The politics of system innovation for emerging technologies:

Understanding the uptake of off-grid renewable electricity in rural Chile

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I hereby declare that this thesis has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

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Summary

Access to sustainable energy in the developing world has become a fundamental challenge in development and environmental policy in the 21st Century, and rural electrification in developing countries constitutes a central element of access to energy goals. However, traditional ways of providing electricity to dispersed rural populations (i.e. through centralised electricity infrastructure or fuel-based on-site generation) is proving to be ineffective, inefficient and less sustainable than the use of renewable energy technologies (RETs) in off-grid settings. Such 'system innovations' for sustainable electricity services in rural areas are the focus of this study, which seeks to understand the reasons underlying success or failure in the diffusion of radical innovations.

Embracing evolutionary and constructivist theories of socio-technical change and sustainability transitions, the thesis attempts to explain the use and diffusion of PV (photovoltaic) and wind technology in off-grid rural electrification over the last 20 years in Chile, a country where access to rural electricity has increased from 53% to 95%. RETs have contributed to nearly 10% of that increment. By using a framework that combines Strategic Niche Management (SNM), systemic intermediation and power, agency and conflicts in decision making, the thesis analyses the dynamics between the development and adaptation of new technologies and their influence in regime shift through replication, scaling up and translation of new socio-technical practices.

The thesis attempts to shed light on processes affecting niche construction and it concludes that internal niche processes are relevant to understanding how radical innovations are structured and stabilised from the aggregation of projects. However, those processes are not only a managerial activity that can be steered but a politically underpinned (and iterative) process between specific (socio-political) settings. The study also highlights the role of systemic intermediaries, government and incumbent actors in the dynamic interaction between emergent niche dynamics and traditional ways of improving electricity access.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AC: Alternating current

BIP: Project Integrated Data Base(*Banco Integrado de Proyectos*)

CBA: Cost-Benefit Analysis

CDEC: Economic Power Dispatch Centre (*Centro Económico de Despacho de Carga*)

CGE: General Electricity Company (*Compañía General de Electricidad Industrial*)

CLP: Chilean Peso

CNE: National Energy Commission

CONAFE: Electric Power National Corporation (*Compañía Nacional de Fuerza Eléctrica*)

CORE: Regional Council

CORE: Regional Council

CORFO: Chilean Industrial Development Agency (*Corporación de Fomento de la Producción*)

DC: Direct current

e7: Fund of the Global Sustainable Electricity Partnership

ENDESA: National Electricity Company (*Empresa Nacional de Electricidad*)

EP/PE: Rural Energisation Programme (*Programa de Energización Rural*)

FNDR: Regional Development National Fund (*Fondo Nacional de Desarrollo Regional*)

GDP: Gross Domestic Product

GEF: Global Environment Facility

GHG: Green House Gases

GORE: Regional Government

IADB: Inter American Development Bank

INDAP: National Institute for Agro-forestry Development (*Instituto Nacional de Desarrollo Agropecuario*)

IRR: Internal Rate of Return

KW/MW: Kilo watts / Mega watts

kWh: kilo watt hour

LAC: Latin America and the Caribbean

LCOE: Levelised costs of electricity

MDG: Millenium Development Goals

MIDEPLAN: Ministry of Planning (*Ministerio de Planificación y Cooperación*)

MLP: Multi Level Perspective

NGO: Non-Governmental Organisation

NPV: Net Present Value

NREL: National Renewable Energy Laboratory (USA)

PER: Rural Electrification Programme (*Programa de Electrificación Rural*)

PERyS: Rural and Social Access to Energy Programme (*Programa de Energización Rural y Social*)

PV: Photovoltaics

RET: Renewable Energy Technology

SAESA: Austral Electricity Company (*Sociedad Austral de Electricidad Sociedad Anónima*)

SAPCO: South American and Foreign Power Co.

SEC: Superintendence of Electricity and Fuels (*Superintendencia de Electricidad y Combustibles*)

SERPLAC: Regional Secretary for Planning

SHS: Solar Home System

SIC: Central Interconnected System (*Sistema Interconectado Central*)

SING: Great North Interconnected System (*Sistema Interconectado del Norte Grande*)

SNM: Strategic Niche Management

SUBDERE: Undersecretary of Regional Development (*Subsecretaría de Desarrollo Regional*)

UNDP: United Nations Development Programme

UP: Popular Unity Government (*Unidad Popular*)

US DoE: United States' Department of Energy

US: United States

UTER: Technical Unit for Rural Electrification (*Unidad Técnica de Electrificación Rural*)

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"The old world is dying away, and the new world struggles to come forth: now is the time of monsters."

Antonio Gramsci

1. Introduction

Access to modern and reliable energy services is a fundamental condition for development and, more crucially, for poverty reduction in the developing world (Modi et al., 2006, GNESD, 2007). Energy is central to determining not only the rate of development progress, but also the possible directions, or pathways, of development. Energy choices today involve extremely closely interrelated decisions about technologies, infrastructures and their underlying socio-economic practices and institutional contexts.

The mutual dependence and interaction between these different elements can define, for example, a trajectory of high or low carbon development, or an inclusive and cohesive society or highly unequal and segregated one. At best, development challenges in the decades to come will demand huge amounts of modern energy such as electricity, heating and transport fuels. It has been estimated that global energy needs will increase 40% by 2030, with a large share of the new demand coming from developing countries, whose carbon emissions would rise from 39% of total current GHG emissions to 52% by 2030 (WBCSD, 2009).

Alongside this prospect of increased energy demand to power development in the 21st Century, a global consensus - backed by robust scientific evidence - has emerged that climate change is produced by human activity (IPCC, 2014), notably through the production and consumption of energy. In fact, carbon emissions from fossil fuel combustion are the main cause of climate change. This adds an enormous pressure to the energy challenge: if a large proportion of the world's population which currently has no access to electricity is to perceive the benefits of the development process, there is an inescapable moral obligation to limit the environmental impact of increased energy provision by adopting and using low carbon energy technologies.

In Latin America and the Caribbean (LAC) more than 34 million people lack access to electricity, mainly in rural areas where the electrification rate (i.e. the proportion of the rural population able to use electricity service regardless of its reliability, cost and security) is around 70% (IEA, 2009b). Globally, it is estimated that there are more than 1.3 billion people without access to electricity (IEA, 2011). In this context, access to modern energy will continue to be a major challenge in coming decades. This embraces not only efforts to increase electrification rates, but also to improve quality of service and ensure sustainable, reliable and productive use of energy. To tackle these challenges a number of rural electrification policies, programmes and projects have been implemented in many countries of the LAC region and elsewhere.

Results have been unevenly distributed and efforts have focused primarily on the satisfaction of basic electrical needs (e.g. light and mobile phone charging) but have generally fallen short of supporting wider economically productive activities (UNDP, 2007). However, policy and practice in the field have been able to generate a political momentum, transforming in some ways the international policy context. A reflection of this momentum was the declaration of the year 2012 as the International Year of Sustainable Energy for All by the United Nations General Assembly and the launch of the global initiative on Sustainable Energy for All (UN, 2011).[1]

This general context defines the primary interest of this thesis: understanding the enormous challenge of reaching the rural poor with modern electricity. Rural electrification is a development enterprise that needs the deployment of huge social and technological capabilities. From a narrowly technical point of view, electricity provision in rural areas can be executed either through grid extension or off-grid systems. Grids are part of the centralised, integrated electricity system whose extension to rural areas constitutes the pervasive technological practice in most western countries; off-grid systems include either stand-alone electricity generation at the point of consumption (e.g. household, school, community centre, etc.) or small-scale power generation distributed locally through mini-grids (e.g. in remote villages).

Off-grid rural electrification can be done through fossil fuelled generators or through renewable energy technologies (RETs). In rural contexts renewable energy offers a huge potential for increasing access to energy and enhancing productive uses. Furthermore, RETs are particularly helpful in achieving development goals, particularly the Millennium

[1] See for example http://www.un.org/en/events/sustainableenergyforall/background.shtml; http://www.se4all.org/

Development Goals (MDGs)[2] (Modi et al., 2006, GNESD, 2007, UNDP, 2007, Cabraal et al., 2005).

This research focuses on off-grid RET rural electrification in Chile. This country increased the rural electrification access rate from 53% in 1992 to 96% in 2011, through the implementation of a national rural electrification programme (PER-'*Programa de Electrificación Rural*') (IEA, 2009a, Ministerio de Energía, 2012, Ministerio de Energía, 2010). While in the early years of the programme the greater part of this electrification progress was achieved via grid extension, the significance of off-grid RETs has increased from the year 2000 onwards and these have since contributed to nearly 10% of the total expansion of rural electrification over that period (Poch Ambiental, 2009). This thesis analyses two different types of projects: off-grid PV (photovoltaic) systems and wind-based mini-grids implemented within the framework of the rural electrification policy in Chile from 1994 to 2010.

These two case studies have been selected to reflect the variety of factors influencing the evolution of the dominant rural electrification practice[3] in Chile. Some of these have reinforced or provided greater stability to mainstream activity, while others have exerted destabilising pressures with respect to those dominant practices. Amongst these shifting forces the following are highlighted: liberalisation of electricity markets; development and adaptation of an institutional framework for rural electrification; technological and infrastructure developments in both conventional and new technologies; and the socio-economic and political imperative to embark on the challenge of the universal provision of modern electricity in rural areas.

Conversely, off-grid RET projects represent a space for variation and for experimentation with new sustainable technologies. RETs are considered a radical innovation because their development and diffusion involve fundamentally different socio-technical configurations, including alternative visions, rules, norms, knowledge, actors, and their related infrastructures and technologies. These emerging 'spaces', in which social and technological dynamics mutually interact, evolve and structure new rules, norms and practices, are referred to as

[2] The MDGs are the concrete translation of the Millennium Declaration agreed by the General Assembly of the United Nations in 2000 and adopted by its 189 member states.

[3] The dominant or pervasive way of 'doing things' is referred to as a socio-technical regime. This concept is further explored in chapter 2 – and is also used and conceptualised throughout the entire thesis. It generally reflects the dominant or incumbent 'socio-technical' practice or "patterns of artefacts, institutions, rules and norms assembled and maintained to perform economic and social activities" (p. 48) BERKHOUT, F., SMITH, A. & STIRLING, A. 2004. Socio-technological Regimes and Transition Contexts. *In:* ELZEN, B., GEELS, F. W. & GREEN, K. (eds.) *System innovation and the transition to sustainability: theory, evidence and policy.* Cheltenham: Edward Elgar.

protected spaces or 'niches' (Rip and Kemp, 1998)[4]. In the case of Chilean rural electrification, off-grid RET projects were initially implemented by organisations external to the rural electricity regime (e.g. NGOs, universities, aid organisations), but have been gradually integrated into the rural electrification policy and associated institutional framework. This process of integration has created the conditions for learning, network building and further technological development, all of which imply the emergence of a niche level of local practices in both small scale PV and wind technologies.

The main aims of this thesis are, therefore, **to understand i) how radical innovations are diffused (i.e. the determinants of niche creation, success and/or failure in widespread adoption of innovations) and ii) the extent to which these new technologies can bring about system (or regime) change**. To do so, this thesis uses the Strategic Niche Management (SNM) approach to transitions to sustainability, through the study of off-grid RET rural electrification in Chile. It explores the key issues of the SNM framework and examines whether it can explain the use and diffusion of RETs in the context of energy access in developing countries.

SNM thinking has been developed with the aim of understanding the role of protected spaces (i.e. socio-technical niches). These are spaces where experiments in sustainable innovation can be further developed in the controlled absence of pressures from the dominant set of rules and institutions around a socio-technical practice (i.e. the regime), such as energy use, housing, transport and so on (see for example Kemp et al., 1998, Hoogma et al., 2002, Kemp et al., 2001). SNM scholars have focused on internal processes that work at the niche level, which articulate dynamics that enhance transformation and adaptation of new technologies so they can be taken up by the market and perhaps lead to regime shift.

It has been suggested that these processes work more successfully when: a) expectations are shared by many actors and are based on tangible results; b) social networks are broad and deep and there is regular interaction between actors; and c) learning processes are both broad and reflexive (see amongst others Raven, 2005, Schot and Geels, 2008). These processes are considered in the context of systemic intermediation so as to permit understanding of niche development and transitions to sustainability (van Lente et al., 2003, Nahuis, 2011, Deuten, 2003).

Recent contributions to theory have highlighted how niches grow from the aggregation of local experiments (Geels and Raven, 2006, Schot and Geels, 2007), leading to the co-ordination and

[4] Niches are considered a protected space in which new technologies are developed in controlled absence of pressures from the dominant socio-technical configuration and practice. The niche concept is also further explored in chapter 2 and the rest of the thesis.

structuring of new rules, practices and configurations. However, the extent to which niche mechanisms allow for the replication, scaling up and translation of niche experiments into regime practice – that is, how niches and regimes are linked and interact dynamically – is not clear (Smith, 2007). The political nature of niche development and niche-regime interaction are thus analysed in this thesis through the lens of decision-making processes which empower actors in the political arena beyond purely managerial practice.

The analysis of how RET niches are created and in this process achieve increased levels of stabilisation and structuration of practices is important when viewed from within the niche. This will be further elaborated in the methodology section (chapter 3), together with the potential of niches to influence wider socio-technical practices and induce regime change, a question which will be examined so as to look at the contexts in which niches are developed and the tensions and power struggles that actors confront.

The empirical base of the study is the diffusion of PV and wind electrification projects in rural Chile. The study stretches from the early independent attempts to implement radical technology (RETs) in isolated and dispersed rural settings to the more coordinated and interrelated practices at various scales and sectors whose objective was to replicate, scale up and eventually translate the use of electricity services from RETs into mainstream practice. By analysing the two cases the thesis seeks to understand the conditions under which such projects become aggregated into niches and as a result might transform the rural electrification regime. In other words, the main objectives of this thesis are as follows:

1. To analyse diverse off-grid RET rural electrification projects from the perspective of SNM in order to contribute to (and critically appraise) this theoretical body by applying it to a developing country context.
2. To understand how off-grid RET niches are built up from the aggregation of individual projects and to analyse internal processes leading to the robustness and enhancement of socio-technical niches.
3. To investigate the mechanisms by which emergent niche dynamics (rules, institutional arrangements, actors' roles and relations, etc.) are translated into mainstream practice or influence the dominant socio-technical regime.

These objectives can be expressed conceptually with the following overarching **research question** that seeks an explanation for the development of off-grid renewable energy niches in rural electrification in Chile:

- **How has off-grid renewable electricity developed in rural Chile, and what factors have driven or constrained this process?**

They can also be expressed by means of the following sub-questions that look at particular empirical and theoretical challenges to understanding the diffusion, success or failure of these new technologies, together with the interaction between niche practices and the dominant (rural electrification) socio-technical regime:

- **How and why have rural off-grid PV and Wind electrification trajectories been different?**
- **To what extent can SNM theories help in understanding those differences and account for particular developing country contexts?**
- **What impact has the development of off-grid renewable energy niches had on the Chilean rural electrification regime?**

Several areas in which this thesis contributes to existing knowledge are anticipated. Firstly, by applying the SNM approach to study diffusion processes in off-grid RETs in Chile the thesis critically assesses the suitability of the framework to undertaking sustainability transitions research in developing country contexts. Most previous studies applying a common theoretical and methodological approach have been conducted in developed country contexts, and relatively little research has already been conducted in poorer countries in Asia and Africa. This is the first doctoral research (as far as I am aware) conducting energy transitions and SNM research in Latin America. Secondly, the thesis tackles an understudied area in transitions and niche-based research by complementing existing co-evolutionary insights with political-economy and agency perspectives so as to understand the problematic and conflict-laden nature of structural transformations of socio-technical niches and regimes. Finally, through a - as comprehensive as possible - investigation of PV and wind projects in rural electrification in Chile, the thesis documents, analyses and synthesises evidence of (successful and failed) access to energy with the aim of contributing to policy development and implementation in an area of increasing interest globally.

The thesis is structured as follows: chapter 2 presents a review of the relevant literature with respect to which the research is situated. Different possible theoretical approaches to understanding technological change processes are explored and the socio-technical transitions and SNM frameworks are selected due to their multidimensional and systematic treatment of the co-evolutionary dynamics affecting innovation processes. The thesis critically assesses the gaps that have been identified from a theoretical perspective in earlier studies and possible analytical options for their integration are proposed in this research. This chapter ends with a detailed re-statement of the overarching research question and sub-questions posited for the research.

Chapter 3 presents the methodology used in this thesis. First, an analytical strategy is developed, and then the conceptual framework and research design are outlined. Case studies are presented, their selection is justified and the methods, sources of data and analysis of the evidence are operationalised.

Chapter 4 offers an overview of the electricity sector in Chile, the evolution of the electrification process during most of the 20th Century and a detailed description of the main features of the rural electrification regime of the last 3 decades. Particular attention is paid to the rural electrification programme (PER) and the implementation of the GEF programme[5] aimed at reducing the barriers faced by off grid RETs in rural electrification in order to enable a market for these technologies in rural Chile.

Chapters 5 and 6 contain the results of the research presented as empirical accounts of the two case studies' findings. The PV case study is presented in chapter 5 whereas the evolution of the Wind niche is reported in chapter 6.

Following the analysis of the two cases, chapter 7 contains a cross-case discussion that synthesises the main findings of the research. The principal conclusions of the thesis are summarised in chapter 8 in a way that attempts to recapitulate the empirical, theoretical and policy implications of the thesis. The limitations of the thesis and suggested areas for further research are also discussed in that chapter.

[5] The GEF programme (Removal of Barriers to Renewable Energy Rural Electrification in Chile), was implemented in the framework of the PER from 2001 to 2010. It is described and contextualised in Chapter 4.

2. Theoretical Framework

2.1 Introduction to the chapter

This chapter presents the theoretical framework of the thesis. It starts with a brief rationale that compares different theoretical approaches that could be relevant for analysing the diffusion of RETs in rural electrification in Chile. This comparative analysis includes neo-classical economic approaches and a variety of evolutionary, constructivist and systemic theories of technological change. The discussion argues that the latter approaches are more appropriate to the study of the dynamics of technological development, adoption and diffusion, and that evolutionary and constructivist approaches are particularly useful in grasping the multiple dimensions affecting the mutual evolution or construction of technology and societies. In particular, it is argued that socio-technical transition theories are useful for analysing the dynamics of the use and diffusion of RETs in rural electrification in developing country contexts.

In subsequent sections of the chapter, socio-technical change theories and their foundational concepts are introduced and discussed (including the multi level perspective – MLP) before the strategic niche management (SNM) approach is introduced. This is presented as a powerful framework for understanding the purposive introduction and diffusion of radical innovations, such as PV and small-scale wind power installations in off-grid rural electrification.

A significant aspect of this thesis is its suggestion, based on an assessment of theoretical and analytical gaps identified in the literature, that SNM lacks an adequate consideration of conflicts, power struggles, agency and political considerations. Some additional ideas and theoretical contributions that might complement the model by addressing this challenge are therefore discussed. These include contributions from different perspectives to the sustainability transitions literature, which include –although might not be conclusive: a) recent literature about the geography of socio-technical transitions developed by a community of economic geographers and transition scholars (Truffer and Coenen, 2012, Raven et al., 2012, Coenen and Truffer, 2012, Lawhon and Murphy, 2012), b) literature about agency and power in transition processes and system intermediation (Avelino, 2011, Geels, 2014, Kivimaa, 2014), and c) a particular approach to the distribution of decision making as a way of considering the politics of niche development and its interaction with regime contexts (see for example Nahuis, 2011). Another, related, aspect of the challenges SNM faces is the still limited extent to which this analytical model has been used in developing countries. An important objective of this thesis is, then, to assess whether a refined SNM framework can be appropriate to studying socio-technical transitions and the diffusion of radical innovation in such contexts.

2.2 Rationale

Much technological innovation, notably the development and deployment of off-grid RETs, has taken place in rural electrification in developing countries over the last few decades as an alternative to the traditional approach of extending electricity grids towards remote and often isolated rural localities. Interest in such a technological alternative has gained support amongst policy-makers, NGOs and innovative firms because the high cost of implementing grid-based electric systems in remote and sparsely populated rural areas reduces their potential for granting access to electrification in such areas of developing countries (Byrne et al., 1998, Cabraal et al., 1996). With the aim of overcoming the perceived barriers to the provision of modern energy services in the low income rural areas of developing countries, a growing practitioner and academic research field has been devoted mainly to economic and technical aspects of RETs (see for example Watson et al., 2012). These include viability appraisals of electrification projects, studies of levelised costs of electricity (LCOE) and optimisation and modelling of renewable energy systems[6]. This tendency to focus on the economic and technical aspects of RETs has a normative motivation as the challenges of increasing access to modern energy services in rural areas of developing countries demand rapid action to meet development imperatives and, moreover, imply the deployment of limited resources, often locally unknown technologies and underdeveloped delivery and institutional models.

However, the scale and scope of these challenges involve a transformation that encompasses not only technology, finance, market development and institutional efforts on behalf of localised interventions. Accessing electricity in rural areas also involves strategic planning and action on the part of governments, the private sector, research institutions, NGOs and the communities themselves. This suggests the need to understand the diffusion of modern energy technologies, particularly RETs, as a dynamic process of mutual interaction in the construction and evolution of technologies, practices, rules, symbolic or cultural meanings, infrastructures, social relationships and interdependencies between actors and institutions[7]. In

[6] In the context of electrification solutions (as here), the term 'system' refers to the technological configurations of a collection of equipment and artefacts (generator, energy storage, distribution, etc.) and does not have any relation to system theory or systemic properties of any kind, as can be implied from 'system innovation' or 'socio-technical systems' also used in the chapter.

[7] In the literature several processes involving economic, social, institutional, technological and cognitive dimensions have been identified as mutually reinforcing dynamics that underlie development pathways. The thesis looks at the multiple interacting 'dimensions' of the 'socio-technical' set of practices, rules, agents and artefacts that define dominant or pervasive ways of doing things that society needs. See for

other words, increasing access to modern energy services implies profound changes in complex socio-technical systems. However, there is a lack of literature on RETs in rural developing country contexts that takes this wider socio-technical systems approach.

In traditional economic literature, technology is considered an exogenous variable in explaining economic development and growth. From this perspective, processes of technological progress, innovation and change are considered as residual, as external factors that explain other changes in the economic system when traditional production factors (e.g. labour, capital) are unable to give a response to the question of changes in productivity. Technology is considered as a 'black box' of tools which are independent of their societal context (Mazzucato, 2013). Evolutionary, institutional and constructivist theorists (amongst others) have commented critically on the limitations of the neo-classical approach for the study of innovation processes.

Alternative approaches to those of the standard (neo-classical) view in the study of economic growth and economic development have a strong, established and, nowadays, long tradition. These theoretical and analytical frameworks are embedded in multidisciplinary approaches and, as Lundvall (2005, p.4) clearly points out, have been developed with the aim of criticising the neglect of dynamic processes linked to innovation and learning. Most of the research in the field of the diffusion of technologies has, however, been carried out in the context of industrialisation and manufacturing processes and around the diffusion of commercial innovations, i.e., those products, processes and organisational structures that aim at improving competitiveness within a firm, a sector, in a region or even at a nation scale. This might raise doubts about its applicability to developing country contexts.

A number of seminal and influential works re-inaugurated a more systemic approach to the study of techno-economic processes and led a generation of scholars to seek to understand the economics of innovation processes, organisational structures, innovation systems and technological change (amongst others Freeman, 1982, Rogers, 2003, Utterback, 1987, Christensen, 1997, Lundvall, 1985). Their focus has been on products and consumer goods which can be introduced in existing or envisioned markets where (more or less) affluent consumers show willingness to buy these goods. Research in this area has made important

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example SMITH, A. 2007. Translating Sustainabilities between Green Niches and Socio-Technical Regimes. *Technology Analysis and Strategic Management,* 19**,** 427-450, RIP, A. & KEMP, R. 1998. Technological Change. *In:* RAYNER, S. & MALONE, L. (eds.) *Human Choice and Climate Change.* Washington D.C.: Batelle Press, GEELS, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy,* 31**,** 1257-1274.

progress in the understanding of disruptive or radical innovations, the iterative and systemic nature of innovation, the role of firms in how the diffusion of innovations takes place and the production processes and organisational arrangements within companies that drive innovative activity and growth.

These approaches, originating from evolutionary economics, include the innovation systems literature which has been developed over the last two to three decades as an alternative to neo-classical economic theories. In his review of systems of innovation, Edquist (2005) attributes the introduction of the concept of national systems of innovation to Christopher Freeman (1987) in his study of the Japanese economy. He defined it as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (p. 1). Lundvall (1992), Nelson (1993), Edquist (1997, 2005) and other scholars further refined the framework in the direction of understanding the determinants of innovation as an interactive learning process between actors and institutions.

Additional contributions to the approach have studied innovation systems at a regional scale (Cooke et al., 1997, Cooke et al., 1998), through sectoral approaches (Breschi and Malerba, 1997), or in technological systems (Carlsson, 1995). This conceptual framework emphasises the systemic nature of innovation and therefore elaborates on the components and relationships within those systems. The innovation system approach explains the success of innovative activity in terms of the systematic interaction and exchanges of knowledge, resources and capabilities of firms, policymakers and other institutions.

However, this conceptual framework assumes that effective innovation systems, including relevant policies and markets, need the existence of complexes of institutions, relationships and functions. In other words, the success of an innovation system is explained by the ability of existing actors and institutions with technological capacities to create such a system. This is not necessarily true in the case of radical innovations that might be needed and developed in contexts where the coordinated ability of actors could be lacking (Smith et al., 2013).

But how well can this approach steer public and private action when new technologies are still unarticulated, actors are not connected and have not developed institutional capacities? How can innovation systems develop in the face of the vested interest of powerful actors who do not share the goals of the underrepresented sectors of society? How can markets for new technologies be created in deprived contexts, where basic needs are underserved and therefore private initiative might be unwilling to invest in the context of uncertain returns?

Other authors giving an endogenous treatment to technology also consider that artefacts are embedded in systems that underpin their functionality, a 'configuration that works'. A system view, as distinct from 'innovation systems', integrates technical, social, economic and political aspects[8]. Hughes (1983) refers to large-scale technological systems, in which it is not only the artefacts which are important but also the skills and knowledge necessary to develop, maintain and operate them. Concepts such as *hardware* and *software* arise as crucial in understanding the functionality of technological systems. There are also institutional arrangements and social elements which interact with the technological process, which are referred to as *orgware* or *socioware* (Dobrov, 1979, IIASA, 2007). This mutual co-evolution between technology and the wider social contexts in which technologies are developed and adopted is normally referred as a 'seamless web' (Hughes, 1987). Using similar lines of argument, socio-constructivist approaches, stemming from the sociology of scientific knowledge, deny technological determinism and emphasise the social shaping of technology in the following way. They argue that a technology will have different meanings for different groups, something which they define as its 'interpretive flexibility', in which negotiation between 'relevant social groups' defines the problems of technological development (Pinch and Bijker, 1987). In particular, they think that when a problem is considered as solved (by the social groups involved in defining the problem and designing and using the technology), the technology becomes stabilized, and a 'closure' then occurs.

