dillion, 2008; CPC, 2006

The reforms which took place under each generation of leaders in China had profound effects on the institutional structures for renewable energy projects, their economic climate, as well as their perceived role in development. After the death of Mao Zedong in 1976, China began wide-ranging reforms to move from a planned economy to a socialist market economy under Deng Xiaoping. Deng's theory of "socialism with Chinese characteristics" (*you zhongguo tece de shehui zhuji*) concluded that China was in an early stage of socialism and would first need to pass through a stage of capitalism, guided by the Communist Party. China pursed a policy of "reform and opening up" (*gaige kaifang*) which involved decollectivising agricultural production, opening up the country to foreign investment, and encouraging the establishment of private enterprises. The focus of the policy was to first deliver high economic growth in key eastern provinces. The final goal, according to Jiang Zemin, was to create a comfortable society (*xiaokang shehui*) with the CPC representing advanced social productive forces, advanced culture and the interests of all people (the Three Represents). At the beginning of the twenty-first century, rising inequality and environmental degradation have prompted adjustments to the economic growth strategy to create a “harmonious society”. Major policies which have focused investment and development efforts in the poorer western provinces include the campaign to “Opening up the West” (introduced in Tenth Five Year Plan, 2000-2005) and to create a “new socialist countryside” (introduced in the Eleventh Five Year Plan, 2006-2010) (Saich, 2011; Dillion, 2008; Fan, 2006; Goodman, 2004; Chai, 2003).

5.2.2 Policy Making and Institutional Structures

Bureaucratic Structure and Power Dynamics

One of the most useful ways of describing the relationship between the policy-making process and the institutional structures in the post-Mao era is the “fragmented authoritarianism” model. The model originated from the work of Lieberthal and Oksenberg (1988) on large-scale energy development projects and was later refined by Lieberthal and Lampton (1992). The authors argue that the policy process to neither purely rational (in which polices are directly related to the problem), nor simply the result of politics at play between top leaders. Instead, the bureaucratic structure itself influences policy outcomes by creating or compounding problems (Lieberthal and Oksenberg, 1988, p. 17). The 1988 study reveals that the structure of authority in the bureaucracy is highly fragmented, making consensus building central to decision making, and the policy process diffuse (that is, protracted, disjointed and incremental). The operational consequences of this are:

- issues tend to rise to higher levels of the system where a coordinating body possesses sufficient leverage to bring together the various parties,
- bargaining at each stage of the decision making process is needed to create and maintain consensus both vertically and horizontally in the system, and

• the enthusiastic support of one or more of the top leaders for a major policy or project is needed to overcome the bureaucratic impasses at lower levels (Lieberthal and Oksenberg, 1988, p. 22-31).

The ways in which power is understood by those involved in governance are important for the understanding of capacity development for renewable energy. At the centre of the policy-making structure are a set of leadership groups each dedicated to coordinating policy a particular functional area. They act as 'gateways' (*kou*) between the top-level leadership and the administrative organs in a particular functional area. Bureaucracies themselves are grouped into 'systems' (*xitong*) which link to these gateways and cover all agencies in a broad functional area, such as party affairs, organisation affairs, and political and legal affairs.

Authority in the bureaucracy is organised vertically and horizontally. The bureaucracies taking care of a functional area, such as energy, exert power vertically and are called 'lines' (*tiao*). The government bodies corresponding to a level of government exert power horizontally to coordinate activities in its geographical region are called 'pieces' (*kuai*). Each unit in the Chinese government is simultaneously responsible to both *tiao* and *kuai* superiors, and the dominance of one or the other in a given situation can influence policy implementation (Lieberthal, 2003; Saich, 2011). The fragmented authoritarianism model remains relevant today and continues to be used to describe energy policy in China (for example, Andrews-Speed, 2010; Downs, 2005; Saich, 2011, pp. 262-3).

Chinese Pragmatism

As a result of a reappraisal of Mao Zedong's policies after his death in 1976, policy-making in China became less ideologically-orientated and more pragmatic (Saich, 2011, p. 68). The new generation of Chinese leadership, under Deng Xiaoping, instigated a series of reforms which transformed the planned economy into a more marketised economy, and opened up China to outside investment. This departure from Marxism-Leninism-Maoism was made for pragmatic reasons to modernise and grow the Chinese economy (Chai, 2003). The reforms created a hybrid system of market economy and authoritarian rule, which, according to Deng Xiaoping Theory, was necessary because China was at an early stage of socialism and needed to develop a "commodity economy" before moving to socialism (Pye, 1986, p. 211).

These reforms were implemented with caution and used a step-by-step approach. National-level changes were made incrementally often after successful experimentation at the local level. Deng called this process "crossing the river by feeling the stones" (Saich, 2011, p. 268).

5.3 Discussion of Policy Domains

5.3.1 Science & Technology Policy

Capacity for renewable energy in IMAR was enabled by China's strong capabilities in science and technology built up since the formation of the People's Republic in 1949. China had initially adopted the former Soviet Union's model of science and technology. The bulk of research and development activities were state funded and was undertaken by public research institutions. This system produced world-class technical personnel and an institutional capacity to direct resources towards high-priority research projects. These capacities were most often mobilised to achieve national security goals and led to achievements in areas such as aerospace and weapons. However, as China began to move towards a market-based economy through its program of economic reforms, it became clear that reforms in science and technology would also be required to fuel technological innovations in the socialist market economy. In particular, China's Soviet-style science and technology system had limited capacity to transfer knowledge created through research and development to improve production as these two activities took place in separate organisations and there were few incentives for technology transfer (Lan, 1997, p. 69-72). Thus, science and technology were identified as one of the Four Modernisations (*se ge xiandiahua*) in the post-Mao era, along with modernisation of agriculture, industry and national defence (Saich, 1989, p. 1).

The framework for the modernisation of science and technology was set by the Central Committee's resolution on the Structural Reform of the Science and Technology System (1985). The resolution stated that the aims of the reforms were to "apply results from science and technology research to production widely and rapidly; to make full use of science and technology personnel; to greatly empower science and technology as the driving force for the economy; and to promote the development of economy and society" (CCCPC, 1985 cited in Lan, 1997). The reform process included:

- reducing government funding for public research institutions to encourage them to seek industry funding,
- installing a public bidding process for government research projects rather than exclusive grants to public research institutions,
- developing technology markets to encourage research and development to be turned into products,
- increasing coordination and integration between research organisations and industrial enterprises, between military and civilian research, and between sectors, and
- granting greater job mobility for research personnel while requiring them to compete for positions (Lan, 1997, p. 73).

Due to this focus on science and technology and the encouragement by the government for closer ties between research and production, China had excellent human resources available for the development of capacity for renewable energy.

5.3.2 Energy Policy

Energy policy is no exception to the highly fragmented nature of policy making in China. However, the sector is currently undergoing reform to bring more coherence. The box 'Key Energy Agency Dates' below shows the increasing recognition of energy issues in the Chinese government with the formation of higher ranking groups focused on energy issues. Prior to 2003, energy policy was spread across various government agencies and no one ministry had oversight of the energy sector. This produced several laws relating to energy which were not always consistent with each other (UNDP, 2009*a*, p. 83). Importantly, the Ministry of Agriculture was in charge of rural electrification and established a network of rural energy offices throughout China. In 2003, the Energy Bureau was established within the new National Reform and Development Commission (NDRC) to take responsibility for energy policy, regulation and administration. However, the bureau lacked the resources and authority to regulate and coordinate between the ministries, commissions and state-owned enterprises responsible for energy. For example, the heads of some large state-owned energy enterprises held ministerial ranking and undercut the regulatory authority of the Energy Bureau by holding meetings directly with leaders of the government (Downs, 2008). Recognising the need for coordination, the State Council established the National Energy Leading Group under the leadership of the Premier, Wen Jiabao. The leading group was supported by the Office of the National Energy Leading Group which was also housed within the NDRC. The establishment of this group reflected the increasing importance of energy issues, but did not change the fractured structure energy bureaucracy itself. In 2010, the Leading Group was replaced by the National Energy Commission which has more authority. The inclusion of military leaders in the Commission signals the increasing importance of energy security.

Key Energy Agency Dates

1980 to 1982 - National Energy Commission headed by two Vice-Premiers.

1988 to 1993 - The Ministry of Energy and Industry was established through the merger of the Ministries of Coal Industry, Hydroelectricity, Oil Industry and Nuclear Industry. The Ministry of Energy was abolished in line with wider market reforms.

2003 to 2008 - The Energy Bureau within the National Reform and Development Commission (NDRC) was responsible for energy policy, regulation and administration.

2005 to 2008 - National Energy Leading Group of the State Council was established and chaired by the Premier coordinating various agencies and ministries on energy issues. The Office of the National Energy Leading Group supported and advised the leading group and drafted energy legislation. The establishment of this group reflected the increasing importance of energy issues, but did not change the structure energy bureaucracy.

August 2008 - The National Energy Administration was established and housed within the NDRC. The National Energy Administration is a vice-ministerial ranking agency. The administration incorporated the former Energy Bureau, Office of the National Energy Leading Group and the nuclear power administration of the Commission of Science, Technology, and Industry for National Defense.

January 2010 - The National Energy Commission was established under the leadership of the Premier and housed under the State Council. This commission includes 21 high-ranking officials from the State Council, relevant ministries and commissions, and the military.

Sources: IEA, 2007; Downs, 2008; Bo, 2010; Cai, 2010

5.3.3 Rural Electrification Policy

China has been very successful in rural electrification, with the proportion of the population with access to electricity increased from 40% in the 1950's to over 99% in 2009 (Luo and Cutler, 2004; IEA, 2010). This success has been attributed to China's unique approach to rural electrification which has included both the expansion of large electricity grids to rural areas as well as local electricity grids mainly based on small hydropower[3] (Zhang

[3]In China, small hydro is defined as plants with less than 25 kW capacity (Luo and Cutler, 2004, p. 493).

et al., 2009, p. 2818-2820). These two types of rural electrification evolved in parallel as the administrative systems for rural electricity and urban electricity operated separately until 2002 (Peng and Pan, 2006, p. 72). The process of rural electrification was divided into three stages (the following is summarised from Peng and Pan, 2006; Luo and Cutler, 2004; Yang, 2003).

The first stage lasted from the establishment of the People's Republic in 1949 until the beginning of economic reforms in 1978. During this tumultuous period, rural electrification progressed slowly (see Figure 5.1 on page 84). Small hydropower stations were installed along with irrigation and drainage works in rural areas to support agricultural production. Investment in small hydro plants was shared equally between central and county governments (which provided capital) and the commune/village (which provided labor). County governments were responsible for managing the mini-grids. Towards the end of this period, industrial development in rural areas increased the demand for electricity.

The second stage lasted from 1979 until 1997 and was characterised by rapid rural electrification, in step with economic growth (see Figure 5.1 on page 84). In 1983, the State Council issued Document No. 190, which instructed local governments with good water resources to develop rural hydropower. This meant that rural electrification became one of the performance and promotion criteria of government officials. Rural electrification was supported by a number of policies[4], including:

- encouraging local investment with a policy of "the one who invests owns and operates",
- subsidies for rural electrification through hydropower of 100-300 million RMB per year,
- special loans for the construction of rural hydropower plants,
- reinvestment of revenue from electricity for further electrification,
- a reduced value added tax rate of 6% (usually 17%), and
- incorporation of smaller grids into larger grids.

Funds for rural electrification were not only sourced from central government subsidies, however. The bulk of investments came from other sources such as bank loans, local gov-

[4]Contained within State Council Documents No. 190 (1983), No. 17 (1991) and No. 2 (1996).

ernments and direct foreign investment. Rural electrification was the responsibility of the Ministry of Water and Power from 1982 to 1992. From 1992 onwards, the responsibilities for grid extension was passed to the newly created Ministry of Electricity (the predecessor of the State Power Grid Company) and the responsibilities for developing local grids was passed to the new Ministry of Water. In 1994, the State Development Planning Commission (a predecessor of the NDRC), the State Economic Trade Commission became active in rural electrification through a project with the Ministry of Energy. They invested 2.1 billion RMB through the Electricity for Poverty Alleviation Project.

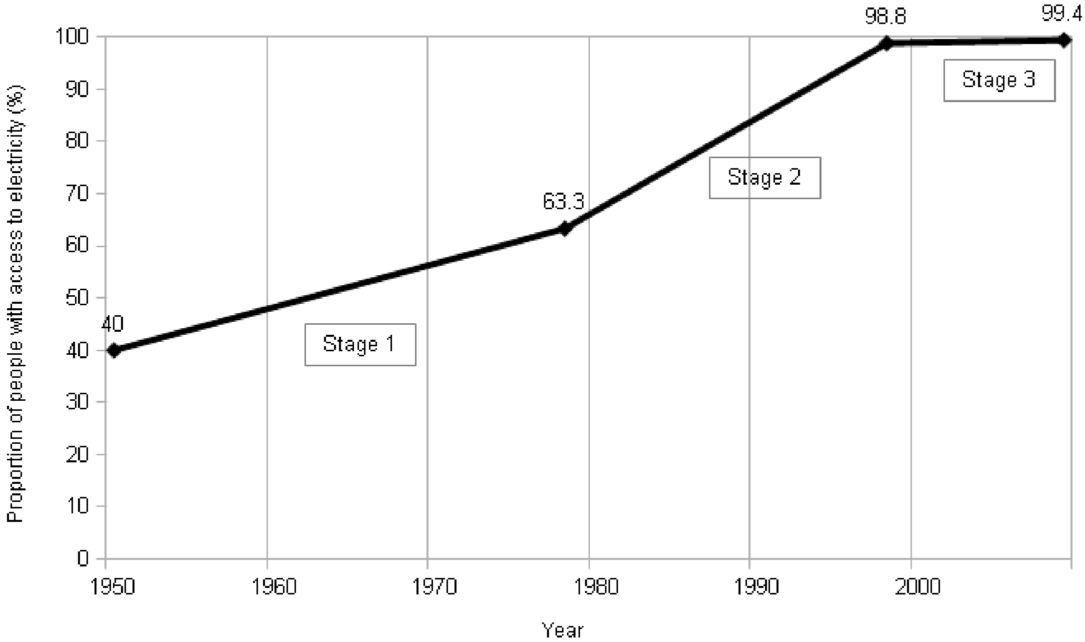
The third stage of rural electrification in China began in 1998, when the central government focused on reforming the institutions for rural electricity and renovating the physical infrastructure. The ownership and operation of rural electricity infrastructure was transferred from local governments to newly created state-owned electricity companies at state, provincial and county levels as part wider electricity sector restructuring (IEA, 2007). These companies were now responsible from electricity supply in both rural and urban areas, and a unified electricity tariff was applied. In 1998, the central government invested 290 billion RMB over five years to improve the reliability and efficiency of rural grids through replacing old equipment and rationalising the layout of the grids.

The Ministry of Agriculture supported rural electrification, as well as the use of other small-scale renewable energy technologies, through a network of rural energy offices at the county level. Beginning in 1979, these offices provided information, training and technical services on small hydropower, improved biomass cookstoves, biogas digesters, solar water heaters, solar cookers and passive solar house design in most counties [5] (Lew, 2000; Oldach et al., 2007, p. 276). Using this direct link to the counties, China has successfully disseminated a large number of solar hot water heaters, improved biomass cookstoves and biogas digesters in rural areas, as well as hydropower stations (Smith et al., 1993; Li and Ma, 2009; Sawin and Martinot, 2011).

Peng and Pan (2006) attribute the success of rural electrification in China to high levels of investment from multiple sources, emphasis on rural electrification in government policies, direct connection between central and county governments, and changes in institutional

[5] Over 100 counties used a rural integrated energy development approach which which considered energy issues in concert with environmental, social and economic development.

Figure 5.1: Proportion of People with Access to Electricity in China



Sources: Pan et al. 2006; IEA 2010

arrangements as rural electrification progressed. Current priorities for electricity in rural areas include:

- increasing electricity consumption (as electrification only refers to a basic level of energy services in China and rural households lag urban households in terms of energy use),
- increasing reliability of supply, and
- providing electricity for the remaining 8 million people in China still without access(IEA, 2010; Pan et al., 2006, p. 41).

The last of these priorities is the most challenging as the unelectrified areas are in some of the most geographically isolated environments, and where incomes are the lowest. In fact, the government had set a goal for 100% rural electrification by 2000, but this goal was not reached despite strong efforts by provincial governments (Byrne et al., 2001, p. 5). In isolated environments, distributed generation options, such as PV and wind systems, may be more appropriate for rural electrification than strategies used in the past. The three project case studies in this thesis are part of this final stage of rural electrification in

China.

5.3.4 Renewable Energy Policy

Key Policies

This section will focus on policies supporting development of PV and wind energy in China as these technologies are used in the case studies that follow. Renewable energy has been supported by the Chinese government at multiple levels since the 1980's. The Chinese government has included renewable energy in general policy directions, and has set specific goals and incentives to encourage utilisation (see Table 5.3). Early policies focused on research and development, and demonstration projects for niche markets such as household PV systems. More recent policies have focused on providing financial incentives and institutional structures for the widespread use of renewable energy.

The Chinese government has now set ambitious targets for renewable energy installation by 2020 through the Renewable Energy Law and has met or exceed its interim goals (see Table 5.2). These plans are supported by a number of renewable energy policies, including feed-in tariffs for PV and wind energy.

Table 5.2: China's Medium and Long Term Renewable Energy Plan for Power Generation

	Target for 2010 (GW)	Actual in 2010 (GW)	Target for 2020 (GW)
Hydropower	190	216	300
Wind power	5	31	30
Solar power	0.3	0.8	1.8
Biomass power	5.5	5.5	30

Source: (Yuan et al., 2014, p. 697)

In 2009, China became the global leader in PV production, with a manufacturing capacity of 4GW per year, and 500 PV enterprises (Martinot, 2010, p. 3). Before 2008, almost all of the PV panels produced were exported, mainly to the European market, because the domestic market was less than 50 MW per year mainly for rural and niche applications (Martinot, 2010; Li et al., 2007). However, PV installations in China began increasing in 2008 due to the government policies. In 2009, about 160 MW of grid-connected PV was added, making China the seventh largest PV market in the world. This growing domestic manufacturing capacity provided cheaper PV system components and local expertise. However, the reliance on export markets meant that the prices and availability of products domestically could be affected by events overseas.

In 2009, China became the top in the world for annual growth of wind power. There are now over 70 wind turbine manufacturers in China, which can produce 1.5MW of wind turbines annually. In 2010, China had installed 31GW of wind power, generating more than 50 TWh (Yuan et al., 2014).

Table 5.3: Key Renewable Energy Policies in China

Year	Policy Document
First Level: General Policy Directions and Guidance	
1981 - 2011	6th to 12th Five-Year Plans
1983	Suggestions to Reinforce the Development of Rural Energy
1992	China Agenda 21
1995	Ten Strategies on China's Environment and Development
1995	State Science and Technology Commission Blue Paper No.4: China Energy Technology Policy
1995	Outline on New and Renewable Energy Development in China, by State Planning Commission, State Science and Technology Commission and State Economic and Trade Commission
1995	Electric Power Law
1996	State Energy Technology Policy
1997	Energy Saving Law
2005 & 2009	Renewable Energy Law
Second Level: Specific Goals and Plans	
1996	Brightness Program and Ride the Wind Program, State Planning Commission
1995	New and Renewable Energy Development Projects in Priority (1996-2010) China, by State Science and Technology Commission, State Power Corporation and State Economic and Trade Commission
1996	9th Five-Year Plan and 2010 Plan of Energy Conservation and New Energy Development by the State Power Corporation
1996	9th Five-Year Plan of Industrialisation of New and Renewable Energy by State Economic and Trade Commission
1998	Incentive Policies for Renewable Energy Technology Localisation by State Development and Planning Commission, and Ministry of Science and Technology
2001	10th Five-Year Plan for New and Renewable Energy Commercialisation Development by State Economic and Trade Commission
2003	Rural Energy Development Plan to 2020 for Western Areas
2007	Medium and Long-Term Development Plan for Renewable Energy in China
2012	12th Five-Year Plan for Renewable Energy Development
Third Level: Specific Incentives and Management Guidelines	
1997	Circular of the Communication and Energy Department of the State Planning Commission on Issuing the Provisional Regulations on the Management of New Energy Capital Construction Project
1999	Circular of Ministry of Science and Technology, and State Development and Planning Commission on Further Supporting the Development of Renewable Energy
2001	Adjustment of Value-Added Tax for Some Resource Comprehensive Utilisation Products by Ministry of Finance and State Tax Administration
2001	Township Electrification Program by State Development and Planning Commission and Ministry of Finance
2006	Circular of National Reform and Development Commission on Notice of Power Supply Construction Program in Unelectrified Regions
2009	Golden Sun Program
2009	Notice on Improving Grid-Connected Wind Power Tariff Policy
2011	Notice on Perfection of Policy regarding FiT of Power Generated by PV

Source: Yang et al., 2003; NREL, 2004*b*; Oldach et al., 2007; Martinot, 2010; Liu and Shiroyama, 2013

Renewable Energy in the Mainstream

Chinese policy-makers, including those in IMAR, considered renewable energy to be viable technologies for rural electrification. The foundation for the widespread acceptance of these small-scale renewable energy technology was laid in the 1960's, when appropriate technologies were introduced in rural areas after the break with Russia. During the Cultural Revolution (1966-1976), China's development policies consisted of "walking on two legs" which simultaneously developed large-scale industry in cities and small-scale industry in rural areas. Small-scale rural industry utilised local resources (including waste from large-scale industry) and appropriate technology. Rural industry was characterised by local initiatives and self-reliance (Akubue, 2000). Micro-hydro power plants are considered one of the most important legacies of the Cultural Revolution and the "walking on two legs" policies (Saich, 2011, p. 50). Thus, for contemporary Chinese policy-makers, small-scale renewable energy are proven paths for rural electrification with a strong ideological link to development. At a time when renewable energy rural electrification projects were still considered to be "experimental" by the World Bank and the Global Environment Facility (Martinot et al., 2001, p. 42), China had already accumulated relevant experience with other small-scale technologies.

Renewable Energy and the Development of Western China

Having long been established as a valid rural electrification method, renewable energy again came to the fore when the development of the western regions of China increasingly became a priority for the central government. The campaign to "Open Up the West" was announced in 1999 by the retiring third-generation leader, Jiang Zemin. Economic development policies since 1978 had orientated investment in key coastal regions, creating economic inequalities between the western and eastern provinces of China. However, the strategy of "two overall situations" had always promised that economic policies and central government support would favour western China once the eastern regions had reached a sufficient level of development (Holbig, 2004). The campaign to "Open Up the West" indicated that vast state resources would be directed towards the social and economic development of China's western regions to ensure social stability.

This emphasis on development in rural regions of western China was reinforced with the articulation of the Scientific Development Concept by the fourth-generation of leadership in 2003 (Hu Jintao and Wen Jiabao). This new guiding principle for the China's development addressed concerns about the rural-urban divide, regional inequalities, science and technology and environmental degradation (Fewsmith, 2004, p. 2). Development should now aim to produce a "harmonious society", rather than simply economic growth.

With development of the western region and environmental protection at the top of China's policy agenda, rural electrification projects using renewable energy, including PV and wind, were in prime position to tap into central government resources. Renewable energy projects were integrated into the development efforts of the central government through its macro-economic planning agency, the National Reform and Development Commission and its predecessors. This level of policy integration between renewable energy and development goals has been identified as a key factor in the success of renewable energy projects worldwide (GNESD, 2007).

5.4 The Inner Mongolia Autonomous Region

5.4.1 Socioeconomic Circumstances

The Inner Mongolia Autonomous Region is located along the northern part of China and shares a border with the countries of Mongolia and Russia (see Figure 5.2). It is China's third largest provincial-level division covering almost 1.2 million square kilometres, but is home to only 24.7 million people or less than 2% of the population of China (NBS, 2011). This low population density means that the average distance between rural households is 2 to 5 kilometres (Oldach et al., 2007, p. 9). Most of IMAR is high steppe-land which provides open pastures for herding livestock, but has a low average rainfall which makes it poorly suited to agriculture (Sneath, 2000, p. 2). 47% of the people in IMAR live in rural areas and rely on herding or agriculture for their livelihoods (IMBS, 2010; Oldach et al., 2007, p. 9).

Figure 5.2: Map of the Inner Mongolia Autonomous Region
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Source: Wikimedia

IMAR is predominately inhabited by people from the Han (78%) and Mongolian (18%) ethnic groups (IMBS, 2010). The area was established as an autonomous region in 1947[6] as it was home to most Mongolians in China. China's constitution (1982) recognises equality between different ethnic groups and contains provisions for autonomous regions where a high proportion of an ethnic minority resides. These rights to self-government include more legislative authority and the appointment of a member of the ethnic minority to the position of chairman of the autonomous region. However, regional autonomy has been limited since the late 1980's due to central government concerns about resistance to its rule in the Tibet and Xinjiang Autonomous Regions (Saich, 2011, p. 179).

Mirroring the economic growth experienced nationally, IMAR has experienced excellent economic growth over the last few decades (see Table 5.4). IMAR has reached a medium level of development when compared with other provinces in China measured using the Human Development Index (HDI). This means that IMAR has good outcomes for life expectancy, educational attainment and income. Since IMAR has relatively good socioeconomic indicators, it was a later addition to the campaign to "Open Up the West" (Goodman, 2004). Figure 5.3 shows the distribution of Human Development Index (HDI) across China, with IMAR having one of the highest HDI's in the country. Table 5.4 compares major socioeconomic indicators for IMAR with the national average and with two neighbouring provincial level divisions (Beijing, which has one of the highest HDI's in China and Gansu, one of the lowest HDI's). Although IMAR has developed rapidly, the income for farmers in rural areas (those most likely to lack access to electricity) remained low (see Table 5.5).

[6]Two years before the establishment of the People's Republic of China.