The systems of innovation perspective acknowledges that "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations" (Edquist, 1997, p.17) have to be included in an innovation system when explaining technological change; some scholars, however, argue about the importance of discriminating between what is included in the system and what has to be considered beyond its boundaries as external factors which are difficult to account for (Edquist, 2005). There are analytical differences as well. Lundvall (2005), for instance, makes clear his view about the usefulness of differentiating between the technical and the organisational nature of change. He refers to innovation as "discontinuities in the technical characteristics of hardware and software" (p.9). By contrast, he sees changes in the organizational structure and relationships of actors as factors which determine the impact of innovation on the economic performance of a system, not as innovation in itself.

[8] A system perspective is referred to as that which analytically and theoretically integrates many dimensions and relationships between parts of that 'system' and not to the more normative characteristics of systems of innovations.

Progress has been made in the systemic and multidisciplinary approaches to the study of innovation, which have also developed from the literature of sociology of science, history of technology and evolutionary economics. These theories of technological change, which also take an evolutionary perspective, encompass techno-economic and institutional aspects and more socially embedded considerations of technological change. The socio-technical context in which new technologies construct their functionality has several dimensions, including societal visions and goals that imply that such system transformations become a *transition* process in which sustainability is nowadays at the centre (see for example Rip, 1992, Schot, 1998, Schot, 1992, Rip and Kemp, 1998, Geels, 2002 for this approach). Insights from these fields contribute to understanding how socio-technical transitions occur and how such structural system transformations towards sustainability might be driven or influenced.

Long term empirical analysis of transitions has mainly been conducted in developed country contexts with a focus on transport, energy and food systems. An emerging area in this field has been a focus on empirical research in developing countries, with particular interest in South East Asia and Africa, but to a lesser extent in Latin American contexts (see for example Rehman et al., 2010, Verbong et al., 2010, Romijn et al., 2010, Drinkwaard et al., 2010). A detailed description of these studies is included in section 2.8.

Evolutionary approaches to technological change also deny linear and progressive views of technological development and are particularly suited to understanding the dynamics underlying the management of such change process (Rip and Kemp, 1998). Evolutionary scholars introduce the concepts of technological regimes and landscapes, arguing that technology evolves against a backdrop of systems or *socio-technical regimes*, i.e. that technology is located in and linked to its environment (e.g. actors, institutions, social practices, etc.). In identifying and understanding the possible trajectories of technological change, evolutionary scholars assume that there has to be some degree of inflexibility in a technology. This is because there are interdependences within the systems and existing capabilities induce certain directions of change while technological performance generates stability and reduces uncertainty in technological development, adoption and use (Rip and Kemp, 1998).

Building upon these perspectives, this thesis is concerned with analysing those change processes that affect the results of innovative activity. This research is not an assessment of impact and the focus is not on the artefacts themselves (RETs for rural electrification), but on the dynamics that explain their use and diffusion within particular contexts in the rural areas of developing countries. In the thesis it is argued that poor rural contexts in developing countries need special treatment and that it might not be possible to automatically translate and apply lessons from diffusion studies carried out elsewhere in order to inform policy and practice. In this sense, (small scale) off-grid RET can be defined as non-commercial innovations, developed, diffused and used beyond a particular firm's capacities. Their diffusion processes deserve specific attention within innovation studies.

Having reviewed different perspectives on the diffusion of innovations, and on the basis of the reasons given in this section, the transitions to sustainability theoretical perspective is proposed as a comprehensive starting point. It is the one which is favoured in the thesis over traditional perspectives in innovation studies. In the thesis it is considered that this framework is adequate in part because evolutionary approaches are also useful in understanding technological change management, a process that has developed with the purposeful introduction of RETs in rural electrification in Chile over the last 15 years. In the next section particular approaches which investigate the dynamics of technological change, the evolution of academic insights over the last two to three decades and particularly the progress and gaps in the *Strategic Niche Management* approach are further explore, from its analytical and policy perspectives.

2.3 General Discussion of Socio-Technical Change

The approach to technological change presented in this section consists of a quasi-evolutionary process of interactions at different levels (Rip, 1992, Schot, 1998, Schot, 1992, Rip and Kemp, 1998, Geels, 2002). The term 'quasi' refers to a distinction between (socio-technical) evolutionary perspectives and 'pure' biological evolutionary approaches. Specifically, change processes develop in the interplay between a broad set of actors and institutions using and exchanging information and knowledge, beyond the individual firm. These processes have a dynamic nature that has to be taken into account and in which the treatment of technology is considered as endogenous (Raven, 2005, based on Duysters, 1995). The most commonly shared understanding of technological change in evolutionary approaches is that proposed by Kemp, Rip and Schot (2001) in which they developed the idea of niche management: "a path dependent cumulative process in which the existing body of knowledge, techniques and tools determine which further steps can be taken at any time" (p. 271). They used this definition to link technology with society in order to understand their interactions and the possibilities for change. This social embedding notion of technological change will be explored in greater depth after analysing some fundamental mechanisms affecting the evolution of technological systems.

In the early development of these approaches, technological change was thought to be much more a function of technology development. By the end of the 1970s Nelson and Winter (1977, 1982) had developed the idea of technological regime within the framework of the problem solving activities of engineers and, then, Dosi (1982) used the term technological paradigm to understand, from the perspective of technological and engineering approaches, possible directions of technological change

As a parallel to biological evolution, evolutionary theories of technological change assign a crucial importance to the mechanisms of *variation*, *selection* and *retention*. Within such theories, it is possible to distinguish between variation, selection and retention *environments*. In a variation environment, technological designs are created. That is to say that in purely evolutionary terms, technological variation is understood as a random search for new designs. A more refined, quasi-evolutionary approach, however, considers that technological variation is rather channelled or influenced by what is expected in a selection environment, or in other words, by what problems are addressed by particular technological variations, the types of designs preferred by technology users that are also improved by technology designers (e.g. scientists, engineers or designer working in a R&D department of a firm). Thus, the selection environment gives direction to the search for such creators of variety. As Schot and Geels (2007) suggest, early developments in evolutionary understandings of technological change paid particular attention to the force of markets (and their underlying policies and regulations) as determinants of selection criteria (economic and regulatory factors).

However, two important caveats are worth highlighting. First, selection is influenced by a broader set of factors. Technologies are not only taken up in the market place; there may well be cultural, ideological and political or institutional requirements for particular technological options. In this way, the selection of technological designs depends on multiple criteria embedded in society at large – something which will be explored later. Secondly, variation is not necessarily a blind, random search. In quasi-evolutionary terms, not only can variation influence selection, but selection can also define the directions of search. Selection environments can be shaped by technology actors, who are also able to anticipate the requirements of the selection environment (Schot and Geels, 2008). The definition and organisation of pilot projects or R&D programmes are examples of how variation and selection mutually interact and shape each other.

When technological designs are repeatedly selected, they become increasingly stabilised. Designs are then subject to improvements, not only in the process of iterative interaction between variation and selection, but also due to the reduced uncertainty achieved through retention. Amongst the mechanisms affecting this repeated selection, routines are considered particularly important. Routines comprise search heuristics, feedback from normal ways of doing things or rules of thumb giving direction to those searches and therefore influencing certain patterns of technological change (Raven, 2005, p.26). Shared routines within communities of engineers and across firms that imitate designs from other firms was the starting point for the definition of technological paradigms (Dosi, 1982) or regimes (Nelson and Winter, 1982). These referred to "normal problem solving activity" (Dosi, 1982, p.152) or "technicians' beliefs about what is feasible or at least worth attempting" (Nelson and Winter, 1982, p.258). The ability of such perspectives to explain possible directions of change and the constraining factors of users' preferences was limited by putting too much emphasis on the role of technicians and engineers and the firms they work for, on the one hand, and the fact that government regulation or policy were still seen as exogenous variables, on the other.

Advances in the theoretical study of technology and society in the last two decades, mainly undertaken by a second generation of scholars who are also concerned with sustainability, take into account a deeper consideration of the mutual interplay of economic, institutional, cultural, social and other factors alongside with technology. The stability and rigidity of the dominant way of using and producing technology are the result of several mechanisms through which lock-in and path dependence are established (Arthur, 1989, Arthur, 1994, Unruh, 2002, Unruh, 2000), and which are thought to act in different dimensions: institutional (laws, regulations, finance), social (actors, networks, culture) and technological (artefacts, production processes, infrastructure) (see for example Geels, 2005, Raven and Geels, 2010).

The approach developed by Nelson, Winter and Dosi, which is also oriented towards the stabilisation of the regimes, focused primarily on the routines embedded in technological firms (i.e. engineering interpretations of problems and possible solutions) and tended to understand innovations as primarily the products of the mindsets of engineers. However, one fundamental criticism of that earlier approach is that retention mechanisms are embedded in a broader set of rules, not only in beliefs and the problem solving activity of engineers, which constitutes a cognitive framework against which technology evolves.

Rip and Kemp (1998) reinterpreted the regime concept as a set of rules, the context of a technology more embedded in social practices. They refer to technological regimes as "the grammar or rule-set embedded in a complex of engineering practices, production process technology, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, way of defining problems –all of them embedded in institutions and infrastructures" (p. 338). They, and other scholars (see for example Kemp et al., 1998, Kemp,

1994) refer to rules both as requirements or orders and also as roles and practices. Once established, such rules are not easily transformed. The regime is considered a semi-coherent complex of practices because it contains a number of dimensions (markets, policies, technologies and infrastructures, cultural meanings, users and producers, and so on) which do not necessarily align themselves automatically. In a regime, rules guide, but do not prescribe, directions of change. The rules include the normal search activities of engineers, and also market structures or the rules of the space in which a variety of factors interact: companies, government regulation incentives or other rules defined by policy, rules defined by finance institutions, and requirements or needs defined by interaction with the users of a particular technology.

Following Scott (1995), Geels (2004) and Raven (2005) both stress that rules do not have only a cultural-cognitive dimension (i.e. beliefs, problem agendas, search heuristics) but also regulative and normative dimensions. Regulative rules are formal or explicit ways of regulating interactions between actors, institutions and organisations (laws, standards, protocols and so on). Normative rules are shared values, moral norms, responsibilities and rights that guide social behaviour.

This broader consideration of a multi-dimensional character of rules seems to better embed technological trajectories into the context within which they develop. Geels (2004, p. 905) introduced the concept of “socio-technical regime” to emphasise the dynamic interaction of various social groups in the definition of the rules that guide technological development and change. Rules are subject to negotiation and change because they are reproduced by social groups. The same is true of socio-technical regimes: rules are aligned in a socio-technical regime and comprise different dimensions or sub-regimes (technological, policy, science, markets, socio-cultural). This alignment process evolves in certain patterns or trajectories that become dominant and more stable. In other words, a socio-technical regime represents the dominant way of fulfilling social needs, such as electricity, mobility or housing (Geels, 2002, Rip and Kemp, 1998). Some regimes can change completely; some new regimes can arise as opportunities are developed for social needs to evolve. These trajectories of change are the concern of the socio-technical transitions literature.

Socio-technical transition scholars have taken a further step in the understanding of innovation diffusion processes (and the subsequent changes at regime level) beyond the scope of the firm and the interaction of actors in market contexts. These of course are influenced by existing knowledge and science bases, government policy and regulation, users’ practices, existing technologies and infrastructure and socio-cultural and cognitive dimensions as well.

Socio-technical transitions refer to structural changes in the way of fulfilling societal needs, against a backdrop of societal goals such as sustainability imperatives. Such transitions are inherently long term multi-dimensional transformations of socio-technical systems.

An additional criticism of earlier approaches to technological change and the diffusion of innovations is the tendency to study changes of an incremental nature, whereas the specific dynamics of more radical technologies and practices (radical innovations and radical regime changes in a broader sense) is left without any definite tools of analysis. How do completely different ways of doing things come about? How could radical innovations which do not have a clear market value or that are unlikely to yield benefits in the short term be selected and then retained by a new radical regime?

These perceived shortcomings of the quasi-evolutionary theory of technological change thus led to its refinement, initially by Dutch scholars in the 1990s and early 2000s, and then by an expanding network of academics and policy actors (see for example Kemp et al., 1998, Geels, 2002, Rip and Kemp, 1998, Kemp, 1994, Schot, 1998). The resulting multi level perspective (MLP) on socio-technical change locates sustainable innovation journeys within a wider context (Geels, 2002). From this perspective, regime shifts happen due to the alignment of processes and mutual interaction at multiple levels whose contextualisation has to be accounted for. Multiple levels are conceived as a nested hierarchy in the sense that that each level is embedded in the subsequent level (Geels, 2002). As a nested hierarchy, the MLP integrates evolutionary and constructivist views of the possible shaping of technological systems, but emphasises that actors are unable to move freely in the construction of meaning (of technologies) as they have little room to modify exogenous factors from the standpoint of local practices.

Landscapes are conceptualised as background factors and thus create the external structure within which regimes change and novelties evolve. As an external factor (or the social context of a technological system), the landscape constitutes the exogenous factors of both material and immaterial nature, which limit the diversity of possible directions of technological change. Landscapes are defined by existing infrastructures, the available stock of natural resources, macro-economic tendencies, political-economy cultures, overarching values and lifestyles, and so on (Geels and Kemp, 2000, cited in Raven, 2005).

Regimes have already been covered in this review of evolutionary approaches. Here, their analysis is taken a little further in the context of discussing the MLP. Regimes constitute the dominant socio-technical system (i.e. the set of rules and institutions enabling or constraining the choices and practices of actors and their embedded technical systems). Regimes are defined by their structure and stability but they also have to be understood in a dynamic sense. Rules, practices and institutions are subject to adaptation and change. Most changes in a regime are of an incremental nature, but pressures (both external and internal) can destabilise and modify structures which determine the way of doing things. Retention occurs in regimes, but this process is "an interpretive, negotiated and contested process of institutionalisation" (Geels, 2010, p.504). Depending on the size and scope of those pressures, and the subsequent windows of opportunity opened for new alternatives, innovations in a regime can be either incremental or radical. As actors in the regime have vested interests, most radical innovations are likely to originate from outside the regime. This is a very important contribution to the quasi-evolutionary model of socio-technical change, because it incorporates the understanding of radical changes in regimes.

The MLP considers that radical innovations are developed in contexts which grant them relative temporary protection from the selection mechanisms of the regime. Local practices and actors are connected and new technologies and related social practices emerge; as these are structured, an increasing level of stability is achieved in a protected interaction with the rules from the regime. Technological variation can appear in niches because distinct selection mechanisms are applied to niche development. In this sense, niches are situated between the selection and variation environments. Niches are conceptualised in the MLP as socio-technical, because experimentation with new technology occurs in social contexts, in real life situations where artefacts are tested, used, adapted and adopted by actors in relative isolation from mainstream rules, although in interaction with regimes and the social context of the technology. This thesis looks specifically at socio-technical niches in an attempt to understand how RETs for rural electrification emerge. In subsequent sections - in which the Strategic Niche Management approach is explored - the conceptualisation of niches, the roles played by niche actors, the mutual interaction between niches and regimes and the processes leading to the structuration of rules in the diffusion of RETs in rural contexts will be expanded.

Figure 1 shows the multiple levels in the MLP graphically. As Raven (2005, p.33) points out, the key insight from this perspective in explaining technological change is that the direction and outcomes of change processes occur in the interplay between levels. Individual level dynamics are unable to induce change in technological systems; it is the linkages between levels that are the main change-orienting factors. The nested hierarchy of the levels in the MLP implies that regimes are embedded in landscapes, so trends in landscape pressures (relative availability of particular natural resources, environmental concerns, and political-economy principles) guide directions of change and can modify the rules of the regime. In the same way, pressures on regime structure and (in)stability can create opportunities for the development of new practices and technologies in socio-technical niches which in turn influence changes in the regime. Mutual dynamics between levels can therefore explain socio-technological change trajectories.

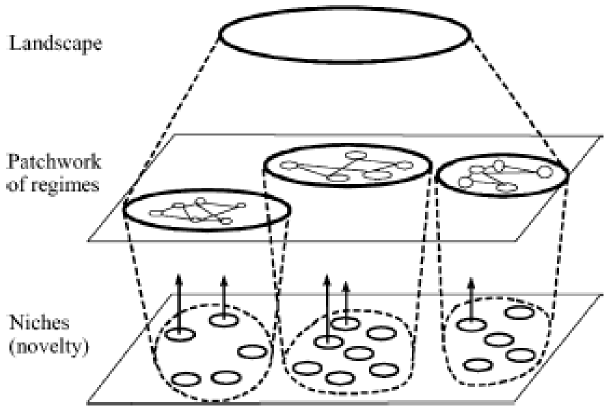

Figure 2-1: Multiple levels as a nested hierarchy (Geels, 2002, p. 1261)**.**

2.4 Managing the emergence of new technologies: the Strategic Niche Management Approach

The foregoing discussion has highlighted how a quasi-evolutionary approach to socio-technical change has developed by considering insights from different disciplines and schools of thought. The main aim of the approach is to understand how socio-technical transitions come about. Its analytical strength is that it places socio-technical trajectories within a co-evolution of multiple dimensions constituting technological systems in which mutual interactions at different levels modulate directions and outcomes of change processes.

In this context, a key question is whether this co-evolution of socio-technical trajectories can be steered and, if so, how this can be done. Addressing this question adds a normative component to the eminently analytical nature of technological change and transition theories. Transition governance approaches –developed within the overall umbrella of transitions research- have a normative aim because they are future oriented: these approaches conceptualise how societies can move towards more sustainable futures. In addition to understanding the determinants of socio-technical change, co-evolutionary scholars have engaged with the policy sphere by trying to develop tools and frameworks that aim to contribute to the management of possible directions of technological development and diffusion. In doing so, co-evolutionary scholars initially suggested that there is a crucial role for three mechanisms: a) experiments with technology in protected spaces (niches), b) the role of entrepreneurs, champions or system builders, and c) the existing body of knowledge, techniques and support for gains that are applied to the possible directions of change (Kemp et al., 1998, Kemp et al., 2001). From this perspective, the niche offers an opportunity for policy action, which can be implemented through different approaches.

This thesis focuses on the dynamics, governance arrangements and processes occurring at the micro level of niches by analysing and comparing two sets of case studies: PV off-grid rural electrification in Central-Northern Chile and wind-based isolated mini-grids in rural electrification in Southern Chile. In the methodology chapter the research is further contextualised into rural electrification practices in Chile and in doing so the selection of case studies is justified.

To study the diffusion of RETs, this thesis applies the **Strategic Niche Management (SNM)** approach. This framework offers a way of overcoming the barriers to the development and diffusion of new technologies. These barriers have been grouped as typologies of factors: demonstration of technological viability, provision of financial means for further development and diffusion, the formation of a constituency of supporters and the occurrence of learning and institutional adaptation (Kemp et al., 1998).

Kemp, Schot and Hoogma define SNM as “the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation with the aim of: 1) learning about the desirability of the new technology and ii) enhancing the further development and the rate of application of the new technology” (Kemp et al., 1998)[9].

The central elements (units of analysis) in SNM research are experiments, protected spaces in which technology is developed or particular projects with new technologies. These projects or experiments constitute a socio-technical niche whose internal dynamics help understanding of the reasons underlying success or failure in a particular innovation journey.

SNM was first developed in The Netherlands as a response to the search for alternative policy strategies in inducing and managing regime shifts. SNM advocates oppose both incentive-based strategies that rest on market responses to those incentives and also centrally planned strategies that impose the creation of particular technological systems. As an alternative, SNM builds on the ”ongoing dynamics of socio-technical change” (Kemp et al., 2001, p. 208).

[9] As Schot and Geels (2008) point out, this definition is based in on the work of Schot, Slob and Hoogma (1996) *Implementatie van Duurzame Technologie als een Strategisch Niche Management Probleem* (Den Haag, Programme Duurazme Technologische Ontwikkeling, 1994), Werkdocument CST3 (In Dutch).

According to SNM scholars, policy makers have to engage in process management so as to exert pressures that modulate those dynamics in desirable directions.

Over the last 15 years SNM research has focused on mechanisms that work at the niche level. To analyse these processes it is assumed that a technological niche[10] precedes the market niche since the former deals with sustainable innovations that differ radically from mainstream practice and technology and that do not follow the dynamics of market innovations and demand from users (Schot and Geels, 2008).

Experimentation with technology arises as a key mechanism in the creation of niches and the development of new technologies. Raven (2005) comments on different types of experiments playing diverse roles depending on the stages of development of new technologies. He builds on earlier research by Hoogma (2000), who argues that experiments can contribute to: a) directing the investigations undertaken by researchers who define problems, anticipate potential users' preferences and explore potential (positive and negative) impacts of technology in the early stages of development (explorative experiment); b) raising awareness about new technological options and opening up debate and policy-making spaces by testing the feasibility and acceptability of a new technology (pilot experiments); c) promoting the adoption of innovations by users who are shown the benefits of such new technologies (demonstration experiments); or d) disseminating practices, methods and techniques that have been tested in new localities (replication experiments).

In line with the ontological basis of quasi-evolutionary technological change approaches, experiments have been explained in both evolutionary and socio-constructivist terms (Raven, 2005). For the former, experimentation in local practices allows the interaction of actors from the variation and selection environments, i.e. technology developers, users, interest groups and policy actors. Experiments are also the locus where protection from the regime is provided. Protection has normally been explained as a means of improving the economic feasibility of new technology (through subsidies or particular R&D contexts where different selection and retention rules are applied). From a sociological perspective, experiments are seen as the place where structuration is constructed and uncertainty is reduced. The construction of rules at the niche level leads to learning about the technology.

However, local experience (experiments or localised projects) is not automatically translated into niches. Niches have to be constructed and developed on the basis of local experience.

[10] Technological niche is used here without distinguishing it from socio-technical niche since the approach to technological change embraced in this research acknowledges that technology is socially embedded.

Niches arise from those local practices in social contexts but are generalised at a cosmopolitan level (Raven, 2005, Hoogma, 2000) in which learning is delocalised and circulated amongst different locations, actors interact and build constituencies in support of a particular technological option, the promises of the technological potential are articulated and visions and expectations become aligned.

To understand niche formation, SNM scholars have focused on particular processes that arguably strengthen the structure and stability of niche practices. Analytically, these processes interact at the niche level and are then normally referred to as internal niche processes. In their conceptualisation, scholars have drawn on insights from the study of technology development in niches from various technological systems (e.g. transport, energy and food/agriculture) in developed country contexts. In the subsequent sections these processes are discussed and some gaps and tensions in relation to their applicability to different contexts (particularly rural areas of developing countries) are identified. Some criticisms that SNM has received in recent years are also analysed in order to integrate a framework for the study of the diffusion of RETs in rural electrification in Chile.

2.4.1 Articulation of expectations.

Expectations about, or positive visions of, the desirability and future of a technology are important in stimulating its development. New technologies often arise due to their potential advantages, which are widely promoted in society by interested actors. A set of positive expectations has to be articulated because the benefits of new technologies are uncertain and do not have a clear market value which would encourage other actors to invest in their development and wider adoption. The roles played by the actors in the initial stages of development of a new technology are diverse and the viewpoints of actors adopting new technology are driven by different interests. The former include commitment from the R&D departments of firms or research institutions, government funded programmes, etc; the latter, community groups promoting different lifestyles, action groups defending particular political positions such as environmental or social justice concerns, or users interested in testing new technological options as a way to differentiate themselves from others. For these reasons, expectations are assumed to be **broad**, **general** and **fragmented** at the beginning of a technological trajectory (Raven, 2005).

Expectations develop in a dynamic way. Changes in visions are affected by interactions within the niche (actors involved in an experiment or between series of projects) or by external factors (such as changes in some of the regime’s rules – e.g. market price signals, legislation -

or dynamics at the landscape level – e.g. resource availability, international environmental or socio-political priorities).

Taking these general assumptions into account, early SNM scholars suggested that for expectations to contribute successfully to niche creation there had to be an increasing level of stability. Kemp et al. (1998) refer to the *coupling* of expectations. Raven (2005), building on Schot, Slob and Hoogma (1996) and Hoogma (2000), elaborates on the concepts of the *voicing* and *shaping* of expectations. With nuances, these authors (see also Schot and Geels, 2008) make a number of observations. First, they suggest that expectations have to be shared by many actors (i.e. become more **robust**) through involvement in an experiment or through the engagement of actors via sequences of projects. Secondly, they argue that expectations can also contribute to niche development if they are able to guide development in some clear directions (i.e. if they become more **specific**), which also means that particular aspects of the technology are addressed in a specific way. Third, they maintain that the quality of expectations increases and contributes to further niche building when these are backed or substantiated by ongoing experimentation, tests, facts and results (i.e. if they achieve higher **quality/credibility**).

However, more recent empirical application of these theoretical insights has demonstrated that the coupling of actors' expectations or the voicing of the promises about a new technology is not an easy and natural process. Cooperation is assumed to be a managerial enterprise in which sufficient support can be gained from a diverse variety of actors when a package of policy measures is provided (Kemp et al., 1998).

2.4.2 Building social networks.

The second internal process identified in niche creation is the configuration of a constituency of actors behind the development of a technology. These actors do not act independently but gather in social networks which include a wide variety or types of institutions and roles. These include technology producers and users, investors, policy-makers, regulators, technology advocates and other interested social groups. Some actors can be part of the regime; others can represent niche actors or even be part of the wider context in which technology is developed and adopted. Social networks facilitate the interaction of stakeholders, mobilise resources (finance, technical skills and knowledge, social and organisational capital), carry and articulate different visions and balance the relative position of underrepresented or interested actors in comparison with more powerful, incumbent actors who might represent vested interests.

In the early stages of niche creation, networks can be small, unarticulated and formed by only some of the social groups relevant to the wider social embedding of a technology. Likewise, networks can lack the capacity to sustain niche development, either because of vested interests (actors defending their regime positions and being only apparently interested in niche formation) or because new actors, regime outsiders, lack sufficient resources to commit to niche development over long periods of relative social and economic uncertainty with respect to the outcomes of the socio-technical development process.

In line with these characteristics, SNM scholars suggest that for networks to be constructive in niche building, they have to achieve a relative balance between their compositional and functional capacities. Firstly, networks need to be **broad**, i.e. they have to bring together diverse kinds of stakeholders and actors. Regime actors are important because they can better articulate emerging rules and dominant, established, regime practices. However, given their position of power and vested interests, regime actors can easily co-opt new actors. Therefore, newcomers, as relative outsiders, have an important role in broadening the composition of networks. New actors can move more freely from the perspective of their cognitive frames, creating new rules and promoting radical visions that can better articulate societal needs and technological models (Schot and Geels, 2008, Raven, 2005, Kemp et al., 1998).