Table 5.4: Comparison of IMAR and other Chinese Provinces: Socioeconomic Indicators

	National Avg.	IMAR	Beijing	Gansu
HDI, 2010	0.693	0.0.722	0.821	0.630
HDI ranking (out of 32 provincial level divisions)	-	5	1	28
GDP per capita, 2010 (RMB)	29,992	47,213	71,938	16,097
GDP per capita, 2000 (RMB)	7,858	5,872	22,460	3,838
GDP per capita, 1990 (RMB)	1,644	1,478	4,878	1,099
GDP per capita, 1980 (RMB)	463	361	1,584	388
GDP per capita, 1970 (RMB)	275	263	824	218
Non-Han (minority) nationalities, 2005 (% of total population)	9 %	22 %	5 %	10 %

Sources: UNDP, 2009*a*; CDC, 2011; UNDP, 2013

Figure 5.3: Map of China Showing the Human Development Index
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Source: UNDP, 2013, p. 2

Table 5.5: Average Income per Capita in IMAR

Main Occupation	Area	Average Income per Capita in 2000 (RMB)	Average Income per Capita in 2005 (RMB)
Farmer	Urban	3,004	4,448
Farmer	Rural	2,101	3,319
Salaried worker	Urban	7,374	16,238
Salaried worker	Rural	6,375	13,887
Average	Urban	6,346	13,614
Average	Rural	3,757	7,016

Source: Veeck et al., 2006

5.4.2 Renewable Energy Policies and Programs

IMAR is rich in conventional and renewable energy resources. It has China's largest proven coal reserves which it supplies to other provinces as raw material and as electricity[7]. IMAR

[7]In 2009, Inner Mongolia produced over 223 billion kWh of electricity in total and supplied over 95 billion kWh of it to surrounding provinces (IMBS, 2010) (including about one third of Beijing's power supply (Lee Kwan, 2010, p. 49)).

also has some of the best wind and solar resources in China, but has few water resources that would be suitable for hydropower [8]. Despite its rich conventional energy resources, the IMAR government recognised that grid extension was not an economically viable option for rural electrification due to the low population density and low level of demand in rural areas (Oldach et al., 2007, p. 9).

Since the 1980's, the IMAR government has concentrated its rural electrification efforts on small-scale, decentralised wind turbines and PV systems (each powering one household) because of its good wind and solar resources (Lin, 1999, p. 1130). IMAR could not adopt the rural electrification approach used in most other provinces using small hydropower (as outlined in section 5.3.3), because the region lacked water resources. By 2000, IMAR had the highest concentration of small-scale wind turbines in the world with a total of 140, 000 to 150,000 turbines installed providing electricity to about one third of the population not connected to the electricity grid (Lin, 1999; Lew, 2001).

The IMAR government began its renewable energy activities through supporting research and development of small-scale wind turbines and pumps. In 1980, the IMAR government formed the high-level New Energy Leading Group to coordinate policy on renewable energy (Lin, 1999, p. 1130). The IMAR Science and Technology Commission announced a priority program for renewable energy development and utilisation. Special attention was given to local development of components for use in remote areas; meeting the production and basic needs of herdsman; reducing costs; improving reliability; and ensuring local people were in charge of the program while providing appropriate government support (Lew, 2000, p. 276). The IMAR government invested 300,000 RMB annually in research and development, and over 20 small-scale wind turbines were developed by universities and research institutes. In 1981, a three-year demonstration project of small-scale wind turbines and pumps was initiated by the Science and Technology Commission. 141 small-scale wind turbines with 18.2kW of capacity was installed in households in remote areas (Zhang et al., 2001, p. 36).

After the success of the demonstration project, the IMAR government began provid-

[8]IMAR has an estimated average wind speed of 9.69 m/s or 520W/m^{2}at 50 m hub height with almost 7900 usable hours/year (Lew, 2000, p. 273). About 80% of Inner Mongolia's land mass has economically exploitable wind resources and accounts for 40% of China's total economically exploitable wind resources (Zhang et al., 2001, p. 34). Inner Mongolia also has 5.5-6.5 kWh/m^{2}of solar radiation per day (Lee Kwan, 2010, p. 51), but only 387 MW of exploitable hydro resource (Byrne et al., 2001, p. 6).

ing financial subsidies using income tax revenue to encourage widespread adoption of the technology (Cherni and Kentish, 2007, p. 3619). In 1984, the New Energy Office was set up to determine policies, as well as to manage research, production and dissemination activities. New Energy Service Stations were established in each banner and most *sumus* to distribute subsidies, provide information and technical support. In 1986, the IMAR government began offering subsidies for small-scale wind turbines and PV systems, and promulgated new regulations to set up a mechanism for providing the subsidies and new energy utilisation [9]. Herders obtained a coupon from their nearest New Energy Service Station and redeemed it at their chosen wind turbine manufacturer. Under the regulation, herders received 200 RMB per 100 W rated capacity for wind turbines and PV panels and 50 RMB per battery, which covered about 15-20% of the system cost. By 2000, the subsidy had been reduced to 100 RMB per 100 W for the wind turbine only. The IMAR government spent 4-5 million RMB annually for the subsidies, with the electricity utility matching this amount. In 1990, the central government began contributing about a third of the subsidy for wind turbines. Thus, by 2000, IMAR had a thriving local small-scale wind turbine industry with 10 manufacturers which could build turbines in the 100 to 25 kW range, and 17 manufacturers producing renewable energy products overall. These manufacturers not only supplied IMAR, but sold products to over 20 provinces in China and exported overseas (Lin, 1999; Lew, 2000, 2001; Zhang et al., 2001).

While small wind and PV systems were developed locally, larger systems were developed through technology transfer from international development projects from the 1990's onwards. Major technical cooperation projects with Denmark, Germany and the USA allowed local organisations to develop manufacturing, design and installation capabilities for larger-scale wind systems and wind/PV hybrid systems. These demonstration projects focused on the technical aspects and the hardware was usually fully subsidised, making maintenance and further installations reliant on the availability of external funding (Lew, 2000; Zhang et al., 2001; Wang, 2004; Oldach et al., 2007).

Due to lower wind speeds in the summer months, PV panels were added to the small-scale wind turbines to form hybrid systems. This meant that economically valuable energy

[9] The *Temporary Rules of Strengthening the Development and Utilization of New Energy* and *Economic Support Measures on Spreading Small-scale Wind Generators and Solar Cells.*

services such as refrigeration for meat could be used in summer when the solar resource peaked. In addition, the PV panels helped to extend battery life by preventing then from being over-discharged during the summer months. Given the utility of wind/PV hybrid systems, the IMAR government committed to installing 60,000 wind/PV hybrid systems over 5 years in 2000 (Lew, 2001). PV panels were added to the existing wind turbine technological system and the same institutional channels were used to popularise the technology. Thus, PV was introduced in an environment where the use of small-scale wind turbines was well established. The technology had been through the stages of research and development, demonstration and had already been widely disseminated. PV panels were merely an addition to these systems to improve their lifetime and reliability.

In summary, the utilisation of renewable energy in the region can be divided into four stages (see Table 5.6 on the following page). The next stage in the utilisation of renewable energy in IMAR was the widespread dissemination of PV, as addition to wind turbines or in PV-only systems. The following three chapters present case studies of the main PV projects in IMAR which made this possible (spanning the period from 2000 to 2008).

Table 5.6: Timeline for Capacity Development for Renewable Energy Rural Electrification in IMAR

	Stage 1: 1980-1981	Stage 2: 1984-2000	Stage 3: 2000	Stage 4: 2001-2008
Description of Stage	R & D and pilot project for small wind turbines led by the IMAR Science & Technology Commission with a focus on innovations by local organisations.	Widespread dissemination of small wind turbines through subsidies administered by a dedicated New Energy Office in IMAR.	Addition of PV to household wind turbines to form hybrid systems, as well as the introduction of larger, centralised systems. The development of these technologies again involved local R & D and demonstration projects, this time with some technology transfer from overseas technical cooperation projects.	widespread dissemination of PV technology
Hardware	household wind turbines	household wind turbines	household & village wind/PV hybrid systems	household & village wind/PV hybrid systems

5.5 Conclusion

This chapter has set out the national structures and policies relating to energy, rural electrification and renewable energy, as well as the local socioeconomic circumstances and renewable energy policies in the IMAR. At the national level, economic reforms since 1978 have dramatically changed the institutional structures which renewable energy projects and technological systems must operate within. In particular, fiscal decentralisation has meant that provincial governments have become more self-reliant for the provision of basic services. The initial pursuit of economic growth in key eastern provinces in the 1980's and 1990's created inequality between the eastern seaboard and the country's interior. This inequality has become a central concern of the Communist Party of China in the twenty first century. The case study projects in this thesis are part of a broader policy push for socioeconomic development in disadvantaged regions.

Compared with other developing countries, China has been very successful with its rural electrification program through its strategy of using small hydropower as well as grid expansion. Direct connection between the central government and counties, as well as local investment have contributed to this success of rural electrification using small hydropower and dissemination of other small scale renewable energy technologies. This policy experience provided a model for further renewable energy projects. The government also put in place policies to support the establishment of a domestic renewable energy manufacturing industry.

At the provincial level, IMAR is relatively well developed when compared with other provinces included in the campaign to Opening Up the West. This means that the education levels and health contribute to higher capabilities and community resources which could support PV technological systems. The IMAR has excellent wind and solar resources, and has a long history of developing and utilising these resources for rural electrification. The use of small wind and PV systems, as well as the entire supply chain were established in the IMAR. Strong government support since the 1980's, including local research and development, local manufacturing and direct subsidies, have been an important factor in the widespread adoption of the technologies. By the beginning of 2000, both the national and provincial institutional environments were favourable for renewable energy. Against this background, the following chapters will present case studies of three major national renewable energy projects implemented in IMAR.

6 Case Study: The Brightness Program Pilot Project

6.1 Introduction

The Brightness Program (*Guangming Gongcheng*) was the renewable energy rural electrification plan for western China between 2000 and 2010. The Brightness Program provided a national framework for rural electrification using renewable energy. A pilot phase of the program was implemented in IMAR, Gansu Province and Tibet Autonomous Region in 2000. Although local renewable energy projects had already been implemented in IMAR by 2000, the Brightness Program was the first national program to be implemented there.

This case study will examine the Brightness Program pilot project in IMAR using the renewable energy capacity pyramid. Section 6.2 provides an overview of the project. Then, each layer of the capacity pyramid will be described and analysed. Section 6.8 will conclude the chapter with an overall analysis of the Brightness Program pilot project in IMAR. In-depth material on the local level was collected from two banners in IMAR, referred to as Banner 1 and Banner 2 in the text.

6.2 Project Overview

The goal for the Brightness Program was to provide electricity for 23 million people in remote areas with an average capacity of 100 W per person by 2010 (that is, a total of 2.3 GW). This was to be achieve through a number of different phases.

The first phase aimed to provide electricity to 8 million people using renewable energy, including 1.78 million household systems, 2000 village systems, 100 frontier stations and 100 wireless communication stations (NREL, 2004*c*; Wang, 2004, p. 78). This phase aimed to achieve the following tasks (Wang, 2004, p. 78):

- set up central and local government investment channels and financing systems
- build up an industrial base to meet market demand and provide high-quality products at a low cost
- build up highly-efficient, regulated sale/service network and market mechanisms
- implement a training system covering different levels (from end-user education to provincial-level technologists).

In order to achieve these goals, Brightness Program pilot projects were implemented in IMAR, Gansu Province and Tibet Autonomous Region in 2000. In IMAR, the pilot project ran in three selected banners for two years starting in 2000. The pilot project provided subsidies for wind/PV hybrid home systems in households which could not be connected to the grid in IMAR. In line with the goals of the first phase of the Brightness Program, the pilot project in IMAR included setting up:

- a network of sales and service companies,
- a government financing mechanism,
- a system to ensure hardware quality, and
- a multi-level training system (Shi et al., 2008, p. 29).

The pilot projects were funded by the State Planning Commission. The budget for the pilot phase was 20 million RMB (see Table 6.1). Brightness companies were established in three selected banners in IMAR and subsidised hybrid wind/PV systems were offered to herders. In total, 5000 wind/PV hybrid systems were installed in IMAR (see Table 6.2).

Table 6.1: Budget for Brightness Program Pilot Projects

Province/Institution	Amount (RMB)
Inner Mongolia Autonomous Region	10 million
Tibet Autonomous Region	3.5 million
Gansu Province	3.5 million
Chinese Academy of Sciences	3 million
TOTAL	20 million

Source: Wang, 2004, p. 83

Table 6.2: Number of Systems Installed for Brightness Program Pilot Phase in IMAR

Banner	Number of systems		Total
	300W wind/ 100W PV hybrid	300W wind/ 150W PV hybrid	
Siziwang	2500	0	2500
East Ujimqin	1000	800	1800
Etouke	0	700	700
Total	3500	1500	5000

Source: Shi et al., 2008, p. 29

6.3 Tools

6.3.1 Hardware

The Brightness Program pilot project offered standardised hybrid renewable energy systems designed to power a single household. The renewable energy systems offered combined a 300 W wind turbine with either 100 W or 150W PV panels. The system also included batteries, an inverter and a charge controller (see Table 6.4 and Figures 6.1 and 6.2). The systems were designed according to the electricity needed by different kinds of households (see Table 6.3 for the assumptions used). The system design was based on those used in earlier projects and those that were sold on a commercial basis in the area (Manager B, pers. comms., 6 Nov 2009; Manager D, pers. comms., 19 Oct 2009).

Table 6.3: Brightness Program System Design Parameters

Category	Average capacity needed / day (kWh)
Low electricity consuming household	0.1
Medium electricity consuming household	0.26
High electricity consuming household	1.85

Source: Wang, 2004, p. 77

Figure 6.1: Brightness Program Wind and PV Components

Table 6.4: Brightness Program System Configurations and Prices

System Type	System Specifications	Load Specifications
300 W wind/ 100 Wp solar hybrid (24V/ 220V)	300 W wind turbine 2 x 50Wp solar panels 2 x 200 Ah batteries 600 W inverter/charge controller	5 x 9 W CFL 25-inch (85 W) colour TV Satellite TV receiver Energy saving fridge (daily consumption $\leq$ 0.6 kWh)
300 W wind/ 150 Wp solar hybrid (36V/ 220V)	300 W wind turbine 3 x 50Wp solar panels 3 x 135 Ah batteries 600 W inverter/charge controller	5 x 9 W CFL 25-inch (85 W) colour TV Satellite TV receiver Energy saving fridge (daily consumption $\leq$ 0.6 kWh)

Source: Inner Mongolia Taifeng Company

One of the aims of the Brightness Program pilot project in IMAR was to implement "a system to ensure hardware quality" (Shi et al., 2008, p. 29). System standards were developed by an expert team and the Solar Energy and Wind Power System Quality Inspection Centre at the Chinese Academy of Sciences. Nine PV manufacturers and eight wind turbine manufacturers submitted their components for testing at the inspection centre. Wind/PV hybrid systems were field tested for up to one year. The expert team then evaluated each system according to the test results and this informed the choice of equipment to be subsidised. The inspection centre also conducted random sample tests on the equipment

Figure 6.2: Brightness Program Pilot Inverter and Battery Components

supplied (Manager B, pers. comms., 6 Nov 2009) (Wang, 2004, pp. 86-7). In addition to this extensive testing, the systems were required to have a 2-year manufacturer's warranty.

6.3.2 Analysis Using the Framework

The overall technical performance of the Brightness Program systems in IMAR was similar to the technical performance of systems installed worldwide. A technical evaluation of household wind/PV hybrid systems in IMAR, including the Brightness Program pilot project, was conducted in October 2003. Of the 5240 wind/PV hybrid systems in the study, 60% were functioning (Haugwitz, 2007, p. 6). An analysis of solar home systems surveys in six developing countries around the same time found that 55% of systems were functioning (Nieuwenhout et al., 2000, p. 9).

Worldwide, charge controllers are a common source of system failures. Low quality charge controllers or bypassing of charge controllers by end-users reduce battery lifetimes (Nieuwenhout et al., 2001, p. 466). The Brightness Program was no exception. The main reasons for hardware failure under the Brightness Program pilot project in IMAR were (Haugwitz, 2007):

- the copper bearings of the wind turbines were unsuitable,
- the charge controller/ inverter unit was poorly designed or used low quality components, and
- the lifetime of the batteries were reduced due to the charge controller/inverter.

Figure 6.3 shows the proportion of system malfunctions due to these problems. Taken together, over 80% of system malfunctions can be attributed to low quality charge controllers and associated damage to batteries.

Figure 6.3: Causes of Malfunction in the Brightness Program Pilot Phase in IMAR
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Source: Haugwitz, 2007

Fieldwork conducted for this study yielded similar results. In Banner 2, an estimated 60% of wind/PV hybrid household systems were functioning, including systems that were no longer needed (Technician C, pers. comms., 9 Nov 2009). Technical issues included problems related to the charge controller/inverter, wind turbine hub and wind turbine blades (Manager D, pers. comms., 19 Oct 2009; Manager G, pers. comms., 7 Nov 2009; Technicians C & E, pers. comms., 9 Nov 2009). The average lifespan of the batteries was 3 to 4 years, but they could last up to 5 years (Manager D, pers. comms., 19 Oct 2009; Manager G, pers. comms., 7 Nov 2009). Ensuring safety standards for all installed systems was challenging as wiring and protection systems for the houses were the responsibility of the house owners.

In conclusion, the renewable energy systems used in the Brightness Program pilot project in IMAR were very similar to systems that were used for previous projects. Efforts were made to ensure the quality of the systems. The technical performance was similar to other renewable energy rural electrification projects with around 60% of systems functioning. Therefore, the overall reliability of the hardware was medium (see Table 6.6).

Table 6.6: Summary of Tools in the Brightness Program Pilot Project

Capacity Layer	Components	Level of Capacity
Tools	reliable hardware	medium

6.4 Skills and Knowledge

6.4.1 End-Users

The household survey (see Appendix 10.4) and interviews with end-users revealed that they had a very high level of technical skills and knowledge for installing, operating and repairing renewable energy systems. End-users were very familiar with using household wind/PV hybrid system because they had been using similar renewable energy system distributed by previous government projects (Manager D, pers. comms., 19 Nov 2009).

Most end-users had existing house wiring or completed the wiring themselves before the renewable energy systems were installed. Although technicians from the Brightness Company did the initial installation of the Brightness Program systems, many users could disassemble and reinstall their own systems. End-users were given half a day of training at the time of installation. Most end-users were literate and could read the system manual for further reference. One person in each village (*gacha*) was selected for further training in Banner 2 (Manager G, pers. comms., 7 Nov 2009).

Operation of the wind/PV hybrid system was partly automatic. The the inverter/charge controller unit managed the load by disconnecting appliances once the battery voltage dropped below a set level. The end-users did not bypass the inverter/ charge controller when it switched off because they knew that doing so would compromise the lifetime of the batteries. There was a strong sense of ownership of the systems (Manager D, pers. comms., 19 Nov 2009). Some end-users actively managed their energy use by reading the battery voltage using a multimetre, which indicated the battery state of charge (End-User I, pers. comms, 21 Oct 2009). The household survey showed that both males and females had high levels of technical skill and knowledge, although males tended to have greater responsibility for the system.

End-users performed all the routine maintenance tasks including, tying down wind turbines to face away from strong winds, oiling rotors and topping up lead-acid batteries with distilled water. They also performed basic repairs such as, replacing wind turbine blades, batteries and wiring. End-users often consulted the technical manual or a more knowledgeable neighbour if they encountered problems with their system. Repairs to the inverter and the wind turbine hub required a consultation with a technician.

6.4.2 Local Technicians & Companies

The technicians at the Brightness companies had excellent skills and knowledge. In Banner 1, one permanent technician and 12 seasonal technicians were employed by the local Brightness Company to install the systems in households. The permanent technician had 4 years of experience (Manager D, pers. comms., 19 Nov 2009). They were trained by a system integration company in Hohhot for two weeks on basic installation skills. Some technicians also received installation training during the Brightness Program period from an expert from Italy (Technician C, pers. comms., 9 Nov 2009; Technician D, pers. comms., 9 Nov 2009). These technicians were based in the banner's economic centre and drove up to 300 km or 6-7 hours on dirt roads to reach the households (Manager D, pers. comms., 19 Nov 2009).

In Banner 2, nine technicians were employed to install systems for the Brightness Program, but only two were retained to provide after-sales service on a full-time basis. The two full-time employees were both local high school graduates and received on-the-job training. Technician C had over 10 years experience, while Technician D had 5 years experience. The technicians also received installation training during the Brightness Program period from the expert from Italy (Technician C & D, pers. comms., 9 Nov 2009). However, it is difficult to enforce safety standards in remote areas and they were not followed consistently during installation, even by experienced technicians.

The managers of the Brightness companies also had excellent technical expertise, managerial experience and commercial skills. In Banner 1, the manager had developed his skills and knowledge by working on small wind projects since the 1970's with the Electricity Department, the Electric Power Company and the State Development Planning Commission (Manager D, pers. comms., 19 Nov 2009).

6.4.3 Analysis Using the Framework

End-users had a high level of awareness and technical skills. As discussed in Chapter 5, there had been several large renewable energy projects in IMAR prior to the Brightness Program pilot project. End-users already had a high level of technical skills and these were utilised during the Brightness Program. Little formal technical training was required from the Brightness Program for the operation and maintenance of the renewable energy systems. Some end-users actively managed their energy use to extend the life of the batteries.

Local technicians had a high level of technical skill. These were acquired through working on previous government renewable energy projects and extended by training offered by the Brightness Program. Managers also had a good level of commercial skills from previous experience in local government departments.

The level of skills and knowledge are summarised in Table 6.7.

Table 6.7: Summary of Skills & Knowledge in the Brightness Program Pilot Project

Capacity Layer	Components	Level of Capacity
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	high
	end-user energy management skills	high
	supply chain technical skills	high
	supply chain commercial skills	high

6.5 Organisational Structures

6.5.1 Local Organisations

The most important local organisation for delivering energy services through the Brightness Program were the Brightness companies. The companies were formed in the participating banners to install systems and provide after-sales service (Manager I, pers. comms., 12 Oct 2009). These small businesses consisted of a manager and several technicians. The State Development Planning Commission provided funding to establish the Brightness companies. The funds were used to cover initial costs such as cars, computers and stock (Manager B, pers. comms., 6 Nov 2009).

Many of the Brightness companies emerged from organisations which were involved in earlier renewable energy projects. Some Brightness companies were founded by former workers from Energy Technology Promotion Stations which were set up by the IMAR Science and Technology Bureau to implement the Small Wind Turbine Program (Oldach et al., 2007, p. 11) (Manager G, pers. comms., 7 Nov 2009). Other Brightness companies were founded by former staff from the IMAR State Development Planning Commission who had worked on energy issues (Manager D, pers. comms., 19 Oct 2009).

In Banner 1, the end-user contacted the local Brightness company if there was a problem with their system and brought parts of the system to the shop for repair. If they could not go the shop or if the parts were too large to transport, then the Brightness company would send a technician to their home on the same day. The local Brightness Company could order spare parts from the manufacturers on behalf of their customers (Manager D, pers. comms., 19 Oct 2009). The procedure in Banner 2 was similar, but the Brightness company would lend the end-user a spare inverter to use if their inverter needed to be sent to Hohhot for repairs (with a turn-around time of 3-7 days). They also provided a battery recharging service for when the wind resource was low (Manager G, pers. comms., 7 Nov 2009). After the guarantee period, the end-users were responsible for the cost of repairs. Each service call would cost about 200 RMB, not including spare parts.

Initially, the requests for repairs for inverters and charge controllers which needed the assistance of the manufacturer were passed from the Brightness companies to Taifeng (a subsidiary of the electricity utility that managed the Brightness Program in IMAR) to the manufacturer. Because the manufacturers were local, they could easily be reached if repairs were needed. Later on in the project, the Brightness companies contacted the manufacturers directly as they had established relationships. Some other component suppliers were from other provinces and harder to reach (Manager B, pers. comms., 6 Nov 2009).

6.5.2 Financial Arrangements

The Brightness Program pilot project offered each household a 3000 RMB subsidy for one wind/PV hybrid system (REDP, 2004, p. 39). End-users could choose from two system designs to suit their needs, but the level of subsidy would remain the same. This meant that the subsidy level varied from about 24% to 29% of the price, depending on the system they chose (see Table 6.8).

Subsidies were allocated to different areas within each participating banner each year. In the beginning, Brightness companies advertised the availability of the subsidy and households registered with the township government. The township government then selected which households would receive the subsidy according to needs. The main selection criteria were that the household was within the project area and did not have a current electricity supply. Taifeng then arranged for the system to be installed through the appropriate Brightness company and reimbursed them 3000 RMB for each system installed. In subsequent years, the Brightness companies and Taifeng assessed subsidy applications instead of the township government (Manager B, pers. comms., 7 Nov 2009; Manager D, pers. comms., 19 Nov 2009; Project Designer A, pers. comms., 26 Nov 2009).

Another way that households accessed systems from the Brightness Program pilot project was through an informal secondhand market or gifts. Systems were sold or given away when they were no longer needed. This was made possible through strong kinship ties and a high level of social capital. The secondhand market will be discussed further in section 6.6.

6.5.3 Analysis Using the Framework

Financial Arrangements

The financial arrangements were sustainable as the end-users owned the renewable energy systems and were able to afford the operation and maintenance costs. The subsidy arrangement was designed to be equitable, while meeting the needs of different households (Oldach et al., 2007, p. 3). However, a credit scheme could have increased the accessibility of the systems. Table 6.9 shows that the cheapest subsidised system cost almost 3.5 times the annual income of farmers in rural areas and almost two times the average annual income in rural areas.