Secondly, networks have to play a sustaining role in niche development. This involves the commitment of resources and the support for the platforms on which actors interact, exchanging visions and lessons and developing emerging rules through alignment processes. SNM scholars have referred to these functions or roles as the **deepness of networks** (Schot and Geels, 2008). Actors represent institutions that carry their own rules, policies, practices. Consequently, institutional arrangements can foster further co-operation between actors and provide formal resource commitments so as to sustain the networks. These commitments also influence actors’ interaction. When resources are available, regular interaction can be sought. Interaction can happen on formal or informal platforms, e.g. industry associations, government structures, task forces, multi-sector committees, market interaction, social movements, users’ platforms, conferences and so on.

2.4.3 Learning through multiple dimensions.

Learning is the third process identified as a crucial articulation mechanism that operates during niche formation. As the locus for the development and adaptation of socio-technical practices, learning has to occur in several dimensions in which technology is defined by actors. These include technical aspects and designs, institutional and policy structures, cultural meanings, market dynamics and users' contexts (user-producer interactions), infrastructure, production and maintenance networks, and side effects from the utilisation of new technology (such as environmental and other societal effects) (Schot and Geels, 2008, Kemp et al., 1998).

SNM scholars refer to learning as articulation processes relating to the needs, problems and possibilities through which new technologies become socially embedded. As the focus of SNM is experimentation, learning plays a defining role because the results which emerge from projects lead actors to adjust either the technology or the social embedding (Raven, 2005).

Further elaborations of the types of learning have identified users as a key actor-role in the realisation of learning. Because SNM consists of a modulation of ongoing dynamics, scholars attribute to users the role of learning about the technology through using it. They are able to provide feedback to producers and wider networks, including policy-makers and regulators. Following Hoogma (2000) for a particular SNM application, but also from the perspective of cognitive-evolutionary learning approaches, some scholars distinguish between first order learning and second order learning (see for example Raven, 2005, Schot and Geels, 2008, Byrne, 2011, Grin and Graaf, 1996) .

First order learning refers to the accumulation of data, facts and experiences that fit in with existing interpretations of reality. Such learning is important in niche development because it leads to improvements in the effectiveness of a technology in achieving goals that have been established against predefined and existing rules, norms and institutions (Raven, 2005). First order articulation of experiences does not challenge existing cognitive frames but leads to improvements in the technical and economic performance of a particular technological practice. It also involves the identification of problems, potential side effects of a technology, social desirability, and eventual paths to increasing the efficiency and the skills and knowledge needed to produce a technology. It focuses on technological solutions and how their testing and improvement can lead to a working technological configuration. However first order learning is not sufficient to explain how the articulation of experiences and knowledge is able to create the new rules needed for a niche to emerge and eventually modify a regime, i.e. to understand the embedding of such configurations that work.

Second order learning, in turn, refers to the process of constructing cognitive frames and maps of reality (Simon, 1957, cited in Raven and Geels, 2010), the development of "sensemaking" (Weick, 1979, also cited in Raven and Geels, 2010). Actors, through their actions, participate in constructing experiences which are subject to interpretation. Actors select and retain some data and experiences that are embedded in their cognitive frames. When they are able to adapt and alter their cognitive frames, second order learning occurs. Second order learning is thus a reflexive process involving the social construction of reality. Established norms, rules and values are challenged and modified. New roles are identified, institutional structures adapted and, therefore, the possibilities of a technology transformed. Second order learning is about the (societal) functions that are investigated rather than the functionality of particular technologies (Byrne, 2011).

In sum, for effective niche creation, SNM scholars argue that learning processes have to be **broad** and **reflexive** (not only in techno-economic dimensions, facts and data but also consider second order learning, i.e. the reflexive social construction of reality) (Raven, 2005, Schot et al., 1996, Schot and Geels, 2008).

2.4.4 Interaction between niche processes.

Internal niche processes represent an analytical categorisation which permits understanding of the process of niche formation. As might be supposed, these processes do not occur in isolation from each other or in sequences that can be implemented by a guiding authority. Indeed, there is a dynamic interaction between and amongst these processes. The outcomes from the activity at the niche level have to be understood as a modulation of ongoing dynamics (Kemp et al., 2001). Expectations are carried by actors, who develop bonds and relationships within networks; the configuration and alignment of those networks influence the development of expectations and visions which consequently influence how experiments are organised. Results from experiments imply lessons which are then interpreted by actors and thus influence their engagement in additional experiments. Outcomes from learning processes induce changes in expectations, but some external factors can also influence how learning is interpreted and therefore impacts on the extent to which visions change. Geels and Kemp (2000, cited in Raven, 2005) provide an initial framework with which to understand the dynamic interaction between internal niche processes that influence the design of real-life experiments with technology. They do not, however, elaborate on how the interaction of niche processes leads to the emergence of a set of rules in a niche, a discussion which would have to take into account two dimensions. The first of these would be the differences between localised technological development and the emergence of a market space in which new technologies become more embedded, i.e. an increase in size and protection from technological niche to market niche and eventually to regime change (see for example Raven, 2005, Hoogma et al., 2002). The second would consist in a more sociological consideration of how stability and institutionalisation emerge from the interaction of local experience in a decontextualised, abstract pattern of shared socio-technical practices, e.g. technical designs, search heuristics, rules, values (see for example Raven, 2005, Deuten, 2003, Geels and Deuten, 2006).

Recent contributions to the theory have highlighted the importance of differentiating between particular local experiments or projects and the aggregation of experiences leading to learning and co-ordination at a more global niche level (Geels and Raven, 2006). This differentiation between local and global levels does not refer to a geographical distinction but to an evolutionary and socio-constructivist differentiation of local experience, knowledge and practices that become shared as cognitive frames, routines and search heuristics which, in turn, point to a particular direction which emerges as a technological path (leading to a regime) or frame. According to these scholars, technological development proceeds simultaneously at the local level of projects and at the global level of emerging communities which share cognitive rules, i.e. socially constructed and cognitively evolving (Raven and Geels, 2010, p.89).

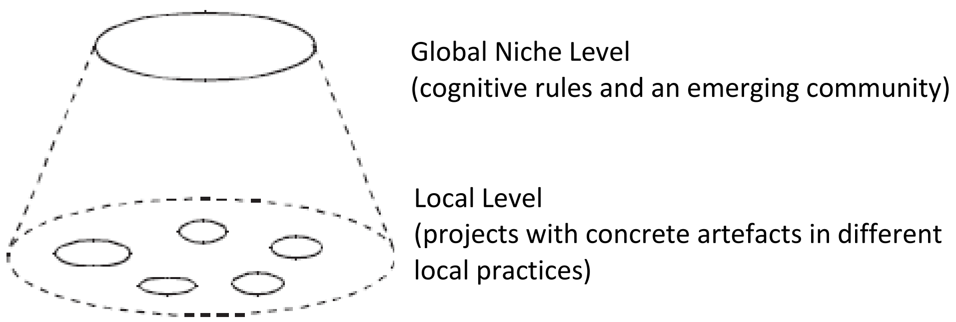

Figure 2-2: Local projects and global niche level (adapted from Raven and Geels, 2010, p.89).

Retention, a key mechanism in the explanation of technological change, occurs, then, not only at regime level, but also at this global, or cosmopolitan niche level. The aggregation, formalisation and codification of local practices forms the basis for retention at the global niche level (Geels and Deuten, 2006). Furthermore, abstraction, rule formation, agenda setting, all of which happen at the global level, decontextualise local experience, specific knowledge and technical designs (i.e. variation in pilot or experimental projects and selection through collective learning) which in turn guide, frame or provide direction to further application in local practices.

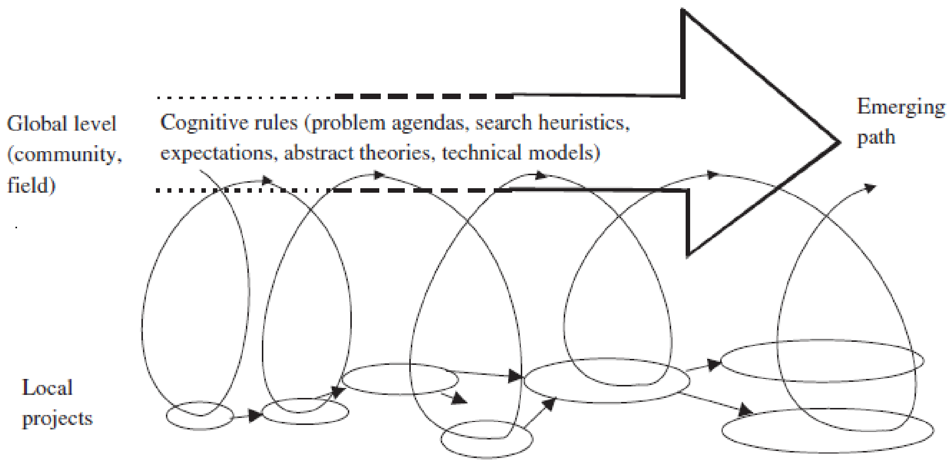

Figure 2-3: From Local to global: Emerging technical path (Raven and Geels, 2010, p.91)

2.5 Intermediary action in niche construction

In addition to the dynamics of visions, learning and the interaction of actors between series of projects (Geels and Raven, 2006, Raven and Geels, 2010), intermediary action occurring at the community level is highlighted as an additional mechanism influencing the emergence of a global or cosmopolitan niche level (Geels and Deuten, 2006). Intermediation is carried out by actors who might not be directly involved in the implementation of a project, or the development of a new technology, but whose role is more systemic. Intermediaries' roles include the monitoring of several projects, aggregating lessons, translating or carrying them from one experiment to the next, circulating knowledge. As Geels and Deuten (2006) stress, intermediary actors, such as professional societies, industry associations or standardisation organisations, perform aggregation activities which are characterised by the "process of transforming local knowledge into robust knowledge... general, abstracted and packaged... global knowledge (that) can travel between local practices" (p. 267).

These scholars distinguish between different phases of knowledge creation: i) a "local" phase in which knowledge is linked to technological solutions at the local level and is not shared or circulated with other local practices; ii) an "inter-local" phase in which knowledge circulates within emerging networks connecting local practices and various actors participating in technological development in one local practice; iii) a "trans-local" phase in which knowledge circulates not for use in local experiences but so as to serve the creation of a decontextualised, collective level of knowledge; and iv) a "global" phase in which knowledge becomes institutionalised as a set of dominant rules. The trans-local phase overcomes the creation of networks of dedicated actors, and intermediaries emerge as a new actor-role. In the global phase, these authors argue, a reversal occurs, because standardised rules and global cognitive practices start guiding activities and practices at the local level (Geels and Deuten, 2006).

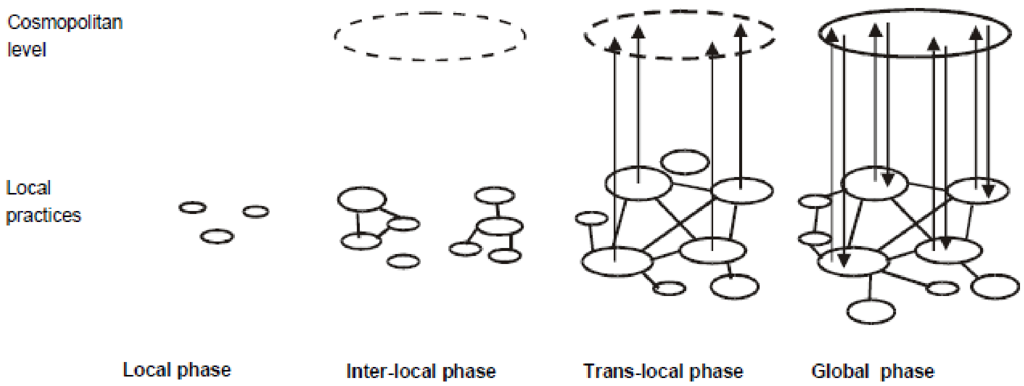

Figure 2-4: Phases of knowledge creation and aggregation in niches (Geels and Deuten, 2006, p.269).

Using a similar line of argument, van Lente et al. (2003) refer to the roles and functions performed by intermediaries. Building on innovation systems and transition management literatures, these scholars focus on organisations that act as intermediaries in innovation processes and in the emergence of new technologies by connecting, translating and facilitating flows of knowledge (p. 248). They add an important element to the analysis of transitions of (socio-technical) systems when they elaborate on the actual and potential roles of *systemic intermediaries*, i.e. organisations that contribute to the management of transitions at a strategic, system level rather than at a bilateral, contextualised level. In this sense, these scholars refer to the systemic instruments and roles of such organisations that perform intermediary action beyond the traditional 'hard' (e.g. financial or diffusion oriented support) and 'soft' (e.g. managerial support to firms) activity of traditional intermediaries.

Van Lente et al. (2003) propose an interesting conceptual crossover with SNM literature, although they do not explicitly refer to the latter approach except as an important notion in what they categorise as a 'take off' phase in transition processes. Their contribution refers to the synthesis of functions that systemic intermediaries undertake. In a way that is reminiscent of the conceptual elaboration of SNM, systemic intermediaries undertake functions that overlap with the processes taking place within a socio-technical niche. These scholars consider the following elements as key functions of systemic intermediaries in transition processes (van Lente et al., 2003, p. 56):

1. *Articulation of options and demand.* This function refers to an alignment between the variation and selection environments in the form of possible application domains and the emergence of technological variety. This process affects the visualisation of possible futures, which is clearly linked to the shaping of expectations and visions.

2. *Alignment of actors and possibilities.* This includes the facilitation of interfaces between actors, the building of networks and the strengthening of linkages within an innovation system. As these scholars build on innovation systems literature, this function remains within the analytical structure of that theoretical framework; however, it is clear that they conceptualise the importance of building dedicated networks around the emergence of a new technology.

3. *Support for learning processes.* The authors refer to feedback mechanisms and mutual adaptation as an outcome of experimentation. There is no further conceptualization of the types and cognitive aspects of learning, but the importance of learning and adaptation in transition processes is highlighted.

Although the ontological basis of the conceptualisation of systemic intermediary roles might differ from those of the quasi-evolutionary theories and the SNM approach, the idea behind bringing this additional element into the review of the literature is to highlight the importance that various scholars assign to intermediary actors in the emergence of new technologies. From the perspective of the SNM literature, intermediation is seen as an important step in the process of the decontextulisation of local practices and the emergence of a collective, global level of knowledge that leads to the embedding of rules. Insights from systemic intermediaries literature builds upon functionalism and complex systems literature by focusing on the roles, tasks or functions played by actors.

These latter theoretical approaches have been criticised for being too metaphorical and for lacking a clear operationalisation beyond the abstract roles of actors and imprecise sociological characteristics (Horgan, 1995, cited in Geels, 2010). A further criticism is that the inherent dynamic of socio-technical change is viewed from these perspectives as a reaction to external disturbances that are internally adapted. Political leaders and experts can decide on how best to redefine objectives and goals and, so, use science and technology insights to that end. However, this technocratic understanding of change processes assumes a top-down policy approach which is at the centre of the criticisms of complex systems and functionalist literatures made by evolutionary and socio-constructivist theorists.

Nonetheless, in both theoretical approaches the notion of intermediary activity acting at a strategic, system level is fundamental and has been little explored. The intermediary action is oriented to ensuring embedding and stimulation of radical innovation in niches.

In this regard, a very recent work by Kivimaa (2014) operationalises an analytical framework to investigate the role of systemic intermediaries to contribute to both niche creation and regime (de)stabilisation. In her study of government-affiliated intermediary organisations she develops a typology of intermediary roles which is in turn linked to internal niche processes. More importantly, additional intermediaries' roles are identified, which are linked to political dynamics in the construction of niches and niche regime interaction. Amongst these roles, the study suggests policy or regime renewal, opinion influencer and change initiator (Kivimaa, 2014, p.1378).

Kivimaa (2014) discusses two important issues that empower intermediaries as systemic actors: a) their independence and neutrality from political, financial and technological biases, and b) the extent to which intermediation is maintained and sustained during sufficiently long periods so system actors can exert their agency over the many phases of transitions processes. These important factors influencing transitions dynamics are further elaborated in the next section.

2.6 Initial Assessment of Gaps in the Theoretical Approximations to Socio-Technical Change and Niche Construction.

2.6.1 Intermediary Action as Political Activity

As will be argued in the thesis, intermediary action is intrinsically linked to decision making and governance dynamics. Governance is considered as the way institutions and actors mutually interact and, in doing so, define roles, confer participative powers and become organised in order to improve and legitimise the social-technical functioning of systems. The emergence and stabilization of rules and the acceptance of a collective knowledge level (e.g. through the codification of designs, search processes, assessment criteria and so on) are outcomes of decisions made in a collective process in which influential actors participate. Intermediaries acting at a system level - beyond particular local practices, assume certain roles and mediate such decision making processes.

In effect, decision making is a political process in which different visions are confronted, the power positions of actors influence the direction and outcomes of deliberative processes and the inclusion of certain groups and interests is mediated by the structure of institutions and participatory infrastructures. These political dynamics depend on how actors, resources, visions and interests are linked together. Innovation systems approaches tend to favour a top-down cockpit model in which experts, authorities and other stakeholders make decisions so as to attain desirable goals. Evolutionary and constructivist approaches, particularly SNM, tend to focus on bottom up, decentralised and inclusive models of decision making, rejecting the technocratic nature of other frameworks.

Although identified as an important element in the dynamics of niche development and transitions trajectories, conflicts, power struggles and, in a broader sense, the role of politics in socio-technical change has not been systematically explored and researched until recently. As a consequence, there is wide acknowledgment of the lack of theoretical conceptualisation of these issues in the evolutionary socio-technical change literature both from critics from other disciplines and from evolutionary scholars whose aim is to advance conceptual models (see for example Smith and Raven, 2012, Smith et al., 2005, Shove and Walker, 2007, Genus and Coles, 2008). Notably, Avelino (2011) explores power dynamics and discourses on sustainability transitions, and Geels (2014) has very recently suggested additions from political economy insights to the multi-level perspective by looking at different forms of power (instrumental, discursive, material and institutional) and how these affect resistance to change by regime actors impeding (de)stabilisation and decline of mainstream socio-technical practice. These issues are further explored in the following section through an analysis of the existing gaps and challenges in SNM and more general transitions literatures.

2.6.2 Niche Regime Interaction

The interplay between niches and regimes has been given a predominant place in transitions research during recent years. Previous SNM research, by contrast, has focused on the internal processes taking place in aggregations of projects in constructing a niche. These processes eventually lead to the transfer to the niche level of a more robust set of rules which have themselves emerged from local practice. However important, new rules, practices and configurations at the niche level often fail or lack sufficient influence to change dominant practices at the regime level. In other words niches are necessary but not sufficient to induce regime shift (Schot and Geels, 2008).

In this context, a current research challenge is to understand the dynamic interaction of niches and regimes (Smith, 2007). This includes the mechanisms by which experiments can be replicated, scaled up and translated into regime practice. These challenges have also been identified from several ontological perspectives. Geels (2010) analyses the possibility that several social science theories offer to the extension of socio-technical transitions research. In particular, he builds on i) criticisms regarding the lack of consideration of agency and the role of power (Smith et al., 2005), ii) the suggestion that more constructivist points of view have to be incorporated into the transitions framework (Genus and Coles, 2008), and iii) that the politics of transition management has to be further elaborated in order to better integrate the complexity of defining, managing and translating desirable sustainable futures into practice (Shove and Walker, 2007).

These challenges refer to a better understanding of i) the dynamic interaction and linking between niches and regimes, ii) how protection in niches is constructed (Smith and Raven, 2012) and iii) how actors deploy their positions of power, interests and internal capabilities to balance the defence of existing structures and stability in regime contexts with opportunities in new domains and niche spaces. Geels (2010) suggests a stronger incorporation of business dynamics into strategic management, from the perspective of evolutionary and constructivist ontological bases. This would include the consideration of how incumbent firms are re-orientated towards niche activities and reconfigure existing capabilities to balance their positions so as to exploit existing technologies and explore new ones.

The above discussion suggests that decision making, not only at a system level but also at a micro-firm level, is an important area that has been understudied. Decision making appears, thus, as an important determinant of both niche construction and niche-regime interaction. The next section explores the politics of niche emergence and distributed decision making processes.

2.6.3 Distributed decision making in the construction of niches and regimes

As has been discussed in previous sections, this thesis investigates how niches are constructed and how the diffusion of RETs occurs in off-grid rural contexts in developing countries. To do so, the research focuses on the conditions under which both aggregations of off-grid PV and wind projects have played a role in building socio-technical niches and the extent to which they have influenced how rural electrification is implemented in Chile.

Niche technologies do not often fit in neatly with prevailing socio-technical practices and regime rules but are linked to them because they compete in the articulation of needs and options. Variation and selection environments are connected not only in evolutionary ways, but also through political mediation, by means of which contested views about technology and society have to be negotiated and deliberated. Decision making is thus a central element of technological change. Technological choices are made in variation and selection environments. Retention, and the construction of common rules and the institutionalisation of socio-technical practices is a matter of the management, coordination and construction of global knowledge, but these activities are also a matter of choice and deliberation.

Rural electrification does not escape decision making processes. Which technologies are promoted, what types of protection measures are applied, whose benefits are considered, which actors are given a voice (and power in decision making) are all elements in the formulation, construction and implementation of policies, including rural electrification policies and programmes. Additionally, public policies in this context are affected by decisions made by actors at several scales of action and deliberations in different arenas or settings. In the case of rural electrification in Chile, for example, distributed decision-making occurs i) in a centralised setting in which a key role is assumed by the Ministry of Energy (defining policy objectives and technical standards, policy guidance and budgetary allocations), ii) in the regional setting (defining implementation strategies and actors involved, or allocation of state subsidies), and iii) in local settings (through the interaction between rural communities and municipal authorities identifying electrification needs and social demands), amongst other settings. This is thus a clear example of a distributed decision making model.

The construction of protection in niches, such as off-grid RETs in rural electrification, is an alignment process that iterates between the content (performance of a technology) and the context (regimes) of innovation. This is a politically underpinned process (Smith and Raven, 2012). Nahuis and van Lente (2008) stress that “the mutual shaping of technology and society takes place in a variety of settings and in all these settings contributions to democratic quality are made” (2008, p. 574). The consideration of these additional elements from a socio-technical change perspective implies that technological trajectories are more than a matter of management. Indeed, democratic control and socio-technical politics are key ingredients in the development and diffusion of new technologies and the social embedding of such new ways of fulfilling societal needs.

Building on Beck’s ideas about the proliferation of sub-politics, or the displacement of politics from representative political institutions to other forms of politics, Nahuis (2011) suggests a framework to understand the dynamics of displacements of decision making through several settings. Such a framework considers *settings* as the direct contexts for contestation. Issues are considered as a public conflict between an interpretation and counter-interpretations of a technology or service, and these are thought of as being articulated, discussed and settled in settings (Nahuis, 2011, p. 320). Decision-making occurs through the displacement of issues through several settings, which can be local administrative bodies, networks of civil servants, societal organisations, the private sphere, the legal system, international institutions (Bovens et al., 1995, cited in Nahuis, 2011) and laboratories or design departments (Nahuis, 2011, building on science and technology studies). Although this list of possible settings might not be comprehensive, it provides an initial context in which analysis of the politics of technological diffusion can be carried out.

The way a setting is arranged or organised is affected by institutional procedures, predominant values, and beliefs, with the result that political debates operate in certain directions and to the benefit or expense of certain actors. Participation in decision making is therefore not only the expression of the political power of actors. This is because control and influence over the definition of political agendas define the extent to which certain actors are accepted (or are able to participate) in the debate about new technologies and decision making process (Nahuis and van Lente, 2008).

This thesis argues that technology (and more broadly societal) actors engage politically in the construction of niches and in the mutual interaction between niches and regimes. Internal niche processes are political in nature because visions and expectations, network formation and the extent to which learning occurs and feeds back into the embedding of a new technology are all politically mediated processes. The construction of rules involves negotiation, deliberation and decision making processes, which are all politically affected. Transitions literature, and particularly the SNM approach, has given little consideration to the contested nature of radical socio-technical change. Co-operation, mutual interest, visioning and alignment, internalisation of learning and reflexivity are difficult endeavours in public policy planning and implementation. Political and ideological interests affect how settings for decision making are arranged, how power struggles are settled and whose interests are given predominance in negotiation and deliberation. Purposive policy action, as suggested by SNM scholars, is then a political activity that lacks an adequate conceptualisation of power and agency (Smith et al., 2005).

2.6.4 Considering scale and spatial aspects of sustainability transitions: recent contributions from economic geography.

Until recently, most of the theoretical gaps identified as a lack of consideration of power, politics and agency in the transitions literature had been highlighted as criticisms and major challenges (see for example Genus and Coles, 2008, Smith et al., 2010, Markard and Truffer, 2008, Shove and Walker, 2007). To overcome these challenges, from economic geography and related fields, there has been an emergent debate about the role of spatial aspects in sustainability transitions (Truffer and Coenen, 2012, Coenen and Truffer, 2012, Coenen et al., 2012), particular multi-level governance dynamics in specific places (Späth and Rohracher, 2012), the influence of power relations and geography in transitions (Lawhon and Murphy, 2012), or more generally, the active engagement with the reasons why some transitions might take place in one place and not in another. More than a critique, this engagement has been active in building and complementing the socio-technical transitions field of research with insights from regional studies, geography and political ecology in a new and expanded field of geography of sustainability transitions.

One of the notable contributions is the development of a refined model of socio-technical transitions (Raven et al., 2012) that explicitly incorporates a spatial scale, understood as relational and relative, where actors and institutions are connected to each other, socially constructing power relations and networks that are dynamically reconfigured, and so are flows of knowledge, resources, technologies and innovations.

These scholars conceptualise a second generation, multi-scalar MLP which explicitly incorporates space as an additional scale in the analysis of socio-technical transitions, which has traditionally focused on the analysis of dynamics in two scales: time and structure (Raven et al., 2012). With this refined framework, the analysis of socio-technical change takes into account "unevenness, heterogeneity and asymmetry in socio-technical systems" (Raven et al., 2012, p. 65), thus conceptually proposing a way of overcoming the several challenges identified in the way of considering the social-institutional embedding of socio-technical change processes.

2.7 Additional gaps in the theory: the particular consideration of developing country contexts

Technological change theories and particularly SNM have been developed in advanced institutional, economic and social contexts. Empirical evidence for the development of theoretical insights comes from specific sectors linked to energy use, food production and consumption and transport technologies, mostly developed and applied in developed countries. In most of the cases that have greatly contributed to the understanding of socio-technical change trajectories, there is a bias towards the development of sustainable technologies, from R&D activity, prototype testing and subsequent use and socio-institutional embedding of new socio-technical practices.