Table 6.8: Price of Brightness Program Pilot Project Systems in IMAR

	300W wind/ 100W PV hybrid	300W wind/ 150 W PV hybrid
Price without Subsidy (RMB)	10,200	12,600
Price with Subsidy (RMB)	7,200	9,600
Subsidy Level (% of price without subsidy)	29%	24%

Table 6.9: Subsidised Price of Brightness Program Pilot Project Systems Compared with Income per Capita in Rural IMAR (2000)

Main Occupation	Income per Capita in 2000 (RMB)	Subsidised price of 300 W wind/ 100 W PV hybrid as a % of Income	Subsidised price of 300 W wind/ 150 W PV hybrid as a % of Income
Farmer	2,101	343%	457%
Salaried worker	6,375	113%	151%
Average	3,757	192%	256%

Source: income per capital data from Veeck et al., 2006

Effectiveness

The Brightness companies had effective organisational structures. They had sufficient staffing levels (workload capacity). The ownership arrangement for the companies meant that there were incentives for good supervision by managers, who were part-owners of the business (supervisory, system, structural and role capacity). The initial grant ensured that the Brightness companies had the resources that they needed to conduct business effectively (facility capacity). Equipment manufacturers and system integrators provided technical support for the Brightness companies, as well as training, spare parts and repairs (support service capacity).

The Brightness companies were highly effective because they evolved from previous organisational structures. This meant that personnel with high levels of skills and knowledge were retained in the local area. Because the organisational structures evolved from earlier ones, it ensured that some existing systems, structural and role capacity were carried through to the Brightness companies. These included information, financial and communication systems, familiar decision-making protocols, roles and responsibilities.

Flexibility

The Brightness companies were flexible and could respond to changes in their operating environment. When the Brightness Program ended, most of the Brightness companies survived by continuing sales and repairs of renewable energy systems, diversifying their product range and opting for more flexible staffing arrangements. A summary of the organisational structures layer is given in Table 6.10.

Table 6.10: Summary of Organisational Structures in the Brightness Program Pilot Project

Capacity Layer	Components	Level of Capacity
Organisational Structures	sustainable financial arrangements	high
	effectiveness	high
	flexibility	high

6.6 Sectoral Networks

6.6.1 Roles & Linkages

The instigator for the Brightness Program was the State Planning Commission. Its Energy Conservation and New Energy Department signed an implementation agreement with the provincial level governments. The provincial governments were in charge of establishing a corporation based on the Brightness Program guidelines to implement the program (Wang, 2004, p. 81-82). In IMAR, The Inner Mongolia State Development Planning Commission asked the Inner Mongolia Electric Power Company (responsible for the electricity grid) to form a non-profit company, Taifeng Company Ltd. (Taifeng) (Inner Mongolia Tai Feng Energy Company ; Manager I, pers. comms., 12 Oct 2009; Wang 2004, pp. 81-2). Taifeng was the main implementation agency. Its stated goals were (Inner Mongolia Tai Feng Energy Company, p. 4):

- establishing stable investment channels and financing mechanisms to ensure the effective use of the national and autonomous region monies,
- improving system configuration according to the financial situation and electricity consumption needs of end-users in order to maximise benefits.
- developing and using the rich wind and solar resources in IMAR by opening up the PV/wind hybrid system market, promoting their use, establish an installation and service network, and a technology training system.
- organising the hardware tenders needed for the Brightness Program and select equipment suppliers from China, under the leadership of the government,
- assessing and supervising the Brightness Program equipment quality and suppliers' after-sales service, supply of spare parts, and project schedule.

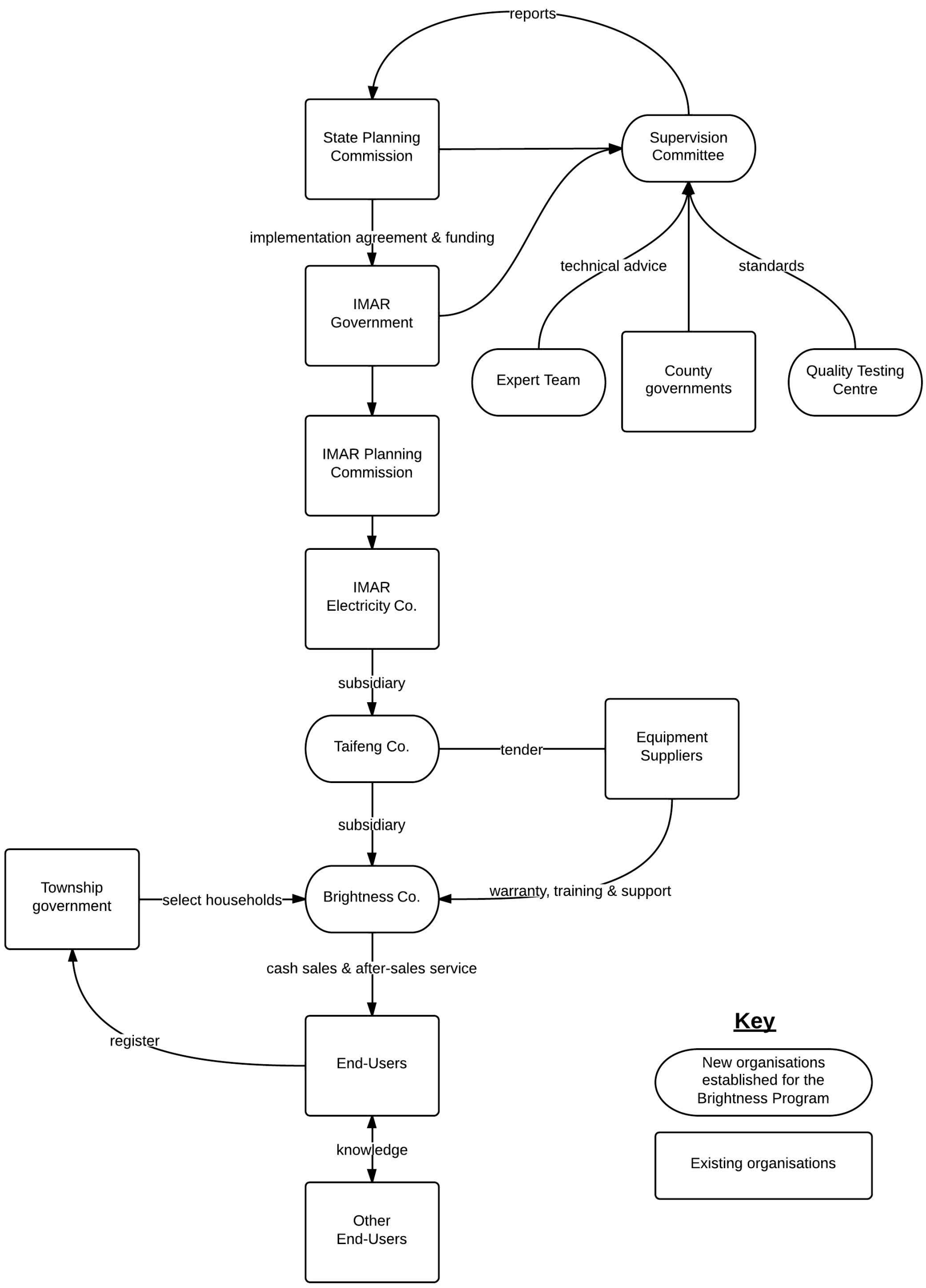
- determining a viable electrification development path for herdsmen and villagers living in the autonomous region's non-electrified remote areas in order to achieve the main goal of the Brightness Program. This would contribute to the economic and social development of the autonomous region.

Taifeng formed subsidiary Brightness companies in participating banners to install systems and provide after-sales service (Manager I, pers. comms., 12 Oct 2009). These 'Brightness companies' were owned by Taifeng (51% share) and either the Energy Technology Promotion Stations or private shareholders (49% share) (Oldach et al., 2007, p. 11).

An expert team was assembled by the High Technical Bureau of the Chinese Academy of Sciences, to provide technical advice, monitor the implementation process and to establish quality standards. The expert team was led by Beijing Jikedian Renewable Energy Development Centre within the Chinese Academy of Sciences (Jikeidan). The Solar Energy and Wind Power System Quality Inspection Centre was responsible for drafting quality standards for the Brightness Program.

A supervision committee was also formed to oversee the implementation of the program and report to the State Planning Commission. The supervision committee included the main stakeholders and experts, including the State Planning Commission, the High Technical Bureau of the Chinese Academy of Sciences, the expert team, provincial Planning Commissions and county governments (Wang, 2004, p. 81-82). The roles of the actors and their linkage are summarised in 6.4.

Figure 6.4: Actors in the Brightness Program Pilot Project



6.6.2 Analysis Using the Framework

Supply Chain

The level of capacity for organisations along the supply chain was medium. The Brightness Program pilot project was able to draw on existing local organisations in the renewable energy supply chain. These included component manufacturers and system integrators. However, the Brightness Program concentrated its support on a limited number of system integration and retailers. This led to the concentration of knowledge and skills in these organisations and allowed quality standards to be maintained. It also gave organisations involved in the Brightness Program pilot project a competitive advantage over other companies. In Banner 1, about ten businesses sold replacement batteries and small wind turbines (Manager D, pers. comms., 19 Oct 2009; Manager G, pers. comms., 7 Nov 2009). In Banner 2, there were four other retail shops offering spare parts. These shops found it difficult to compete with Brightness companies because they did not receive government support and could not sell systems at a subsidised rate.

Informal sectoral linkages were important for the functioning of the Brightness Program. Ongoing relationships between equipment suppliers and Brightness companies meant that knowledge was easily accessible to technicians. The Brightness companies had established a good reputation for quality since they grew from Energy Technology Promotion Stations. Strong social linkages between end-users also meant that knowledge could be shared.

These strong informal linkages allowed a secondhand market to form. An informal secondhand market has emerged for household renewable energy systems, including the Brightness Program systems. Households sold their renewable energy systems to neighbours when the systems were no longer needed. For example, when a household was connected to the electricity grid. Demand for secondhand systems were driven by households with expanding electricity use, but could not get a second subsidised system from the Brightness Program. The end-users usually installed the secondhand system and accessed the Brightness companies if repairs were needed (Manager D, pers. comms., 19 Oct 2009).

Learning Networks

The level of capacity in terms of learning networks was high. Knowledge diffusion through networks was very good as the whole supply chain was in China. Organisations along the supply chain were able to interact and improve the reliability of the systems. Component manufacturers were able to offer training for technicians and technicians were able to contact manufacturers when problems occurred.

Advocacy Coalitions

The level of capacity of advocacy coalitions was high. The strongest advocacy coalition for renewable energy rural electrification evident in the Brightness Program was within the Chinese government. There was strong support from the central and IMAR governments. By the time that the Brightness Program pilot phase was implemented, the renewable energy sector had gained legitimacy. As the organisation responsible for the implementation of the Brightness Program pilot project in IMAR, Taifeng functioned effectively as a system facilitator or market facilitation organisation. It established financial mechanisms, ensured system quality and matched end-user needs with technical specifications.

In conclusion, the Brightness Program pilot project in IMAR supported a limited number of local organisations along the supply chain and strengthened their capacity. This meant that the organisations involved had a high level of capacity as they had received extended government support. Learning networks between these organisations was also strong. Informal linkages between actors was vital in passing on skills and knowledge, and the creation of a secondhand market. One key factor in forming strong linkages is the ability of the IMAR government to coordinate activities between government agencies. This will be explored further in the next section. Table 6.11 summarises the sectoral networks layer of capacity.

Table 6.11: Summary of Sectoral Networks in the Brightness Program Pilot Project

Capacity Layer	Components	Level of Capacity
Sectoral Networks	organisations along the whole supply chain	medium
	learning networks	high
	advocacy coalitions	high

6.7 Institutional Environment

6.7.1 Policy Formulation

The Brightness Program pilot project in IMAR was not an isolated project. It was one of several pilot projects that were the first steps in reaching the broader goals of the Brightness Program. The Brightness Program was also aligned with international development goals. The Brightness Program was announced at a meeting of Heads of State at the World Solar Summit in Zimbabwe in 1996 (NREL, 2004*c*). The Solar World Summit convened by the Government of Zimbabwe and UNESCO. It launched the Harare Declaration on Solar Energy and Sustainable Development, formed the World Solar Commission, which later adopted the World Solar Programme 1996-2005. The Brightness Program was a major part of China's contribution to this work at the international level.

6.7.2 Implementation Approach

The State Development Planning Commission followed normal policy procedures to apply for funding from the Ministry of Finance for the Brightness Program pilot phase (Project Designer B, pers. comms, 4 Dec 2009; Project Designer C, pers. comms., 3 Dec 2009).

The formal roles of the actors in the Brightness Program pilot project in IMAR were well defined in the project design (see 6.4 on page 112). The Brightness Program pilot project in IMAR made use of existing government agency structures to implement the project. It made use of the strong top-down, bureaucracy that flowed from central government to provincial government, and various government agencies. The Brightness Program pilot project in IMAR was instigated via a vertical chain of authority (*tiao*) the State Planning Commission. However, the Brightness Program pilot phase project implementation was flexible and differed according to the circumstances in each province. The involvement of the IMAR government exerted horizontal authority (*kuai*) in order to coordinate the implementation of the project within IMAR. The IMAR government was able to coordinate the IMAR State Planning Commission and the Inner Mongolia Electric Power Company. However, the IMAR Science and Technology Bureau and the Ministry of Agriculture, were not part of the Brightness Program. They had previously been involved with small wind turbine programs in IMAR through the Energy Technology Promotion Stations. These stations were converted to Brightness companies. This transfer of responsibilities was possible through the coordination role of the IMAR government.

6.7.3 Analysis Using the Framework

Long-term Policy Frameworks

The capacity level for long-term policy frameworks was high. Chapter 5 showed that there was an enabling environment for renewable energy in China and IMAR at the time that the Brightness Program pilot phase was implemented. Renewable energy was already a well established rural electrification option. The growth of the renewable energy industry was supported by long-term policies at the national and provincial levels. The long-term policy framework and integrated planning for the Brightness Program was made possible because it was part of the socialist planning paradigm embodied by the State Planning Commission. The State Planning Commission formulated centralised planning objectives and implemented them through a hierarchy of plans through the different layers of government and the issuing of directives. In an environment where top-down planning was the norm, the Brightness Program had a strong policy framework to support it.

Integrated Planning

The Brightness Program was also well integrated into national development plans as it was sponsored and implemented by the State Planning Commission. The State Planning Commission was the macroeconomic management agency under the State Council. The development of western China was a priority for the central government to ensure social stability. Rural development efforts in western China were coordinated by the State Planning Commission and the Brightness Program was an important part of its development efforts. The Brightness program pilot project in IMAR was also well integrated with the electricity sector as a subsidiary of the electricity utility, Taifeng, acted as the market facilitation organisation at the local level. This arrangement not only allowed renewable rural electrification planning to be integrated with grid extension plans, it provided the necessary technical capacity for energy supply planning, program delivery, performance monitoring and stakeholder engagement through electricity utility branches. Therefore, the level of capacity for integrated planning was high.

Alignment with Values and Norms

The level of capacity in terms of alignment with values and norms was high. The Brightness Program pilot project in IMAR used the step-by-step policy approach of “crossing the river by feeling the stones”. The pilot phase of the Brightness Program was a way to test possible policy solutions at a small scale before a period of accelerated rural electrification efforts. In IMAR, the Brightness Program pilot project formed the basis of the Inner Mongolia New Energy Electrification Program (2001 to 2005) and the Inner Mongolia Electrification Program (2007 onwards). The Brightness Program was aligned with both central and provincial-level government plans because it was implemented with applications from provincial-level governments for central government funding.

Favourable Macro-Economic Environment

The Brightness Program pilot project was made possible through a favourable macro-economic environment. As discussed in Section 5.3.4, China had experienced strong economic growth in eastern China and was now investing in western regions through programs such as the Brightness Program. The economic growth strategies that the Chinese government used included heavy investments in R&D and technical education. These investments made the skilled labour at all levels and research capabilities available as existing capacity for the Brightness Program. Strong economic growth and government fiscal decentralisation also allowed the IMAR government to continue investment in renewable energy rural electrification after the Brightness Program ended.

Policy Learning Processes

The capacity level for policy learning processes was high. The government departments involved in the Brightness Program pilot project in IMAR had high capacity in this area as they had excellent relational, knowledge and mobilisation resources. For example, the project used the network of State Planning Commission offices at the national, provincial and township levels to collect the data needed for planning, to recruit participants and the disperse the subsidy. The hardware and project design relied heavily on the high level of skills and knowledge within government departments. However, this meant that there was little direct input from end-users and businesses in the project design. Table 6.12 summarises the institutional environment layer of capacity.

Table 6.12: Summary of Institutional Environment in the Brightness Program Pilot Project

Capacity Layer	Sub-Capacity	Level of Capacity
Institutional Environment	long-term policy frameworks	High
	integrated planning	High
	alignment with values and norms	High
	favourable macro-economic environment	High
	policy learning processes	High

6.8 Conclusion

This chapter has used the capacity pyramid to analyse the Brightness Program pilot phase (see Table 6.13 for a summary). This case study showed that high levels of local skills and knowledge can be retained and developed through careful project design. One of the most important success factors was that the project was part of a step-by-step approach (involving multiple projects, one after the other) that allowed local capacity to be built over time. The Brightness companies were the latest incarnation of older local organisations that provided renewable energy services.

This case study demonstrated that layers of capacity are linked in a number of ways. Using similar hardware (tools) to previous projects meant that norms were maintained and allowed the continued build-up of local skills and knowledge. Resilient local organisations retained and sustained skilled and knowledgable personnel. Informal sectoral linkages also helped to build up local skills and knowledge. Most importantly, an enabling environment provided strong policy framework to support sectoral linkages and organisational structures. Favourable economic circumstances also supported the development of skills and knowledge, organisational structures and sectoral networks by providing a basic level of capacity.

Table 6.13: Summary of Capacity in the Brightness Program Pilot Project

Capacity Layer	Sub-Capacity	Level of Capacity
Tools	reliable hardware	medium
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	high
	end-user energy management skills	high
	supply chain technical skills	high
	supply chain commercial skills	high
Organisational Structures	sustainable financial arrangements	high
	effectiveness	high
	flexibility	high
Sectoral Networks	organisations along the supply chain	medium
	learning networks	high
	advocacy coalitions	high
Institutional Environment	long-term policy frameworks	high
	integrated planning	high
	alignment with values and norms	high
	favourable macro-economic environment	high
	policy learning processes	high

7 Case Study: The Renewable Energy Development Project

7.1 Introduction

The China Renewable Energy Development Project (REDP) was a joint project of the World Bank and the National Reform and Development Commission, with additional funding from the Global Environment Facility. It ran from December 2001 until June 2008 in nine provinces and autonomous regions in western China, including the IMAR. The overall aim of the project was the "development of sustainable markets for wind and photovoltaic technologies, in order to increase supply of electricity in an environmentally sustainable way and improve access of isolated rural populations to electricity service" (World Bank, 1999, p. 2). The REDP is an important case study because it was one of the largest PV project funded by the World Bank at the time, and the project has been recognised internationally for its market-based approach. This case study will apply the capacity development analytical framework in Chapter 4 to the REDP case study. Section 7.2 will outline the project and the sections that follow will analyse each layer of the capacity pyramid. Section 7.8 will conclude the chapter by providing an overall assessment of the REDP in IMAR. In-depth material on the local level was collected from two banners in IMAR, referred to as Banner 1 and Banner 2 in the text.

7.2 Project Overview

The aim of the project was "to foster development of a sustainable market for PV technologies and demonstration of the viability of commercial wind development in the coastal regions". It used "state-of-the-art and cost-effective wind and PV technologies to supply electricity in an environmentally sustainable way and to provide modern energy to dispersed rural households and institutions" (World Bank, 2001).

The project's objectives were to:

- Reduce greenhouse gas emissions by producing electricity from renewable energy;
- Reduce costs of renewable energy to permit long-term financial sustainability; and
- Remove barriers to the large-scale commercialisation of the technologies (World Bank, 1999, p. 2).

The project's activities were split into three distinct components (World Bank, 1999, p. 6-8):

- The photovoltaic component.
  - A direct grant from the Global Environment Facility of $US1.50/Wp for a total of 10 MWp of PV systems. This would be given directly to system integrators to help them to improve product quality, improve warranties, improve after-sales service, strengthen business capabilities and increase marketing efforts.
  - A market development program for system integrators. This included a public information campaign, capacity building for PV company staff on business skills, a study to assess the suitability of payment mechanisms and market monitoring.
  - Institutional strengthening for quality assurance and project management, which included establishing national PV testing and certification centres, establishing component and system standards, capacity building to improve the quality control of manufacturers, as well as project implementation, monitoring and evaluation.
- The technical improvement component.
  - Competitive cost-sharing grants to companies for technology innovation projects which would reduce production costs and improve product quality.
  - A quick response fund for urgent cost-shared projects of up to US$10,000.

  - Production investment loans through commercial banks for purchasing production equipment, follow-up investment to grant-financed activities or other investments.
  - Institutional strengthening which supported project management, capacity-building for staff at participating companies and special studies to improve the implementation of the project.

- The wind farm component[1].
  - Financing for five wind farms totalling 190 MW of installed capacity. The sites were in IMAR (100 MW), Hebei (50 MW), Fujian (20 MW) and Shanghai (20 MW)[2].
  - Institutional strengthening to help overcome barriers to wind farm development.

Changes to the REDP took place during implementation. The main changes were:

- The creation of the Market Development Support Facility which supported proposals from participating companies for market development activities.
- The project increased its coverage to include Yunnan and Shaanxi.
- The subsidy increased from $US1.50/Wp to $US2/Wp in order to support the achievement of more stringent standards for PV modules required by the project.

The budget for the REDP totalled US$ 317 million (see Tables 7.1 and 7.2[3]).

[1]Note that this case study is focused on rural electrification and will not discuss the commercial-scale wind farm component of the REDP.

[2]The REDP goals and financing arrangements were revised between the project approval by the World Bank (in 1999), and the signing of all the loan, grant and project documents (in 2001) because some of the wind farms originally planned could not obtain power purchase agreements (due to restructuring in the Chinese electricity sector) or could not obtain approval due to concerns about their environment impact (World Bank, 2009, p. 2)(Group, 2010, p, 5). The loan was restructured so that the wind farm component of the project was reduced to 20 MW of wind farms in Shanghai (the rest of the project remained unchanged). The PV component remained the same. Because of this delay, progress during this intervening time was assessed by the World Bank to be unsatisfactory (World Bank, 2009, p. 5) and it lengthened the preparation stage of the project (REDP, 2008).

[3]In 1999, a loan of US$100 million from the International Bank for Reconstruction and Development (IBRD) and a US$35 million grant from the Global Environment Facility (GEF) were approved for the project. US$ 309.2 million of loans and equity was provided by Chinese companies, financial institutions and government. But, as previously discussed, three wind farms were removed from the project. As a result, both the IBRD loan and GEF grant were reduced to US$13 million and US$27 million respectively. Financing from Chinese entities was also reduced to US$165.45 million. Thus, the financing for the project was reduced by more than 50% after the three wind farms were removed from the project scope when the project was restructured. Although the wind component and the Technology Improvement component set aside for wind technology were drastically reduced, the budget for the PV component remained the same after restructuring.

Table 7.1: Sources of Finance for the REDP

Sources of Funds	Type of Financing	Actual/Latest Estimate (USD millions)
IBRD	Lending	12.94
GEF	Grant	26.86
Sub-borrower (State Power Corporation of China)	Equity	5.31
Borrowing Country's Financial Intermediaries	Lending	8.21
PV, Technical Improvement Companies & End-User Contributions	Equity	263.95
Government of China (SETC)	Lending	-
Total		317.27

Source: World Bank, 2009, p. 26

Table 7.2: REDP Budget

Components	Actual/Latest Estimate (USD millions)
Wind farm Investment	25.58
Wind farm Institutional Strengthening	1.50
PV System Investment	91.60
PV Market Development Program	3.34
PV Institutional Strengthening	1.96
Technology Improvement Investment	190.00
Technology Improvement Institutional Strengthening	1.95
Total Project Costs	*316.83*
Interest During Construction	0.31
Front-end fee IBRD	0.13
Total Financing Required	*317.27*

Source: World Bank, 2009, p. 25

By the end of the project, more than 400,000 systems, totalling 11.1MW_p had been sold under the REDP. This exceeded REDP's own goals of installing 350,000 systems with a capacity of 10 MW_p (World Bank, 2009, p. 29). At the start of the project, an estimated 500,000 households in developing countries used solar home systems (Cabraal, 2000, p. 1). This made REDP one of the largest household PV projects implemented at the time. In IMAR, only 4,700 PV systems were installed under the program with a total capacity of 174 kW_p (World Bank, 2009, p. 47).

7.3 Tools

7.3.1 Hardware

The design for the REDP systems was left to the system integrators and the designs varied from province to province. Thus, the REDP was able to account for differences between regions, including the end-users' needs and the renewable energy resources (Manager A, pers. comms., 25 Sept 2009; Manager H, pers. comms., 30 Nov 2009). A system had to include PV panels, an inverter/controller and batteries, but other components could be added (Manager F, pers. comms., 28 Oct 2009). For the systems installed in IMAR, a wind turbine was usually added to form a wind/PV hybrid system designed to power one household. Wind/PV hybrid systems were considered by the system integrators to the most suitable to meet the higher electricity demand of households in IMAR and better suited to the renewable energy resources found in the area. These systems were a similar design to household renewable energy systems that had been propagated through successive government projects in IMAR (Manager F, pers. comms., 28 Oct 2009; Manager C, pers. comms., 15 Oct 2009).

End-users were able to choose from several standard designs offered by each system integrator. The local retailer helped them to make this selection (Manager F, pers. comms., 28 Oct 2009). The standard system designs offered in IMAR are shown in Table 7.3.