Among evolutionary, constructivist and system theories, many scholars focus on technological change as an important aspect of sustainable development. Furthermore, the SNM approach, as reviewed in this chapter, is a comprehensive systemic approach. However, the tendency of evolutionary approaches to focus on developing radical sustainable innovations, forces the analytical and policy models towards R&D activities, testing of technologies in real life contexts, and adapting them to users' and regulatory contexts, and in this way SNM expands its framework into the social embeddedness of technological change.

The SNM framework has been developed mainly to suit cultural, market, policy and technological contexts in developed countries, offering a promising path to new modes of economic growth that will dramatically reduce pollution and the use of raw materials (Hoogma et al., 2002, p. 6). SNM scholars recognise that the shift towards new growth paths can in turn benefit developing countries through the diffusion of new promising technologies and eventually foster economic growth in less advanced countries. However, there is an important gap in the approach: promising new technologies are hardly ever developed in less advanced countries because of the lack of technological capacities, adequate policy frameworks that foster technological innovation, or due to resource constraints and a narrow involvement of actors in innovative activity.

As technologies are not often developed in less advanced countries, more attention should be given to the introduction of relatively available sustainable technologies in these countries (although those technologies might still be at a niche level stage and have not yet developed in markets or regime contexts)[11]. Technological diffusion has then to be reframed in order to suit the capacities and needs of developing countries. The social embedding of a technology appears thus as a more important issue than the actual development of the technology. This is an important difference, because it represents an analytical change of direction which leads to a different entry point into the analysis and steering of technological change in developing countries, particularly in poor social contexts in which such technologies promise to solve sustainability problems. Poor rural areas are an example in which RETs represent a promising alternative way of fulfilling energy needs.

Building on these analytical differences an additional gap arises here because the understanding of sustainability in the poor rural contexts in developing countries can be quite different from that of developed and industrialised countries. Social inequality and the lack of access to modern services that fulfil societal needs at the local level (such as access to energy, sanitation, communications, housing, education and so on) might be more dominant political

[11] See for example Bell's distinction between technologies that are 'new to the world' and those that are 'new to a particular geographical region/market context' BELL, M. 2009. Innovation Capabilities and Directions of Development. *STEPS Working Paper 33.* Brighton: STEPS Centre.

and social issues than environmental problems at local or global scales (such as environmental pollution or climate change).

Although many social and environmental problems in locally poor contexts in developing countries are connected to global sustainability challenges (e.g. some of the most acute early impacts of climate change are likely to be felt by developing countries), responsibility for decided action about global issues such as climate change remains contested between developed and developing countries. Thus, the urgency of improving access to basic services in poor rural contexts in developing countries is more a moral imperative to respond to local needs than a responsibility on the part of poor communities to contribute to global challenges. For example, the relative contribution to climate change due to the use of polluting lighting devices – normally candles or lights powered by fuels such as gas or kerosene - is relatively small compared to the widespread use of fossil fuels in centralised electricity generation in developed countries or even in more developed contexts of developing countries.

Political and moral imperatives are therefore directed to improving energy access in such poor contexts rather than improving the environmental sustainability of the economic system as a more abstract concept. Whilst the fact that environmental sustainability is dynamically connected to social and economic development, it is important to note that access to technology is a key determinant of increased levels of development. Lack of access to technology and the consequent fulfilment of societal needs (particularly in poor contexts) impact directly on relative wealth levels; therefore improved access to eco-innovations can underpin economic development in developing countries (Ockwell et al., 2010).

The above discussion does not mean to neglect the importance of steering technological change towards sustainability in developing countries. The objective of highlighting these issues is to provide a context for the complex discussion about sustainability and to add meaning to the construction of problems and solutions in terms of the social, environmental and economic needs of developing countries.

2.8 Previous applications of the SNM framework in Developing Countries

Although it has been developed mainly in European contexts, the SNM framework has also been applied to the study of emerging energy transitions in developing countries. The intention has been to expand the scope of application and test whether it is appropriate for the analysis of the emergence of niche technologies in such countries. Particularly, a special issue of *Environmental Science and Policy* (Vol. 13, Issue 4, Berkhout et al., 2010) included several publications that applied the SNM framework in developing county contexts, with a focus on sustainability experiments in South and East Asia.

Contributions were made in the following areas: how the SNM framework complements learning-based approaches in the study of the determinants of success and failure of biomass-energy projects in rural South India (Romijn et al., 2010); the consideration of technology customization and innovative financing for solar PV lighting diffusion in the residential sector of rural India (Rehman et al., 2010); the extent to which incumbent regimes in developing countries (in a case of biomass gasification in India) show signs of persistent instability, so support for regime stability could allow niche breakthrough and in this context market niches appear as a promising starting point rather than the development of technological niches (Verbong et al., 2010); the interaction of niche development with more than one regime (dairy production and electricity) as shown in a case of the transformation of waste into energy in India (Patankar et al., 2010); and the importance of political and institutional factors and the engagement of heterogeneous actors on various scales in the understanding of urban sustainability experiments (Bai et al., 2010). These studies respond to several challenges identified in the literature, including a deeper consideration of learning, an exploration of finance linked to niche development, and the interaction of niches and regimes, a key theme that is covered in this thesis.

Other studies of the emergence, diffusion and use of new technologies have also applied the SNM framework and transition theories in other contexts. For instance, some studies using SNM tools have looked at transitions and niche development in biofuel production in Africa (van Eijck and Romijn, 2008), where the authors find that niches are still in such an early stage of development that it is difficult to anticipate possible changes in dominant regimes. In another analysis of biofuel production in Tanzania, Romijn and Caniëls (2011) complement the SNM framework with an analysis of conflict-driven dynamics that are mainly affected by the extent to which reflexive learning about sustainability impacts are considered. Byrne (2011) also contributed to the understanding of SNM internal processes in his thesis about the learning dynamics in the PV niche in East Africa. Another interesting example is the study of the governance of clean energy by Lucy Baker, who looks at the political economy of socio-technical transitions in South Africa's electricity sector (Baker, 2012), although she does not explicitly apply the SNM model. In a study in which the SNM framework has been applied in Latin America, Drinkwaard, Kirkels and Romijn (2010) examine the diffusion of micro hydro power in Bolivia and find that local engagement is crucial for long-term technology operation and system functioning. However, more research projects using SNM and evolutionary theories of technological change have not been found in the context of Latin American transitions studies.

2.9 Re-statement of RQ's

Against the backdrop of the literature review presented in this chapter, it is now time to revisit the questions guiding this PhD research. These are organised in such a way that an overarching question encompasses the main aim of the thesis and sub-questions focus on particular theoretical and empirical objectives of the thesis.

The overarching question seeks to find an explanation for the development of the off-grid renewable energy niche in rural electrification in Chile:

- **How has off-grid renewable electricity developed in rural Chile, and what factors have driven or constrained this process?**

Sub-questions look at particular empirical and theoretical challenges to understanding success and/or failure in the diffusion of new technologies and the interaction of new socio-technical practices with dominant rules and technologies.

I. **How and why have PV and Wind-based off-grid rural electrification trajectories been different?**

II. **To what extent can SNM theories help to understand those differences and account for particular developing country context conditions?**

III. **What impact has the development of off-grid renewable energy niches had on the Chilean rural electrification regime?**

2.10 Chapter Conclusions

This chapter has presented a review of the literature that critically unpacks the theoretical bases of the thesis. The thesis attempts to understand the processes of emergence and diffusion of new technologies for the sustainable provision of electricity services in rural areas of developing countries. Off grid RETs are radical innovations because they involve new ways of fulfilling societal needs and demands that encompass alternative social and technological practices, rules, norms and relationships amongst actors and institutions, compared to traditional grid-based access to electricity in rural contexts. As such, the focus is on the leading edge of a technological change process. A review of different approaches that seek to understand these changes, such as traditional (neo-classical) and evolutionary approaches, has been presented.

On the basis of the analysis of the literature, this chapter has argued that the system innovation and sustainability transitions literatures are better placed than others to understand socio-technical changes because they do not treat technology as an endogenous factor influencing socio-technical change trajectories. Within transitions theories, the review of the literature has focused on the development and adoption of radical innovations (RETs in rural electrification), and the Strategic Niche Management framework is considered particularly helpful and useful. SNM has been developed to understand and direct process of creation and social embedding of radical innovations and new technological arrangements.

Acknowledging the robustness of the SNM framework (particularly the articulation of internal niche processes i.e. expectations, networks and learning), the literature also highlights a number of challenges and gaps in the approach, such as the lack of attention to conflicts, power struggles and agency, or in other words, the politics and governance of niche development. In order to complement the theoretical framework, this chapter has included: i) a review of literature on the distribution of decision making in the process of technological development and diffusion of new technologies, ii) a better articulation of theories of systemic intermediaries and globalisation – or de-contextualisation at a more general level - of knowledge and rules in emerging niches or protected spaces in which radical innovations are developed, and iii) a review of the early development of the geography of socio-technical transitions literature and conceptual articulations of spatial and scalar dimensions in the analysis of emergence and transformation of socio-technical systems. This literature seems to be particularly useful in understanding social-institutional processes of niche formation and niche-regime interaction, characterised by heterogeneous, asymmetric and uneven networks, in which actors and institutions exert power.

In the next chapter the research design and the operationalisation of the theoretical framework into an analytical framework are introduced. In the development of the methodology, particular tools and techniques for data collection (including sources) and analysis are presented. The limitations of this thesis are also discussed.

3. Methodology

3.1 Introduction to the chapter

This chapter presents the conceptual and analytical framework used in the thesis, which is built and organised to operationalise the theoretical foundations of the dissertation and answer the research questions. To this end, a detailed design of the research is elaborated which outlines the key concepts and dynamics identified in the literature in the context of the Chilean Rural Electrification process.

The overall aim of the thesis is to understand how RET niches are created and through an increased level of stabilisation and structuration are able to influence wider socio-technical practices and induce regime change. In particular, the research aims to study the diffusion of PV and wind rural electrification projects in Chile in order to:

4. analyse diverse off-grid RET rural electrification projects from the perspective of SNM in order to contribute to (and critically appraise) this theoretical body by applying it to a developing country context.
5. understand how off-grid RET niches build up from the aggregation of individual projects and to analyse internal processes leading to the robustness and enhancement of socio-technical niches.
6. investigate the mechanisms by which emergent niche dynamics (rules, institutional arrangements, actors' roles and relations, etc.) are translated into mainstream practice or influence the dominant socio-technical regime.

The chapter is structured as follows: section 3.2 presents a tailored conceptual framework that introduces theoretical insights and develops a particular scheme to be used in the analysis of RETs projects in Chile. In section 3.3 the research design is developed and the various research methods used are explained and operationalised. Case study selection and justification is also presented in section 3.3 together with the sources of data and collection methods and the analysis of the evidence. Section 3.4 discusses the limitations of the methodological approach and section 3.5 contains details of links between this research and other projects and research networks.

3.2 Conceptual Framework

As was mentioned in the introductory chapter, this thesis is concerned with the underlying reasons for the success and/or failure of the diffusion of radical innovations. Off-grid RETs are understood as radical innovations in rural electrification because they are disruptive ways of realising social demands and fulfilling rural communities' electrification needs which depart completely from the traditional means and practice of accessing energy services (e.g. from technological, managerial, institutional, commercial and symbolic or cognitive perspectives). With the aim of interrogating and understanding RETs-based rural electrification process and progress, the project has applied the Strategic Niche Management (SNM) approach to transitions to sustainability to the study of the use and diffusion of such technologies in rural electrification in Chile. That approach is complemented with insights from intermediaries' literature and the roles that agency, decision-making and power struggles play in the diffusion of radical socio-technical innovations.

The dynamics of socio-technical development and the construction of stability and institutionalisation around aggregations of off-grid RETs projects have implications at the level of niches, but also in the interplay between niches and the regime. The emergence of a niche can be interpreted as a synergetic activity of mutually dependent processes happening within that niche, but also as the result of the dynamic interaction between the processes taking place both within the niche and in its wider context (or the regime). Taking this assumption as a starting point for an analytical model, the study of the emergence of off-grid RET (PV and wind) rural electrification is carried out from two perspectives.

First, from the project level perspective, the thesis examines the development of local practices, routines and organisational arrangements. From this perspective, the analysis focuses on how particular or individual off-grid RET projects have been developed and implemented and the extent to which these have contributed to replication and emergence of local rules and practices around RETs, developing learning, expectations and strengthening networks of actors. The analytical focus is therefore on structuring processes, niche building forces, and the stabilisation of local-global practices at the niche level.

Second, from the aggregated perspective, the thesis evaluates a global or cosmopolitan (aggregated) level of projects (niches) and the dominant way of making rural electrification happen (regimes). From this perspective, the analysis looks at the dynamic interaction between RET projects and traditional grid extension, investigating the influences and interactions between these different socio-technical styles, creating –or allowing for the emergence of- alternative trajectories. Particular analytical attention is paid to the means by which niche practices are protected from regime pressures and to the way decisions affect trajectories, and how tensions are modulated and potential conflicts between competing socio-technical alternatives are overcome.

These two perspectives represent an analytical differentiation in the methodological approach, rather than constituting separate theoretical perspectives. In other words, these analytical perspectives define the scope of the study and the direction from which data is looked at, within the overall context of an SNM approach. On the one hand, cases (and projects) are investigated from the perspective of their local context and, on the other hand, data is analysed from the standpoint of an aggregated or broader context. Consequently, both the individual niches and the regime which these niches attempt to transform define together the analytical scope or boundaries of the research.

With this analytical perspective in mind, the conceptual framework gathers the key factors, concepts or variables to be studied and the dynamics and relationships amongst these elements (Miles and Huberman, 1994, p.18). As the research is concerned with niche creation processes and their influence on (and interaction with) mainstream practice in the Chilean rural electrification regime, the conceptual framework involves three different strands or levels within an analytical approach that includes the identification and analysis of off-grid RET rural electrification projects developed and executed in the framework of rural electrification policies in Chile:

i) The development of individual off-grid RET rural electrification projects as experiments,

ii) The aggregation of these projects so as to contribute to the emergence of a niche (level), and

iii) Niche-regime interaction, i.e. interplay between (and the influence of) off-grid RET and traditional means of grid extension.

These three strands in the investigation are described graphically in Figure 3.1.

At the level of specific/individual projects the key concern is with the socio-technical characteristics of the experiments, including guiding principles, actor involvement and roles, institutional arrangements for the experiments, technological options and user needs assessment methods, the organisational and market structures developed, and the lessons and key outcomes or results from each project. In other words, this stage aims to analyse how new routines and socio-technical practices are configured at the level of local projects and to identify links between local projects.

At the (emergent) niche level, the aggregation of experiments, replication and scaling-up of local practices will guide the analysis. Mechanisms underlying structuration processes are investigated (including success and failure). At this level two socio-technical niches are identified and analysed (i.e. off-grid PV systems and wind-based mini-grids) by applying the SNM framework. Internal niche processes, as suggested by the theory, guide the analysis by focusing on how and which expectations are developed, the extent to which actor networks are created, the role actors within the network play in supporting and developing niche emergence, how learning processes occur and affect the outcomes of projects and the extent to which learning helps to strengthen the rules and socio-technical arrangements fostering institutionalisation of niches. Intermediation processes are investigated in particular as a mechanism helping to de-contextualise local (project) experience, practices and rules, so constructing a cosmopolitan or global niche level.

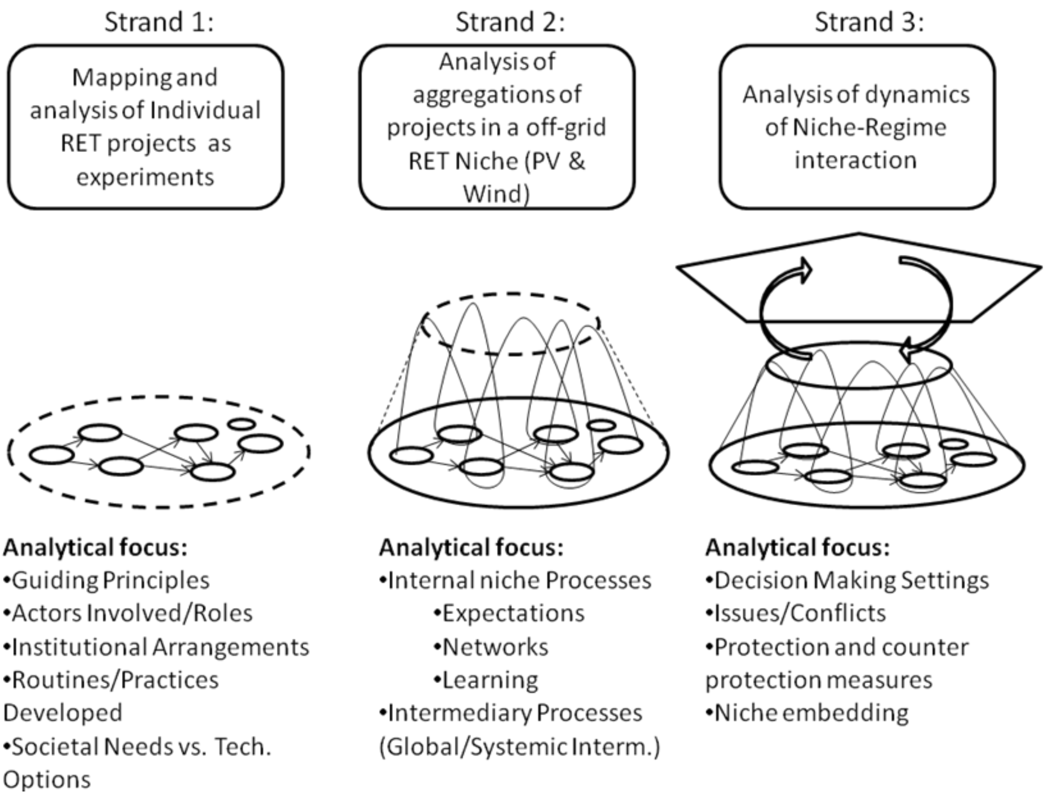

Figure 3-1: Graphic description of analytical strands in the methodology

Finally, at the level of interplay between niches and regimes, the translation and influence of emergent (niche) practices into policy (a type of second order learning) and the extent to which mainstream (grid extension) practice changes are analysed. At this level, decision making processes are investigated (i.e. the involvement of actors in decisions concerning dynamics in niches and regimes, how decision-making settings are constructed, how issues are displaced to different settings and the extent to which conflicts and power struggles are considered and resolved). Additionally, protection measures that enable niche experiments to be further developed are also analysed. Key analytical concerns are the way protection has been built around niche projects and how existing protection from regime practice is removed or lowered. Protection measures and decision-making are considered from a political-economy perspective in order to understand the extent to which actors' agency, power positions and the institutionalisation of niche dynamics play a role in further niche embedding.

The conceptual framework adopted in the thesis does not make use of landscape factors influencing the emergence of new socio-technical practices (RETs in rural electrification) and potential transformation of regimes. Although the three levels conceptualised in the MLP are considered as a nested hierarchy, for focus and scope reasons needed in an empirical study of emergence and embedding of new ways of accessing rural electricity, the conceptual framework proposed here is limited to look at the development of niches and their interaction with regime practice, and leave landscape pressures, such as climate change concerns, energy access programmes and policies enacted at the global level but with a local manifestation and technology development trends at the international scale –particularly changes in cost and performance of PV technology over the last decade[12], as an important background factor that in not considered in the analysis.

The main unit of analysis is, therefore, off-grid RET rural electrification projects. Socio-technical dimensions, niche processes, systemic intermediary action, protection measures and institutionalisation of practices, decision-making processes, power position of actors and conflicts and power struggles comprise the main analytical variables.

Table 3.1 below shows in more detail how the analytical process described (organised in three strands or levels) is structured, identifying general objectives, analytical focus, processes and variables at each level of the conceptual framework.

[12] The thesis looks at the implementation of RETs off-grid projects in remote areas of Chile. Although the reduction in cost and improvement of performance in PV technology can certainly affect the economics of any solar project, this is important but not particularly relevant for the decision making process through which rural electrification projects are assess and deliberated in the country. PV panels are a small part of the total cost of an off-grid PV project (more weight is given to batteries, construction costs and logistics) and other variables and factors influence whether a PV project is considered in the rural electrification pipeline. In fact, RETs projects are only considered if grid extension projects are technically or financially un-feasible. This is discussed in Chapters 5, 6, 7 and in the conclusions of the thesis.

Table 3.1: Analytical Framework (based on Berkhout et al., 2010, Smith and Raven, 2012, Rehman et al., 2010, Drinkwaard et al., 2010)

Strand of the Methodology	General Objective	Analytical locus/level	Analytical focus	Analytical Process	Analytical variables/Concrete questions under investigation
1. Mapping of experiments/RET projects (PV and wind tech.).	Set out an historical overview of the niche on the basis of individual projects. Characterise and describe its main elements: social (actors, needs, guiding principles); institutional (normative, regulative, cognitive); and technological features (infrastructure, artefacts, configurations).	Local experiments / RET projects.	Development of new routines and socio-technical practice.	1.1 Describe experiments (projects) that build up PV and wind niches in rural electrification and analyse socio-technical characteristics of individual projects.	Characteristics: Experiment objectives, technology, beneficiaries, funding and other financial features, actors' roles (developer, executor, funding body, others), operational and management scheme, routines developed, shared practices, etc.

Strand of the Methodology	General Objective	Analytical locus/level	Analytical focus	Analytical Process	Analytical variables/Concrete questions under investigation
2. Analysis of experiments in light of SNM internal processes.	Understand how networks, expectations, and learning are developed and affect niche construction. Investigate systemic intermediary processes as a relevant determinant of niche stabilisation and growth. Investigate what contextual factors (i.e. developing country) provide grounds for alternative explanations/departure from mainstream SNM/transition theories.	Local/global niche interaction.	Experiment aggregation: replication, scaling up, structuration.	2.1 Investigate HOW and WHICH EXPECTATIONS have been articulated/aligned.	What discourses have been articulated around RET? Who has shaped them? Are they broadly accepted? By whom? What concrete projects have backed the development of visions/expectations (and how)? How does context (developing country) affect the extent to which expectations are shaped?
				2.2 Analyse the underlying ACTOR-NETWORK.	Who/which are the actors/institutions participating in the network?; What roles do they play? Which resources do they contribute/commit to project implementation? How do actors interact?; How is intermediation done, who are those intermediaries, what roles do they play?
				2.3 Understand HOW LEARNING PROCESSES contribute/affect the outcome of experiments/projects (local level) and the development of the niche (global level).	What types of technical and economic lessons have been drawn from the execution of local projects? How have lessons been transferred from project to project (and how do actors interact)? What types of institutional lessons have been drawn from the implementation of projects and public policy action? How do learning feed-back into decision making processes?

Strand of the Methodology	General Objective	Analytical locus/level	Analytical focus	Analytical Process	Analytical variables/Concrete questions under investigation
3. Analysis of niche-regime interaction and protection-stabilisation forces.	Investigate how protection has been articulated around niche practices and how niches interact with the regime.	Niche/Regime interaction.	Structuration / (de)stabilisation / decision-making.	3.1 Analyse how niches and prevailing regimes interact; how protection is structured (in both niches and regimes) and how conflicts and power struggles are played out in decision-making processes	What types of protection measures have been developed and removed in both niches and regimes? What types of measures have been taken to nurture and empower niches from an institutional, technological and social perspectives? How have the power positions of actors affected decision-making processes? How have conflicts between niche and regime interests been confronted?

3.3 Research Design: Operationalising SNM in rural electrification research

3.3.1 Strategy and approach

The strategy used in this thesis consists of a comparative-historical case-study. Comparative-historical methods are particularly useful to understanding both the dynamics and processes underpinning social change, including technology development (Lange, 2013). Socio-technical change, as conceived in this dissertation, is an increasingly socially embedded phenomenon of the co-evolution of technology and society and therefore its analysis may need to make use of several methods or techniques in order to optimise insights. As Lange points out, "comparative-historical methods are mixed and offer an important example of how to combine diverse methods... Comparative-historical methods also offer an example of how to deal with another dilemma facing the social sciences: balancing the particular with the general" (Lange, 2013, p.2).

The operational design of this thesis consists in tracing the events, processes and dynamics of technological change and the diffusion of RETs for rural electrification in accordance with the theoretical framework embraced. SNM and co-evolutionist theories of socio-technical change normally use case-study approaches because these link events happening (or that have happened historically) in real life contexts that are connected and define trajectories of interdependent change. Comparative-historical approaches are characterised by the analysis of events that happen within cases. These examples of "process tracing" or "process analysis" (Mahoney, 2004, George and Bennett, 2005) offer a temporal and historical perspective and comparative approaches allow identification and analysis of similarities and differences with explanatory power as well as permitting generalisation of findings. In other words, the use of comparisons between cases helps not only to "highlight the particular features of each case" (Skocpol, 1984, p.370) but also to identify general patterns across the cases. In this sense, comparative-historical approaches are helpful in identifying causality in the processes involved in the cases studied (Skocpol, 1984).

The approach adopted in this thesis is a case study based methodology. The use of case studies allows an inductive process of testing existing theories and building or complementing new insights into the existing literature with an explanatory aim. The perspective taken in this thesis starts from case study methods but also mixes grounded and critical theory from a methodological point of view. The study of RET diffusion in rural electrification in Chile starts from a particular theoretical strand (SNM and evolutionary perspectives of technological change), which in a sense could contravene grounded theory principles. However, the analytical aim of the thesis is not only to test whether the theories explain a particular phenomenon in a different context (diffusion of radical innovations in developing country contexts), but also to contribute to and enhance the theoretical frameworks themselves on the basis of empirical research coming from comparative cases. As Mjøset defines it (2005, p. 41, cited in Lundvall, 2005), "grounded theory is based on the experience of knowledge accumulation through the craftwork of qualitative social research, fieldwork, and participant observation in particular. Theories are built as the researcher shuttles between empirical research and efforts to analytically distinguish the major explanatory factors. Although rooted in the tradition of case-studies, explanation-based theories are not restricted to knowledge derived from such studies".

A theory is not built without a predefined theoretical framework in which to anchor the analysis, and therefore the perspective of this thesis is also critical since it complements evolutionist insights with political-economy, agency and conflict-based approaches in order to challenge traditional approaches to analysing policy and market practices by considering how conflicts are faced and decisions about technological development made. Mjøset (2005, p. 43, cited in Lundvall, 2005) continues: "like grounded theory, critical theory relies on sensitivity towards specific cases. Critical theory is grounded theory applied in contexts marked by a certain level of social conflict over the legitimate claims of at least one social group".