Table 7.3: REDP Standard System Designs in IMAR

System Type	Company	System Specifications	Load Specifications	Price (RMB)*
PV only	Company 2	100 Wp solar panels ; 100 Ah battery; 250 W inverter/charge controller	3 x 9W compact florescent lights (CFL's); 19-inch black and white television	5,400
wind/PV hybrid	Company 1	200 W wind turbine; 100 W solar panels; 2 x 160Ah batteries; 300 W inverter/charge controller; 20 m electricity cable	-	8,400
wind/PV hybrid	Company 1	300 W wind turbine; 100 W solar panels; 2 x 200Ah batteries; 600 W inverter/charge controller; 20 m electricity cable	-	9,850

wind/PV hybrid	Company 2	300 W wind turbine; 150 Wp solar panels; 3 x 135 Ah batteries; 600 W inverter/charge controller	3 to 5 x 9 W CFL's; 20-inch colour TV and satellite receiver; Mobile telephone; 100L freezer	12,000
wind/PV hybrid	Company 1	300 W wind turbine; 150 W solar panels; 3 x 165Ah batteries; 600 W inverter / charge controller; 20 m electricity cable	-	12,450

* Prices without REDP subsidy

Source: Manager F, pers. comms., 28 Oct 2009; Manager C, pers. comms., 15 Oct 2009

System integrators could only select components from a list of products which met REDP technical standards. The REDP Project Management Office drafted these standards with the involvement of Chinese research and testing organisations, manufacturers and international experts. The draft standards were reviewed nationally and internationally before being disseminated to manufacturers (Cabraal, 2000, p. 2). The standards became more stringent over time, as the capacity of manufacturers improved. This included the phasing in of an international standard for PV modules (GB9535-1998 / International Electrotechnical Commission (IEC) 61215) (REDP, 2008, p. 12).

The REDP standards focused on the quality of each individual component and there were no standards for system integration until December 2005 (when the "Solar Home Systems Implementation Standard", modelled on the IEC 62124, was required) (D'Agostino et al., 2011). There were also no standards for wind turbine components in wind/PV hybrid systems (Manager A, pers. comms., 25 Sept 2009; Manager F, pers. comms. 28 Oct 2009) and no standards for system installation as many of the systems subsidised by the project were very small, 'plug and play' systems (Manager A, pers. comms., 25 Sept 2009).

The REDP required system integrators to provide warranties for the system components. These were: ten years for PV modules; two years for charge controllers; one year for batteries, inverters and lights; and six months for radio cassette players (Wheldon and Rawlings, 2008, p.5). Some companies in IMAR provided extensions on their warranties in order to increase the standing of their brand (Manager C, pers. comms., 15 Oct 2009).

7.3.2 Analysis Using the Framework

The technical performance of the REDP systems was measured by the Project Management Office in two ways during the project:

- Product quality testing of samples obtained from retail outlets, and
- Surveys of end-users, including their level of satisfaction with of the system's performance and details of any breakdowns.

Quality tests for products from different provinces were conducted in 2004, 2005 and 2007 (REDP, 2008, p.24). A comparison between the 2005 and 2007 test results show significant improvement in the quality of most components (see Table 7.4). However, there were still serious quality issues, especially for batteries. Although all the system integrators had gained quality management certification under the International Organisation for Standardisation (ISO) 9000 family of standards by 2007, they did not always check component supplier test results (REDP, 2008, p.25). There were also claims of mislabelling by system integrators and component suppliers, as well as substitution of lower quality parts by system integrators due to downward price pressure from increased competition (Jikedian, 2005, p.3).

Table 7.4: Comparison of product quality in 2005 and 2007 retaliative to 2007 REDP standards

Test items	2005 % qualified	2007 % qualified	Change
PV module	36%	60%	up 24%
Charge controller	9%	75%	up 66%
Battery	36%	45%	up 9%
DC lighting	11%	53%	up 42%

Source: REDP, 2008, p. 25

A 2003 survey (Ban, Cheng and Kang, 2003)[4] which included two banners in IMAR, as well as areas in Qinghai and Xinjiang found that a large majority of systems were functioning (91%). Few end-users (13%) encountered problems with their PV system, with only 66% needing replacement parts (mostly still covered under warranty). The difference between the number of PV systems needing replacement parts and the number of end-users who reported that they encountered problems with their PV system indicates that they do not consider repairs to be a problem. As a result of good technical performance, 75% of end-users were satisfied with the PV systems and 78% believed that the system fulfilled their anticipated electricity needs (see Table 7.5 for details). Note that the systems were less than two years old at the time of the survey and many of the systems would have been still under warranty.

[4]Note that of the 103 households visited for the 2003 survey, only 19 were located in IMAR. So the results for IMAR are not statistically significant, but do give an indication of the situation. Later surveys did not include IMAR, but indicate a good initial technical performance and an average level of end-user satisfaction over the long-term.

Table 7.5: 2003 End-User Survey Results

Survey Question	Results
Problems encountered by end users using the PV system	No problems: 87% Problems include inverter, wind turbine, lights, batteries not working, interference of TV and radio, and early automatic shutoff (possibly due to failing batteries or poor weather conditions).
Percentage of PV systems in use	91% Reasons for stopping use of the PV system include the availability of grid electricity (50%) and system failures (50%).
PV system parts replaced (Note: interviewees could select more than one answer, so the sum of the percentages is more than 100%)	No replacements: 66% Battery: 29% Inverter: 12% Lamps: 6% Other: 8%
User satisfaction with the PV system	Satisfied: 75% "Just so so": 19% Dissatisfied: 4.8% Not sure: 1.4%
Users believing that the PV system meets their anticipated needs	78%

Source: Ban, Cheng and Kang, 2003

In conclusion, the hardware design for the REDP in IMAR was very similar to household systems already in use in the region. The REDP emphasised component quality standards and the reliability of the hardware was acceptable to the majority of end-users, although there were some system breakdowns. Therefore, the reliability of hardware is medium (see Table 7.6).

Table 7.6: Summary of Tools in the REDP

Capacity Layer	Components	Level of Capacity
Tools	reliable hardware	medium

7.4 Skills and Knowledge

The REDP distributed hardware that was very similar to the ones already in use in IMAR (including the Brightness Program). Thus, the skills and knowledge of the end-users and local technicians were very similar to the Brightness Program.

7.4.1 End-Users

The REDP built upon the existing skills and knowledge described in the Brightness Program case study (see Section 6.4 on page 104). End-users had a sophisticated understanding of household renewable energy systems and actively managed their energy use. Some end-users were able to install their own systems as they had used similar systems before (Manager C, pers. comms., 15 Oct 2009). End-users did routine maintenance tasks and basic repairs using spare parts brought from a local shop (Manager C, pers. comms. 15 Oct 2009). The REDP produced simple, generic operation instructions for end-users and produced promotion materials (Wheldon and Rawlings, 2008, p. 5).

7.4.2 Local Technicians & Companies

In IMAR, the household renewable energy systems were sold, installed and repaired by a retailer in each banner. These were existing companies that had been involved with renewable energy projects in the past. Most of these companies had been set up for the Brightness Program. That is, they were former Brightness companies, although some had changed their name since the end of the Brightness Program. The retailers used their existing capacity to carry out the activities for the REDP. Thus, the installation procedures and other maintenance arrangements for the REDP in IMAR were very similar to the Brightness Program (see Section 6.4 on page 104). The local technicians performed the most common repairs, but more complex repairs were sent to the system integrator to resolve (Manager C, pers. comms., 15 Oct 2009). The REDP conducted training for installers.

7.4.3 Analysis Using the Framework

End-users had awareness of renewable energy and had excellent technical skills. Some end-users were able to actively managed their energy use. These had been developed through previous government renewable energy projects. The REDP produced generic awareness raising materials and manuals, which were probably too basic for some end-users in IMAR.

Technicians had a high level of technical skills and managers had excellent commercial skills. Both were developed during previous government projects and were retained through the former Brightness companies.

In conclusion, the REDP relied on the existing skills and knowledge of end-users and local technicians in IMAR. The REDP had several project activities targeted towards raising awareness of renewable energy by potential customers, conducting training for installers and producing basic manuals. However, the end-users and technicians in IMAR already had a high level of skills and knowledge for the household renewable energy systems distributed through the REDP. This high level of skills and knowledge is reflected in the assessment of the skills and knowledge capacity layer in Table 7.7.

Table 7.7: Summary of Skills & Knowledge in the REDP

Capacity Layer	Components	Level of Capacity
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	high
	end-user energy management skills	high
	supply chain technical skills	high
	supply chain commercial skills	high

7.5 Organisational Structures

7.5.1 Local Organisations

The most important local organisation for delivering energy services in the REDP were the system integrators and retailers. Three system integrators from IMAR qualified for the subsidy, but only two companies were active throughout the project. Most systems sold in IMAR were sold by these two companies (although companies from other provinces could sell systems in IMAR, the local businesses had better connections with the local market and dealer networks) (Manager A, pers. comms, 25 Sept 2009). The other qualifying company was a telecommunications technology firm that had used renewable energy in its network projects in the past, but did not have many links to the household renewable energy systems market.

The system integrators engaged one retailer in each banner to sell, install and service their systems exclusively (Manager F, pers. comms., 28 Oct 2009; Manager C, pers.

comms., 15 Oct 2009). Nearly all of the retailers involved were former Brightness companies. The system integrators and retailers who cooperated for the REDP often had ongoing business relationships.

The REDP improved the existing organisational structures of participating companies by offering:

- management training and International Organisation for Standardisation's Quality Management Systems certification (ISO9001),
- Competitive Grant & Quick Response Facilities which provided cost-sharing grants for improving quality and reducing costs, and
- the Market Development Support Facility and market information services which allowed managers to make better decisions.

7.5.2 Financial Arrangements

The REDP subsidised participating system integrators for each system sold. Companies were chosen based on their track record, business plan and ability to comply with REDP's standards (REDP, 2008, p. 17). Unlike other projects that had been implemented in IMAR, the REDP subsidy was aimed at improving product quality, warranties, after-sales service, business capabilities and marketing efforts, rather than a direct subsidy for the cost of the system being sold. This market-oriented approach aimed to bolster the commercial market which would continue to sell and service renewable energy systems after the project had finished (Manager H, pers. comms., 30 Nov 2009).

The system integrators shared part of the subsidy with retailers to support sales, installation and service costs (Manager A, pers. comms. 25 Sept 2009). End-user contacted the local retailer or the system integrators in the capital city to buy the systems, but did not receive the subsidy directly (Manager F, pers. comms., 28 Oct 2009; Manager C, pers. comms. 15 Oct 2009). End-users paid the retailer for the full cost of the renewable energy system up-front (i.e. there were no financing mechanisms in the REDP). Although a financing scheme was planned, the REDP Project Management Office felt that there was insufficient time to introduce a pilot scheme and that the cash market was sufficiently large (World Bank, 2009, p. 7).

The subsidy rate was initially US$1.50 per Wp, but increased to US$2 per Wp in 2005 for modules meeting international standards (REDP, 2008; World Bank, 2009). The subsidy was set quite low (at about 20% of the system costs) in order to encourage the commercial market for renewable energy system which already existed in the provinces in which the REDP was implemented (Manager A, pers. comms., 25 Sept 2009). Since the subsidy was in US Dollars, the subsidy received by the PV system companies in Chinese Yuan varied with the exchange rate. During the life of the REDP the Chinese Yuan was pegged at 8.28 RMB: US$1 until 2005, when the Chinese Yuan was pegged to a basket of currencies selected by the Chinese government and the RMB appreciated to an average of 6.87 RMB: US$1 by 2008. Thus, the subsidy received by the system integration companies was 12.42 RMB until 2005 and an average of 13.74 RMB in 2008, despite the increase of the subsidy in US Dollars by 30%.

The actual subsidy dispersed was lower than US $1.50/Wp or US$2/Wp because the REDP reduced payments if documentation was incomplete or if quality standards were not met. In late 2007, the REDP rationed the subsidy as grant funds were becoming exhausted (REDP, 2008, p. 18). One system integrator estimated that only 80-90% of the systems they sold were successful in gaining the subsidy and they accounted for this in passing on a reduced subsidy to their customers (Manager C, pers. comms., 1 Nov 2009). The REDP introduced standard receipts and labels and electronic submission of reports to increase the number of systems that could be verified and receive the subsidy (REDP, 2008, p. 18).

The systems were owned and operated by the end-users. Some people owned several REDP subsidised systems even though each person was only supposed to receive one REDP system according to the subsidy rules (Ban, Cheng, Kang and Cheng, 2003, p. 1-2).

7.5.3 Analysis Using the Framework

The financial arrangements for the REDP were sustainable. End-users owned the renewable energy systems and were able to pay the operation and maintenance costs. Like the Brightness Program, a credit scheme would have improved access to renewable energy systems for the poorest segment of the community. Therefore, the level of capacity in terms of sustainable financial arrangements is medium.

The effectiveness of local organisations was high. The REDP built on existing organisational structures in IMAR and improved the quality of the management systems. Sufficient staff with the appropriate training and experience were already employed by the system integrators and retailers (workload capacity). The companies already had sufficient work facilities and technical support from manufacturers (facility and support service capacity). The REDP enhanced the supervisory, systems, structural and role capacity of the companies through management training and ISO9001 certification. The REDP tended to strengthen the most effective existing system integration companies as only companies with good existing organisational structures could meet the required quality standards.

The system integrators and retailers were flexible and adjusted their structures and practices in order to participate in the REDP. For example, the reporting and verification process required for the REDP were different from the previous government projects, such as the Brightness Program. Table 7.8 summarises the organisational structures layer in the REDP.

Table 7.8: Summary of Organisational Structures in the REDP

Capacity Layer	Components	Level of Capacity
Organisational Structures	sustainable financial arrangements	medium
	effectiveness	high
	flexibility	high

7.6 Sectoral Networks

7.6.1 Roles & Linkages

The former State Economic and Trade Commission was the borrower of the International Bank for Reconstruction and Development (IBRD) loan and was responsible for implementing the REDP. It set up a Project Management Office in Beijing to implement the PV and Technology Improvement components of the project (NREL, 2004*c*, p. 2). Responsibility for the REDP was transferred to the newly formed National Reform and Development Commission in a restructuring of Chinese government agencies in 2003. This caused some delay to the implementation of the project, but did not have a major impact on the project outcomes (Manager H, pers. comms., 30 Nov 2009; Project Designer C, pers. comms., 3 Dec 2009) (World Bank, 2009, p. 22). The National Reform and Development Commission managed the REDP through its Energy Research Institute and approved the project expenditure. The REDP reported to the National Reform and Development Commission at annual meetings, along with other international cooperation projects.

The REDP sought to include all parts of the supply chain, which it saw as including:

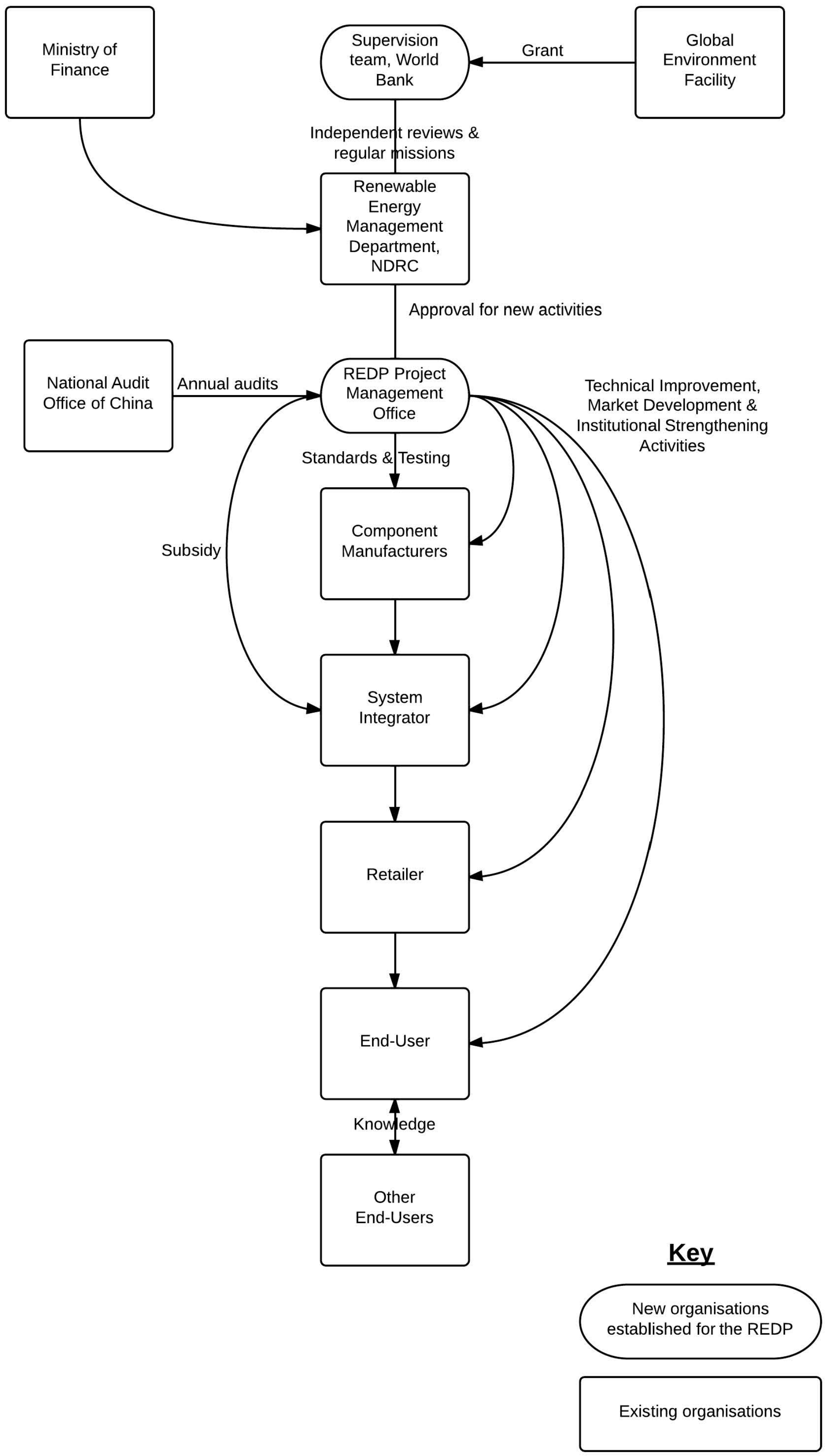
- equipment suppliers who manufactured the renewable energy system components (such as PV panels, inverters, lights, etc),
- system integrators who designed the system, procured the components and assembled them into PV systems, then distributed the renewable energy systems to local sales, installation and service organisations,
- sales, installation and service organisations (retailers) who were located near their customers, and
- customers who lived in remote areas and had no previous access to electricity.

An overview of the actors and their relationships is shown in Figure 7.1 on the next page.

These sectoral networks persisted after the REDP finished. One system integrator in IMAR felt that their branding benefited greatly from REDP activities, with customers continuing to seek out their products after the project had ended (Manager A, pers. comms., 25 Sept 2009; Manager H, pers. comms., 30 Nov 2009; Manager C, pers. comms., 15 Oct 2009). After the REDP ended, the company continued to work in the area by supplying their small wind turbines as a component of household renewable energy systems for new projects (Manager C, pers. comms., 15 Oct 2009). They continued to buy components from manufacturers which were on REDP's qualified components list as these were perceived to make good quality products (Manager C, pers. comms., 15 Oct 2009). The linkages continued to be fostered through Chinese renewable energy industry associations as a continuation of REDP's work (Wheldon and Rawlings, 2008). This networking of industry actors was one of the REDP's major contributions to the renewable energy sector in China.

International linkages were formed during the REDP through funding of trade missions and training overseas. These linkages also persisted well beyond the REDP. For example, some REDP component manufacturers and system integrators supplied components for

Figure 7.1: Actors in the REDP



subsequent World Bank PV projects in Asia and Africa because they developed a reputation for high-quality products (Manager H, pers. comms., 30 Nov 2009).

Existing informal linkages at the local level between end-users, retailers, PV system companies and component manufacturers were important for the implementation of the REDP in IMAR. The existing linkages were important for setting up the supply chains. For example, system integrators negotiated exclusive rights to sell their products with retailers in each banner with whom they had existing business relationships. Information sharing and repairs were also facilitated by existing business relationships between organisations in the supply chain.

Informal linkages also propagated a secondhand market for renewable energy systems in IMAR. This relied on existing relationships between end-users who sold their household renewable energy systems to neighbours when the systems were no longer needed. The REDP systems also became part of the secondhand market.

7.6.2 Analysis Using the Framework

Supply Chain

The level of capacity in terms of organisations along the supply chain was high. At the beginning of the REDP, all of the organisations in the supply chain were already present in IMAR. Even though the number of systems sold under the REDP in IMAR was low, the project did fill a gap in project activity for household renewable energy systems in IMAR between 2000 and 2007 (the REDP ran from 2002 to 2008) (Manager C, pers. comms., 15 Oct 2009). It helped system integrators and local retailers to stay afloat. However, the REDP reinforced the dominance of the most well established companies which were able to meet its quality standards.

Learning Networks

There was a high level of capacity in terms of learning networks. Knowledge development for new products and cost reduction was encouraged through cost-sharing grants available through the REDP's Competitive Grant & Quick Response Facilities. This mobilised private capital towards investment in renewable energy products. The REDP played a major role in facilitating knowledge diffusion through networks. As discussed earlier, the REDP linked companies along the supply chain that could meet its quality standards. The project also funded several overseas trade missions and training courses that helped the companies establish international linkages.

Advocacy Coalitions

The level of capacity in terms of advocacy coalitions was high. The World Bank and the NDRC were effective advocates for renewable energy rural electrification. The REDP Project Management Office acted as the market facilitation organisation for the emerging PV market in China. The REDP linked suppliers and system integrators, performed market research, prepared awareness raising materials, set industry standards and provided policy advice. The REDP aided market formation by nurturing a niche market for PV in remote areas where distribution and quality assurance is still a challenge. The REDP also helped to create legitimacy for a commercial PV industry by using the prize money it won from the Ashden Award to create a PV industry association (Wheldon and Rawlings, 2008).

In conclusion, since the number of REDP systems sold in IMAR was relatively small, one of the major contributions that the project made was in strengthening sectoral networks between existing organisations in the renewable energy supply chain. Table 7.9 summarises the sectoral networks layer of capacity in the REDP.

Table 7.9: Summary of Sectoral Networks in the REDP

Capacity Layer	Components	Level of Capacity
Sectoral Networks	organisations along the whole supply chain	medium
	learning networks	high
	advocacy coalitions	high

7.7 Institutional Environment

7.7.1 Policy Formulation

The project design for the REDP was the culmination of a number of joint studies undertaken by the World Bank, UNDP and Chinese government agencies from 1996 onwards[5]

[5] By 1995, the Chinese government had shown support for renewable energy through its New and Renewable Energy Development Program (1996-2010) and the 1995 Electricity Law.

(World Bank 1998, p2; Finch, Dollar et al. 2007, p35; World Bank 2009, p1). Importantly, these studies had extensive input by the former State Economic and Trade Commission, which went on to implement the REDP. These reports included:

- *Clear Water, Blue Skies: China's Environment in the 21st Century*[6] (Johnson et al., 1997) and *China: Issues and Options in Greenhouse Gas Emissions Control*[7] (Johnson et al., 1996) which highlighted the local and global environmental impacts of China's continuing reliance on coal for its economic growth. The latter concluded that, although energy efficiency was the best short-term strategy, China needed an expansion of renewable energy sources to reduce greenhouse gas emissions in the long term.

- *China: A Strategy for International Assistance for Accelerating Renewable Energy Development*[8] (Taylor and Bogach, 1998) which drew on two earlier studies - *China: Renewable Energy for Electric Power* (Bogach, 1996) and *China: Renewable Energy for Thermal Applications* (SETC, 1996). The study presented a road map for the development of various renewable energy technologies in China and opportunities for international assistance. The need for a market-based approach (as China was moving from a planned economy to a market system at the time) and the need for capacity development (acknowledging the continued role of the state, along with support for new enterprises) were articulated in this report and went on to become key features of the REDP. The study also concluded that grid-connected wind and PV for rural electrification were close to commercial viability, and these technologies became the focus of the REDP.

Thus, the REDP was implemented after a relatively long period of research and design, with collaboration between the Chinese government and the World Bank.

[6] This report was prepared by the World Bank in close collaboration with the National Environment Protection Agency and the former State Planning Commission.

[7] The team for this 3-year study included representatives from the National Environmental Protection Agency, the former State Planning Commission, the United Nations Development Programme and the World Bank.

[8] This report was prepared by the World Bank, but involved extensive discussions with the State Economic and Trade Commission and other Chinese agencies.

7.7.2 Implementation Approach

The REDP was led by the World Bank and their market-based approach dominated the project design and implementation. Prior to the REDP, the World Bank had already implemented twelve photovoltaic projects over a decade. Their experience indicated that quality throughout the supply chain is essential for the widespread dissemination of PV systems. This led to a large emphasis on quality standards for the REDP. At the time, the REDP was the second largest renewable energy project the World Bank had approved (World Bank 2010, p2). The REDP was seen by the World Bank as experimental because there was "not enough accumulated experience to provide definitive answers about best practices" in that there was "no one correct method for PV dissemination" which could be applied across all contexts (Cabraal 2000, p1). At the completion of the REDP, the project's PV and Technical Improvement components were still described as "innovative" (World Bank 2009, p4).

The project itself followed the World Bank's procedures throughout the project cycle (see Figure 7.2 on the following page). So before the project could be implemented, the Country Assistance Strategy, project identification, preparation, appraisal and approval stages had to be completed by the World Bank and the Chinese government. The documents associated with these early stages explain the rationale of the project. The project was designed to be in line with the World Bank's China Country Assistance Strategy[9] (1997) goal of "energy supply increased in an environmentally sustainable way and access of isolated rural population to electricity services improved" as well as the Global Environment Facility's goal of "promotion of the adoption of renewable energy by removing barriers and reducing implementation goals" (World Bank 1999, p28). The Project Information Document cites reducing greenhouse gas emissions, reducing local pollution and rural development as the reasons for implementing the REDP (World Bank 1998)[10].

The project was implemented through the REDP's Project Management Office. It in-

[9]The World Bank's Country Assistance Strategy for China was designed to support the policies of the Chinese government. Specifically, the 1997 strategy aimed to support the priorities set by the Chinese government in their Ninth Five Year Plan and Fifteen Year Perspective Plan.

[10]However, after the project was implemented the rationale also included financial and private sector development, as well as trade facilitation and market access as areas where the project contributed World Bank (2009). Implementation Completion and Results Report on the China Renewable Energy Development Project. Washington, D.C., World Bank.

Figure 7.2: World Bank Project Cycle
This figure has been removed due to Copyright restrictions.
Source: Bank, 2010

teracted with the supply chain and reported to the World Bank, the Global Environment Facility and the National Reform and Development Commission. The REDP Project Management Office dispersed the PV subsidy and grants centrally. Since the REDP was not managed by the Chinese government, the project could not make use of established lines of accountability through government departments.

The REDP used a market-based approach which relied on businesses interacting in a quality-controlled market to deliver sustainable energy services. The PV supply chain of component manufacturers, system integrators and retailers were linked in a commercial setting. That is, each was free to choose between different linkages as long as they met REDP's quality requirements. Companies from across China could work in each province. In this way, the REDP improved the quality of hardware and services by linking organisations along the supply chain that could meet quality standards.

The REDP used a "technology-neutral and bottom-up approach" that avoided prescribing designs and sizes. This was critical in unleashing the creativity of businesses in developing products that meet local needs (Group, 2010, p. 23). This flexibility in implementation meant that the the designs and the distribution network fit in with the dominant model in IMAR. It also meant that end-users were familiar with the hardware design as it was very similar to existing renewable energy systems in IMAR. The technology was already well acculturated.

The REDP was also flexible during implementation and made the following changes:

- The Market Development Support Facility was developed in 2003 to provide grants to system integrators participating in the REDP to help them with developing their commercial skills and markets. The Market Development Support Facility was a suggestion from the Project Management Office and participating system integrators because the Project Management Office found it difficult to design market development activities which matched the needs of the participating companies (Manager A, pers. comms., 25 Sept 2009.

- The PV grant was increased from US$1.50/Wp to US$2/Wp in 2005 due to an increase in module standards to international standards (IEC 61215-1993 or GB 9535-1998). This increase was negotiated with system integrators, who initially pushed for the grant to be increased to US$2.50/Wp to allow them to upgrade their equipment to comply with the tighter standards (D'Agostino et al., 2011, p. 3157).

- The REDP project period was extended by one year to compensate for the disruption caused by the Severe Acute Respiratory Syndrome (SARS) epidemic in 2003. Control measures, such as travel restrictions within the country, had prevented retailers from visiting customers (Manager H, pers. comms., 30 Nov 2009.

7.7.3 Analysis Using the Framework

Long-term Policy Frameworks

The level of capacity in terms of long-term policy frameworks was high. The REDP was well supported by the long-term policy frameworks of the Chinese central government, the IMAR government and the World Bank. An enabling environment for renewable energy was in place in China and IMAR (see Chapter 5). Previous projects, such as the Brightness Program, had established renewable energy as a viable rural electrification option. The Chinese government was in the process of scaling up the renewable energy industry with the support of long-term policies.

As well as general support from renewable energy policies in China, the REDP fit in with the dominant paradigm of household renewable energy systems in IMAR. The system design, sales, installation and service networks were left to the system companies in each province. This flexibility in implementation meant that the REDP could align itself with the long-term policy frameworks of the IMAR government.

The REDP also formed part of the World Bank's engagement with China and was supported by their policy frameworks. The project was designed to be in line with the World Bank's China Country Assistance Strategy[11] (1997) goal of "energy supply increased in an environmentally sustainable way and access of isolated rural population to electricity

[11] The World Bank's Country Assistance Strategy for China was designed to support the policies of the Chinese government. Specifically, the 1997 strategy aimed to support the priorities set by the Chinese government in their Ninth Five Year Plan and Fifteen Year Perspective Plan.

services improved" as well as the Global Environment Facility's goal of "promotion of the adoption of renewable energy by removing barriers and reducing implementation goals" (World Bank, 1999, p. 28). The World Bank continued to support individual renewable energy developments, municipal projects and the China Renewable Energy Scale-Up Program.

Integrated Planning

The capacity level in terms of integrated planning was low. The REDP did not coordinate with other projects as they were initiated by different government agencies. The REDP was an initiative of the State Economic and Trade Commission, and the Township Electrification and Brightness Programs were led by the State Development Planning Commission. Although all three projects would be managed by the National Reform and Development Commission after the restructuring of government agencies in 2003, the projects did not coordinate with each other at the planning stage. However, the projects did mutually reinforce renewable energy technology in IMAR (Manager H, pers. comms., 30 Nov 2009). The REDP also did not coordinate its activities with electricity utilities and their plans for grid extension.

In IMAR, the REDP was not well integrated with other renewable energy projects. Other projects had a major influence on the uptake of REDP subsidies in IMAR. Sales of REDP systems in IMAR was less than other provinces because the level of subsidy offered by the REDP were lower than other programs operating in IMAR at the same time (Wang, 2004, p. 22). At the time, the Township Electrification Program did not require the end users to pay any capital cost of the PV/wind hybrid power stations. The Brightness Program provided a subsidy of about 25-30% of system cost, while the REDP only provided a subsidy of about 20% of the system cost (Wang, 2004, p. 23).

Herders were also reluctant to buy REDP systems because they were waiting for further announcements of subsidies from the IMAR government and to see if their area would be covered by the Township Electrification Program. The existence of high subsidies shifted the attitude of potential customers to expect electricity to be heavily subsidised by the government (Manager H, pers. comms., 30 Nov 2009).

Other factors which may have affected the number of systems installed under the REDP in IMAR were:

- One of the two active system integration companies which qualified for the REDP subsidy also won the bid for system integration and installation of the Township Electrification Program systems in IMAR. They may have concentrated more on implementing this program rather than the REDP during this time (Wang, 2004, p. 22).
- Household renewable energy systems were already widely used in IMAR due to previous government projects and most demand for new systems came from people who wished to replace their systems (the market was saturated). Thus, the demand for systems may have been lower than in other provinces where renewable energy systems were introduced recently (Manager F, pers. comms., 28 Oct 2009).

Alignment with Values and Norms

The level of capacity in terms of alignment with norms and values was medium. The market-based approach used by the REDP was a departure from the central planning paradigm that had dominated Chinese policy-making and rural electrification in the past. However, there had been indications that the Chinese government was moving towards a market-based approach for renewable energy. For example, the Brightness Program had aimed to create "highly-efficient, regulated sale/service network and market mechanisms" for renewable energy rural electrification across China (Wang, 2004, p. 78). Although the REDP's market-based approach was novel, it was aligned with long-term policy directions.

Favourable Macroeconomic Environment

The REDP was supported by a favourable macro-economic environment. The REDP's market-based approach is in line with China's move from a planned to a market economy. Renewable energy businesses had been created from former government departments responsible for renewable energy as part of the Brightness Program pilot project in IMAR.

The REDP was implementing in a macroeconomic environment that encouraged manufacturing and export, including of renewable energy products. Over the life of the REDP, the Chinese PV market expanded rapidly with an accumulated installed capacity of 65

MW in 2004 growing to 150 MW by 2008 (Li and Ma, 2009, p. 41). The REDP systems accounted for about 13% of the increase in installed capacity between 2004 and 2008. However, the market in China remained small by world standards and only accounted for less than 1% of global sales in 2007 (Zhao et al., 2007). Chinese PV cell manufacturing expanded exponentially over the life of the REDP and the country became the top PV cell manufacturer in the world in 2007. Nearly 95% of solar cells produced in 2008 were exported (Li and Ma, 2009). This expansion in PV manufacturing helped to build capacity, reduce costs and improve product quality.

Policy Learning Processes

The capacity level in terms of policy learning processes was high. The rigorous preparation phase was acknowledged as a major success factors for the REDP. One of the lessons learned from the project highlighted by the World Bank was that extensive market studies lay the foundation for good project design (World Bank, 2009, p. 23). The REDP was also able to make adjustments throughout the implementation to cater to the needs of system integrators.

Table 7.10 provides a summary of the institutional environment layer of capacity.

Table 7.10: Summary of Institutional Environment in the REDP

Capacity Layer	Components	Level of Capacity
Institutional Environment	long-term policy frameworks	high
	integrated planning	low
	alignment with values and norms	medium
	favourable macro-economic environment	high
	policy learning processes	high

7.8 Conclusion

This chapter analysed the REDP in IMAR using the renewable energy capacity pyramid developed in Chapter 4 (see Table 7.11). The REDP took an innovative market-oriented approach that focused on improving hardware quality and expanding access to sustainable energy services. There was a low number of systems installed in IMAR as part of the REDP due expectations of higher subsidies for renewable energy systems from other projects. Thus, the main contribution of the REDP in IMAR was not in the number of systems installed, but in strengthening capacity. The REDP built on existing capacity and strengthened:

- hardware (tools) quality through specifying standards,
- organisational structures of system integration companies through training and certification to improve their management systems, and
- sectoral networks between quality organisations throughout the supply chain.

An enabling institutional environment supported the REDP's market-based approach. The flexibility of the REDP meant that the existing capacity at the tools; skills and knowledge and organisational structures levels could be fully utilised.

Table 7.11: Summary of Capacity in the REDP

Capacity Layer	Component	Level of Capacity
Tools	reliable hardware	medium
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	high
	end-user energy management skills	high
	supply chain technical skills	high
	supply chain commercial skills	high
Organisational Structures	sustainable financial arrangements	medium
	effectiveness	high
	flexibility	high
Sectoral Networks	organisations along the supply chain	medium
	learning networks	high
	advocacy coalitions	high
Institutional Environment	long-term policy frameworks	high
	integrated planning	low
	alignment with values and norms	medium
	favourable macro-economic environment	high
	policy learning processes	high

8 Case Study: The Township Electrification Program

8.1 Introduction

The Township Electrification Program (*Song Dian Dao Xiang*) built over 1000 renewable energy mini-grid systems between 2002 and 2005 in 11 provinces and autonomous regions in western China (Bai and Han, 2006, p. 9). The Township Electrification Program was described as “both ambitious and unique” because it was initiated and funded by the Chinese Government, implemented at great speed and at an unprecedented scale (Ku et al., 2003, p. 56). The Township Electrification Program was the largest renewable energy rural electrification program in terms of investment volume ever carried out by a national government (Shyu, 2012) and marked the transition from pilot projects to large-scale use of renewable energy in China (Zhang and He, 2013, p. 396).

This case study will examine the Township Electrification Program using the renewable energy capacity pyramid. Section 8.2 provides background on the project. Then, each layer of capacity will be detailed and analysed using the framework in Chapter 4. Section 8.8 will conclude the chapter by providing an overall assessment of capacity development. In-depth material on the local level was collected from one township in IMAR and is referred to throughout the text.

8.2 Project Overview

The aim of the Township Electrification Program was to complete electrification of all townships[1] (Project Designer A, pers. comms., 24 Sept 2009). Renewable energy technologies were used since these offered the most economically viable option for remote areas. The program ran from April 2002 to December 2005 (3.5 years). The project covered much of western China, including Tibet, Xinjiang, Qinghai, Gansu, IMAR, Yunnan, Sichuan, Shaanxi, Hunan, Chongqing and Jiangxi[2]. In total, 1013 townships received renewable energy mini-grid systems (with a total capacity of 314.4 MW). The technologies included PV, micro-hydro and PV/wind hybrid mini-grid systems, as well as household PV systems (Bai and Han, 2006; Wang et al., 2005) [3].

In IMAR, 42 systems were installed[4] in 38 townships with a combined population of 11,400 people (Bai and Han, 2006, p. 9). The number of mini-grid systems installed under the Township Electrification Program is shown in Table 8.1.

Table 8.1: Systems installed for the Township Electrification Program in IMAR

	No. Systems Installed	Capacity (kW)	Expected Annual Output (GWh)
PV	11	PV: 425	-
PV/wind hybrid	31	Wind: 315	-
Total	42	740	1

Source: Bai and Han, 2006, p. 8-11

[1] the direct translation for the Township Electrification Program from Chinese is "delivering electricity to townships"

[2] The number of provinces which participated in the Township Electrification Program increased over time. Documents from the early stages of the project state that only nine provinces and autonomous regions were involved: Tibet, Xinjiang, Qinghai, Gansu, IMAR, Yunnan, Sichuan, Shaanxi and Hunan (Ku et al., 2003; NREL, 2004*a*). Whereas the final official Township Electrification Information Compilation states that renewable energy systems were also installed at Chongqing, Jiangxi and the Xinjiang Production and Construction Corps (Bai and Han, 2006, p. 1). These changes were characteristic of the Opening Up the West campaign overall, as the geographical boundaries of the "west" shifted over time. The campaign originally only covered Xinjiang, Tibet, Ningxia, Qinghai, Gansu, Shaanxi, Sichuan, Yunnan, Guizhou and Chongqing. But IMAR, Guangxi, Xiangxi, Hunan, Enshi, Hubei and Yanbian were added to the definition of "western China" at a later date (Goodman, 2004, p. 319-320).

[3] The number of townships where systems were installed was adjusted from 1065 to 1013 during the implementation of the Township Electrification Program (bringing electricity to 1.5 million people). The reasons included: migration, relocation of the township government, expansion of the electricity grid, implementation of micro-hydro power plants outside the project, amalgamation of townships and natural disasters (Bai and Han, 2006) (Project Designer A, pers. comms., 24 Sept 2009).

[4] 39 systems were originally planned, but this changed to 42 because some townships had been connected to the electricity grid and some of the systems were split into smaller ones and installed elsewhere. The budget in IMAR was revised down from RMB 71.1 million to RMB 45.8 million(Bai and Han, 2006, p. 8).

The total budget for the Township Electrification Program was RMB 4.7 billion, funded by the NDRC and participating provincial-level governments. The NDRC procured the hardware by issuing a national tender. System integrators were selected to design and install the systems in each province or autonomous region.

8.3 Tools

8.3.1 Hardware

The size of each system was indicated in the tender for system integrator companies (Manager B, pers. comms., 9 Oct 2009). The Chinese government had committed to providing an average capacity of 100W per capita (Ma, 2004), so the systems were designed to deliver this while taking the local renewable energy resources into account (Ku et al., 2003). A reserve system capacity of 30% of the estimated current load was added to cover 5 years of demand growth (Ku et al., 2003; Bai and Han, 2006, p. 80).

In IMAR, the systems installed were PV or wind/PV hybrid mini-grid systems with sizes from 7kW to 57kW, (Huade, 2005, p. 50). These consisted of a PV array, wind turbines, battery bank, charge controller, inverters and overhead power lines (see Figures 8.1, 8.2,8.3 and 8.4).

Figure 8.1: Township Electrification Program Wind Turbine

Figure 8.2: Township Electrification Program PV Array

Figure 8.3: Township Electrification Program Inverters and Charge Controllers

Figure 8.4: Township Electrification Program Battery Bank

Some of the Township Electrification Program funding was used to upgrade or repair existing renewable energy mini-grid systems (Oldach et al., 2007, p. 20) (Manager K, pers. comms., 28 Oct 2009). PV household systems were also used in the program and these were similar to the existing designs in IMAR.

Detailed technical standards for the PV panels, inverter, batteries, control room and safety systems were specified by the SDPC/NDRC in the tender documents. These included reference to international standards where applicable (Bai and Han, 2006, p. 10-11).

Inspection missions were used to check equipment before final acceptance by the Township Electrification Program, although regulations for how these were conducted was poor (Ma et al., 2007, p. 159). System integrators were required to guarantee their systems for 3 years and provide maintenance in that period (Bai and Han, 2006, p. 83).

8.3.2 Analysis Using the Framework

The performance of the Township Electrification mini-grids was measured through surveys. The Energy Research Institute of the NDRC conducted a survey of 66 systems installed under the Township Electrification Program in seven provinces (including IMAR) in 2005 (Wang et al., 2005). They found that, on average, each system experienced 1.5 major problems that resulting in power cuts since the systems were installed. Figure 8.5 shows that the most common problems were the transmission lines, control equipment and inverters. This indicates a major issue with the quality of electronic system components as the systems had only recently been installed at the time of the survey. However, the problems were resolved relatively quickly as they systems were still under warranty. More than 50% of power outages in all provinces were fixed within 3 days and 75% were resolved within one week. A small number of cases took 1 to 3 months to be resolved.

Figure 8.5: Proportion of Technical Problems Found in Township Electrification Program Systems

This figure has been removed due to Copyright restrictions.

Source: Wang et al., 2005, p. 33

In IMAR, the system integrator self-reported that most of the systems were working well in 2007, although battery problems had emerged in a small number of systems (Oldach et al., 2007, p. 13). The average lifetime of the batteries in IMAR was 4 to 8 years, depending on the type of battery and the usage pattern (Manager K, pers. comms., 28 Oct 2009). Other problems were to do with wind turbines: twisted wires in the hub, mechanical failure, broken oil seals, damage from strong winds and lightning strikes (Manager K, pers. comms., 28 Oct 2009).

These technical problems meant that electricity supply was intermittent. When scheduled and unscheduled outages occurred, end-users were dissatisfied with the Township Electrification Program systems (Shyu, 2013). In conclusion, the reliability of the hardware was low (see Table 8.2).

Table 8.2: Summary of Tools in the Township Electrification Program

Capacity Layer	Components	Level of Capacity
Tools	reliable hardware	low

8.4 Skills and Knowledge

8.4.1 End-Users

End-users were not involved with the operation and maintenance of the Township Electrification Program systems. However, the reliability of renewable energy mini-grid systems depend upon electricity usage patterns. Excessive use of electricity (through using high-power devices, for example) can dramatically shorten the lifetime of batteries or force the system operator to shut down the system in order to preserve the batteries. Regulations for what could be connected to the Township Electrification Program systems were in place, but were left to the system operator to reinforce. No hardware was used to limit daily electricity use by individual households.

Where systems were not functioning well, end-users had coping strategies. In one township in IMAR where the electricity supply was intermittent due to battery failure, several families and the township's general store installed second-hand household wind/PV hybrid systems to provide a more steady supply. This coping strategy emerged because IMAR had a long history of using household renewable energy systems and end-users were familiar with them. End-users in other provinces also used a variety of energy sources to cope with the intermittent availability of electricity from the Township Electrification Program systems (Shyu, 2013).

8.4.2 System Operators & Engineers

Two trained system operators were responsible for the day-to-day operation of the system. They were paid from the tariff collected from the use of the system and were accountable to the Township government (Manager B, pers. comms., 9 Oct 2009). In one township in IMAR, two system operators were selected by the township government and received two weeks training from the system integrator. They were responsible for checking the battery state of charge and other system readings daily, checking the connections, stopping the wind turbine in strong wind, controlling the electricity supply if the batteries were too depleted or need to be recharged fully (the charge controller has an automatic shut off point, but can be overridden manually), minor repairs (e.g. untangling distribution wiring damaged in strong winds) and relaying information about the systems precisely and concisely to the system integrator. The system operator also contacted the system integrator for major repairs. About half of the technical problems could be solved by the system operators, while the remainder needed the assistance of the system integrator (Wang et al., 2005).

The system integrator's technicians and engineers installed the mini-grid systems following the *Township Electrification Program Construction Management Method* published by the NDRC (Bai and Han, 2006, p. 9). In IMAR, the system integrator sent engineers every 6 months during the warranty period. During each visit, the engineers completed routine maintenance, provided training, conducted tests on the equipment and collected technical data (Wang et al., 2005, p. 20). Repairs also required technicians from the integrators to visit the site. The system integrator could only repair system components which they had manufactured themselves (the wind turbine and some inverters). For other components, they had to order parts from the manufacturers and replaced them (Manager K., pers. comms., 28 Oct 2009).

In IMAR, the technicians and engineers at the system integrator had previous experience with household renewable energy systems. They built on their expertise and developed their technical skills in renewable energy mini-grids through participation in a Sino-German project. The company developed the skills and knowledge to manufacture large inverters which were used for the Township Electrification Program.

The Township Electrification Program included extensive technical training. The Beijing Jikedian Renewable Energy Development Centre (Jikedian) was responsible for the training components for the Township Electrification Program and leveraged technical assistance from international and bi-lateral aid organisations. The US National Renewable Energy Laboratory (NREL), the German Technical Co-operation (GTZ) and UNDP supported a training program for 135 local trainers and 115 service engineers across China. In turn, the trainers ran courses for at least two system operators from each township. This framework was later accredited by the Institute for Sustainable Power (the international standard for training in renewable energy). However, no formal training for new staff was available after the project period. Jikedian and NREL also published a village power system manual to support these training activities in February 2003 (Ku et al., 2003, p. 58-60)(Bai and Han, 2006, p. 11).

In March 2003, a training regulation stipulated that the system operators must hold a Rural Electric Worker Certificate (a pre-existing program certified by the Labour Department or the Electric Power Training System), a certificate for general knowledge and basic skills in PV and PV–wind hybrid systems (issued by local trainers who were trained by Jikedian), and a certificate for operating and maintaining their power system (issued by the system integrator) (Ku et al., 2003, p. 59-60)(Bai and Han, 2006, p. 11).

In IMAR, the system integrator provided intensive training and detailed guidelines for system operators. These included the daily maintenance procedure, a handbook for equipment maintenance, and record books for operation and maintenance (Wang et al., 2005, p. 21)(Bai and Han, 2006, p. 83). They also sent 3 people to be trained as trainers at Beijing Jikedian. At the end of 2004, the system integrator had trained 141 system operators and issued them with certificates (Bai and Han, 2006, p. 83).

There were also skilled and knowledgable technicians that supported the secondhand market for household renewable energy systems which emerged where the Township Electrification Program system was no longer providing reliable electricity supply. In one township in IMAR, the general store owner bought and sold second-hand renewable energy system components as part of his business. He taught himself to repair inverters beginning around 2000, and orders spare parts from Chinese inverter manufacturers (Manager J, pers. comms., 20 Oct 2009). Thus, a high level of technical expertise for household renewable energy systems was accessible to people in the township.

8.4.3 Analysis Using the Framework

End-user awareness of renewable energy was high as they had extensive experience with using renewable energy systems. However, their knowledge was limited to smaller systems suitable for individual households. End-user's technical knowledge and skills were not transferrable the Township Electrification Program because the systems were larger and more complex. End-users were not involved in operation and maintenance of the mini-grid system. Therefore, the end-users technical skills were low.

End-users did not manage their energy use to improve the lifetime of the renewable energy system. There were no incentives to do so because end-users paid a flat tariff on the electricity they consumed. They also did not have hardware tools to help them with energy management. This compromised the reliability and lifetime of the mini-grid system. When the Township Electrification systems failed, end-users in IMAR reverted back to using household renewable energy systems because they had high levels of technical skills for these kinds of systems.

The technical and commercial skills of the local organisation involved were high. Extensive training for technicians and system operators was provided through a national training framework during the implementation phase of the Township Electrification Program. The engineers at the system integration company were well trained through involvement in previous renewable mini-grid projects. Unfortunately, the skilled and knowledgeable personnel could not be retained or utilised after the Township Electrification Program because there were no sustainable financial arrangements for the operation and maintenance of the Township Electrification systems until 2007. These staffing issues will be discussed in the next section. Table 8.3 summarises the skills and knowledge layer of capacity for the Township Electrification Program.

Table 8.3: Summary of Skills & Knowledge in the Township Electrification Program

Capacity Layer	Components	Level of Capacity
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	low
	end-user energy management skills	low
	supply chain technical skills	high
	supply chain commercial skills	high

8.5 Organisational Structures

8.5.1 Local Organisations

The most important local organisations for delivering energy services in the Township Electrification Program were the system integrators and township governments. The system integration companies selected for the Township Electrification Program were responsible for the detailed design and installation of the systems, as well as major maintenance and repairs during the warranty period. The system integrator in IMAR was established in 1993 as a state-owned science and technology enterprise. It had implemented several major national, provincial and international cooperation projects in IMAR. The company manufactured charge controller/inverters (for domestic use and export) and wind turbines up to 5kW. The company had manufacturing, R&D, testing, monitoring and training facilities. Although the main market for the company was IMAR, the company had expanded the marketing of its products into other provinces. It also performed system integration, installation, maintenance and repairs of renewable energy systems. The company had marketing, projects, technology, finance and administration departments.

In each township government, two operators were responsible for the operation and maintenance of the mini-grid. They liaised with the system integrator and were accountable to the township government. However, there was no other technical support for the two operators after the warranty period. It was unclear how these two operators were to share their role and operators often left their posts due to low pay levels and there were no provisions to train new personnel (Wang et al., 2005, p. 41). In one township in IMAR, one operator lived in the local area and the other lived in a nearby town. The operators rotated the role every 2-4 weeks, until the operator who lived in town got a job as a driver for the county chief.

8.5.2 Financial Arrangements

The capital cost of the renewable energy mini-grids was fully subsidised by the NDRC and the provincial governments. The total budget for the program was RMB 4.7 billion, of which RMB 2.96 billion came from treasury bonds and RMB 1.74 billion from provincial-level government funds (Wang et al., 2005, p. 4)(Bai and Han, 2006, p. 1 and 9). The cost-sharing arrangements varied for each province as the economic circumstances of each provincial-level government were different. The percentage share paid by the State Development Planning Commission ranged from 50% to 80%. In IMAR, the State Development Planning Commission paid 50% of the costs (NREL, 2004*a*) (Manager B, pers. comms., 9 Oct 2009). The total budget in IMAR was RMB 71.1 million (Bai and Han, 2006, p. 8).

Funding for the hardware was released to the system integrators on the following basis:

- 30% within 7 days of signing the contract (as an advance payment),
- 30% within 7 days of checking of all equipment,
- 30% within 7 days of acceptance by an authorised mission,
- 10% at the end of the guarantee period (to ensure quality).