Through the methodological approach adopted, this thesis critically assesses the existing theoretical building blocks of the SNM approach by incorporating new conceptualisations of the roles of actors and intermediaries in socio-technical diffusion processes. It also considers the conflicts, power positions and ways of dealing with agency struggles in the process of introducing radical innovations into existing socio-technical contexts. But the critique is not only theoretical. This thesis is also engaged in exploring and devising new ways of socio-technical organisation. Off-grid RETs rural electrification is investigated from an explanatory perspective (understanding how these new socio-technical trajectories have evolved) and from a constructive emancipatory perspective (how new ways of socio-technical organisation can be promoted and put in practice). To that end, a case study based approach is adopted and cases are selected, organised and used in order to investigate, interpret and explain the diffusion of RETs in rural electrification. As Yin (Yin, 1994, p. 13) defines it, 'a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context; especially when the boundaries between the phenomenon and context are not clearly evident;' and in which multiple sources of evidence are used. These are the main reasons why comparative case studies are used in the thesis.

3.3.2 Case Study Selection

The thesis looks at off-grid RET projects implemented in the framework of rural electrification policies in Chile, particularly the Rural Electrification Programme (PER), co-executed by the National Energy Commission[13] (CNE) and the Undersecretary of Rural Development (SUBDERE) between 1994 and 2010, and subsequent policy programmes from 2010 to 2012 (i.e. PERyS[14] developed by the Ministry of Energy and the Energisation Programme of SUBDERE). This period is further extended backwards in the past to the beginnings of the 1990's in order to incorporate insights from initiatives and events developed prior the official launch of rural electrification policies in Chile.

Chile represents an interesting and informative case in the context of social energy research. The selection of energy technology innovations for rural electrification is a response to the fact that the rural energy regime has evolved in Chile due to a number of factors, notably: the liberalisation of electricity markets, the development of an institutional framework for rural electrification, technological and infrastructure developments and socio-economic imperatives. In addition, off-grid RET projects represent a space for variation and experimentation with new sustainable technologies, and as such constitute protected spaces fostered by policy initiative. Off-grid RET projects were initially executed by outsiders to the rural electricity regime (NGOs, aid organisations), but they have gradually been integrated into the policy framework, creating the conditions for learning, network building, and the coupling of expectations leading to further technological development, all of which suggests the emergence of a niche level of local practices.

Moreover, despite the relative macro-economic progress of Chile over the last 30 years, the country still has one of the most unequal income distributions globally and exhibits the highest income inequality amongst OECD countries (OECD, 2013, *The Economist*, 2012), which Chile joined in 2010. The thesis is interested in understanding socio-

[13] The Ministry of Energy took on all rural electrification roles assigned to the National Energy Commission from its creation in early 2010.
[14] PERyS stands for 'Rural and Social Energisation Programme' *(Programa de Energización Rural y Social'*in Spanish)

technical change dynamics and processes in the poorest and less advanced rural areas of Chile. As it is a developing country, Chile is therefore a good example of a new setting in which existing theoretical approaches can be applied with the aim of critically appraising the usefulness and robustness of socio-technical transitions and niche based theories in such contexts. Additionally, social energy research is a relatively understudied field in developing countries, so this research and its results can help better inform policy and practice in these countries.

One of the contributions of the selection of rural areas in Chile is that there are several project localities in Chile which have 'developing country' characteristics (and where most RET projects have been implemented), but there are also localities and institutions that may be less so and which even may exhibit more middle-income or developed country characteristics. These differences in terms of development dynamics between different scales and places, and the relationships between actors and institutions in those diverse contexts, allows for a more nuanced observation and analysis of niche processes and the interaction of niches and regimes under conditions that are considered current challenges in the study of sustainability transitions, particularly through the vantage point of economic geography (Truffer and Coenen, 2012, Coenen et al., 2012, Coenen and Truffer, 2012, Raven et al., 2012).

The thesis focuses particularly on the development of off-grid PV (solar photovoltaic) and wind electrification projects in central-northern and southern Chile respectively. These two technologies represent the RET options in rural electrification in Chile which have most support at a niche level. There are also some mini and micro hydro projects, but their development has not been as widely promoted as PV and wind during the implementation of the PER. As will be described in more detail in chapters 4, 5 and 6, PV projects account for the greater part of off-grid rural electrification executed in the country, and therefore represent to some extent a success in technological diffusion. Wind projects, on the other hand, in spite of being a promising technology, have not been so successful and there are even projects which have been identified and developed in an extensive pipeline that have not been executed at all despite technical, financial and institutional support alongside other protection measures were provided.

The development of these RET projects, regardless of their levels of success, have involved new actor networks, the emergence of guiding principles, diverse institutional, organisational and market structures, new infrastructures and technological configurations and the development of cognitive and learning processes. The aggregation of PV and wind projects constitutes two case studies defining socio-technical niche trajectories. PV and wind projects represent both successes and failures in technological diffusion. These two technologies are ‘new’ to the rural electrification context in Chile (and still niche technologies elsewhere, even in developed countries). The inclusion of successful and failed projects offers symmetry in the kind of explanations investigated (Bijker et al., 1987). Not all PV projects are successes and not all wind projects represent failures, but the research gives the same explanatory power to the successful and failed projects identified and analysed.

Because the cases selected represent promising socio-technical configurations not only in Chile, but in vast areas of the developing world, this research aims to contribute to and improve the knowledge base relating to the socio-technical dynamics, adoption and diffusion of innovations in such contexts. In the following sections (3.3.3 and 3.3.4), the sources of evidence and particular techniques and methods of data collection and analysis are further elaborated.

3.3.3 Case Study Protocol

As Yin (1994, p. 63) argues, the case study protocol is an important tactic in increasing the reliability of research. It contains the instruments, the procedures and general rules to be followed. A detailed procedure to select and conduct the analysis of the case studies is developed in this subsection.

a. Selection of data to be included in the cases

Particular projects within each case study have been identified through a detailed review of the policy and programme documentation available from the National Energy Commission, the UNDP office in Chile, GEF Project Documents and other archival records, such as RET project databases obtained from the National Energy Commission. Complementing these various sources of information, the researcher’s own experience and knowledge derived from previous involvement in policy design and implementation and engagement in several consultancy projects has allowed him to identify an initial list of PV and wind projects developed and/or implemented in the framework of the Chilean Rural Electrification Programme.

An initial list of RET projects was compiled and triangulated with key informants from the Ministry of Energy, the GEF Programme and the UNDP. Additional information about project details, such as relevant dates (identification, design, and implementation), key actors and institutions, sources of funding, delivery and management models implemented and so on was compiled. Using snowball techniques, additional key informants were identified and contacted with the aim of expanding the original list of projects. Once as robust and as complete a project database as possible had been compiled, all PV and wind projects were identified. Additional desk based research was conducted to retrieve and analyse all possible information and evidence from documents, archival records and interview notes from previous studies conducted into these two types of projects. The selection of these two cases responds to a logic that hopes to produce contrasting results and thus allow theoretical replicability (Yin, 1994). The PV projects case study will explain why and how a niche emerged whereas that concerning wind projects will explain why and how a niche has been more difficult to construct. In both cases, the same procedures, rules and instruments have been applied. A complete database of off-grid PV and wind-based projects is presented in Annex 1 and a summary of the list of these rural electrification projects is presented in Chapter 4.

b. Data Collection: Field work procedures and rules

The methodology involved the use of qualitative research methods to collect primary and secondary data. Case study evidence was primarily collected through interviews with a broad range of relevant actors, including central, regional and local government staff, international cooperation organisation officials and consultants, private sector electricity distribution companies, RET providers and technicians, O&M service companies, academics and researchers, RET users and NGOs, amongst several stakeholders.

Additionally, direct observation at RET projects sites have enabled the collection of relevant behaviours and the environmental or contextual conditions in which projects have been implemented. Direct field observation complemented evidence obtained from interviews and has been a good source for the triangulation of data. During field visits, physical artefacts have also been observed. Both casual field observation and knowledge of physical artefacts have been relevant sources of evidence which has enhanced understanding of the technology at work, and how project development and implementation have been evaluated by a broad range of actors, including rural community members, so as to appreciate and obtain a good grasp of the organisational and managerial arrangements to make RETs operational and fulfil community electricity needs. The problems and limits of the technologies and the emergence of additional application domains (e.g. additional or emerging energy needs) are further understood by means of the direct observation and analysis of physical artefacts.

Based on the RET projects database compiled in the early phase of the research, relevant actors and institutions were linked to each project. A list of key informants and actors was compiled from the list of field interviewees. This list was triangulated with GEF programme and Ministry of Energy staff to complement and assess the relevance of including these and other actors. Additional potential interviewees were identified through snow-ball techniques while conducting interviews. A formal statement or letter about the research project was drafted and sent to all potential interviewees explaining the purpose and aims of the thesis, the types of cases and projects being studied and requesting their collaboration to undertake interviews and field visits (when relevant). As a follow-up to initial contact with the potential interviewees, additional information, such as the type of questions to be asked, was sent to those actors who requested it. A complete list of interviewees is presented in Annex 2.

Pilot interviews were conducted with key informants from the GEF programme so as to assess the relevance of questions, to identify additional areas of interest and to test whether the instrument was adequate and easy to understand by interviewees. As a result, the interview protocol was thus reworded to make questions less theoretical and more connected with rural electrification practice.

Once the protocol had been finalised, interviews were scheduled in Santiago, where most actors were based, and field visits were coordinated with the collaboration of regional governments in Atacama, Coquimbo, Los Lagos (Chiloé) and with local authorities in northern and southern municipalities (San Pedro de Atacama, Empedrado). Project contacts introduced by key informants at the Ministry of Energy and the GEF programme were identified and communicated with prior to undertaking field visits. The researcher’s previous engagement in RET rural electrification was also helpful in identifying key informants and accessing interviewees.

Preparation of fieldwork and pilot interviews was organised in Santiago between January and March 2011. Field visits and interviews in Santiago and elsewhere were coordinated and implemented between March and June 2011. Project sites were visited in the regions of Coquimbo (Coquimbo SHS-PV project, PV based electrification of rural schools and clinics, PV-based water pumping stations), Atacama (Atacama SHS-PV project), and Los Lagos (Tac Island wind project, Desertores Islands wind mini-grids, Quenu and Tabón wind projects, Chiloé wind-based rural electrification plan). Local councils were visited in San Pedro de Atacama (Camar PV mini-grid, PV based electrification of rural schools, San Pedro SHS-PV projects) and Empedrado (SHS-PV projects, PV-based water pumping stations) in northern and central Chile respectively.

Interviews were mostly conducted in person but phone interviews were also arranged when face-to-face meetings were not possible. Field visits were organised, preferably with the cooperation of local council staff. Community members were visited in their homes or in community centres. Field visit and interview notes were taken while applying the interview instrument or during visits to rural villages. After every interview or field visit, notes were revised and complemented. Gaps and additional data needed were identified during the revision of notes and some interviews were followed up by email or phone.

c. Interview Protocol

The interview protocol was designed to investigate processes of RET niche development following the theoretical framework embraced in the thesis. Based on the review of the literature, theoretical insights were translated into the conceptual and analytical framework presented in section 3.2. The interview protocol is a response to the different analytical strands and questions have been organised to interrogate the following areas of the research:

1. General context and off-grid RET project development.
2. Internal niche processes and their role in project aggregation/niche creation (including intermediaries' roles and decision making processes).
3. Niche-regime interaction (including the interaction of niche and regime actors, protection measures at both niche and regime levels, conflicts, power struggles and the institutionalisation and stabilisation of niche practices against a backdrop of context developments).

Interview questions are generic and have been adjusted according to the role and position different actors have played in the development of experiments (off-grid RET projects). Overall, semi-structured interviews were conducted using a mix of open-ended and focused questions. This strategy made it possible to gain insights into the informants' opinions regarding events and RET experiments, and these produced propositions that fed back into additional areas of inquiry (Yin, 1994). In addition, when following specific questions, interviews permitted the corroboration of certain facts that have been already investigated (through literature or documents' review) or obtained from previously held interviews. Interviews were conducted in a broad range of settings, including interviewees' offices, project sites and neutral places (such as cafes, libraries, and technology-focussed congresses, events and fairs). Most interviews lasted between one hour and an hour and a half. Because of their deep knowledge about the whole rural electrification process in Chile (including traditional and off-grid RET options) and due to the need to triangulate findings from other interviews, key respondents, such as GEF and Ministry of Energy staff and authorities, were interviewed several times. In initial interviews, most of these actors provided additional documentation to be reviewed, so new interviews were also scheduled to discuss particular issues about new aspects relevant to the research.

- **Interview template:**

I. Context and project development

1. Under what circumstances and how did you/your organisation become involved in RET rural electrification?
2. Why and how is off-grid rural electrification different to grid extension from the perspective of your role in the process?
3. What sort of rules/methodologies/practices have been developed for off-grid RETs? Do they have a particular role in creating confidence between actors?

II. Niche Processes

- **Expectations:**

1. What has motivated your/your organisation's participation in off-grid RETs rural electrification?
2. What does your organisation intend to obtain from engaging in RET rural electrification?
3. What role do you think RETs will play in rural energy provision in the future (10-20 years)?
4. How do you think the directions of RET development might change and which new applications domains could emerge in this field?
5. In your opinion, what are the main reasons why RETs are a promising alternative for rural energy provision? Where do opportunities for and benefits of RETs have a more significant impact (social/environmental/economic impacts)?

6. Do off-grid RET projects fulfil social demands in rural areas? Are there other needs/demands which have not been considered in the development of projects (different application domains/interaction or complementarity of domains)?
7. Who are the main actors participating in the implementation of experiments/projects? Who of them has/have been most (and least) prominent and influential?
8. With what actors have you interacted most closely? Who represents the most distant actor with respect to your own intentions and the role you play/work you do?
9. What is your personal opinion about the success or failure of the projects in which you have participated?
10. Why do you think these projects can be catalogued as successful/failed? What are the main reasons behind their success/failure?
11. What types of resources (financial/technical/knowledge/social interaction, etc.) have been mobilised through interaction with other actors?

- **Learning:**

1. What types of learning (by trying, by interacting, by doing) have been important in the development of projects and diffusion of RETs? (Explore each type further with examples.)
2. What are the main lessons from the implementation of projects regarding...
   - Institutional arrangements and institutional roles in the electrification process?
   - ‘Configurational’ properties of RETs in rural electrification (different components of energy systems) ?
   - The role of standards, technical designs, infrastructure/user preferences and practices?
   - Management and operational schemes/contractual arrangements/economics of RETs?
   - Incentives and subsidies/financial mechanisms and options?
   - Rural electrification policies and other related policies/regulations/laws?
   - Access to information and knowledge about RETs (including availability of energy sources)?
   - Training of users and other actors ?

3. To what extent have previous projects with similar characteristics (technology/social context/geographical area) influenced the implementation of subsequent experiments/projects? What were the key lessons from previous experience?
4. Are there any political lessons that can be drawn from the rural electrification process in the region/area, beyond particular projects?
5. How have you interacted with other actors (users/policy makers/technology providers/energy companies/O&M technicians/etc) and what have you learned in the process?
6. How has technology performance changed during the implementation of different projects? Are there particular technical, economic and regulatory lessons that can be drawn from the experience?
7. What have been the key adaptations of the technology to fit local needs and local capacities?
8. To what extent has users' training affected technology performance?
9. How do you think that rural livelihoods have changed with the implementation of RET projects relative to rural communities without electrification/with electricity from the grid?
10. How has the implementation of projects affected the understanding of energy in rural development?
11. What are the crucial roles in successful rural electrification projects at the local/regional level?
12. What roles are most needed at the central level (from the perspective of government and energy companies)?

- **Network building:**

1. Who/which actors have been crucial in supporting and advocating off-grid RET projects?
2. What type of work have they done? With whom have they linked?
3. What type of activities have been the most important in bringing actors together to work in off-grid RET project implementation (e.g. conferences/ workshops /technical visits to other projects/ team building/ informal gatherings)?
4. Can you identify different roles/actors in different stages of project implementation (identification/development/implementation/operation)?

5. What type of resources have they contributed to the network of actors?
6. What type of capacities have they offered/received during project development/implementation?
7. How would you describe the flow of information/knowledge between actors?
8. How important is it that actors are geographically close to each other?
9. Do you think that social differences (different interests/political affiliations/social background) have impeded the smooth development of projects?
10. What are the main institutional adaptations/transformations you can identify in the rural electrification process?
11. When you think of off-grid rural electrification, are there important new actors (outside the regime/traditional stakeholders) playing key roles in this new field? Do they play a role in initial stages or do they become more active in later stages of project implementation?
12. When did regime actors become involved in off-grid rural electrification?

III. Niche-Regime Interaction

1. If you think of your experience 15 years ago, how well did rural electrification programme (policy perspective) and market (commercial perspective) serve the needs of the rural population?
2. Has the electricity service in rural areas improved during the last 2 decades? What are the main features (good or bad) of the electricity service?
3. In your opinion, how have distribution companies adapted their business practices and market structures to fit into smaller scale and decentralised generation models?
4. Do you think that RETs represent an opportunity or a burden for electricity companies? Why?
5. To what extent have policies, regulations and support mechanisms been adapted, created or transformed in the rural electrification regime, in the context of the introduction of off grid RETs in the last 10 years?
6. Do you think there is room for new uses (domains) for RETs in rural areas (for instance, telecommunications, irrigation, heat generation, agricultural industries, home/small scale entrepreneurship, etc)? What has the experience been up until now?

7. How would you catalogue the level of knowledge, experience and access to information about RETs in this area?
8. At the institutional level, what are the main barriers preventing the replication of RET projects? Are there other types of barriers?
9. Are there other experiences (projects/experiments) that have been influential in fostering the local development of technologies and projects?
10. Do RETs make any difference (e.g. social, economic or environmental effects) in comparison to conventional off-grid fossil fuel electricity generation?
11. What are the main conflicts relating to the way decisions are made about RET projects?
12. What are the main reasons for project success and failure in the experiments developed in the (geographical) area? What was learned from the first failures?
13. What is the role of the following stakeholders in rural electrification decision making? Do they have different roles depending on the technology used (RETs/conventional electrification)?
    - Central Government
    - Local Government
    - Energy Companies
    - Users

d. Interviewees

Semi-structured interviews were conducted with the broadest possible range of stakeholders who have participated in rural electrification projects in Chile. Both niche (RETs) and regime (conventional fuels or grid-based electrification) actors were considered at the local, regional and national scales. International actors and experts were also interviewed in the case of organisations such as the GEF Latin American Bureau and the UNDP, which have been crucial institutions supporting and pushing for policy and practice change in RET rural electrification in Chile.

A full list of interviews is presented in Annex 2. A summary of the roles and types of actors considered is shown as follows:

a) Public sector:

- Government Officials and Authorities at the central level
- Government Officials and Authorities at the regional level
- Municipal staff and local authorities (Council Mayor)

b) Private Sector:

- Electricity distribution companies
- Actors involved in the operation and maintenance of RET equipment
- Project developers and RET consultants
- Technology providers (RETs)

c) Co-operation Agencies and NGO's:

- International Cooperation Agencies (UNDP; GEF)
- Local NGO's
- Technical Support and Consultants

d) Research Organisations and Academics:

- Research staff at universities
- Technical institutes and technology research centres

e) Users and Community members:

- Families, farmers, head of schools and other users of RET systems in both niches (PV and Wind)

A total of 55 interviews and 14 field visits were conducted between March and June 2011. Some interviews were held as follow-up interviews during 2012 and 2013. Data from 2 additional interviews conducted during the preparatory stage of the research (2010) was also included in the data collection. Field visits combined direct observation, interaction and interviews with users and understanding of RET systems functionality (technological artefacts).

3.3.4 Data Coding and Analysis

Field evidence and data from interviews were coded and compiled in a data extraction template that reflected the variables and categories of the conceptual and analytical framework. Notes from fieldwork (interviews and project site visits) were reviewed and complemented after every interview and field activity was conducted. These notes fed into a meta-table (template) that contained all relevant concepts, processes and relationships as devised in the conceptual framework. An analysis of every interview code and a cross-analysis of all data was then undertaken so as to identify relevant and consistent opinions, contradictory events and processes and emerging concepts which contribute to the analysis and discussion of the cases.

The analysis was structured according to the overarching and sub research questions. These questions had been translated into analytical strands and a conceptual research design, presented in section 3.2, which looked at general context conditions, internal niche processes, intermediary action, niche regime interaction, decision-making processes within the rural electrification programme and the power positions of actors and the dynamics of struggles and conflicts in the diffusion of niche technologies. By following theoretical propositions consequently reflected in the conceptual framework, the analysis of data relied on a strategy of testing how relevant the literature is to RET rural electrification case studies in Chile and also to the production of new insights that complement and expand existing knowledge and causal explanations about the diffusion of new energy technologies in rural contexts.

The case studies have been analysed on the basis of evidence from multiple projects developed and implemented within each niche (PV and wind) collected in interviews and field visits. For each case study a pattern-matching logic was used (Yin, 1994). Predicted patterns (socio-technical trajectories, niche processes and niche-regime dynamics) are compared with empirically based information. This logic enhances internal validity. Rival explanations are anticipated for each case study as technological dissemination outcomes differ depending on the case (PV success and wind failure broadly speaking). This logic is complemented with an explanation-building analytical strategy that seeks to analyse the cases while building a causal explanation or links between processes and dynamics. This strategy is iterative by nature and involves, at least, starting from theoretical propositions (the conceptual framework based on the review of literature), examining case study evidence, revising theoretical propositions, re-examining empirical evidence in the search of new perspectives and so building casual links in processes and events studied (Yin, 1994). Finally, a cross-case analysis is conducted, based on the results of each case study.

Case study reports were prepared for the analysis of PV and wind diffusion in rural electrification and a detailed discussion of the results elaborated so as to shed light on additional determinants of niche construction. Case study reports and cross-case analysis discussion have been structured as a chronological narrative that identifies and traces sequences of events and processes which define the dynamics of niche construction, as well as similarities and differences between cases that feed back into a theoretical synthesis.

3.4 Limitations of the methodology

A number of methodological limitations can be identified. Careful thought has been given to how to address these within the research design. Where it has not been possible to address them within the time and resources available, care has been taken to state the limits of the findings as appropriate. Limitations can be identified in relation to both the nature of the methodological strategy and the specific contextual conditions in which the research is conducted. Case study research and comparative-historical methods are prone to shortcomings that have been carefully considered and to which corrective and/or adaptive measures have been applied.

The first of these limitations is linked to the research design. Although the strategy, conceptualisation of theoretical variables and analytical framework have been developed as comprehensively as possible, the complex nature of SNM research, including dynamic interactions between transition levels (Geels, 2002, Raven, 2005) poses limits to the study of all processes and dynamics in niche construction[15]. To overcome these shortcomings the conceptual and analytical framework has been created from methodological and analytical steps proposed by various scholars and used in studies conducted elsewhere, including the consideration of studies analysing transitions and niche construction in other developing countries. Additionally, the selection of appropriate projects within each case study has been done relying on archival records, official documents, interviews and the researcher's own experience. However, given their large, it was not possible to undertake field visits to every project, so on the basis of the triangulation of data and interviewees' opinions, the most representative projects in both niches were selected. Likewise, the selection of interviewees has attempted to be as inclusive and broad as possible, identifying key informants and actors in various sectors.

Another limitation of the methodology relates to the availability of evidence and information. As the research looked at processes which have occurred over the last 20 years, it is possible that some documents and other sources of evidence have been lost

[15] One of the shortcomings of the methodological design might come from the focus on niche and regime dynamics leaving background factors or landscape forces outside the focus of this study. See clarification on section 3.2 Conceptual Framework.

or could not be found. This is especially true in the context of rural electrification in a developing country, since the first projects implemented – and those that reveal initial failures, barriers and problems - were executed without any type of institutional support by independent institutions that might no longer exist or no longer have current operations in the country. No official evaluation reports or other documentation have been kept from those projects other than some grey literature from books and conference presentations. Evidence was collected relying on the memory and testimony of key actors and the best attempts were made to triangulate data with other actors and institutions involved in RET rural electrification.

On the other hand, little peer reviewed literature about RET and conventional rural electrification in Chile was found. Most of the written evidence of rural electrification in Chile consists of reports and documents (project proposals, technical designs, assessment and evaluation reports, policy statements and documents, methodological procedures and guidelines for policy implementation and so on) produced by government departments and international organisations. To avoid biased evidence (e.g. condescending evaluations, an exclusive or primary focus on reachable or easily achievable implementation plans), every attempt was made to systematically review various sources of evidence (both written and oral) and continuously reported events or processes (e.g. yearly implementation reports and independent mid-term and final evaluations of the GEF Programme).

Biased data and interview responses are an additional source of limitations. Some interviewees might have been subject to their feelings, interests and partial knowledge of events and processes. This limitation is often present in case study research and the triangulation of data through various interviews and additional documentation or archival records have been used to mitigate such limitations. The design of interview questions to focus on a given aspect of niche development or niche-regime interaction from different perspectives has facilitated a greater degree of impartial and broad evidence collection and analysis.

In addition to interviewee bias, the researcher's own experience might constitute a source of bias. For several years, the researcher has been involved in RET rural electrification in Chile and elsewhere. Appointments included GEF and UNDP engagement both as a consultant and a member of staff. On the one hand, prior experience and knowledge of alternative (off-grid RETs) rural electrification in Chile might influence a biased positive appreciation of the potential of RETs. On the other hand, previous experience has contributed to the researcher's understanding of the context, challenges and institutional arrangements around rural electrification in Chile. In undertaking this research, every attempt has been made to remain neutral in terms of attitudes, sensitivity and integrity during the course of both desk-based and field research.

Finally, time and resource constraints may have also limited the extent to which the methodology has been comprehensive. While this PhD has been funded by a scholarship granted by the Chilean Government and fieldwork was accurately organised, scheduled and budgeted, long distances between rural electrification projects, extended periods of field visits and a large number of interviews have consumed resources and time beyond what had been planned. PV projects in northern Chile are located more than 3,000 km away from wind projects in Chiloe. Research involved visiting remote islands and mountain villages that can only be reached by boat or after hours of off-road trails respectively. Collaboration with other projects and institutional support given by the Ministry of Energy contributed to easing resource constraints and facilitating access to key informants, particularly from regional governments. While these institutional links between an independent researcher and the Government of Chile might create additional limitations regarding biased responses or cautious attitudes, every effort was made to fulfil ethical considerations, such as maintaining independence from official studies and institutions and the anonymity of data.

3.5 Collaboration with other projects and engagement in research networks

During the course of this research several links to other projects have been pursued. The first of these projects was a study commissioned by the Ministry of Energy (Chile) to 'Identify Barriers and Gaps in the Development of Small Scale Renewable Energy projects at a Local Level'. In the engagement as lead researcher the collection of data through fieldwork and some additional interviews were undertaken to analyse the implementation of projects within the Chilean Rural Electrification Programme and other policy initiatives concerning access to energy in Chile. Conceptually, the socio-technical transitions perspective and the SMN framework were used as analytical and normative tools. The use of these approaches was useful in piloting and testing the appropriateness of the theoretical and analytical strands proposed in this thesis. Study results were presented to the Chilean Government, UNDP, World Bank and IADB staff. Complementing an analysis of barriers and gaps, an Action Plan (at the national scale, including a Pilot Plan of regional relevance) proposal was developed to contribute to policy and practice development in the context of inclusive energy access policy in Chile.