End-users were required to pay a tariff for the electricity that they consumed. Although, consumption of electricity by the township government office was often free (Wang et al., 2005, p. 20 and 35). Tariffs were predominately set by the township governments and varied from 0 to 3 RMB/kWh. Tariff collection was done by either the system integrator, township government or county power company (see Table 8.4). In IMAR, the fee was collected by the township government.

Table 8.4: Township Electrification Program Tariffs & Collection Method

Province	Tariff (RMB/kWh)	Organisation Collecting Fee	Tariff Setting
Tibet	0.4-1.5	System integrator and township government	Self setting
Qinghai	1-2	System integrator and township government	Self setting
Xinjiang	none		
IMAR	0.5-3	System integrator and township government	Self setting
Gansu	0.8	System integrator	Self setting
Sichuan	0.4-0.8	County power company	Self setting
Shanxi	0.49	County power company	Unified tariff across the province

Source: adapted from Ma et al. 2007, p. 50

There were no financial arrangements for the operation and maintenance of the mini-grid systems beyond the three-year guarantee period by the system integrators in the project design. This was widely discussed by Chinese renewable energy policy experts and several long-term solutions were proposed (for examples, see Beijing Jikedian Renewable Energy Development Center, 2008; Bai and Han, 2006; Wang et al., 2005). In 2007, the NDRC set up a support scheme for the Township Electrification Program systems which provided

4000 RMB/kW to support maintenance, plus extra funds for battery replacement. In some provinces, 100% of the funds came from the central government. In other cases, the arrangement was 50% from the central government and 50% from the provincial-level government (Project Designer A, pers. comms., 24 Oct 2009). However, some systems in IMAR were no longer in the township seat due to township amalgamation and therefore ineligible for support (Operator A, pers. comms., 20 Oct 2009; Project Designer A, pers. comms., 24 Oct 2009; Technician F, pers. comms., 19-21 Oct 2009).

8.5.3 Analysis Using the Framework

Financial Arrangements

The sustainability of the financial arrangements was low. For many systems, the electricity consumption for the township was much lower than the expected because the system size was estimated based on the current population on the township (without taking actual loads or future trends into account). The income from the tariffs was also lower than expected. In most cases, the tariff collected was only sufficient to cover the salary for the system operator (Wang et al., 2005, p. 37). In IMAR, the tariff collected was enough to cover the system operators salaries, and fuel costs for keeping the batteries warm in winter (Oldach et al., 2007, p. 13). Table 8.4 shows the tariff for most of the provinces that participated in the Township Electrification Program. It shows that the IMAR collected a relatively high tariff of 0.5-3 RMB/kWh. Analysis of the socio-economic status of herders in IMAR indicated that they could afford to pay at least 20 RMB/month, that is 2 RMB/kWh assuming a consumption rate of 10kWh/month (Oldach et al., 2007, p. 13). Thus, some townships in IMAR had tariffs which were unaffordable for the end-users. Even though the tariff was relatively high, it did not cover all of the ongoing costs of the systems.

The long-term sustainability of the Township Electrification Program systems were major concerns to policy-makers after the project was completed (Bai and Han, 2006, p. 13-14). The main issues revolved around the financial arrangements for operation and maintenance of the systems. In 2005, Wang et. al. estimated that the operation and maintenance cost for 2006 to 2020 (15 years) for all the mini-grids installed under the Township Electrification Program would be about 846 million RMB or 5126 RMB/kW over 15 years. Over 50% of this would be for battery replacement. Revenues from the tariffs and township governments would not be able to meet these costs (Beijing Jikedian Renewable Energy Development Center, 2008, p. 6). In IMAR, Huade estimated that the operation and maintenance costs for the 42 centralised systems from 2006 to 2020 (15 years) will be about 30 million RMB or 2755 RMB/kW over 15 years. In some cases, the tariffs or the electricity demand have been too low to sustain the system operators and they have moved on to other positions (Ma et al., 2007, p. 46). Some system integration companies continued to provide maintenance after the guarantee period, using their profits from the project to cover costs (Beijing Jikedian Renewable Energy Development Center, 2008, p. 10).

It was unclear who was responsible for the operation and maintenance of the systems because ownership of the systems was unclear (Beijing Jikedian Renewable Energy Development Center, 2008; Ma, 2008; Wang et al., 2005, p. 4-5). The Chinese government covered the capital cost of the systems, but the systems were not listed in official documents as state-owned assets and therefore, were not within the scope of the State-owned Assets Supervision and Administration Commission (Ma et al., 2007, p. 41). None of the parties involved wanted to take ownership of the mini-grids because they were not financially viable at the tariff level set by the township governments.

Effectiveness

Both the system integrators and the township government had strong organisational structures. The system integrator had developed excellent organisational structures from participating in previous government renewable energy projects. The system integrator had sufficient staffing levels and supervision systems across its departments (workload and supervisory capacity). These were supported by facilities, such as workshops, and support services, such as administrative staff and drivers (facility and support service capacity). The system integrator was structured as a state-owned enterprise, which gave clear guidelines for information flows, decision-making and responsibilities (structures, systems and role capacity). Similarly, the township governments had an existing governance structure which the system operators fit into. Thus, the Township Electrification Program utilised existing organisational structures of the system integrators and township governments. However, a lack of clear ownership of the systems and lack of ongoing funding meant that the township government could not access the technical expertise of the system integrators after the warranty period. The organisational structures supporting the systems were good during the warranty period, but was insufficient afterwards. Therefore, the overall effectiveness of the organisational structures was low over the long term.

Flexibility

The overall level of flexibility of the organisations involved in the Township Electrification Program was medium. The system integrator in IMAR was flexible in its approach. They had diverse product and service lines, and expanded their market to other provinces. They had also participated in a number of other government projects. Although the system integrator was unable to continue servicing the Township Electrification Program systems after the warranty period, it continued its other business activities. This meant that their technical expertise was available once funding arrangements for operation and maintenance were eventually made. The township government had little flexibility in obtaining funding for the Township Electrification Systems. Table 8.5 summarises the organisation structures layer of capacity for the Township Electrification Program.

Table 8.5: Summary of Organisational Structures in the Township Electrification Program

Capacity Layer	Components	Level of Capacity
Organisational Structures	sustainable financial arrangements	low
	effectiveness	low
	flexibility	medium

8.6 Sectoral Networks

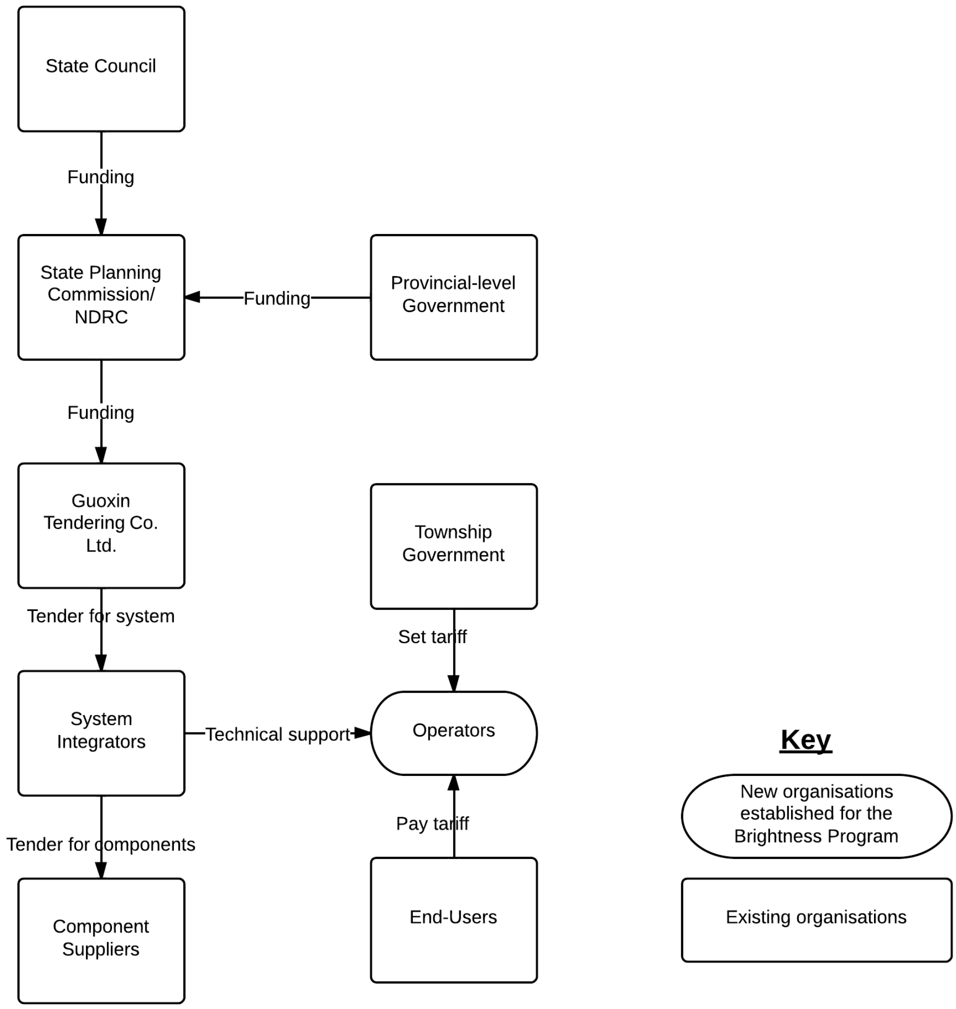
8.6.1 Roles & Linkages

The Township Electrification Program was jointly funded by central and provincial level governments and operated through their top-down administrative structure (Ku et al., 2003, p. 57). The program was led initially by the State Development Planning Commission (SDPC), but responsibility for the program was transferred to the National Reform and Development Commission (NDRC) in 2003 after restructuring within the Chinese government (Project Designer C, pers. comms., 3 Dec 2009).

The SDPC/NDRC used a national public tendering process through Guoxin Tendering Corporation Ltd. for system integrators in each province or autonomous region. In IMAR, a local company that had previously installed centralised renewable energy systems for a Sino-German project won the bid (NREL, 2004*a*). The system integrators then made detailed designs, issued international tenders for system components, installed the systems, provided training for system operators and maintained the systems for the first 3 years (Bai and Han, 2006, p. 9).

Townships more than 15km away from the electricity grid were eligible for the Township Electrification Program. Provincial-level governments made applications on behalf of townships for inclusion in the Township Electrification Program (Wang, 2004, p. 68). The SPDC/NDRC (through their provincial-level organisation) then decided which townships would receive renewable energy systems, the approximate size and the configuration of the systems. The system integrator was responsible for a more detailed system design. The township governments were responsible for the wiring, metering, operation and tariff collection in IMAR (Project Designer A, pers. comms., 26 Nov 2009; Project Designer B, pers. comms., 4 Dec 2009). These roles are shown in Figure 8.6 on the next page.

Figure 8.6: Actors in the Township Electrification Program



8.6.2 Analysis Using the Framework

The level of capacity for organisations along the whole supply chain was medium for the Township Electrification Program. The whole supply chain for the Township Electrification Program systems was present in China. However, only a few businesses were involved as system integrators and component suppliers. Strict technical standards had to be met, so the project had the effect of supporting a limited number strong system integration companies with expertise in renewable energy mini-grids (NREL, 2004*a*). Therefore, the diversity of businesses along the supply chain was relatively low.

The level of capacity for learning networks was low. Knowledge diffusion through networks in the Township Electrification Program was limited as the short implementation timeframe did not allow for new designs during the project period. However, international workshops were held during the project design phase to learn from projects overseas.

The level of capacity for advocacy coalitions was high. The main advocacy coalition for renewable energy rural electrification in the Township Electrification Program was within the Communist Party of China's Politburo Standing Committee and the State Council. They were able to leverage multi-channel government investment in the Township Electrification Program. This created a niche market for renewable energy within China and mobilised investment in renewable energy. These wider issues will be discussed in the following section on the institutional environment. Table 8.6 summarises the sectoral networks layer of the Township Electrification Program.

Table 8.6: Summary of Sectoral Networks in the Township Electrification Program

Capacity Layer	Components	Level of Capacity
Sectoral Networks	organisations along the whole supply chain	medium
	learning networks	low
	advocacy coalitions	high

8.7 Institutional Environment

8.7.1 Policy Formulation

The primary interest of the political leaders in driving electricity access in remote areas in western China was maintaining social stability. As discussed in Section 5.3.4 on page 88, vast inequalities existed between eastern and western China due to economic development policies that had prioritised key coastal regions since the 1980's. This concern over regional inequality was articulated by the Chinese leadership in 2003 through the Scientific Development Concept. The aim of this guiding principle for China's development was to produce a "harmonious society" and addressed concerns about the rural-urban divide, regional inequalities, science and technology and environmental degradation (Fewsmith, 2004, p. 2).

The Township Electrification Program was one component of China's rural development efforts. The policy problem that the Township Electrification Program addressed was regional inequality. The NDRC formulated the Township Electrification Program as part of its 'Opening Up the West' (*xibu da kaifa*) campaign, which aimed to develop the western region of China (Bai and Han, 2006, p. 1) (see 5.3.4 on page 88 for further background on the campaign). This campaign started in 2000 and appeared in China's Tenth Five-Year Plan (Goodman, 2004). Investment in transportation, telecommunications and electricity infrastructure were key components of the plan (Shyu, 2012, p. 844). This included expanding energy access in remote areas of western China (Shyu, 2010, p. 38). The Township Electrification Program's strategic significance within 'Opening Up the West' was "not to take the traditional old industrial development route", but to use the new concept of sustainable development and lay the foundations for designing renewable energy power stations, to gain experience in constructing them and to create a reference point for future renewable energy projects (Bai and Han, 2006, p. 12).

Renewable energy was chosen for rural electrification because of the remote locations of the areas yet to be electrified and the Chinese government's plans to promote renewable energy. These plans were driven by a need to address energy security issues and international environmental concerns (see Section 5.3.4 on page 88 and 5.3.3 on page 81). Renewable energy was seen as appropriate where electrification via grid extension was not economically feasible (Wang, 2004) (Project Designer A, pers. comms, 26 Nov 2009).

The policy formation process for the Township Electrification Program was "centralised and closed top-down" with little input from the local level (Shyu, 2010, p. 72). The NDRC formulated the Township Electrification Program and the State Council formally adopted the program into effect after gaining support from the Politburo Standing Committee of the CPC.

8.7.2 Implementation Approach

The implementation could be characterised as central public infrastructure provision. The project relied strongly on the central power of the NDRC. The project was implemented within a very short timeframe (due to budgetary period constraints) and some mini-grid system designs were poorly integrated with planning undertaken by other agencies (Ma et al., 2007, p. 40-42). In IMAR, many of the townships with systems installed under the Township Electrification Program were subsequently connected to the electricity grid, amalgamated with other townships or had significantly reduced populations due to migration because of desertification. As these systems were no longer needed, the IMAR Government asked the system integrator to move nine systems to other locations (mostly in border regions controlled by the military). The systems were either moved as a complete unit or split into several smaller systems. While no official information on grid extensions was available, anecdotal evidence suggested that up to 30 of the participating townships would be connected to the grid in the near future (Oldach et al., 2007, p. 13 and 20) (Manager B., pers. comms., 9 Oct 2009; Manager K., pers. comms., 28 Oct 2009). In one township, street lighting had been installed as part of the Township Electrification Project where houses were not yet built (Oldach et al., 2007, p. 20).

The implementation approach included learning from past experience. The design of the Township Electrification Program drew upon China's experience in the Brightness Program. The planning process also included a workshop on lessons learnt from village power programs around the world (Ku et al., 2003, p. 62).

8.7.3 Analysis Using the Framework

The Township Electrification Program was well integrated into China's long-term policy frameworks for rural development. It had support from the highest level of Chinese leadership and was implemented by the powerful macro-economic agency, then NDRC. As a result, the project was completed at a very short timeframe. However, integrated planning was poor and some amendments by the IMAR and NDRC after the project ended was needed.

Alignment with local values and norms in IMAR was low. In IMAR, the mini-grids was not the dominant approach to renewable energy rural electrification. The region had invested in developing capacity for household-scale systems. Much of this existing capacity was not used for the Township Electrification Program, partly because the mini-grids were larger and more complex than household renewable energy systems. The Township Electrification Program was deeply embedded in long-term policy frameworks of the central government which exerted its power vertically. The design and goals of the project served elite interests of social stability, rather than provincial-level plans (Shyu, 2010, p. 72-78).

The Township Electrification Program proceeded in a favourable macroeconomic climate that allowed funding to be raised from multiple levels of government. The macroeconomic climate had also allowed quality renewable energy businesses to thrive and provide the technical expertise required for the project.

There were also policy learning processes between projects. Experiences from the Brightness Program pilot phase and international experiences fed into the project design stage for the Township Electrification Program. The central government made further arrangements for funding maintenance after the Township Electrification Program was finished due to feedback from policy analysts and advisors. Lessons learned from the Township Electrification Program also influenced subsequent projects (for example, see Ma et al., 2007, 2006). Table 8.7 summarises the institutional environment layer of capacity for the Township Electrification Program.

Table 8.7: Summary of Institutional Environment in the Township Electrification Program

Capacity Layer	Sub-Capacity	Level of Capacity
Institutional Environment	long-term policy frameworks	high
	integrated planning	low
	alignment with values and norms	low
	favourable macro-economic environment	high
	policy learning processes	high

8.8 Conclusion

This chapter described and analysed the Township Electrification Program using the framework presented in Chapter 4 (see Table 8.8 for a summary). The project was characterised by poor hardware performance and an initially unsustainable financing model for operation and maintenance. Even though highly skilled and knowledgeable personnel embedded in strong organisational structures were available through the system integrator, they could not be accessed after the warranty period. The Township Electrification Program did not nurture diverse and strong sectoral networks to support further renewable energy mini-grid installations. The Township Electrification Program had strong support from the central government and the project formed part of the government's long-term policy strategy. However, the project design reflected the viewpoint and priorities of the central government, and left little time for integrated planning.

The Township Electrification Program demonstrates that an enabling environment and the availability of skilled and knowledgable personnel are not sufficient. Attention needs to be paid to ongoing organisational structures and sectoral networks to ensure that the impacts of a project can be sustained. Ownership and financial arrangements for operation and maintenance are most important. Without these, organisational structures and sectoral networks cannot be put in place to link macro-level policy goals with existing local capacity. The Township Electrification Program demonstrated the importance of implementing projects through government systems as it allows policy learning processes to occur. The project also showed that when new energy systems fail, end-users may revert to energy technologies that they are familiar with and which have higher local capacity.

Table 8.8: Summary of Capacity in the Township Electrification Program

Capacity Layer	Sub-Capacity	Level of Capacity
Tools	reliable hardware	low
Skills & Knowledge	end-user awareness of renewable energy	high
	end-user technical skills	low
	end-user energy management skills	low
	supply chain technical skills	high
	supply chain commercial skills	high
Organisational Structures	sustainable financial arrangements	low
	effectiveness	low
	flexibility	medium
Sectoral Networks	organisations along the supply chain	medium
	learning networks	low
	advocacy coalitions	high
Institutional Environment	long-term policy frameworks	high
	integrated planning	low
	alignment with values and norms	low
	favourable macro-economic environment	high
	policy learning processes	high

9 Discussion

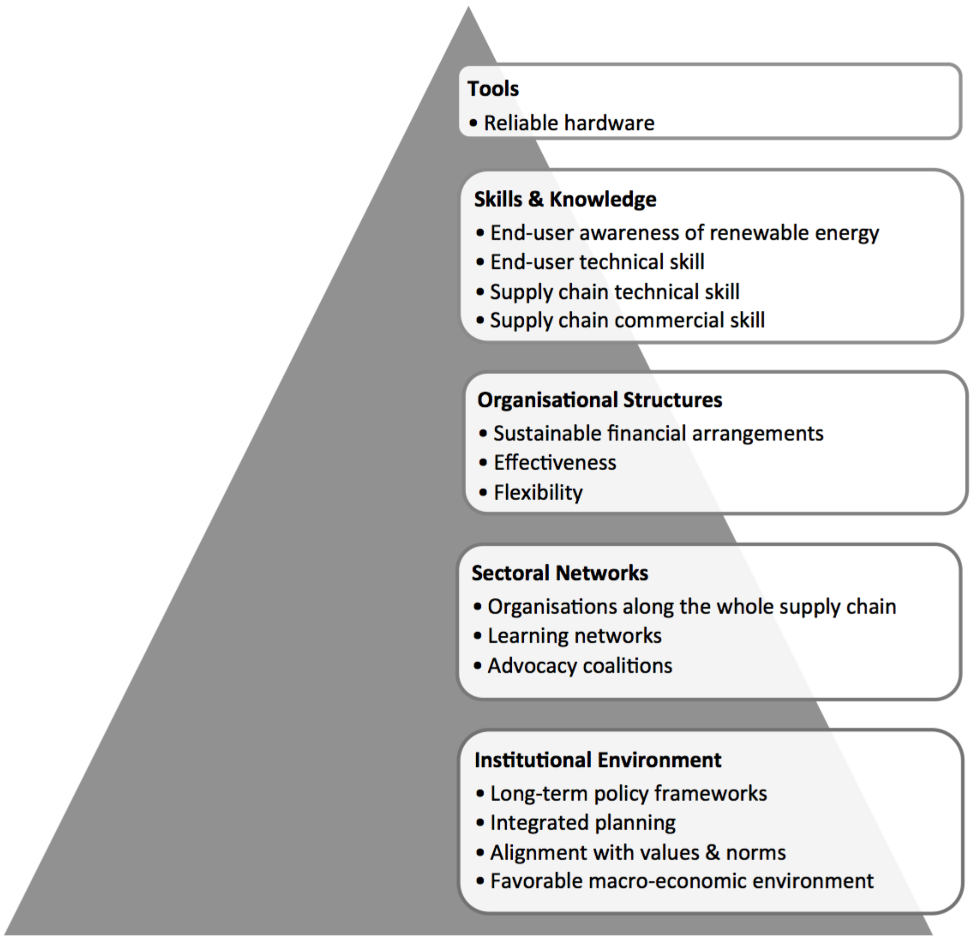
9.1 Introduction

This chapter syntheses the results from the three case studies using the Renewable Energy Capacity Pyramid framework presented in Chapter 4. Delivery of sustainable energy services in rural areas is a complex task, but it is possible to discern strategies for success. This chapter identifies useful strategies for developing each of the layers in the capacity pyramid. These layers are deeply interrelated, so this section will also discuss the ways in which they interact as capacity develops. Drawing upon this discussion, conclusions for the thesis will be presented in the next chapter. This thesis argues that access to sustainable energy services in rural areas is best analysed through the lens of a systems approach to capacity development. There are multiple, inter-related components to delivering energy services to rural communities. These include:

- robust tools,
- the skills and knowledge of individuals,
- local organisational structures,
- sectoral networks, and
- an enabling institutional environment.

These components are related to each other in a hierarchy (see Figure 9.1). In the renewable energy pyramid, an enabling institutional environment supports sectoral networks, sectoral networks support organisational structures and so on. However, the lower layers of the pyramid are not a prerequisites for the higher layers of the pyramid. All components of the Renewable Energy Capacity Pyramid are important for the delivery of sustainable energy services. The placement of the components do not indicate that there is an order of importance. Their placement in the Renewable Energy Capacity Pyramid indicates the level of complexity and the amount of time needed for that component to develop. Thus, an enabling institutional environment is the most complex and requires more time to develop. The discussion below will begin from the institutional environment of the Renewable Energy Capacity Pyramid as the institutional environment is broader and forms the foundation for other layers of capacity.

Figure 9.1: The Renewable Energy Capacity Pyramid



9.2 Institutional Environment

The foundation of the Renewable Energy Capacity Pyramid is an enabling institutional environment. It consists of the policies, plans, values, norms and macro-economic trajectory that allows sustainable energy services to thrive in rural areas. These components of the capacity pyramid are outlined in Table 9.1. Chapter 5 identified that the institutional environment in China was very favourable for renewable energy rural electrification. This section analyses the institutional environment presented in Chapter 5 and discusses how it operated in each case study.

Table 9.1: The Renewable Energy Capacity Pyramid: Institutional Environment

Capacity Layer	Components
Institutional Environment	long-term policy frameworks
	integrated planning
	alignment with values and norms
	favourable macro-economic environment
	policy learning processes

9.2.1 Long-term Policy Frameworks

Long-term, coherent policy frameworks that outline a specific role for renewable energy in national development plans are essential for the ongoing delivery of sustainable energy in rural areas. Without a long-term strategy and support, capacity for energy service delivery is likely to dissipate after a project ends. One of the most important elements for the development of capacity for renewable energy in IMAR was the sustained support from the provincial-level government. The goal of the IMAR renewable energy policy was no less than to "solve the problem of energy shortage in husbandry and remote area[s]" (Lin, 1999, p. 1130). In other words, the main strategy of the IMAR government was to use small wind turbines and PV systems in areas where extension of the electricity grid was uneconomical. This strategy was not unique to IMAR, as renewable energy has been a key element of China's rural energy strategy since the formation of the People's Republic in 1949. As mentioned in Chapter 5, China's high electrification rate can be attributed to the widespread use of micro-hydro systems in rural areas with large local investment, in parallel with expansion of the electricity grid. China also used biogas digesters and solar hot water heaters in many rural areas. This utilisation of renewable energy throughout China was well supported by science and technology policies.

By 2000, renewable energy rural electrification projects were a key element in China's development plans for the western region. This provided sustained multi-channel financial support from central and provincial-level governments. Both the Brightness Program and the Township Electrification Program made explicit links to regional development goals. The REDP and other initiatives from international organisations contributed to the development of renewable energy, under guidance from the Chinese government. This clear policy vision encouraged investment in renewable energy manufacturing and distribution networks and built up capacity that was available to successive projects. Thus, all three case studies contributed to and benefited from long-term policy frameworks supporting renewable energy electrification.

It is important to note that renewable energy policy frameworks, also affect the broader institutional environment. These include rural development; education; population; and science and technology domains. These interactions could be highly complex and further development of integrated planning and policy learning processes are needed in order to manage change holistically (these are discussed in the following sections).

9.2.2 Integrated Planning

Renewable energy projects must be well integrated with other plans in order to maximise their impact. These include plans in other non-energy sectors, overall energy plans, other rural electrification projects and other renewable energy projects (for example, see To et al., 2012).

The three case study projects were well integrated with central government plans for rural development and renewable energy as the projects all involved the macroeconomic planning agency, the NDRC. However, as discussed in Section 5.2.2, Chinese policy-making is characterised by "fragmented authoritarianism". That is, the implementation of policy made by the central government can be influenced by the agendas of vertical agencies and geographic regions as the policy is implemented. In operation, this means that decisions are made incrementally through bargaining to maintain consensus. High-level leadership is often required to overcome resistance from lower levels of bureaucracy and coordinate activities between different parties (Lieberthal and Oksenberg, 1988).

This tension between the need for policy coherence and a fragmented bureaucracy are apparent in the renewable energy policy space in China. The capacity for renewable energy in IMAR was established under the leadership of the provincial government from the 1980's onwards. In other words, the IMAR government exerted power horizontally (*kuai*) to coordinate renewable energy policy within the autonomous region. The Brightness Program, Township Electrification Program and the REDP were all managed by the NDRC (and its predecessors), which exerts its power vertically (*tiao*) through a corresponding agencies at each level of government. The same units and businesses established under the leadership of the provincial government (*kuai*) were utilised by the NDRC (*tiao*) in the implementation of the three case studies.

The resulting dynamic between the *tiao* and the *kuai* was different for each of the case study projects. The Brightness Program adopted a bottom-up approach, with pilot projects proposed by the provincial level governments. The IMAR Brightness Program project design was therefore well integrated with other IMAR renewable energy projects and the model was expanded after the end of the Brightness Program ended. The project was implemented by a subsidiary of the electricity utility company, and was also integrated with rural electrification plans.

The Township Electrification Program was administered by the National Reform and Development Commission using its own network of local Reform and Development Commissions and a national tendering process. This meant that the Township Electrification Program was well integrated with the rural development policies for western China of the central government, but was less well integrated with provincial-level plans. The IMAR government had previously focused on household renewable energy systems. The capacity for the larger systems used in the Township Electrification Program was limited in IMAR as it required a different set of technical skills that had not previously been developed. As a result, further financial support for the systems installed under the Township Electrification Program needed to come from the central government through the *tiao*.

The REDP stood apart from this dynamic between the *tiao* and *kuai* because it was implemented by a dedicated Project Management Office (as was common practice for World Bank projects) and because of its market-orientated stance. The approach was flexible as it allowed businesses in each province to design and market products that were most suitable for the area. The PV subsidy component of the REDP was largely subsumed under the dominant systems set up by the provincial government (*kuai*) as it utilised the businesses set up by the IMAR's renewable energy projects and served to strengthen these businesses. However, the project was not well integrated with other renewable energy projects in IMAR. The uptake of the REDP was limited due to the availability of higher subsidies from other projects in IMAR.

9.2.3 Alignment with Values and Norms

In addition to being well integrated with other plans, the project implementation approach needs to align with local values and norms. This is important because successful capacity development is an endogenous process based on locally driven agendas, and not driven by the values and norms of donors (Boyd, 2009; Bolger, 2000). The assumptions, approach and philosophy of the project greatly influence the outcomes of a project because it influences the project boundaries, structure and communications.

The Brightness Program pilot project built upon previous projects by using similar hardware, the same skilled and knowledgeable personnel and existing organisations to form Brightness companies. After the successful Brightness Program pilot project in a limited number of banners, the IMAR government scaled up the model to cover the entire autonomous region through the Inner Mongolia New Energy Electrification Program (2001 to 2005) and the Inner Mongolia Electrification Program (2007 onwards). This step-by-step approach can be described as Chinese pragmatism and is a feature of Chinese policy-making (discussed in Section 5.2.2 on page 77) and is partly the result of the fragmented authoritarian nature of the policy-making in China. Deng Xhaoping called this process "crossing the river by feeling the stones" (Saich, 2011, p. 268). Thus, the Brightness Program aligned with the values and norms for project implementation at the national and provincial level.

The REDP was driven by international organisations, but included deep involvement from the Chinese government's macroeconomic planning agency, the NDRC. The project design reflected the shared priorities of the World Bank, GEF and the NDRC for sustainable development. The market-oriented approach and the compliance measures taken by the project reflected the values, norms and project experience of the World Bank. The REDP was carefully designed with the flexibility to fit into the norms of each provinces.

The Township Electrification Program was implemented using a top-down approach driven by the NDRC. The project was well aligned with priorities, values and norms of the central government and elites (Shyu, 2010). The project addressed central government concerns for rising inequality and environmental degradation and was part of the "Opening Up the West" campaign to develop the western region. The project was implemented using the existing national tender system. This had the advantage of being able to implement the project at a large scale and great speed. However, the project was less well matched with implementation norms in IMAR which had previously focused on household renewable energy systems. The IMAR government had strong capacity and was able to make adjustments to the distribution of Township Electrification Program systems to match the changing needs of the townships.

The three projects demonstrate three possible positions with respect to international, national, provincial and local values and norms. It is important to consider who's values and norms are being privileged in a project. The experience in the case studies suggests that attention to local and provincial norms and values lead to greater long-term success, although alignment with national and international priorities are important for mobilising funds.

9.2.4 Favourable Macro-Economic Environment

During the time of the case studies, China had a very favourable macro-economic climate that provided stability, funding and inputs needed for the three case study projects.

Renewable energy projects require human security and stability in order to succeed. Conflicts can affect project logistics, destroy infrastructure and create a risk adverse situation that is not open to innovation. For example, armed conflict in Nepal created an insecure environment. Poorer villagers in this unstable environment were reluctant to take part in renewable energy projects because they feared that adopting new technology practices would place more strain on their difficult situation. In addition, villagers that had a more antagonistic relationship with armed insurgents wanted to avoid further harassment by avoiding associating with outsiders implementing renewable energy projects (McKay et al., 2007). No such difficulties arose in the three case study projects due to the relatively stable environment in China.

Strong economic growth in China meant that funds were available for renewable energy rural electrification projects, including the three case studies. Beginning in 1978, economic development policies that focused on key locations in eastern China have been very successful. As a trade-off for this investment in the eastern region, the central government had promised that investment in western China would follow. Policies, such as the campaign to "Open Up the West" and the Scientific Development Concept, signalled this shift of investment for social and economic development of the western region to address inequality and to ensure social stability. All three case studies were linked directly to these policies.

Renewable energy projects also require economic stability in order to succeed, especially where hardware and expertise need to be imported. In Indonesia, the Asian financial crisis in 1997 caused several ambitious renewable energy projects to fail due to dramatic devaluation of the Indonesian Rupiah against the US Dollar (Retnanestri, 2007, p. 30-31). The three case study projects were relatively protected from fluctuations in exchange rates because few of the hardware components and expertise were imported. However, the REDP was affected by the change in the exchange rate when the Chinese Yuan was pegged to a basket of currencies instead of the US Dollar in 2005. The REDP offered subsidies fixed in US Dollars, which were converted to Chinese Yuan before payment to participating companies. The increase in the value of the Chinese Yuan against the US Dollar was compensated for through an increase in subsidy level offered by the REDP. Appreciation of the local currency is unlikely to occur in less robust economies. However, the risk of large currency fluctuations should be assessed during the project planning stage.

The macro-economic environment can influence the availability of labour and financing for renewable energy organisations. For example, China's science and technology policies provided the educational infrastructure to train technical personnel. This provided the basis for skills and knowledge to be developed for renewable energy projects. Thus, the institutional environment layer of capacity is linked to the skills and knowledge layer.

9.2.5 Policy Learning Processes

Policy learning processes are important for ensuring the health of the renewable energy ecosystem and the long-term success of renewable energy projects. These processes "provide access to relevant stakeholders and room from various types of knowledge resources" (Breukers and Wolsink, 2007, p. 94). In particular, bringing all stakeholders together for knowledge sharing activities helps to improve renewable energy project design through improved understanding of the context for the project (Tukunga and Outhred, 2012).

Policy learning processes are facilitated by an environment of mutual trust and shared understanding between stakeholders; recognition of different types of knowledge resources; and meaningful involvement of all stakeholders in decision-making (Breukers and Wolsink, 2007, p. 94).

For renewable energy projects, this often takes the form of needs assessments, stakeholder consultations, monitoring and evaluations within the project cycle (for example see Wade, 2003; IEA-PVPS, 2003*b*). Participatory approaches are useful for including community members in project planning (for example, see To et al., 2006). In China, communities were not consulted directly. The reach of the Chinese bureaucracy assisted in the collection and dissemination of information. The Brightness Program and the Township Electrification Program relied on the network of township and county-level units to feed quantitative data up the command chain via the *tiao* or *kuai* to higher-level policy-makers. The distortion of statistics as they are fed up the chain due to various incentives for cadres are well documented (Chen, 2010), but the perception of government performance remains high relative to other governments at the same economic level (Saich, 2011, p. 145-148).

Policy learning processes over longer timeframes are also important because capacity takes a long time to develop and different interventions may be appropriate at different stages of capacity development (see Section 3.3.2 on page 40). One of the most important features of the experience in IMAR was that there was learning from one project to the next. The NDRC played an active role in all three case study projects and made efforts to transfer lessons from one project to the next. For example, scoping studies were undertaken for a Village Electrification Program that drew upon lessons learned from the Township Electrification Program. (Ma et al., 2007, 2006). It was also apparent that the NDRC and the IMAR government was deliberate in its sequencing of projects. They focused on pilot projects through the Brightness Program first before implementing the REDP and Township Electrification Program which had a much larger scale.

Also important is local ownership of project outcomes and the authority to make changes after the end of a project. The IMAR government had the capacity to make adjustments to the Township Electrification Program after the project ended. This contrasts with typical aid-funded projects where capacity disappears after the end of the project. Communities may abandon renewable energy systems if problems occur or if the systems no longer meet their needs. Communities may revert to energy technologies that they had used previously, for which a higher level of capacity exists. For example, some end-users installed secondhand household renewable energy systems when the Township Electrification Program mini-grids were not operating properly.

Sectoral Networks

A technological system can be defined as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology" (Carlsson and Stankiewicz, 1991, p. 93). Thus, a technological system consists of organisations, networks and institutions. A useful measure of the health of a technological system is its ability to fulfil the functions of an innovation system (discussed in Section 3.4.3 on page 50). A renewable energy sector with strong linkages between a network of organisations are needed for sustainable energy service delivery in rural areas. The components of capacity that are most important for renewable energy sectoral networks are summarised in Table 9.2.

Table 9.2: The Renewable Energy Capacity Pyramid: Sectoral Networks

Capacity Layer	Components
Sectoral Networks	organisations along the whole supply chain
	learning networks
	advocacy coalitions

9.2.6 Organisations along the Supply Chain

An important part of delivering sustainable energy services using renewable energy is building up a strong network of organisations along the supply chain. This includes component manufacturers, system integrators, retailers, and end-users. Long-term policy frameworks for renewable energy at the national and provincial level had allowed organisations along the renewable energy supply chain to flourish in IMAR. Many of these organisations emerged from government agencies involved in previous renewable energy projects. For example, the Brightness companies in IMAR emerged from renewable energy service stations involved in previous renewable energy subsidy projects. Favourable macro-economic circumstances in the previous decades had allowed the formation of these organisations. This meant that all of the organisations along the supply chain were already well established and formed strong relationships with each other before the three case study projects were implemented. The three case study projects were able to build upon this existing capacity and strengthen the network by providing new business opportunities.

Countries with less favourable institutional environments may struggle to form strong organisational structures along the supply chain. In addition, domestic manufacturing for all system components may not be suitable in some developing countries (Bruce, 2007). Not all organisations along the supply chain need to exist in-country, but strong linkages between organisations still need to be ensured.

A diversity of organisations are especially important in the formative stages of a technological system to maximise sources of innovation. These may then be consolidated into vertically integrated organisations at a later stage to take advantage of economies of scale (Freeman, 1991). In IMAR, vertical integration was beginning to occur as some system integrators also manufactured some of the system components for all three case study projects.

Project implementation agencies can contribute to capacity development at the sector level by becoming system facilitators that enhance the linkages between organisations. For example, the REDP linked system integrators with quality component suppliers. These linkages persisted beyond the project period as system integrators wanted to continue buying quality components. The contribution of renewable energy projects to the development of the sector could serve as a measure of project success.

Informal linkages can be important for sustained energy service provision after a project has ended. The case studies highlighted the importance of these informal linkages between end-users for learning. One of the main sources for information and assistance that end-users had for purchase and maintenance of renewable energy systems was other end-users. The informal network between end-users also facilitated a secondhand market for renewable energy systems. In IMAR, renewable energy systems were often sold directly between end-users, given as gifts or through local shops. The Brightness Program and the REDP systems were also traded in this way. This allowed the renewable energy systems to be reallocated when needs changed and allowed poorer households to access the renewable energy systems. Although some previous studies cover secondhand markets for renewable energy systems (for example, Acker and Kammen, 1996; Retnanestri, 2007), few project evaluations focus on informal linkages between end-users. Inclusion of end-users in discussion of supply chains is important for renewable energy in rural areas as they play an important role in operation and maintenance of the systems.

9.2.7 Learning Networks

Jacobsson and Bergek (2006) identified two types of networks that are important to fulfil system functions in developing countries. First, learning networks allow the transfer of tactic and explicit knowledge (knowledge diffusion through networks). Learning networks also influence expectations about the technology, perceptions about what is desirable, and guide investment decisions (guidance of the search).

Knowledge diffusion between organisations was facilitated by having the whole supply chain within China. For all three case studies, technicians could access training and support in Chinese at the system integrator's site. These interactions between organisations were important for developing products that were suitable for the context. In the Brightness Program and the REDP, the system design was refined through communication between the Brightness companies, system integrators and the project management office. This form of iteration during implementation is one way of determining the needs of end-users. The Township Electrification Program did not allow for this kind of interaction as the implementation timeframe was very short.

Community consultation has been acknowledged to be an important success factor in renewable energy projects in developing countries. However, it is sometimes difficult for end-users to articulate their preferences without first interacting with new technology. New technologies may first be interpreted using old cognitive categories. As people learn about the new technology through everyday usage, their beliefs and preferences may change (Geels, 2005, p. 44). In such cases, a process of iteration would be more productive.

9.2.8 Advocacy Coalitions

The second type of network is advocacy coalitions which seek to influence the political agenda (Jacobsson and Bergek, 2006) . Advocacy coalitions can have profound influences on R&D funding (guidance of the search), support policies (market formation), project funding (resource mobilisation) and create legitimacy for a technological system. Advocacy coalitions link the sectoral network layer of the capacity pyramid to the institutional environment layer by seeking to influence it.

In China, advocacy coalitions within the Communist Party of China and the government provided the initial guidance of the search, resource mobilisation and legitimacy for the renewable energy during the formative stages of the technology. Later, state-owned and private businesses involved in renewable energy in China formed an advocacy coalition in the form of an industry association as one of the outcomes of the REDP. This organisation has focused on providing strategic advice to the Chinese government at the national level, facilitating investment, and facilitating knowledge exchange within the industry.

9.3 Organisational Structures

Strong organisational structures at the local level are important for the reliability of renewable energy systems in rural areas. Taking an open systems approach, an organisation obtain inputs from its institutional environment, use the inputs to organise production, and produce outputs. Organisations need to be flexible and adapt to changes in the institutional environment, as well as produce outputs that are useful for stakeholders. This, in turn, allows the organisations to obtain inputs or resources. The institutional context provides incentives for organisations (Communities, 2005, p. 8). Thus, organisations are constantly interacting with their environment in complex ways. The components of capacity that are required in the organisational structures layer are summarised in Table 9.3.

Table 9.3: The Renewable Energy Capacity Pyramid: Organisational Structures

Capacity Layer	Components
Organisational Structures	sustainable financial arrangements
	effectiveness
	flexibility

9.3.1 Sustainable Financial Arrangements

One of the most important components of capacity in terms of organisational structure is sustainable financial arrangements. Financial arrangements are needed for the initial purchase of hardware, as well as ongoing operation and maintenance. It is also important for balancing cost and hardware quality. Thus, financial arrangements play an important role in determining the level of access to and the quality of the sustainable energy services provided.

The Brightness Program used a subsidised cash sales model where subsidies were given to end-users when they purchased a renewable energy system. The REDP provided subsidies to the system integrators to offset the cost of higher quality components and improved processes. This reduced the cost of systems for the end-users, so they received the subsidy indirectly. In IMAR, cash sales were viable because the majority of end-users were able to pay for systems upfront. Credit schemes can make renewable energy systems more accessible to poorer households. In IMAR, no credit was bundled with renewable energy systems. Poorer members of the community brought secondhand systems as a way to access sustainable energy services. This was possible through a high level of end-user skills and knowledge and informal linkages. Although the secondhand market in IMAR was informal, facilitating a secondhand market could be one way of reaching poorer households if a credit scheme is not a viable option.

The Township Electrification Program used a centralised government infrastructure provision model for financing the hardware. The project made use of multiple sources of government funding to fully subsidise the cost of purchasing and installing the hardware. End-users paid a tariff for the use of the electricity, but the tariff varied from province to province and was often insufficient for ongoing maintenance and repair of the system. This lack of financial arrangements for operation and maintenance meant that the systems were not maintained and repaired properly. The central government later remedied the problem.

Financial arrangements have been acknowledged as important for the the success of renewable energy projects in the literature, but the role of sustained financial support in capacity development has not been examined. Sustainable financial arrangements retain local skills and knowledge and maintain strong organisational structures. This forms an important link between organisational structures and skills and knowledge layers of capacity. Subsidised system sales under the Brightness Program pilot project and the REDP sustained a network of local companies that were able to install and repair household renewable energy systems. The Township Electrification Program systems were unable to access engineering expertise available in the capital city because of a lack of funding for operation and maintenance. In addition, the tariff collected was often tool low to pay for a system operator, so many left their posts.

9.3.2 Effectiveness

Trained personnel need to be supported by efficient and effective organisational structures in order to exercise their skills and knowledge. Effective organisational arrangements link learning activities with capacity development outcomes (Otoo et al., 2009). At the same time, individual learning is linked with organisational capacity (Johnson and Thomas, 2007). Potter and Brough (2004) highlighted several aspects of organisational capacity that relate to its effectiveness:

- Workload capacity: appropriate staffing at sufficient levels.
- Supervisory capacity: appropriate reporting and monitoring systems, clear lines of accountability and, effective incentives and sanctions.
- Facility capacity: appropriate and sufficient facilities for work to be carried out, e.g. workshops.
- Support service capacity: access to support services, e.g. administrative staff, research facilities, quality control services.
- Systems capacity: Timely and effective flow of information, money and managerial decisions, information management system, communication with community.
- Structural capacity: effective and accountable decision-making forums.
- Role capacity: authority and responsibilities clearly defined for individuals, teams and committees.

The local organisations involved in installing, operating and maintaining the Township Electrification Program systems in IMAR were the system integrators and the township government. Two system operators were employed by each township government and the system integrator provided a regular maintenance and repair service during the warranty period. Both these organisations had the capacity to execute their work effectively. However, the lack of ownership and financial arrangements after the guarantee period meant that there was no funding for services from system integration companies. There was no other form of technical support for system operators. Staffing for the system operator role was also problematic as tariff levels were insufficient and system operators often had to do other jobs part-time or left their posts. There were no arrangements for training new system operators if a system operator left. The Township Electrification Program case study emphasises the importance of including plans for ongoing funding to sustain organisational structures in the project design.

The Brightness Program included setting up strong organisational structures in the project design. Brightness companies sold, installed and repaired renewable energy systems within their local area. The REDP utilised the Brightness companies in each banner to distribute and service their products through the Brightness companies' association with system integration companies. The REDP strengthened organisational structures through management training and support for ISO9001 certification for system integration companies.

Both the Brightness Program and the REDP depended upon local companies to deliver energy services in each banner. The Brightness companies had a high level of existing capacity in terms of organisational structures because of their previous experience. This was strengthened by further investment and training. Future projects could consider strengthening existing local organisations in order to deliver energy services.

9.3.3 Flexibility

Training to improve skills and knowledge will have maximum impact if organisational structures are set up to support trained personnel efficiently and effectively. These organisational structures need to evolve over time and be resilient after the end of the project. Flexibility in organisations is also important to cope with financial disruptions. Most of the Brightness companies were able to cope with the end of the project by continuing sales and repairs of renewable energy systems, diversifying their product range and opting for more flexible staffing arrangements. This included retaining a few full-time staff and employing several others on a casual basis to cope with peaks in workload.

Organisational structures need to evolve with a changing institutional environment in order to remain relevant. In IMAR, the Brightness companies evolved from previous renewable energy work stations. The Brightness companies were jointly owned by the electricity utility (a state-owned enterprise) and business managers. This was in line with China's move towards a market economy. The skills and knowledge from previous projects were retained in this new organisational form which was able to participate in the market economy as well as future government projects.

9.4 Skills and Knowledge

Skilled and knowledgeable individuals are needed to install, operate, maintain and repair renewable energy systems in rural areas. Local skills and knowledge are especially important in rural areas as site access is often difficult. This means that repairs are often time consuming and expensive. The most important skills and knowledge for sustaining energy services in rural areas using renewable energy technologies are the skills and knowledge of end-users and local technicians. The components of capacity in the skills and knowledge layer are summarised in Table 9.4.

Table 9.4: The Renewable Energy Capacity Pyramid: Skills & Knowledge

Capacity Layer	Component
Skills & Knowledge	end-user awareness of renewable energy
	end-user technical skills
	end-user energy management skills
	supply chain technical skills
	supply chain commercial skills

In contrast to experience in other developing countries, end-users and local technicians in IMAR demonstrated a very high level of technical skill and knowledge for household renewable energy systems. In the Brightness Program and the REDP, end-users performed routine maintenance tasks, managed their energy use strategically and completed simple repairs. Some end-users were able to install their own renewable energy system. Local technicians in IMAR also demonstrated very high levels of technical skill and knowledge. For the Brightness Program and the REDP, local technicians based in each banner offered installation and repair services.

This high level of skills and knowledge for household renewable energy systems were built up over several successive projects. The skills and knowledge required for the Brightness Program were built up through previous projects by the IMAR government promoting household wind turbines and agricultural machinery. The REDP then relied on the skills and knowledge enhanced during the Brightness Program. Technicians had up to three decades of experience working for successive renewable energy projects.

Neither project emphasised end-user training, but end-users in IMAR had three decades of experience with household renewable energy systems, as well as basic literacy and numeracy skills. As discussed in Section 5.4.1 on page 89, IMAR has reached a medium level of development when compared with other provinces in China and is one of the richest provinces included in the Opening Up the West campaign. Communities IMAR has good outcomes in education, life expectancy and income when compared to communities in other developing countries. This means that end-users have a higher level of human capital which they can deploy to operate and maintain their renewable energy systems.

The Township Electrification Program did not have the advantage of end-users and local technicians with high levels of relevant skills and knowledge. Although a national training program for local system operators was established, no ongoing training was provided. The project relied on the skills and knowledge of engineers in the system integrator which was located in the capital city. The system integrator had built up its expertise by taking part in previous government and international cooperation projects using renewable energy. Access to this expertise was limited after the warranty period because sustainable financial arrangements were not made until 2007. This shows that systems are at risk of failure if skills and knowledge are not available locally. Therefore, it is vital that existing local skills and knowledge for end-users and technicians be assessed during project design. Realistic timetables for acquiring skills and knowledge should be set. After the skills and knowledge are acquired, they can be drawn upon to ensure good system performance and for implementing future projects.

Recent assessments of skills and knowledge required for the renewable energy sector (such as ILO, 2011) have focused on the supply chain, support services and policy-makers. The Brightness Program and REDP show that end-users can acquire advanced technical skills and knowledge. Project designers can consider advanced skills for end-users as a viable way of providing maintenance and repair for renewable energy systems if similar systems have been used by the community for many years and there is a sense of ownership of the systems by the end-user.

9.5 Tools

High quality and reliable hardware is important for sustainable energy delivery in rural areas. Renewable energy systems often operate in harsh conditions, in locations which are difficult to access should repairs be needed. Therefore, a key criteria for success is the reliability of hardware installed (see Table 9.5).

Table 9.5: The Renewable Energy Capacity Pyramid: Tools

Capacity Layer	Component
Tools	reliable hardware

9.5.1 Reliable Hardware

The Brightness Program specified component quality standards and also issued a standard system design. The REDP focused on improving quality along the supply chain which included specifying component quality standards. The performance of the hardware for both projects was similar to experiences with household renewable energy systems in other developing countries. The Township Electrification program used international and national standards for all system components. Systems for testing and certifying system components were set up for all three case studies. The Township Electrification Program also had a commissioning process for checking the hardware installed.

Many studies on renewable energy hardware reliability focus on quality standards. However, the case studies show that the ability for the hardware to be repaired locally can have a profound effect on reliability. One of the most important linkages in the capacity pyramid is the link between tools and skills and knowledge. Capacity development benefits from a consistent form of hardware because forms of hardware are linked with skills and knowledge. In IMAR, end-users and local technicians built up skills and knowledge for household renewable energy systems from previous government projects. The Brightness Program pilot project and the REDP used these familiar forms of renewable energy hardware, and thus made use of the existing local skills and knowledge. The Township Electrification Program used larger, more complex renewable energy systems. The hardware was less well understood by end-users and local technicians. Therefore, hardware design should be informed by the local availability of skills and knowledge for operation, maintenance and repair. If the new hardware is not analogous to other technologies in common use, more investment needs to be made on building up and retaining local skills and knowledge.