The second of these projects was an IDRC[16] research project implemented by the Institute of Science and Technology Studies (IESCT) at the University of Quilmes (Argentina) and the Policy Innovation Analysis Group (GAPI) at University of Campinas in Brazil on 'Technologies for social inclusion in Latin America'. This aimed at (theoretically and methodologically) advancing the understanding of 'social technologies' and their role in fostering inclusive development in the region. The investigation mapped experiences and institutional capacities for the development of social technology projects across the region in different sectors (energy, housing, food and agriculture, etc) and developed a network of researchers and practitioners in Latin America. As part of this project, the researcher was engaged in undertaking analysis of renewable energy projects in Chile. The results were compiled in a case study paper presented to IDRC which contained a preliminary version of case study reports which were later translated into the case study chapters of this thesis.

3.6 Chapter conclusions

This chapter has developed a detailed conceptual and analytical framework that operationalises theoretical concepts and the particular approach taken in this thesis into a research design, strategy and analytical process whose objective is to undertake research into the particular context of off-grid PV and wind rural electrification in Chile. Starting with a revision of the aims and objectives of the thesis, the conceptual framework developed and presented in section 3.2 builds on all the theoretical insights reviewed in the previous chapter and is put into practice in three analytical strands: i) individual projects, ii) aggregation of projects into niches and iii) niche-regime interaction.

Case study justification and selection has also been covered in this chapter. Based on the proposed analytical framework, the research design describes detailed methods, tools, techniques and sources of data, together with the process undertaken to analyse the evidence collected and organised in 2 case studies. The limitations of the methodology and the steps taken to minimise or mitigate these shortcomings have also been discussed. In the next chapter a general context of the electrification process in Chile is

[16] The International Development Research Centre (IDRC) is a Canadian Crown corporation established by an act of Parliament in 1970 to help developing countries find solutions to their problems (http://www.idrc.ca)

presented, offering a deeper discussion of the last 20 years during which RETs have been promoted and off-grid projects implemented throughout the country. Case studies, based on fieldwork reports, are presented in subsequent chapters.

4. Rural Electrification Context in Chile

4.1 Introduction to the chapter

This chapter describes the evolution of electrification in Chile. The argument begins with the introduction of the first electricity generation units for public lighting in 1883 in Santiago and how this influenced the structure of the markets, governance and networks of actors around electricity systems within Chilean society. As the focus of the chapter is on the rural electrification regime in Chile, the description moves to the development of rural electrification in the last half of 20th Century and then rural electrification is contextualised within the liberalisation of the electricity sector at the beginning of the 1980s. Particular attention is given to the institutionalisation of a rural electrification regime through the creation of specific policy instruments and governance arrangements, i.e. the Rural Electrification Programme (PER). Supporting mechanisms, financing schemes, assessment and evaluation methods and processes are analysed in detail, together with an overview of rural electrification progress in the last 2 decades. Finally, particular attention is given to the development and execution of PV and wind-based rural electrification projects throughout the country in the last 20 years.

4.2 The Origins of Electricity in Chile

The first evidence of electricity use in Chile dates back to 1851 when telegraph pulses were powered by generation units in Santiago and Valparaíso. However, the magic of lighting really captured the attention of Chilean society with the introduction of a public electricity service in the *'Plaza de Armas'* (the central square) in Santiago in 1883. Electricity provision expanded rapidly in cities and towns during the first decades of the 20th century. As a result, most affluent people discovered the benefits of electricity and it clearly started to change the domestic and working habits of a modern society (Biblioteca Nacional, 2013, Chilectra, 1996).

The relentless activity of dozens of small companies triggered the development of electricity in urban settings. Many of those companies were owned by foreign investors, such as the London based Parrish Brothers, which reached an agreement with the Municipality of Santiago in 1897 to implement an electric tram system. The contract was soon transferred to the Chilean Electric Tramway and Light Company, also registered in London, which started the construction of three direct current (DC) generation units of 600 kW, but as the challenge of electrifying the capital was monumental, the '*Sociedad Alemana Trasatlántica de Electricidad'* (German Transatlantic Electricity Company) entered into the project to build the 'Florida' power plant (13.5 MW) which started operation in 1910. The Chilean owned '*Compañía Chilena de Electricidad Industrial*' (Chilean Industrial Electricity Company) deserves a special mention given the geographical scope of its operations, from San Bernardo, on the outskirts of Santiago, to Temuco in the Araucanía region (Chilectra, 1996, Biblioteca Nacional, 2013). But it was not only the electricity companies that defined the emergence of the power sector in Chile, as many mining companies started to build and operate their own power plants with the aim of improving and changing the nature of mining operations, mainly in the Northern regions of the country (CORFO, 1952).

The 1920s were years of intense activity. After World War I shares in the '*Sociedad Alemana Trasatlántica de Electricidad'* were auctioned in London and bought up by Chilean capital gathered in the newly formed '*Compañía Nacional de Fuerza Eléctrica'* (Electric Power National Company). This latter company and the Chilean Electric Tramway and Light Company were then merged into the *'Compañía Chilena de Electricidad Limitada'* (Chilean Electricity Company Ltd.), traditionally known as Chilectra S.A., the main electric company in Santiago and central Chile in the 20th Century. In addition to participating in the rush of activity within Santiago, the company built the first transmission line between the capital and the coastal cities of Viña del Mar and Valparaíso between 1921 and 1924, sowing the seeds for what would become the national grid (interconnected system) in the future (Chilectra, 1996).

In 1925, with the increasing expansion of electricity generation, transmission and distribution activities, the government began to regulate the sector for the first time through Decree Law Nº252 or 1st Electric Services Act. This provided a uniform regulatory framework which established the conditions which had to be fulfilled by companies which wished to compete in the supply of electricity (Chilectra, 1996, Biblioteca Nacional, 2013). By the end of the decade, electricity services were being used by industrial, commercial and residential consumers in urban areas, some rural users and the tramways, which had grown steeply to reach more than 9,000 km of tramline. Electricity companies also opened shops to offer electrical appliances, a crucial step forward in cultural changes in a wide social sense (Chilectra, 1996).

The following years were characterised by the enactment of regulations and by new mergers and acquisitions. The South American and Foreign Power Co. (SAPCO) took over the '*Compañía Chilena de Electricidad'* and merged it with many other smaller regional electrical companies. SAPCO started negotiations with the government on tariff regulations, water rights concessions and settlement of municipal debts. At the same time, state involvement in the electricity sector was deepened. Tramlines were transferred into state ownership, separating the electric transport business from the electricity market, and in 1931 the '*Decreto Fuerza Ley Nº244*' (Decree with Force of Law) was enacted to frame what became the second Electricity Services Act (CORFO, 1952). This new law granted regulation of tariffs to national government, withdrew municipal authority over electricity services and made it easier for customers to demand an improved service. In 1935 the state obtained representation on the board of the '*Compañía Chilena de Electricidad*', signalling a stepping-stone in the involvement of the state in planning sector growth.

But it was only in the late 1930s that rural electrification started to take off when rural electric cooperatives were formed in response to demands for support for agricultural development in the fertile lands around the cities in the central valleys of the country (McAllister and Waddle, 2007). Initially the '*Compañía General de Electricidad Industrial*' (CGE) focused on the electrification of regional capitals in the central valley and acquired small electric companies in the cities of Concepción and Talca. In the following decades rural electrification made slow progress as the customer base was still very limited[17].

State involvement in the sector was enhanced in 1940s. The *'Empresa Nacional de Electricidad'* (ENDESA), a vertically integrated state-owned corporation, was created in 1943 as a subsidiary of the stated-owned *'Corporación de Fomento de la Producción'* (CORFO)[18] (Basañes et al., 1999). In 1945 the state became a shareholder in SAPCO through the acquisition of the tram services (Beyer, 1988). The downside of greater state involvement was that between 1950 and 1960 political pressures tended to keep electricity prices low, thus creating financial distress in the industry. ENDESA played a crucial role as the agent in charge of strategic planning in the electricity industry, expanding generating capacity and transmission infrastructure and reaching isolated areas (Basañes et al., 1999). It did not, however, meet the needs of an ever growing market.

Subsequently, in 1959 the third Electricity Services Act was passed *('Decreto Fuerza Ley Nº4'*) (Beyer, 1988). In that period, an ample investment programme was agreed between the government and Chilectra under the new legal framework, covering the

[17] McAllister and Waddle (2007) report that the largest of the rural electric cooperatives had less than 25,000 customers at the time of the sector reform of the 1980s.
[18] CORFO is often referred to as the Industrial Development Agency in Chile. The literal translation is Production Promotion Corporation.

construction of power plants, substations, transmission lines and distribution infrastructure. The *'Renca'* power station started to operate in Santiago in 1962 and the *'Ventanas'* power complex near Valparaíso was launched in 1964 and expanded in 1977 (Chilectra, 1996).

On August 1970, a few weeks before Salvador Allende was elected president, CORFO was allowed by law to acquire utilities and so Chilectra was nationalised together with other 51 large distribution companies, virtually nationalising the entire industry (Basañes et al., 1999). During the *'Unidad Popular'* (UP)[19] government (1970-1973) industry profitability and investment plans were affected by the political turmoil and economic stagnation which ended up in the tragic *coupe d' etat* of September 1973. The rise of the military dictatorship profoundly changed the values and ideas that had driven the sector over the previous decades and a radical neo-liberal sector reform was planned and implemented in the late 1970s and early 1980s.

4.3 1980s: Sector Reform and Liberalisation of the Power Market

The National Energy Commission (CNE), the highest energy policy entity[20], and the Superintendence of Electricity and Fuels (SEC) were created in 1978. The role of the former was to provide policy guidance and strategic planning while the latter has since been the energy sector enforcement agency. Both have regulatory powers. With the creation of these new institutions, the government relinquished its role as public service provider and assumed instead a regulative, enforcement and guidance role. Moreover, this new institutional architecture was accompanied by more fundamental legal and governance frameworks.

Amongst these, the fundamental structure under which property rights and commercial information are given robust protection is provided by the 1980 Chilean Constitution, enacted by the military government (1973-1990). As Basañes et al. (1999) and Pollitt (2004) argue, the legal system is very old-fashioned, preventing the judiciary from acting in pursuit of reasonable cause and guiding its actions based on tangible proof of illegal activity. Additionally, the constitutional arrangements and the specificity of the

[19] UP was the left wing political coalition behind Salvador Allende's government between 1970 and 1973

[20] The National Energy Commission (CNE) has been the principal governmental institution in charge of guiding policy and advising on energy issues since sector reform. In 2009, the Ministry of Energy was created by Chilean Law 20.402, and took over – and expanded - some of the competencies of the former Commission. Until the creation of the Ministry, CNE had been under the direction of either the Ministry of Economy or the Ministry of Mining (which was then referred to as the Ministry of Mining and Energy), in accordance with presidential priorities.

regulation of laws designed under the military government have limited the scope for interpreting legal frameworks and made changing them very difficult. These structural political pillars have provided great stability to the electricity regime over the last three decades.

Under the constitutional framework, a new Electricity Services Act was introduced in 1982. The Electric Services Act (*'Ley General de Servicios Eléctricos'* or *Decree with force of Law Nº 1, 1982*) thus created the fourth and most rigid framework for the electricity sector ever designed in the country. This law highlights the techno-economic rational that allowed the subsequent liberalisation and privatisation of the sector, and the divesture programme that took place in the late 1980s and 1990s (Pollitt, 2004). The current Electricity Act (in place since 1982 and amended in 1999, 2004, 2005, 2009 and 2012) allowed private companies to enter the electricity sector again. Until then, the state controlled and had ownership of 90% of electricity generation, 100% of transmission and 80% of distribution (Moguillansky, 1997). The core ideas behind the reform of the sector are the vertical disintegration of companies operating in generation, transmission and distribution of electricity and the creation of power (electricity) markets (Pollitt, 2004). Designers of the reform, many of whom had been educated in the neo-liberal Chicago school of thought, concentrated on three main areas: i) the separation of generation and distribution companies which traded power based on cost recovery, ii) the creation of an efficient marginal cost pricing dispatch system and iii) the creation of a power trading system (SPOT market) among generators to allow them to fulfil supply contracts with their customers (Moguillansky, 1997).

Following the break-up of the previously integrated stated-owned electricity companies, regional power markets were established in 1986 under the management of independent system operators ('*Centros Económicos de Despacho de Carga'*-CDEC). These are – however - formed by the main electricity companies (limiting *de facto* their independence). There are currently two main interconnected systems, the SING (3,963 MW), covering the northern regions where thermal generation and industrial (mining) consumers are key features, and the SIC (12,365 MW), covering central and southern regions where a mix of hydro and thermal generation provides electricity for most of the population. Additionally, there are two smaller electricity systems in Aysén (47 MW) and

Magallanes (100 MW)[21]. Figure 4.1 provides a graphic representation of the power market and infrastructure in Chile.

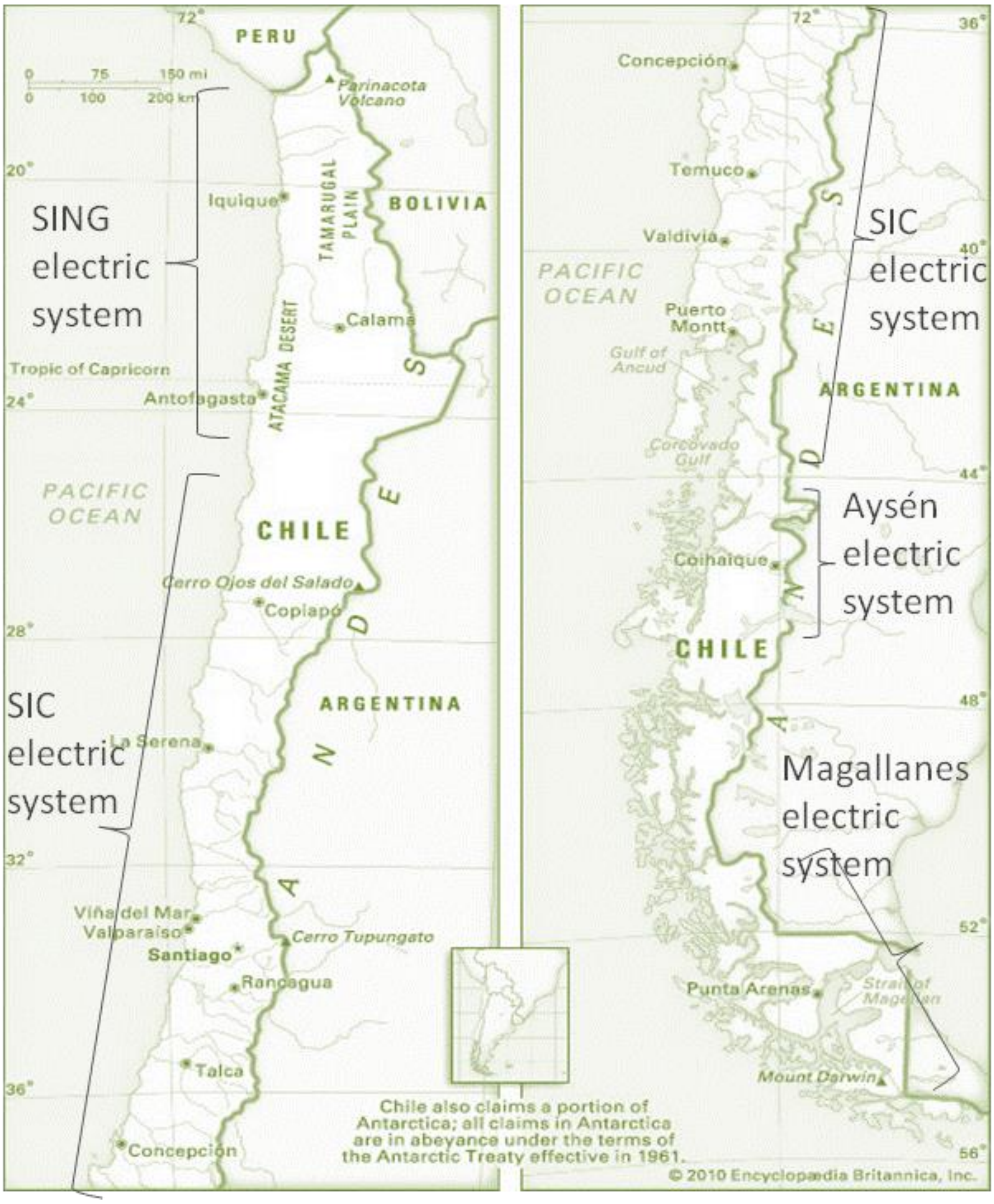

Figure 4-1: Interconnected Electricity Systems (National Grids) in Chile. Author's elaboration based on CNE 2012.

Privatisation was undertaken on the assumption that generation was a potentially competitive market and that transmission and distribution were local and natural monopolies (Basañes et al., 1999). In 1980, the government sold two subsidiaries of Endesa which operated in the south (Frontel and Saesa), and then this extensively

[21] Figures are updated to Dec, 2011. Data from CNE 2012 (www.cne.cl)

integrated company was split into 14 companies: 6 generators (Endesa - which kept ownership of the transmission system in central Chile - Colbún, Pehuenche, Pilmaiquén, Pullinque and Edelnor – in the northern system), 6 distribution companies (Emelat, Emec y Emelectric, Emelari, Eliqsa y Elecda) and 2 smaller isolated companies (Edelaysén and Edelmag) which provided generation and distribution services in the southernmost regions of the country. Chilectra, the major electricity company servicing Santiago and other central regions was split into one generation company (Chilgener – Gener since 1999) and 2 distribution companies (Chilquinta in the Valparaíso region and Chilectra Metropolitana in Santiago) (Basañes et al., 1999).

Most of the privatisation of electricity companies was carried out between 1986 and 1989. Four mechanisms were used: i) the selling off of the generation and distribution subsidiaries of Endesa through public bidding (Saesa and Frontel cases in 1980); ii) the auctioning of blocks of shares in larger companies on the stock exchange market; iii) sales of shares to public employees and civil servants at a price below the normal market price (also called 'popular capitalism', the mechanism through which most of Endesa and its transmission system was privatised); and iv) the selling off through start-up investment of two distribution companies (Chilquinta and Chilectra Metropolitana), in which customers accessing the network were repaid in shares for their reimbursable financial contribution (Basañes et al., 1999). According to Pollitt (2004, p.7) the privatisations of electricity companies yielded US$1,200million in year end 1995 prices. Further privatisation of the few companies still controlled by state agencies was done in the 1990s and in 2001 the remaining third of Colbún (35.6%) was completely privatised through an auction on the Santiago Stock Exchange.

These structural reforms allowed new actors to sustain expansion plans based on a clear economic rationale, which yielded improved financial returns and improved efficiency performance. However, financial performance was respectable before sector reform and a huge redundancy programme had been implemented in the late 1970s, something which helps explain efficiency gains (Pollitt, 2004). One of the most notable outcomes of the liberalisation process has been the great expansion of the electricity system. SIC's installed capacity grew from 2,713 MW in 1982 to 6,991 MW in 2004 (4.4% p.a.) to 12,365 MW in 2011 (8.5% p.a.), while installed capacity in the SING has expanded from 428 MW to 3,634 MW (10.2% p.a.) to 3,963 MW (1.3% p.a.) in the same years. Electricity supplied in the country has increased on average by 6.2% p.a. to 61,973 GWh in 2011, outstripping economic growth in the same period (GDP grew at a rate of 4,7% p.a. on average between 1982 and 2011) (Pollitt, 2004, Ministerio de Energía, 2012).

Electric grid expansion has resulted in market concentration and has largely been driven by the pursuit of profit by electricity companies. The former has had implications for the increasing integration of the electricity market after privatisation through subsidiary companies controlled by powerful economic groups and corporations operating in the different subsectors of generation, transmission and distribution. Endesa, now controlled by Endesa España (Spain) and Enel (Italy), Colbún and AES-Gener concentrate a share of 84% of total electricity generated in the SIC. In the SING, likewise, 94% of the generation market is controlled by only three firms (E-CL, AES-Gener and GasAtacama). (Maldonado, 2011).

High concentration gives existing firms dominant market power and hinders the entrance of new actors. Moreover, high concentration in the market has also inhibited the expansion of electricity systems to less profitable sectors such as low population density and distant rural areas. In fact, although the electricity market grew rapidly following sector reform, it did so mainly in urban, peri-urban and adjacent rural areas. By 1982, 95% of urban households had an electricity supply compared to only 38% of rural families (Pollitt, 2004). Therefore growth came from increasing intensity of demand rather than from the extensive expansion of the electricity system. Soms (2010) argues that in a context of profound neo-liberal reforms, which promoted the contraction of the role of the state during the 1970s and 1980s, social investment programmes - including rural infrastructure - were reduced.

Market concentration was also a consequence of sector reform in the distribution of electricity although to a lesser extent than in generation. The previously high number of small distribution companies and cooperatives decreased by a third in the two decades following privatisation and many of the cooperatives and local distribution utilities were bought out by more powerful utility competitors. The process continued in the 2000s and today three groups, CGE, Chilquinta and SAESA, concentrate most of the electricity distribution at a regional scale, including urban and rural areas[22]. This shift towards what McAllister and Waddle (2007) characterise as market consolidation was coupled with an internationalisation of the ownership of electric companies. SAESA, a powerful

[22] Apart from these three companies which operate in all regions, Chilectra S.A. is the major distribution company providing electricity services to the metropolitan region of Santiago, and which accounts for more than 45% of distributed consumption. It belongs to Enersis Group, owned by Endesa Spain and Enel.

conglomerate controlling distribution, transmission and generation in the southern regions of Araucanía, Los Rios, Los Lagos and Aysén is owned by Ontario Teachers Pension Fund and Alberta Investment Management Corp (SAESA, 2011). Chilquinta, dominating the distribution market from Valparaíso to Concepción (practically all central-southern fertile valleys and cities), is now owned by Public Service Enterprise Group of San Diego, California (PSEG) (CHILQUINTA, 2011). Last but not least, CGE Group, controlled by Chilean capital and which distributes electricity to more than 2,400,000 customers (40% of electricity sales) between the very northern Arica and Los Ríos region in the south and the market in Magallanes region, has attained a powerful position in the electricity sector over the years (CGE, 2011).

4.4 Rural Electrification Following Sector Reform

Access to electricity in rural areas increased gradually in the 1980s thanks to the persistence of several small distribution companies, mainly rural electricity cooperatives, and a couple of larger utility companies. Rural cooperatives were small and played a fundamental role in mobilising resources and creating the organisational and governance structures necessary to undertake important capital investments in electricity and other infrastructure projects. Cooperatives were also a central actor in rural society, since they provided ancillary services such as favourable and flexible credit for domestic and agro-processing equipment or agricultural inputs. Cooperatives also provided water and irrigation services and supported health and education activities within rural communities. Rural cooperatives acted as key intermediaries in aggregating demand to ensure fair and low prices. Their ability to keep electricity and other services tariffs low was also ensured by their involvement in a series of commercial activities in rural areas (McAllister and Waddle, 2007). Many of the cooperatives grew with the industrialisation of agriculture, such as the fruit and dairy industries in the central and southern regions of the country.

However, the consolidation of the electricity distribution sector after reform had important effects on the structure and geographical scope of the market in the 1980s. As the electricity distribution activity concentrated around rent seeking companies (whose values contrasted strongly with those of many of the electricity cooperatives in rural areas in earlier years), extension of electricity services made slow progress towards outlying and poorer rural areas. By 1992, only about 50% of the rural population had access to electricity services. But the reforming wave also had profound implications for the governance of rural electrification. Firstly, the institutional arrangements were reorganised towards a more decentralised model. Responsibility for infrastructure planning, implementation and oversight were transferred from the national administration to the Regional Governments (GOREs)[23]. National government institutions assumed a role of policy planning and guidance, allocating funding to regional budgets and designing planning assessment tools. In practice, GOREs have led the development of rural electrification projects through a strict process of formulation, assessment, decision making and execution (which is further explained in section 4.5).

Together with the institutional changes, a normative and regulatory framework was devised in the privatisation process. CNE and SEC define technical standards and set price caps for different tariff categories. SUBDERE, the Undersecretary of Regional Development, which is answerable to the Ministry of Interior, allocates funding from the Regional Development National Fund (FNDR)[24] to the GOREs once projects have been granted planning permission in accordance with MIDEPLAN's rural electrification assessment methodology.

The Electricity Act (1982) defined a new market and service provision structure. Within this framework, electricity distribution providers (private utilities or cooperatives) could only obtain the right to use public property or be granted public right of way for the construction of electricity lines and other infrastructure by becoming concessionaires. As a concessionaire, a distribution provider was subject to regulated tariffs as defined by the CNE and had the obligation of servicing users within the concession corridor or area (depending on how the concession was formed) in perpetuity. In exchange, these entities alone had non-exclusive rights.

By 1990, most of the cooperatives had applied to become concessionaires, something which forced them to compete with more powerful and normally better organised private distribution companies. These latter utilities had long-established project management practices and professional staff, as well as several sister companies providing construction and other ancillary services, and were more experienced in competitive markets; cooperatives, by contrast, relied on small organisational structures providing a number of rural infrastructure and other services in a far less efficient way.

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[23] GOREs are headed by a regional governor (*Intendente regional* in Spanish), who is appointed by the President of the Republic. The regional council (CORE), the principal decision making body at the regional scale, also headed by the *Intendente,* is formed of a board of regional councilors who are elected by the municipal councilors, who are respectively elected through direct vote.

[24] FNDR is the main vehicle for funding infrastructure and other services at a regional scale. As such, it is the principal organ through which the State fulfils its subsidiary role.

The CNE also decreed the separation of electric and non-electric activities (which affected primarily rural cooperatives) and the strict reporting of financial operations for monitoring and tariffs definition purposes. In practice, these obligations prevented the use of cross-subsidies between different business units within cooperatives and caused financial losses in their electricity distribution departments. This further deepened the privatisation of the sector and the emergence of powerful private electricity conglomerates.

During the first years after the reform, the restructuration and consolidation of the distribution market allowed for market competition and cost efficiency in both the provision of infrastructure and electricity services. However, with the later rise of quasi-monopolistic distribution companies, powerful utilities have been cross-subsidising *de facto* as they can outbid proposals in areas where they have competitors and overcharge the state in projects submitted for capital subsidy in areas where they are monopolies (McAllister and Waddle, 2007, Interview 21).