10 Conclusions

This thesis aimed to identify strategies that have been most successful in enabling access to sustainable energy services in rural areas of developing countries. A capacity development approach was adopted in order to build up a picture of the appropriate socio-technical configuration for supporting renewable energy in rural areas. The "Renewable Energy Capacity Pyramid" was developed from three empirical case studies in IMAR, China and comparing with existing capacity development and technological systems frameworks, against . The key findings of the thesis are captured in Sections 10.1 and 10.2. Section 10.1 first summarises the strategies identified using the Renewable Energy Capacity Pyramid from the discussion in the previous chapter. Section 10.2 then identifies broader success factors for enabling access to sustainable energy services in rural areas of developing countries. Contributions of the thesis to policy and theory are discussed in Sections 10.3. Finally, the limitations of the study and avenues for further research are discussed in Section 10.4.

10.1 Summary of Strategies for Capacity Development

This section will recap the strategies for renewable energy capacity development identified in this thesis using the renewable energy capacity development pyramid.

10.1.1 Institutional Environment

An enabling institutional environment is the foundation for developing capacity for renewable energy in rural areas of developing countries. Strategies for enabling access to sustainable energy services within the institutional environment layer of the capacity pyramid include:

- provide a clear policy vision and long-term policy frameworks that specify a role for renewable energy within national and provincial policy priorities,

- ensure that renewable energy projects complement each other and are integrated with planning in other sectors,
- prioritise local values and norms in project implementation,
- take macro-economic factors into account in project planning, and
- ensure access by all stakeholders to project planning and include lessons from previous projects into planning processes.

These strategies are long-term and can take several decades to realise. Many of these strategies are outside of the scope of any individual renewable energy project and intersect with discussions on governance and development. Thus, the policies that may have a profound influence on renewable energy may be the result of broader policy choices.

10.1.2 Sectoral Networks

A renewable energy sector with strong linkages between a network of organisations is needed for sustainable energy service delivery in rural areas. Strategies for enabling access to sustainable energy services within the sectoral networks layer of the capacity pyramid include:

- nurture the establishment and growth of local organisations along the supply chain for renewable energy,
- recognise formal and informal networks, including end-users, in project planning,
- encourage the diffusion of knowledge through formal and informal learning networks during project implementation, and
- strengthen advocacy coalitions for renewable energy within government and industry.

10.1.3 Organisational Structures

A lack of strong local organisations has been one of the biggest challenges for ensuring sustainable energy services in rural areas. Strategies for enhancing the organisational structures layer of the capacity pyramid include:

- establish sustainable financial arrangements for operation and maintenance of systems, and for maintaining skills, knowledge and organisational structures,
- boost effectiveness of existing organisations to deliver energy services through investment, training and certification, and
- allow flexibility in organisational structures to cope with changes in the institutional environment.

10.1.4 Skills and Knowledge

The skills and knowledge of individuals at the local level are required for sustainable energy access in rural areas. Strategies for enhancing the skills and knowledge layer of the capacity pyramid include:

- assess and realise the potential for end-users to gain technical skills in installing, operating and repairing their own renewable energy systems, as well as managing energy use, and
- assess and retain local technical and commercial skills

The case studies demonstrated that end-users and local technicians can gain a sophisticated understanding of renewable energy systems over a number of decades through using the technology, sharing knowledge informally and assisting each other. Formal training programs are only one component of the learning process.

10.1.5 Tools

Renewable energy systems often operate in harsh conditions, in locations which are difficult to access should repairs be needed. Strategies for enabling sustainable energy services for the tools layer of the capacity pyramid include:

- ensure high quality components and system designs through appropriate standards, certification and testing, and
- ensure that hardware design is locally repairable.

10.2 Success Factors for Renewable Energy in Rural Areas

The strategies for each layer of the capacity pyramid summarised in Section 10.1 must be deployed with reference to changing circumstances and the level of existing capacity. Not all strategies can or should be deployed at once. Capacity development for renewable energy is complex and multiple pathways to development exist. However, it is possible to discern broader patterns for success for enabling sustainable energy access in rural areas of developing countries. This section identifies these broader success factors.

10.2.1 Continuity and Sequencing

Continuity through all layers of capacity is vital for enabling sustainable energy access in developing countries. The Brightness Program and REDP case studies clearly demonstrate that success in capacity development results from building upon existing capacity through successive projects. The literature on technological change offers an insights into the underlying mechanics. Section 3.4 on page 43 outlined two views of technological change - the linear model of innovation and the systems perspective on technological change. Both approaches reinforce the need for continuity for capacity to develop.

The linear model of innovation suggests that technologies move through a life-cycle of emergence, growth, maturity and decline. The initial focus in IMAR was on research and development, then on pilot schemes, before ambitious renewable energy projects were implemented at a large scale. As a technology progresses through its life-cycle, the performance and adoption of the technology is slow at first, then accelerates and then declines over time. This variation in the rate of change over time can be described as an s-curve or mathematically as logistical function. This means that results will initially be slow during an era of ferment as different designs compete. Then adoption accelerates when one dominant design is selected and becomes the industry standard. After this, the industry focuses on incremental changes. This suggests that there is a ‘tipping point’ for capacity development for renewable energy after which adoption accelerates. Continuity of support up to that point is essential.

Continuity is also important from the end-users’ point of view. The s-curve also describes how renewable energy gradually diffuses in each community. Adoption is initially slow, (with innovators and early adopters) then accelerating as the majority of people adopting the technology, and finally slowing down as laggards also adopt the technology. Each household needs time to moves through Rogers' (1995) process of technology adoption - knowledge, persuasion, decision, implementation and confirmation. In developing countries, this is often influenced by the level of risk to their livelihood that adopting a new technology presents.

Positive feedbacks in the development of a technological system can create continuity. The systemic perspective on technological change suggests that small advantages gained at the beginning can lead to market dominance due to increasing returns to scale. These mechanisms include economies of scale, learning economies, adaptive expectations and network economies. These form positive feedback loops that reduce costs as production accelerates. These returns are reinforced by technological paradigms which guide incremental progress along technological trajectories. These mechanisms have traditionally been associated with the path dependence and technological 'lock-in' of fossil fuels. However, these same mechanisms can accelerate technology performance and adoption of renewable energy. In IMAR, household-scale renewable energy systems dominated energy service provision.

Different capacity development interventions may be more appropriate during different stages of the life-cycle. The renewable energy capacity pyramid developed in this thesis suggests that the layers of capacity support each other in a hierarchy. An enabling institutional environment allows a diversity of organisations to flourish and for organisations in the supply chain to form strong networks within the sector. Good sectoral networks strengthen organisational structures through learning and advocacy. Strong organisation structures help train and retain skilled and knowledgeable individuals. Skilled and knowledge are often linked to specific hardware. Local skills and knowledge and organisational structures can remain resilient through different projects and changes in the institutional environment.

This suggests that the foundations of an enabling institutional environment needs to be in place before interventions such as skills training can take full effect. Thus, case studies reinforce the validity of Kaplan's (1999) observation that capacity development benefits from proceeding from intangible to tangible elements. However, it may not be possible to include such broad, long-term goals in all renewable energy projects. In such cases, governments and international organisations need to plan for further projects in the context of a border capacity development programme for renewable energy that includes sectoral and institutional dimensions.

10.2.2 Incremental Approach

Section 10.2.1 highlighted the importance of continuity and sequencing of capacity development interventions. However, ensuring sustainable energy access in rural areas is highly complex and there are multiple pathways to achieving the goal. The case studies show that incremental approaches can be a very effective way of navigating through the complexity and uncertainty.

Baser and Morgan (2008) classified capacity development into planned, incremental and emergent approaches. Renewable energy in rural areas is often implemented using a planned approach, often in the form of projects funded by governments or donors. Projects have a fixed time period and consist of a number of stages that form the project cycle. These stages include country strategy, identification, preparation, approval, implementation and evaluation (for example, see Bank, 2010). The evaluation phase provides feedback for the next cycle of projects by providing input for the country strategy phase. Governments and donors often impose short timeframes on projects because of accountability and budgeting concerns. This may undermine capacity development because development of all layers of capacity requires time (especially in the institutional environment). Like many renewable energy projects, the Township Electrification Program failed to sustain delivery of energy services due to the limited timeframe and resources of the project. But further proposals were eventually developed to support the Township Electrification Program systems. This shows that centrally controlled planned approaches that make use of project management techniques are unsuitable for complex situations. However, planned approaches may be useful when there is flexibility to design further projects and where funding exists for support systems.

At the other end of the spectrum, emergent approaches have a high degree of flexibility. Emergent approaches do not identify specific goals, but create a protected space that allows capacity to grow from complex, often ad hoc, interactions between individuals and organisations. This protected space is created by participants agreeing on a set of rules for conduct, a common set of values and a collective identity. Emergent approaches fully acknowledge the complexity of the capacity development process. However, they are unsuitable on their own for renewable energy as there is often conflicting priorities, politicisation of the issue and objectives often need to be reached within a definite timeframe.

Incremental approaches sit between planned and emergent approaches and offer a practical way of combining formal project structure with the need for flexibility in implementation (Land et al., 2009, p.5). Incremental approaches do set overall objectives, but these can be adjusted as the project progresses. This incremental approach is also useful because it deals with the complexity of capacity development. Capacity development creates a new set of conditions that have to be taken into account, but cannot necessarily be predicted. This approach balances the long-term need for capacity development and donor needs for accountability and funding cycles. Lindblom (1959) describes decision-making in the policy arena as an incremental process of "successive limited comparisons" where policies are constantly revised by considering a limited set of new policies which differ marginally from current practice. The chain of previous policy choices shape and inform present policy choices. In IMAR, an incremental approach was used for the household-scale renewable energy. The Brightness Program was part of a series of government projects that built on the capacity established in previous projects. The REDP was also designed with flexibility to be implemented differently in each province and adjustments to the project were made during implementation. It should be noted that the Chinese government did not explicitly set out to develop capacity for renewable energy in rural areas. However, the Chinese pragmatic approach of "crossing the river by feeling the stones" and the fragmented authoritarian nature of its policy-making is inherently incremental.

10.2.3 Local, Provincial and National Levels

The renewable energy capacity pyramid takes into account multiple levels of capacity across different levels of human organisation - from individual to institutional. However, systemic capacity can also be divided according to different levels of geographical scale or administrative levels. That is, local, provincial and national levels. The case studies show that this geographic scale is also important.

Local capacity is the most important for energy service delivery and yet is the most difficult to develop due to geographical isolation. High levels of capacity at the local level can sustain energy services in the absence of projects and credit schemes through a secondhand market for renewable energy systems. Local entrepreneurial activity (whether it is based in the public or private sector) are vital stores of local skills and knowledge, as well as organisational structures. End-users are not only passive consumers of electricity, but make strategic decisions around household finances and energy use. Projects which aim to enhance local capacity should be seen in this context of active energy choices.

Leadership by the provincial-level government was crucial for capacity development in IMAR. Beginning in the 1980's, the IMAR government focused its rural electrification efforts on developing and implementing household-scale wind and solar technologies because they were the most economically viable option. The IMAR government provided sustained technical, financial and organisation support for these technologies. This provided the continuity needed for capacity for renewable energy to develop in IMAR.

Leadership at the national level is also vital for sustainable energy access in rural areas of developing countries. In China, renewable energy rural electrification was a central part of the rural development strategy for the western region. The central government implemented a number of major projects, including the three case studies in this thesis. High-level political support provided the leverage needed to implement the programme through a highly fragmented bureaucracy. Flexibility in program design for the Brightness Program and the REDP allowed these national initiatives to link with existing provincial and local capacity.

The case studies show that involvement and leadership by government agencies are vital. Strong leadership by provincial-level and national-level are important because they are in a unique position to create an enabling environment for renewable energy rural electrification to thrive. The case studies also show that governments have the resources to catalyse capacity development within their own borders. Inclusion of government agencies in capacity development activities and ownership of the process can sustain capacity development. Governments have long-term interests in electrification and are able to make adjustments in approach between projects (an incremental approach). Thus, an individual renewable energy project can be seen as a stage of capacity development and part of a suite of interventions that address each layer of the capacity pyramid. Experiences with renewable energy projects in other developing countries indicate that such a multi-pronged approach with engagement beyond the project period is useful (Mulugetta et al., 2000).

10.2.4 Resilience

Resilience or the ability to self-sustain in a constantly changing environment is central to capacity development (Ubels et al., 2010, p. 4). Resilience is an indication that high levels of capacity exist. Resilience is a property of every layer in the renewable energy capacity pyramid. Tools need to be robust and easily repairable to be reliable. Skills and knowledge need to be retained and updated. Organisational structures need to be flexible in order to adapt to changes in the institutional environment. Sectoral networks need a diverse range of organisations with strong linkages, learning networks and advocacy coalitions to create legitimacy. Stability and robust processes in the institutional environments allow sustained support for renewable energy.

One of the outstanding features from the case studies has been the resilience of skills and knowledge, as well organisational structures at the local level. Experience with capacity development in other contexts suggests that resilience emerges from informal, intangible aspects of a system. This can include an internal sense of mastery and confidence arising from past achievements, faith in leadership and expectations of external support based on legitimacy (Baser and Morgan, 2008, p. 66). In IMAR, many end-users and local technicians developed these qualities in their handling of household renewable energy systems.

Experience also suggests that organisational structures must have formal structures that can withstand stress and disruption (Baser and Morgan, 2008, p. 66). In IMAR, local organisations have been able to change structures, modify processes and diversify their business to cope with fluctuations in project funding.

Local resilience with regard to organisational structures, skills and knowledge have allowed energy services to be sustained beyond the implementation period of any one project in IMAR. End-users and technicians able to repair systems. A secondhand market has been established organically. These are clear demonstrations of local energy resilience.

10.3 Contributions of the Thesis

The main contribution of this thesis to sustainable energy in developing countries is the renewable energy capacity pyramid. The framework captures the lessons learned from three case studies in IMAR, as well as the literature on capacity development and technological change. This thesis is the first to use a systemic capacity development to sustainable energy service provision in rural areas. This thesis identified strategies for developing appropriate socio-technical configurations. In this thesis capacity development is not used as an instrument for overcoming barriers to renewable energy deployment. Instead, it provides an framework for analysing how renewable energy can contribute to sustainable development. The renewable energy capacity pyramid provides a useful way to evaluate existing capacity, design projects and evaluate renewable energy projects. More importantly, the framework and the case studies highlight the importance of an overall strategy for the development of sustainable energy technological systems in rural areas. The framework can therefore be used to engage stakeholders and guide the development of long-term roadmaps for renewable energy that span multiple projects.

The findings in this thesis have implications for further renewable energy deployment and manufacturing in China. China has continued to set ambitious goals for renewable energy development. The case studies in this thesis suggest that it would be advantageous to:

- continue high-level leadership support for renewable energy will be necessary,
- encourage capacity development at the provincial level with a focus on organisational structures, skills and knowledge and tools that are appropriate for local circumstances, and
- continue financial support for operation and maintenance of renewable energy systems from government funds where necessary.

The wider applicability of the renewable energy capacity pyramid to other developing countries will be discussed in Section 10.4 on the next page.

The Renewable Energy Capacity Pyramid developed in this thesis makes theoretical contributions to both the capacity development and the technology studies literature. In terms of the capacity development literature, the renewable energy capacity pyramid extends the work of Potter and Brough (2004) on the capacity pyramid. Potter and Brough's formulation of the capacity pyramid was rooted in their experience in the healthcare system, a relatively well established social institution. Their analysis therefore stopped at the organisational level and did not include institutional and sectoral factors. Technological systems around renewable energy systems in rural areas are less fixed. The renewable energy capacity pyramid makes additions to Potter and Brough's formulation by elaborating on the organisational, sectoral and institutional dimensions. This thesis provides further details on the ways in which the layers of capacity interlink and support each other. It also provides insight into the mechanisms that operate within each layer of capacity.

In terms of the technology studies literature, both the innovation systems literature the multi-level perspective make reference to the institutional environment in which technology operates. When applied in the context of a developing country, these approaches are limited by their lack of focus on the role of politics in technology transitions (Smits, 2011). The Renewable Energy Capacity Pyramid gives a more in-depth treatment of the policy, politics and institutional dynamics of instituting a technological system.

10.4 Limitations of the Study & Further Research

The Renewable Energy Capacity Pyramid developed in this thesis is grounded in empirical case studies in IMAR, China. There are substantial differences between China and other developing countries. For example, long-term cross-subsidies are considered appropriate in a socialist market economy (Clark II and Li, 2010), but may not be politically viable in other countries. In addition, other developing countries may not have the extraordinary flexibility in changing policies according to circumstances that the Chinese pragmatic outlook affords (Pye, 1986). However, the development of the framework was done with careful reference to existing literature summarising experience from other developing countries to ensure that it would be relevant in other situations. For example, the discussion on sectoral network acknowledges that domestic manufacture of all system components may not be appropriate for all developing countries.

No model for providing sustainable energy services can be directly transferred from one context to another. The systems approach to capacity development emphasises attention to existing indigenous capacity, rather than wholesale transfer of lessons from one country to another. The Renewable Energy Capacity Pyramid may be used as a prism for examining these differences and devising an appropriate course of action. Further case studies in other developing countries would be useful in highlighting different components of capacity in each layer.

This thesis has focused on sustainable energy services. However, the challenges of providing sustainable services to rural communities in developing countries is not unique to the energy domain. The capacity development approach and strategies discussed in this thesis is especially relevant for deploying other types of infrastructure in rural areas. For instance, further research could be done on applying and adapting the framework to to examine water, housing and road infrastructure.

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Appendix 1: Interview List

Interviewee	Date
Manager A	25-Sep-09
Manager B	9-Oct-09
Manager C	15-Oct-09
Manager D	19-Oct-09
Technician A	19-Oct-09
Official A	21-Oct-09
Manager D	21-Oct-09
Technician B	21-Oct-09
Manager D	22-Oct-09
Manager E	13-Oct-09
Manager F	28-Oct-09
Manager C	1-Nov-09
Manager G	7-Nov-09
Technician C	9-Nov-09
Technician D	9-Nov-09
Technician E	9-Nov-09
Manager A	23-Nov-09
Manager H	30-Nov-09
Project Designer C	3-Dec-09
Technician F	19 to 21-Oct-09
Engineer A	19 to 21-Oct-09
Project Designer B	24-Sep-09

Project Designer A	24-Sep-09
Manager I	12-Oct-09
Manager B	13-Oct-09
End-User A	19-Oct-09
End-User F	20-Oct-09
Operator A	20-Oct-09
Manager J	20-Oct-09
End-User C	20-Oct-09
End-User D	20-Oct-09
End-User B	20-Oct-09
End-User E	20-Oct-09
End-User G	21-Oct-09
End-User H	21-Oct-09
End-User I	21-Oct-09
Manager K	28-Oct-09
Manager I	3-Nov-09
Manager B	6-Nov-09
End-User J	7-Nov-09
End-User K	8-Nov-09
Project Designer A	26-Nov-09
Project Designer B	4-Dec-09

Appendix 2: Data Collection Questions

The following table guided semi-structured interviews, observations and document collection.

<table>
<tr><th colspan="3">PROJECT</th></tr>
<tr><th>Goals (Why?)</th><th>Renewable Energy Project Implementation (How?)</th><th>Outcomes (To What Effect?)</th></tr>
<tr><td>National, Provincial and Local Levels
• What were the nominal aims of the project?
• Which were the key policies directing the renewable energy project?
• Who were the main proponents of the project?
• Did these plans change? Why?
• When did each group of actors become aware of the project?
• What did each group of actors expect to result from the project?</td><td>Technical Aspects
• What was the technical design of the system?
• Who designed the renewable energy hardware?
• What design criteria did they use?
• How was the design criteria arrived at?
• What main end-uses were the systems designed for?
• How many of each type of system were installed/sold?
• What is the average lifetime of the batteries?
• Were there any hardware-based energy management systems?
Organisational Aspects
• How much did the systems cost? How much did the electricity cost? How did this compare to other energy service options? Did the end-users find it affordable?
• How were the systems financed?
• Who owned the renewable energy systems?
• How was the distribution or sale of</td><td>End Users
• Did the project meet end-user's expectations?
• What were the most significant changes for the end-users?
• How did the renewable energy project fit into the energy mix used in the village?
Renewable Energy Businesses
• Did the project change business operations or business areas?
• Did the number and size of renewable energy businesses increase or decrease?
• What was the effect of the project upon the business's profitability?
• Did changes in technique or technical innovations result from the project?
Project Facilitators
• How were the outcomes measured?
• Did the project meet expectations?
• What were the lessons learned?
Project Sponsors
• How were the outcomes measured?</td></tr>
</table>

<table>
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<td></td>
<td>renewable energy systems organised?

Who installed the systems?
Were new jobs created or jobs made redundant?
What measures were taken for quality assurance?
How did each of the actors learn about renewable energy systems? Did they receive training? How was knowledge shared?
How was maintenance, repair and spare parts organised during the project period?
Were there plans for post-project maintenance, repair and component replacement?
How was energy use managed?

Cultural Aspects

How was the implementation model designed?
Who was involved in the design of the implementation model?
What were the energy service needs of the end-users?
During what hours were the renewable energy systems used?
What end-uses did the renewable energy

</td>
<td>

Did the project meet expectations?
What were the lessons learned?

Local, Provincial and National Policy-Makers

How were the outcomes measured?
Did the project meet expectations?
What were the lessons learned?
Did the lessons learned impact on future decision-making, especially about renewable energy projects? How?

Changes to Renewable Energy Technological System

Did new actors emerge from the project?
Did the connections between different actors become stronger or weaker?
Did certain actors become stronger or weaker as a result of the project?
Did the technical, organisational and cultural aspects set up during the renewable energy project persist after it ended? Why/ why not?

</td>
</tr>
</table>

	systems support? • Did the end-uses change over time? • How did these changes affect the technical outcomes of the project? • What was the level of awareness about the role and limitations of renewable energy systems? • How was renewable energy technology perceived? • Did anyone modify the system outside of the design criteria after the system was installed? • Were any of the systems decomissioned? Why? Who was responsible for this? •	
INSTITUTIONAL ENVIRONMENT		
Formal • How does the Communist Party influence the objectives and implementation of renewable energy projects? • What geographical administrative divisions are used to formulate different levels of policies? • Is there coordination between	**Formal** • How did different actors try to accommodate for local conditions and institutions? Were they successful? • How does implementing a renewable energy project in an Autonomous Region differ from a Province? • How did the institutional environment affect	• Were there changes to the renewable energy technological system as a result of the project? • Did the project strengthen or weaken the insitutional support structure for the renewable energy technological system? • Where there changes to the formal and informal institutions which came into contact

<table>
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<td>
agencies on energy and renewable energy project planning?

How do sectoral policies affect renewable energy project plans?

Energy: power sector reform, renewable energy, rural electrification
health,
education,
rural development,
climate change

Are renewable energy projects integrated within sectoral policies? e.g. health, education, etc
What discourses do renewable energy project announcements appeal to? e.g. climate change, rural development, scientific development, etc.
How are renewable energy projects in remote areas seen in relation to renewable energy projects in urban areas and the development of a renewable energy industry?

Informal
</td>
<td>
the relative price of renewable energy-generated electricity?

Which institutions affect the operation of different types of enterprises? E.g. state-owned, private companies
Were there any major political changes in the area at the time? Did they affect the project?
When were contracts required? Were they enforced?
What other economic opportunities were available to the actors? Did they take them up?
What was the exisiting capacity for renewable energy program administration, system design, manufacture, entrepreneurship, maintenance and operation? E.g. local technical education, manufacture of other electronic devices, exisitng enterprises management expertise, availablity of capital, guanxi.

Informal

How was guanxi utilized?

</td>
<td>
with the renewable energy project? Was there a co-evolution?

How did perceptions about the roles and limitations of renewable energy technology change?

</td>
</tr>
</table>

• How do traditional governance structures influence renewable energy plans? • Who were the main proponents for the renewable energy project? • How did the main proponent try to align other agencies to achieve its goals?	• Where was trust required? • Did ethnicity, social hierachies, traditional governance and cultural practices affect the project? • How did gender impact on the technical design, organisational aspects and cultural aspects of the renewable energy project? • How did gender, culture, spiritual beliefs, daily routines, weather and geographical location impact on the end-uses of renewable energy systems? Did the introduction of renewable energy systems alter these? • What is considered to be progress or development for each of the actors involved?	

Appendix 3: Household Survey

The following survey was used to collect data while visiting households with renewable energy systems.

Household Renewable Energy System Survey

Household Background

House Number:	Occupation:
Number of people:	Number of sheep/income:
Ethnicity:	Interviewee (gender, age group):

Current System

Year installed	
Program How did you find out about it? Why did you get this new system? Has it met your expectations?	
Price	
Wind Capacity:	Repairs needed
PV Capacity:	
Battery Capacity: Voltage measurements: Year batteries were replaced: Cost of battery replacements:	
Inverter Capacity: Indicators:	
End uses	

Appliance	W	Time of Use

Availability At the time of the visit, there was an issue with the inverter overloading. During day: Seasonal:

Previous Systems

Year installed		
Program How did you find out about it?		
Price		
Wind Capacity:		Repairs needed
PV Capacity:		
Battery Capacity: Voltage: Year batteries were replaced: Cost of battery replacements:		
Inverter Capacity:		
End uses		
Appliance	W	Time of Use
Availability During day: Seasonal:		

Maintenance & Repair

1. Do you manage the energy use?

2. How did you learn about the technical aspects of the system? (e.g. initial training, from other end-users)

3. Do you do any maintenance?

4. Does anybody come to do regular maintenance?

5. Has the system needed any repairs or replacements? If yes, how did you arrange for it to be fixed? How long did it take? How much did it cost?

6. Did you make any changes to the system?

Other Electricity Sources

1. Energy sources before electricity?

2. Price of local grid electricity:
3. Other electricity sources:

4. Future expansion?