As part of the decentralisation process, the government devised a subsidy scheme for public infrastructure projects, including rural electrification. Capital subsidies, funded through the FNDR, were established to fund grid extension. Normally those subsidies have covered 70% of the cost of infrastructure, while the remainder is split between distribution companies (20%) and users (10%). This is recognised as one of the main reasons for the heavy engagement of distribution companies in rural electrification in Chile, a process far less profitable than the growth of electricity consumption in urban areas. As McAllister and Waddle (2007, p. 204) explain, companies were able to add infrastructure at a fraction of its actual cost, profiting from construction costs (as they would contract related subsidiaries for the works) and without worrying about low electricity sales in the rural areas, which would soon experience demand growth as they developed more rapidly after infrastructure was in place. Additionally, companies could benefit from fiscal credits equivalent to the total value of project infrastructure, while having spent only a fraction of actual costs.

As a result of the regulatory and legal changes in the electricity sector after liberalisation and privatisation, electricity access in rural areas made only decent progress in the 1980s, expanding service towards those rural areas in which distribution companies benefited the most and financial returns were acceptable. This market driven process meant that isolated communities (in which projects were more expensive) and rural areas which were more difficult to electrify (due to technical and geographical challenges) were lagging behind. This was a particular problem in very sparsely populated regions, such as Coquimbo in central northern Chile, and southern regions characterised by dense forests, mountains, isolated islands and extreme weather.

4.5 Regime Stabilisation: Chilean Rural Electrification Programme (PER 1994-2010)

The return to democracy in 1990 brought back to the political arena the need to revitalise depressed poor rural areas and so ensure a fairer distribution of the benefits of the development process the country was experiencing. The still heavily polarised political transition context in which the country was embedded provided the framework for the new poverty reduction policies and rural infrastructure programmes. An example of the latter was the launch of the National Rural Electrification Programme (*Programa de Electrificación Rural* - PER) in 1994. On the one hand, liberalisation of the electricity market had not evaluated the provision of adequate incentives to extend access to electricity to low density population and comparatively poorer rural areas; on the other, there was a widespread feeling that the market aperture and increasing wealth levels experienced by the country were not reaching all citizens equitably. This led the government of President Eduardo Frei to launch an ambitious and aggressive rural infrastructure programme at the heart of which was rural electrification (Poch Ambiental, 2009).

As mentioned before, by the beginning of the PER in 1994, the rural electrification rate was slightly higher than 50%. In its first phase (1994-2000) the programme aimed at increasing access to electricity to 75%. Adopted as policy, the programme's targets were later raised to 90% by 2006, at both national and regional scales during the presidency of Ricardo Lagos, and 96% by 2010, by the government of President Michelle Bachelet, when the PER was reformulated into a broader Access to Energy Programme[25].

[25] The PER was implemented between 1994 and 2010. The lessons from its implementation and the identification of new needs and application domains beyond the residential sphere led to the creation of two new governmental programmes: the Rural and Social Access to Energy Programme (PERyS, *Programa de Energización Rural y Social*) under the responsibility of the Energy Access and Equity Division (DAEE) of the Ministry of Energy (former Rural Electrification Unit of the National Energy Commission) and the Rural Energisation Programme (PE, *Programa de Energización Rural*) in charge of the Undersecretary of Regional Development (SUBDERE) of the Interior Ministry.

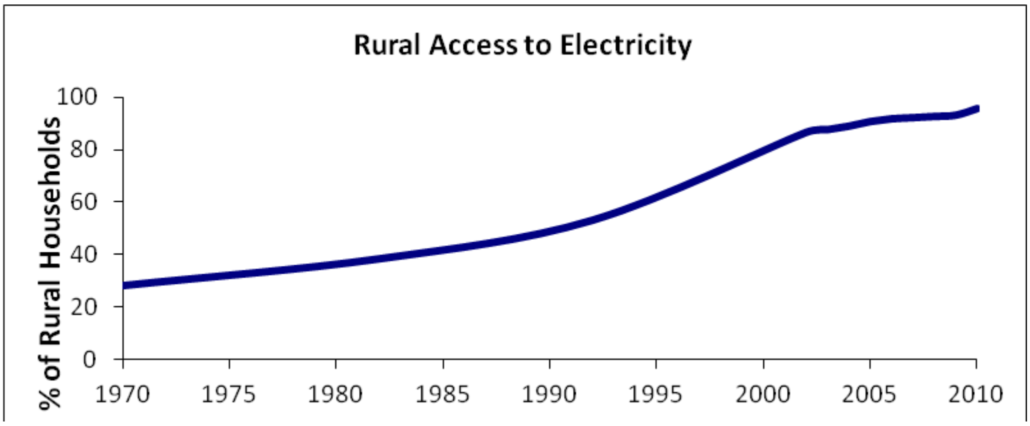

Figure 4-2: Rural Electrification Progress in Chile (1970-2010)

Source: Author's elaboration on the basis of data from Ministry of Energy (2010)

This government-led initiative responded to the policy objectives of poverty reduction and social inclusion as well as, to some extent, economic development and environmental protection (Government of Chile, 2005, Argomedo, 2009). However, as the focus of the programme was on rural residential electricity services, success indicators have been based on the number of residential connections, while the impact on rural business development has been of secondary importance (McAllister and Waddle, 2007).

As a subsidy scheme already existed (SUBDERE's FNDR) but had been underutilised to expand rural electrification access, the PER redefined priorities, established long term objectives, created specific supporting mechanisms and assisted projects that would have not been undertaken by the private sector as their financial returns were negative. Subsidies were reorganised in such a way that the PER aimed at efficiency (least cost), efficacy (targeted towards the poorest and to the projects most in need of financial support) and minimal market distortion (McAllister and Waddle, 2007).

PER's policy design established an institutional framework in which project development processes and actors' roles were clearly defined. Initially, all policies, guidelines and tools were designed for conventional grid extension projects. Aligned with a more decentralised governance structure, actors involved in the electrification process encompassed institutional agents from both the central and regional governments, local municipal authorities, distribution companies (mainly distribution utilities but also rural electric cooperatives) and rural communities. Overall, the institutional structure reproduced market dynamics and the power positions of those incumbent actors in the electricity distribution regime in Chile.

The rural electrification process was intended to be as decentralised as possible, with a crucial role for rural communities, which organised themselves into rural electrification committees (*comités de luz*) which identified lighting needs and requested the support of the local council to develop projects. The municipality then formulated a project with the support of and inputs from distribution utilities or cooperatives. The process had to follow the guidelines of the rural electrification project assessment methodology designed by the Ministry of Planning and Cooperation (MIDEPLAN's Rural Electrification Methodology). Once a project was designed and assessed it was included in an official project database (*Banco Integrado de Proyectos*-BIP) and submitted to the respective GORE for review and approval.

Each GORE administered its projects portfolio according to the following process. Once included in the BIP, a rural electrification project was reviewed by the Regional Ministerial Secretariat of MIDEPLAN (a regional unit called SERPLAC). Within this regional unit, an 'energy sector specialist', responsible for all energy projects, reviewed the applications and decided whether a project should be granted planning permission. This process normally involved interaction and consultation between SERPLAC, municipalities, other regional authorities and distribution companies.

If the project was approved (and hence received a Satisfactory Technical Recommendation, 'RS'), it was submitted to the *Intendente's* bureau, which has the authority to prioritise projects from all sectors (i.e not only rural electrification projects), and consequently present them to the Regional Council (CORE) for its budgetary allocation (subsidy) and approval. In those regions with the highest rural electrification deficits, additional support and management of the rural electrification process was offered by dedicated units called Technical Units for Rural Electrification (UTERs)[26]. The creation of this mid-level institutional structure was a prerequisite laid down by the Inter-American Development Bank (IADB) for the approval of a loan that would finance the implementation of PER's projects. UTERs were created in Coquimbo, Araucanía and Los Lagos regions.

Once a project was finally granted approval and funding, execution and oversight activities became the responsibility of either rural councils or regional governments, depending on the administrative scope of the project. The respective institution, most

[26] UTER stands for Technical Rural Electrification Units, which were established in several Regional Governments to manage the rural electrification process in coordination with central and regional authorities.

usually the local municipality, contracted the works to the concessionary company or through a public bidding process if no concession area had been established (this was the case with off-grid electrification and some grid extension projects).

Although the Rural Electrification Programme was intended to be decentralised, central government institutions have played a key role in its development. SERPLACs are located at the regional scale, but they answer administratively to MIDEPLAN (a centralised ministry) and come under the latter's authority. CNE (currently the Ministry of Energy) has coordinated actors and institutions at the regional, municipal and central scale with regard to PER implementation since its inception in 1994, playing a vital role in aligning visions and lobbying for projects to be developed. CNE has also provided technical assistance, particularly for off-grid rural electrification projects. Finally, SUBDERE, the main central government institution supporting regional development, has been the pivotal actor linking the Treasury and GOREs in allocating resources. Additionally, in 2003, SUBDERE assumed institutional leadership as PER coordinator (now co-implemented by the CNE), because this institution was the official recipient of the IADB loan for PER implementation.

The idealised PER project cycle design has been, however, subject to tensions and frequent negotiations between actors. Community participation has been limited and electrification committees have been formed only as a prerequisite to the formulation of a project, in a process driven by municipal direction rather than through a bottom-up process of social coordination and cooperation. As such, they have in general fulfilled an administrative step rather than formed a long-term governance structure. (Poch Ambiental, 2011). In some cases, the political influence played by rural committees has yielded results and local authorities have backed community demands and have supported project development over long periods of time, such as in the case of the San Pedro de Atacama council (Interview 31). However, in many other cases, rural electrification committees have been influential neither in the process nor in the outcomes of rural electrification in their regions. In these cases, rural electrification projects have been used instrumentally for political reasons, as is the case with many projects in Chiloé, or have been implemented in a top-down manner, even at the local scale. In such cases, rural electrification has been driven thus by rural municipalities or distribution companies (Poch Ambiental, 2011).

Notwithstanding the tensions and uneven regional progress, PER results are considered as utterly successful, at least in meeting their quantitative electrification targets

(McAllister and Waddle, 2007, IEA, 2009a). The programme has consistently achieved its rural electrification targets over the three phases and Chile stands out for the degree of rural electrification access achieved in one and a half decades. Most of the electrification over the period 1994-2010 has been done through grid extension (90% of electrified households). However, while electrification targets were being achieved in larger rural villages closer to the grids, remote and scattered non-electrified rural communities became more expensive and technically more complex to connect by traditional methods. In those cases, off-grid RETs, such as solar home systems (SHS) or isolated RET-based mini-grids have also been evaluated and implemented throughout the country, initially as pilot or demonstration projects and consequently as an increasingly institutionalised practice (Poch Ambiental, 2009). Sub-section 4.6 discuss in more detail off-grid rural electrification in the context of PER activities.

4.5.1 MIDEPLAN's project assessment methodology

As has already been mentioned, the PER was a centrepiece in a broader rural infrastructure investment programme established during President Frei's administration. The rationale behind those programmes was the extension of service provision at a residential level. For that reason, most of the technical support and dedicated funding was targeted at the provision of basic services to rural households and complemented services in schools, health clinics and community centres. Productive activities were not considered as a priority at that point but as the secondary result of basic infrastructure provision (McAllister and Waddle, 2007, IEA, 2009a).

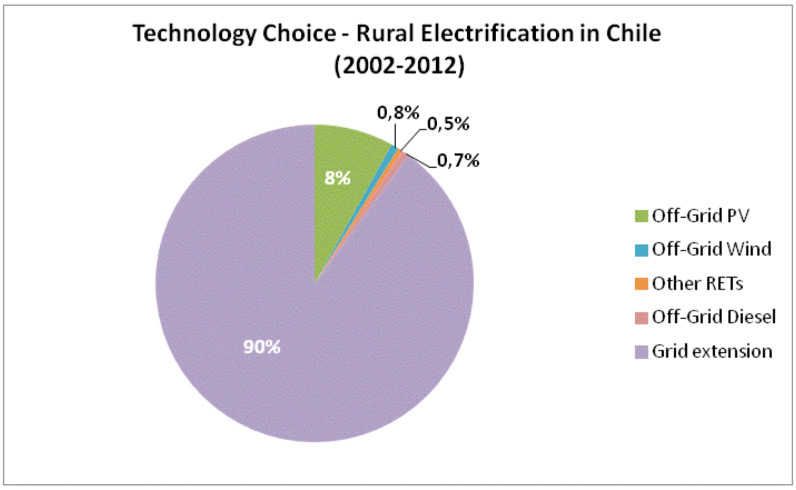

Figure 4-3: Share of technology source in Rural Electrification in Chile (2002-2012)

Source: author's compilation of data from Ministry of Energy (2010) and GEF (2011a)

A crucial feature of all rural infrastructure programmes (including PER) was the provision of investment subsidies through the National Fund for Regional Development (FNDR). As rural electrification was considered the backbone of much rural investment, in 1996 a dedicated budgetary line within FNDR (called 'FNDR-ER', following the Spanish acronym for Rural Electrification 'ER') was created specifically to subsidise rural electrification projects. Funds flowed from the Treasury, through the administration of SUBDERE, to the Regional Governments, whose Regional Council boards had autonomous powers of deliberation and allocation. All projects applying for FNDR funding must be assessed (and approved) in terms of the project assessment methodology developed by MIDEPLAN. This assessment is based on a Cost-Benefit Analysis (CBA) which is undertaken to evaluate both wide (social) net benefits and financial (private) benefits. Following strict assessment procedures and defined parameters, the tool allows the calculation of a maximum level of subsidy.

The rationale behind subsidised rural infrastructure programmes lies at the heart of the neo-liberal state. The limits to free market resource allocation are defined by the forces of the market, in this case private distribution companies seeking to maximise profits, something which in practice defines the what, the how and the to whom in the provision of a public service. In other words, distribution utilities devised strategic investment plans consistent with sectoral regulations and designed series of rural electrification projects in accordance with their own decisions about quality of service, technological choices and geographical distribution. As distant and dispersed rural electrification projects have never been an attractive business, with the implementation of the PER the state assumed its constitutional subsidiary role, which assigns the responsibility to governmental institutions to fulfil a societal need only when the market is unable to do so in an appropriate way. In other words, the state remains involved in public service provision only in those areas in which demand cannot be met through the market, i.e. through the initiative of private actors. State entrepreneurial action is limited by constitutional rule, which protects private property and private entrepreneurial initiative.

Within this context PER policy design included a detailed procedure for the assessment of infrastructure provision projects subject to financial support from public funds. For this, the major tool has been MIDEPLAN's methodology. In the case of rural electrification the methodology guides project design and assessment processes. For a project to receive a FNDR subsidy, two conditions must be met. Firstly, the project's economic benefits over a given lifespan have to exceed the project's total costs[27]. Secondly, financial benefits (i.e. those benefits accruing to the distribution company as a cash flow of electricity sales) must be less than total investment and operating costs during the same project's lifespan. Whenever the two conditions are met, a subsidy is set in order to reach a break-even point. The maximum subsidy can therefore cover only the capital cost of infrastructure and never operating costs. If, on the contrary, financial benefits are higher than costs, a sufficiently positive net present value (NPV) and an attractive internal rate of return (IRR) should persuade private utilities to embark on the project on their own.

Economic benefits (also referred to as social benefits) are valued by means of a theoretical demand curve which is estimated from two points (baseline and projected energy consumption and prices). In the baseline case, consumption and expenditure are taken from census data (for most grid extension projects) and surveys of beneficiaries (mainly in the case of RET-based off-grid projects). Typical values of baseline demand for non-electrified communities are 3-5 kWh/month equivalent per household (mainly candles, kerosene or carbide lamps and batteries) at a market price of about US$5-10/month. Projected demand varies with region and socio-economic stratum, but typical values for grid extension and mini-grid projects are about 25-30 kWh/month and 10-15kWh/month for RET-stand alone off-grid electrification[28]. Electricity prices are defined by regulated distribution tariffs in the case of grid extension and, for most off-grid projects, tariffs are piecemeal, although there is a trend to estimate cost recovery tariffs. Net benefits are calculated by annualising investment cost (on year zero) and operating costs, estimated economic benefits and revenues from electricity sales. NPV is calculated over the project lifespan (30 years for grid extension and 10 for RET-based electrification)[29] at a discount rate set by MIDEPLAN (between 12% and 8% during PER implementation).

Financial benefits (also referred to as private benefits) are valued at market prices and calculated as a traditional financial cash flow of investment cost, annual operating cost,

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[27] These economic benefits include direct returns/income from electricity sales and other external benefits such as increased welfare as a result of better quality of service (i.e. higher energy consumption at lower prices than in a baseline scenario) and extended productive time or study hours.

[28] Values taken from Project Designs and official PV project submissions to FNDR.

[29] RET projects have a lifespan of more than 10 years, but the methodology uses this very limited period due to the technological uncertainty of RET projects. This represents in fact a counter protection measure for RETs compared to the long period in which conventional technologies can recover investments (30 years).

depreciation, interest payments and revenues from electricity sales. As the NPV in this case must be negative, the maximum subsidy to be considered is the portion of the capital investment that turns the financial cash flow (NPV) positive discounted at the 'social' rate defined by MIDEPLAN. This methodology is very efficient in supporting projects that are viable for the country and attractive for private distribution companies (when subsidies are provided).

Although the methodology was designed particularly for grid extension projects (in which case most of the variables and parameters could be estimated from previous experience in grid extension projects), the same methodology has been applied to off-grid RET projects. In such circumstances, certain assumptions are made, such as future electricity tariffs, unknown maintenance costs and other baseline parameters, which increase private investors' perception of risk. Furthermore, the seminal PER policy paper (1994) and its subsequent versions have made explicit that where possible grid extension is to be sought: off-grid RET projects are to be considered as a last resort alternative in rural electrification, even if the per user cost of grid-based projects is higher than alternative sources (Covarrubias et al., 2005, MIDEPLAN, 2007).

A substantial step towards regime stabilisation was taken in 2007 when the broadly accepted MIDEPLAN methodology (CBA) was radically changed (MIDEPLAN, 2007). This was a response to recognition that the most pressing electrification targets were not being achieved due to i) the higher cost of grid extension to extremely remote rural areas and ii) the increasingly reduced capacity of centralised and decentralised institutional actors to negotiate and incentivise distribution companies to implement projects. This change removed the requisite of carrying out Cost Benefit Analysis (CBA) for the remaining non-electrified rural households. It was decided instead that least cost grid extension options should be sought and projects should be assessed according to a Cost Effectiveness approach. To that end, a reference cost cap per household was established (which varied according to region), increasing historical electrification costs so projects would become attractive to distribution companies, no matter how economically viable they were (given the high subsidies these would receive). Off-grid RET electrification continued its modest progress in those areas included in the national project portfolio (which is described further in next section). This change of methodology implied that many grid extension projects that otherwise could have been considered for RET electrification became open to subsidies and hence finally executed, at an even higher cost than the off-grid RET alternative.

4.6 In Search of Alternative Solutions: the Emergence of Off-Grid Rural Electrification and the Dissemination of Renewable Energy Technologies.

As accessing electricity services comprises radical changes in both social and technological dimensions, rural electrification is considered as a process of technological change. As such, path-dependence and lock-in (see for example Arthur, 1989, Arthur, 1994, David, 1985, David, 1994, Unruh, 2000, Unruh and Carrillo-Hermosilla, 2006, Berkhout, 2002) are two of the characteristic dynamics of the process. These represent one of the reasons for policy and practice to tend to approach the challenge of supplying electricity to rural customers through grid extension, a centralised and traditional (or regime) energy technology. However, rural electrification access can also represent socio-political emancipation from dominant technological practices and products. From this perspective, RETs offer not only a new technical alternative for electricity production and consumption, but also a (potentially radical) different structure of socio-political organisation. RETs in rural electrification are envisaged from a different framing. However, as will be discussed later on the thesis, there might not be 'one' unique different framing but 'diverse' framings with which to (co-)construct a RET-based rural electrification process.

On the one hand, PER structure and functions promoted grid extension (including existing infrastructure, business models, building practices, ancillary services, regulations and so on) from urban centres where distribution companies were already operating, to nearby rural areas. However, a significant part of the rural population lives in extremely dispersed and scattered geographical conditions or in small villages at a great distance from existing electricity infrastructure, making the physical extension of electrical networks economically unviable. In such instances, off-grid, self-generating energy systems are frequently the only alternative, and RETs are arguably the most efficient and effective way of providing electricity service from an economic, social and environmental perspective.

The vision of promoting RETs in rural electrification was also a response to the increasing challenges of expanding conventional technology. Soon after the PER was launched, regional and central authorities began to become concerned about the existence of considerable proportions of the rural population who could not be connected through grid extension. One factor in the difficulty of expanding grids to remote rural areas was cost. Between 1992 and 1999 average grid extension costs per connection rose from US$1,480 to US$2,295, an increase of 55%. In some regions costs were even higher. For instance, per connection costs in the El Maule region increased by more than 130% (McAllister and Waddle, 2007). Distribution utilities justified the rising cost of electricity connections by reference to the longer distances being covered by grid infrastructure. Nonetheless, another factor in the rising cost of electrification is the inability of government institutions to negotiate with powerful and often monopolistic distribution utilities, which manage to avoid open disclosure of unit costs, together with the lack of accountability methods and rules (Interview 21, Interview 7).

Technical variables also played a role; in northern regions, for instance, the extremely scattered and distant nature of rural populations, resulted in low demand levels at residential scale and thus made grid extension unviable. In southern regions, the difficulties of extending the grid through dense forests or between islands were more technical than cost-related, though cost also played a role. Technological alternatives, such as off-grid RET systems, were not widely known and had only been tested in few pilot projects in which the involvement of the government and electric companies had been limited.

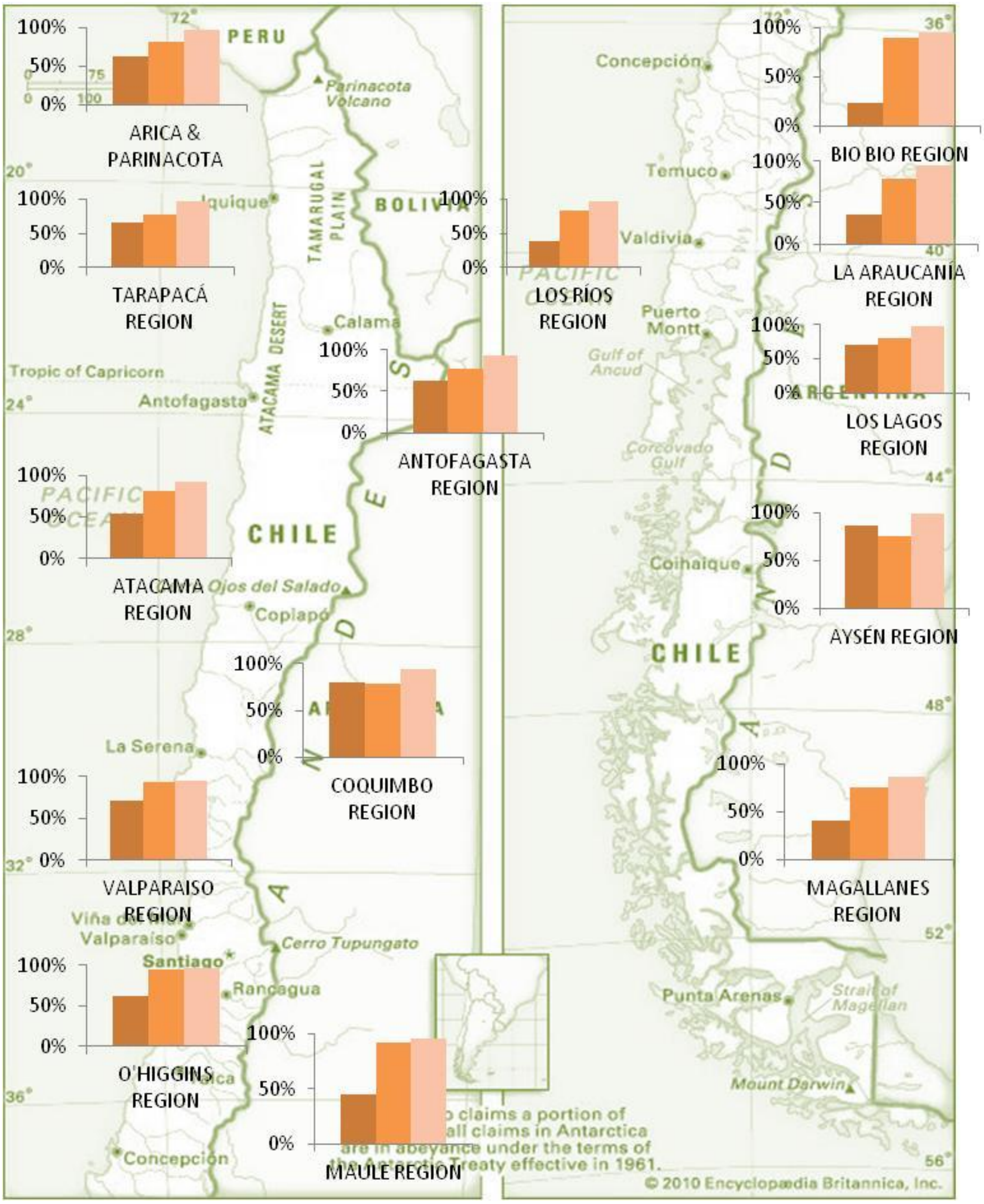
Institutional and cultural factors could also help explain the difficulty of reaching the poorest and most isolated rural families. From an institutional perspective, the policy approach favoured a model of subsidy provision to distribution firms and cooperatives and a centralised, eminently top-down approach in which rural communities and even municipal actors had little influence over how decisions were made and how funding was allocated (see previous sections). The outcome of such an approach is that most electrification projects have been driven by the strategies and interests of the private companies with which central and regional governments had to negotiate (Interview 36, Interview 6). The cultural effects of such an approach have also been important. Rural communities and local authorities (municipal and communal) are supposed to participate in planning processes but the evidence shows that they have little say in decision making. In other words, local actors - mainly communities and councils - lack the influence and tools to participate in planning processes and thus become mere recipients of centralised state aid. The state in turn, as an abstract entity, is culturally understood as being responsible for solving gaps in social service delivery, such as health, education, energy, water or housing.

The complex interplay of these factors revealed the limited ability of the grid extension model to reach remote rural communities. However it also opened up opportunities for new approaches to overcoming the perceived barriers to rural electrification. The pockets of non-electrified remote rural areas were distributed throughout the country, although they were most heavily concentrated in a few regions: Coquimbo, Araucanía and Los Lagos[30]. Within this scenario, off-grid electricity systems were thus envisaged as an alternative to be pursued and the need to explore new business and delivery models was understood. Figure 4.4 presents a regional break down of the increase in rural electrification over the last two decades.

Diesel or petrol gen-sets[31] had already been installed in a number of off-grid rural villages, in which electricity was distributed through rudimentary mini grids to community members and other buildings, such as chapels, schools or community centres. However, those gen-sets are very expensive to run and maintain, and operation responsibilities, including a mix of municipal and community roles without a stable support framework, were often blurred or inadequately defined. As a result, the electricity supply was unreliable and was normally provided for only a few hours a day. As a means of bridging the gap in rural electrification, renewable energy attracted the attention of authorities and policy makers as a promising technical solution. However, as noted above, knowledge relating to such technologies was still limited and the vision of a brighter future in which rural communities would power their development process through renewable energy was extremely vague, although apparently broadly accepted and supported (Interview 15, Interview 7, Interview 14).

[30] In 1992, 237,520 rural homes had no access to electricity. Out of that total, 52% were concentrated in only 3 regions: 16,127 rural households without electricity in Coquimbo; 53,977 in Araucanía and 53,685 in Los Lagos. In 10 years the national deficit had been reduced by more than two thirds to 77,180 rural homes. Progress had been important in the critical regions and deficits had been reduced to 7,952; 18,370 and 19,507 respectively. However, by 2002 these three regions represented 59% of non-electrified rural households. In October 2007, Los Lagos was split in two regions: Los Lagos in the southern part of the former region of Los Lagos, and Los Ríos in the northern area (Ministry of Energy 2010)

[31] Electricity generator sets.



Graph Legend:

Electrification Rate 1992 (%)

Electrification Rate 2002 (%)

Electrification Rate 2010 (%)

Figure 4-4: Rural Access to Electricity in Chile: regional breakdown 1992-2002-2010.

Source: Author's elaboration of data from Ministry of Energy (2010)

The first off-grid RET rural electrification projects had been implemented in the country even before a concerted policy effort was put in place in 1994. Many of these RET electrification projects – as will be described in more detail in chapters 5 and 6 (case studies) – were promoted by NGOs and international cooperation initiatives. They tended to focus too much on the provision of equipment (certainly showing a blind faith in technological fixes) and too little on system functionality and the capabilities required at various levels so as to trigger substantial innovative technological capacity and socio-technical diffusion at the local scale. Although many of the pilot projects implemented throughout the country were highlighted as promising alternatives and successful experiences, they vanished soon after the installation process had been executed and financial support had ended.

It was not until 2001, however, that more concerted and systemic support for the development of RET rural electrification was institutionalised. As PER efforts to meet electrification targets were becoming increasingly difficult, the project "Removal of barriers to rural electrification with renewable energies in Chile" (UNDP, 2001) was designed to be executed by the CNE's Rural Electrification Unit. The project received a US$6 million grant funded by the Global Environmental Facility (GEF), together with US$25 million from the Government of Chile and was implemented through the cooperation of the UNDP in Chile. The project was in fact a country-wide programme (hereafter referred to as the GEF programme) promoting the use of RETs in rural electrification. It aimed at overcoming a series of technological, institutional, regulatory and capabilities barriers that hindered the successful use of RETs in rural electrification, thus creating the conditions for the emergence of a market for these technologies (UNDP, 2001).

The GEF programme activities began to unfold at the beginning of 2002. One particularity of the implementation strategy was the formation of a cohesive directive team under the leadership of the programme's Principal Coordinator[32], who acted as the main authority for programmatic implementation, and a Technical Operations Chief, who led the development of specific projects and oversaw the technical matters and decisions (UNDP, 2001). These two people worked at the Rural Electrification Unit of the CNE, under the guidance and supervision of the Unit Director. The latter also acted as GEF Programme Director and was the key political actor linking GEF programme activity and rural electrification policy at the national level. Complementing this team, the

[32] Also referred to as Principal Technical Advisor

person acting as focal point for energy and climate change at the UNDP Chile's office acted as a strategic advisor to the GEF programme, and in fact devoted one third of his time on this particular programme (Interview 36, Interview 14, Interview 15).

All these actors were Chileans, with experience of international cooperation, rural electrification and climate change mitigation policy. On the basis of the experience acquired through their involvement in the few RET-based rural electrification projects executed in the country at the beginning of the PER, when the GEF programme began, they were some of the most experienced people in the country with respect to small scale renewable energy for rural electrification purposes[33]. Although the know-how relating to renewable energy was still limited (both in the country in general and also within this expert team), the GEF programme leadership group had the ability to understand both technical issues and challenges associated with RETs and the underlying social context in which rural electrification was being implemented. This was a key asset which they took advantage of to start implementing an engagement strategy with public sector regional and municipal actors, and with actors from utilities, RET developers and technology suppliers.

To that end, the GEF director hired a group of consultants who became part of the project team and were in practice the field extension of the GEF programme. This team undertook fieldwork data collection activities, as well as engagement on a very local scale with municipal actors (both authorities and municipal staff), and with rural communities. They also undertook data analysis, technical design and techno-economic assessments of identified projects. This team travelled throughout the country visiting rural communities without electricity to raise awareness of RETs for rural electrification and to conduct surveys of rural families. The data from these surveys was then used for project assessment and evaluation purposes.

The GEF programme had two priorities with respect to political concerns connected with the results of PER implementation in the previous 5 years. The first of these was the implementation of a demonstration PV project in the Coquimbo Region for some 6,000 rural families living in extreme isolation and too far from existing grids, for whom the

[33] This assessment is also supported by the personal opinions of several interviewees DUHART, S. 20 May 2011. *RE: Interview 15, Public Sector.* Type to OPAZO, J, COSTA, L. 18 May 2011. *RE: Interview 14, Int. Cooperation.* Type to OPAZO, J, GARCÍA, C., DÍAZ, H. & ZATTERA, P. 09 June 2011. *RE: Interview 18, Public Sector.* Type to OPAZO, J, PAVEZ, A. 06 May 2011. *RE: Interview 40, Public Sector.* Type to OPAZO, J, DOUGLAS, C. 10 June 2011. *RE: Interview 21, Public Sector* Type to OPAZO, J..

most realistic technical solution was stand-alone SHS. The second was the electrification of the Chiloé Archipelago, a group of 30 to 40 islands in the Los Lagos region, in which some 3,500 fishing and farming families lived in very small villages, also in extreme isolation, and for whom the most reasonable technical solution was the construction of hybrid wind-fuel mini-grids. The pre-selection of these two technological options was a consequence of previous experience (various SHS projects installed in Coquimbo and a pilot wind mini-grid project in Tac Island in Chiloé) and of the tacit knowledge of solar and wind potential in those two regions.

Overall, the GEF programmes promoted private and public investment in off-grid RET projects (mainly PV and wind) in order to alleviate poverty as well as reducing carbon emissions. At the heart of this programme was the idea that electricity service provision in extremely isolated rural areas was a social enterprise, with economic development and environmental co-benefits relegated to a secondary level (Interview 36). The GEF programme was instrumental in reaching neglected rural communities living in extreme poverty. It also played a crucial role in making visible the radically different challenges faced by these people and their local networks (which are normally organised around the provision of palliative care services from rural councils) in assembling functional governance and coordination arrangements so as to ensure sustainable, workable and long term provision of electricity services. The GEF programme contributed to meeting electrification targets in regions in which this would not have been possible though grid extension alone. But the GEF programme also helped to advance the development and adoption of RETs in rural electrification through a series of activities connected with niche construction (i.e. learning, network building and expectations alignment), together with other processes which will be discussed in later chapters through the analysis of particular cases.

With the active support and involvement of the GEF programme, after more than 10 years of implementation, by 2011 an extensive portfolio of off-grid RET projects had been identified, designed or executed throughout the country. These projects encompassed different technologies (PV, wind, mini hydro and hybrid systems) and various community sizes (ranging from a few households to more than 3,000 scattered rural families in the northern region of Coquimbo). Taken together, these projects involve some 11,000 rural families (Canales, 2011a). To date, only a third of these households have actually been electrified through off-grid RET, representing only 9.1% of the total rural electrification over the period 2002-2009 (Poch Ambiental, 2009).

As has already been mentioned, this thesis focuses on the study of PV and wind-based rural electrification projects developed as part of the Rural Electrification Programme of the Chilean Government (whose selection as case studies has already been discussed in Chapter 3). PV (solar photovoltaic) projects account for the majority of off-grid rural electrification projects executed so far, representing to some extent a success in technological diffusion. These projects have reached isolated households in the central and northern regions of the country and involve diverse organisational and market structures, networks of actors and learning processes. Hybrid wind-fuel mini grid projects, another promising RET, were considered for the electrification of a vast area of islands in the Chiloé archipelago and other villages in central and southern regions. However, such projects (or the socio-technical practices involved) have not been so successful or have not been executed at all even though specific technical and financial support, alongside other protection measures, was provided.

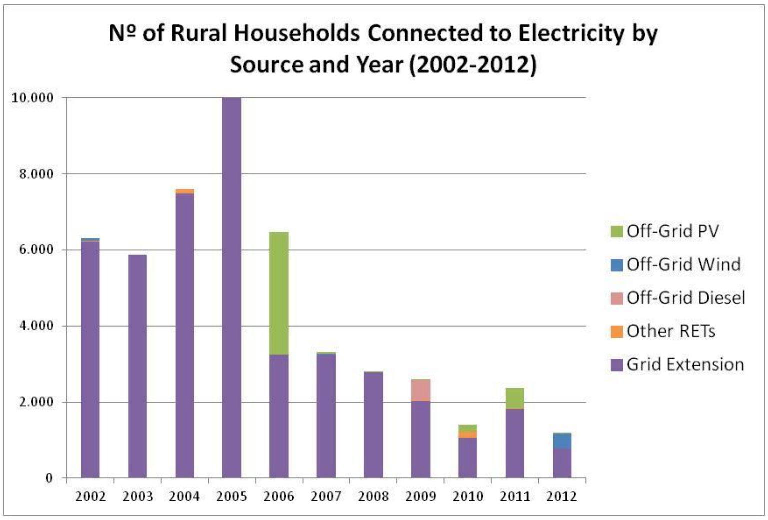


Figure 4-5: Nº of Rural Electrification Connections to Electricity (2002-2012)

Source: Ministry of Energy (2010), Poch Ambiental (2009), Canales (2011a)

But in addition to the development of specific projects (identification, design, techno-economic analysis, etc.), the GEF programme undertook other activities. These included the establishment of technical standards and certification procedures for off-grid RETs, awareness campaigns and training programmes (for technology users, technicians and policy makers, etc.), conferences and workshops and many other efforts to create an enabling environment for the diffusion of these technologies in rural electrification (Poch Ambiental, 2009). Although few off-grid RET projects have been executed, demonstration of technology proves that a broad set of institutional, technological and socio-economic processes are co-evolving and affecting the performance and functionality of different projects. Moreover, the incumbent set of rules, institutional arrangements and networks of actors supporting conventional rural electrification remains powerful, so RETs are still at the stage of experiments that need particular incentives and probably special policy treatment (Poch Ambiental, 2009).

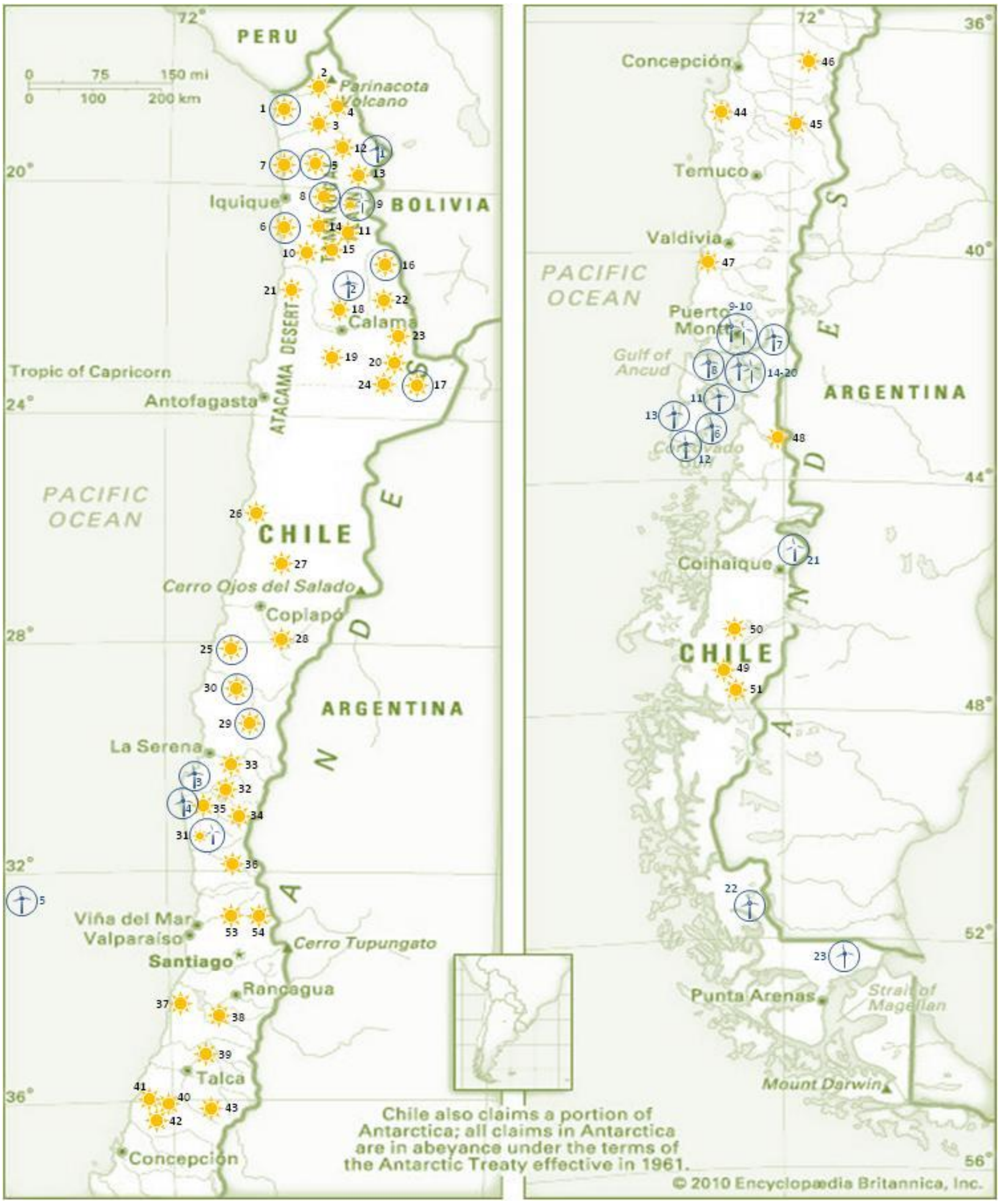


Figure 4-6: PV and Wind power Rural Electrification Projects in Chile 1990-2012

Source: Author's elaboration based on Ministry of Energy and GEF Programme information (Ministerio de Energía, 2010, Canales, 2011a) and data gathered during field work.

Table 4.1: List of PV and Wind power projects shown in Figure 4.6.

ID	Project Name	Nº of Households	Installed capacity (KW)	Execution Date
PV-1	Chaca PV Hybrid Project	25	in project pipeline	
PV-2	PV Electrification: 10 Rural Schools and a Health Clinic in Arica-Parinacota	11	20	2011
PV-3	PV Camarones	50	in project pipeline	
PV-4	PV Putre	76	in project pipeline	
PV-5	Nama Hybrid Project	28	in project pipeline	
PV-6	San Marcos Hybrid Project	70	in project pipeline	
PV-7	Sibaya Hybrid Project	40	in project pipeline	
PV-8	Achacagua Hybrid Project	35	in project pipeline	
PV-9	Huatacondo Mini-grid hybrid proj.	80	23	2010
PV-10	PV Electrification: 8 Rural Schools and 5 Health Clinics in Tarapacá	13	25	2011
PV-11	PV Pica	6	in project pipeline	
PV-12	PV Huara	16	in project pipeline	
PV-13	PV Colchane	21	in project pipeline	
PV-14	PV water pumping Pozo Almonte	3	3	2010
PV-15	PV Salar del Huasco	unknown	unknown	2003
PV-16	Ollague Hybrid Project	80	in project pipeline	
PV-17	Camar Hybrid Project	22	10	2008
PV-18	PV Calama	40	in project pipeline	
PV-19	PV Electrification: 6 Rural Schools and 5 Health Clinics in Antofagasta	11	29	2011
PV-20	PV San Pedro	26	18	2006
PV-21	PV Province of Tocopilla	11	in project pipeline	
PV-22	PV Ollague & Puquios	26	8	2006
PV-23	PV Machuca	23	10	2006
PV-24	PV Escuela E-26	unknown	5,8	2010
PV-25	Carrizal Bajo Hybrid Project	100	in project pipeline	
PV-26	PV Caleta Pan de Azucar	20	2	2010
PV-27	PV Region of Atacama	462	46	2011
PV-28	PV existing systems Atacama	200	in project pipeline	
PV-29	Almirante Latorre Hybrid Project	70	in project pipeline	
PV-30	Los Morros Hybrid Project	42	in project pipeline	
PV-31	Electrification Totoral Rural School, Canela	10	3	2008
PV-32	PV Region of Coquimbo, rural households	3.064	383	2006
PV-33	PV Region of Coquimbo, Schools and Health Clinics	34	78	2011
PV-34	PV existing systems Coquimbo	1500	unknown	1994
PV-35	PV water pumping Coquimbo	4	2	2008
PV-36	PV Petorca	38	5	2006
PV-37	PV O'Higgins coast sector	30	8	2009
PV-38	PV Region of O'Higgins	200	in project pipeline	
PV-39	PV Region of El Maule	365	in project pipeline	
PV-40	PV Empedrado I (Provoste)	21	5	2006
PV-41	PV Empedrado II	44	10	2007
PV-42	PV water pumping Empedrado	1	0,5	2007
PV-43	PV El Melado	21	5	2006

ID	Project Name	Nº of Households	Installed capacity (KW)	Execution Date
PV-44	PV Arauco	238	in project pipeline	
PV-45	PV Bio Bio	164	in project pipeline	
PV-46	PV Ñuble	164	in project pipeline	
PV-47	PV Tres Chiflones	41	13	
PV-48	PV Futalefú	223	in project pipeline	
PV-49	PV Cochrane	63	in project pipeline	
PV-50	PV Capitán Prat (Cochane, Tortel & Villa O'Higgins)	90	46	2010
PV-51	PV Capitan Prat II	120	61,2	
PV-52	PV Isla Toto	unknown	unknown	2006
PV-53	Solar PV Irrigation National Programme	unknown	255	2013
PV-54	Solar PV Irrigation several rural Municipalities	32	3,5	2012
Wind-1	Colchane Wind Hybrid Project	40	in project pipeline	
Wind-2	Cupo Wind Hybrid Project	12	11	2007
Wind-3	Caleta Talcaruca Wind Hybrid Project	10	in project pipeline	
Wind-4	Caleta Totoral Wind Hybrid Project	10	in project pipeline	
Wind-5	Juan Fernández Island Wind Hybrid Project	300	in project pipeline	
Wind-6	Acuy Island Wind Hybrid Project	22	in project pipeline	
Wind-7	Chaullin Island Wind Hybrid Project	26	in project pipeline	
Wind-8	Teuquelin Island Wind Hybrid Project	11	in project pipeline	
Wind-9	Tabon Island Wind Hybrid Project	131	54	2012
Wind-10	Quenu Island Wind Hybrid Project	46	18	2012
Wind-11	Tac Island Wind Hybrid Project	82	30	2000
Wind-12	Chonchi Wind Project	unknown	unknown	2003
Wind-13	Rahue-La montaña Wind Project	unknown	unknown	2003
Wind-14	Auteni Island Wind Hybrid Project (Desertores)	25	22,5	2012
Wind-15	Llanchid Island Wind Hybrid Project (Desertores)	19	11	2012
Wind-16	Chuit Island Wind Hybrid Project (Desertores)	35	25	2012
Wind-17	Imerquiña Island Wind Hybrid Project (Desertores)	6	6	2012
Wind-18	Nayahue Island Wind Hybrid Project (Desertores)	31	22,5	2012
Wind-19	Talcan Island Wind Hybrid Project (Desertores)	48	24	2012
Wind-20	Chulin Island Wind Hybrid Project (Desertores)	50	43	2012
Wind-21	Puesto Viejo Police Station Wind Hybrid Project	5	3	2007
Wind-22	Villa Renovales Wind Hybrid Project	12	unknown	unknown
Wind-23	Villa Tehuelche Wind Hybrid Project	50	unknown	1995

Table 4.2, provides an overview of the main areas in which the GEF Programme has delivered results, showing the systemic nature of the processes developed in the last 10 years of RET promotion and diffusion for rural electrification purposes.

Table 4.2: GEF Programme Overall Objectives, Activities and Progress up to 2011
(Canales, 2011a, Poch Ambiental, 2009)

1. Development of a Portfolio of RET rural electrification projects	100 identified projects reaching 11,049 rural households (HH) and rural centres. 45 out of 100 projects were developed and considered for financing through public investment (7,484 HH). Total investment amounts to circa US$30 million.
2. Establishment of Technical Standards for RET equipment	44 approved standards (*Normas Chilenas Oficiales*) for: Wind Energy, PV, Mini Hydro and Hybrid Systems.
3. Development of Certification Guidelines and Procedures	Guidelines and procedures have been adapted and established; certification centres have been selected amongst universities and equipment has been provided. More than 3,100 PV SHSs have been certified through this scheme.
4. Implementation of an awareness campaign	A promotion and awareness strategy has defined topics and activities to be implemented through the project website, leaflets, radio and media. Several events and workshops have been executed in order to promote the project and RET amongst rural communities, public servants and the private sector.
5. Design and implementation of a training (capacity building) programme	This was aimed at rural users of RET, technicians (design and maintenance), public servants and consultants. 17 thematic workshop and seminars were implemented and all final users of RET projects were trained in general operation and maintenance.

6. Design and execution of a PV demonstration project	4,000 SHSs installed in isolated and disperse rural households in Central and Northern Chile. Installation and maintenance of the PV Coquimbo project was commissioned to a distribution company (CONAFE), ensuring long term operation. Similar schemes were adopted in large PV projects. Operation subsidies contributed to financial sustainability.
7. Productive Uses of RET's	From 2007 onwards, 5 PV water pumping stations and 1 bio-digester have been installed as pilot projects. 221 additional PV water pumping projects have been included in a project portfolio, starting a shift in policy towards a more comprehensive approach to energy services in rural areas.
8. GHG mitigation through RET plugged in to diesel generators in use	Only 1 out of 36 identified projects has been executed (PV-diesel). 12 wind-based mini-grids (in Chiloé) were under implementation at the time of writing. Hybrid projects have proved to be far more complex than stand alone PV systems. This kind of project tends to include mini-grids.
9. Development of technical capacities to assess wind power potential and design small wind projects	Wind monitoring stations have been installed in 52 rural areas throughout the country. Awareness has been raised, training provided and an emergent market for wind ancillary services has emerged, both in rural electrification and large scale wind farms (grid connected). However none of the identified wind or hybrid projects have been completed so far. Wind resource potential is openly accessible and publicly available.

4.7 Chapter conclusions

This chapter has reviewed the history of electrification in Chile in an attempt to demarcate the context in which the study of RETs in rural electrification is undertaken. It started with a description of the first development of electricity services in Chile, showing how these grew out of the entrepreneurial activity of rural cooperatives and electric companies in the 1940s and 1950s. During that period, progress in creating access to electricity was slow and mostly linked to agricultural production in the fertile valleys of Central Chile. The chapter then described how State involvement was enhanced in the 1950s and 1960s through more strategic planning and investment programmes developed by the state-owned ENDESA, in a process that prepared the ground for an active role on the part of government institutions.

Demand growth (and not geographic extension of services) was the main driver of sector development, implying that the electrification process remained confined for the most part to urban areas. During the 1970s (in the years following the *coup d'etat* of 1973) the electrification process made modest progress due to competing political-economy priorities and social unrest. State ownership of electricity companies was radically contracted from the 1980s onwards through the liberalisation of the electricity sector (a sector reform affected by reforms in other sectors, such as the liberalisation of the water regime, a key input of the hydroelectric market) and a privatisation process that took place in the late 1980s and 1990s.

Against this general backdrop the analysis has focused on the main policy of increasing access to electricity in rural areas in Chile from the introduction of modern energy services in the country. This is the Rural Electrification Programme, launched in 1994 during the presidency of Eduardo Frei, which was extended until 2010 and has permitted the extension of electricity services to nearly all inhabitants in the country. The PER demarcates the rural electrification regime in Chile because the institutional structure was robust enough to establish socio-technical practices, market structures, norms, rules and guidelines that have influenced infrastructures, user-producer dynamics, beliefs and cognitive frames. It has become a stable and structured ‘way of doing things’, which represents a mutual interaction of society and technology. This chapter has described and analysed in detail how the rural electrification regime operates in Chile, including actors and institutional roles, assessment methods and criteria, financing schemes and regulations, amongst various dimensions of the regime.

In turn, the chapter has also described how new technological options (or innovations) have been promoted and supported. The focus is on the RET rural electrification projects, which were devised as a way of surmounting the limitations of the PER policy so as to overcome the barriers to reaching extremely isolated villages and rural families, for which purpose 'traditional' technology could not be used. To support the development of such projects, the GEF Programme "Removal of barriers to rural electrification with renewable energies in Chile" (UNDP, 2001), which involved cooperation between the Global Environmental Facility and the Chilean Government, was implemented within the PER's institutional structure from 2001 to 2011. This thesis focuses on the diffusion of two types of RET projects: off-grid PV and wind rural electrification (for a justification of this selection of cases please refer to Chapter 3).

The overview presented in this chapter has identified and mapped what is (very likely) the most comprehensive database of RETs rural electrification projects in Chile. The systemic approach of the GEF programme has also been described in detail. This was designed to achieve results beyond the mere provision of 'hardware' (RET project infrastructure) and thus to contribute to the emergence of a 'space' for the development of these technologies within the context of rural societies. It is probably too early to conclude that a RET market has taken off in the Chilean rural electrification process, but it can be affirmed that 'socio-technical niches' have been constructed and a complex process of emergence is under way in the country.

When the extent to which projects have been developed and implemented throughout the country is considered, it can be seen that the PV niche has been more successful than the wind niche. However, the interest of the thesis is not in discussing whether more projects have been developed and in doing so have determined a successful niche emergence. The aim is to understand the dynamics within both 'spaces' and thus complement the literature through the analysis of additional determinants linked to the roles certain actors play in the diffusion process, particularly intermediaries and incumbent actors.

The case studies that follow (see next two chapters) focus on two technologies: PV and wind. Although the case studies refer to technology, they are not really technical stories, but highlight, rather, the socio-technical dynamics of the process of RET rural electrification. The cases are organised chronologically, in an attempt to trace changes in visions (whether alignment or divergence occurred), how learning has influenced the development of technological capabilities, the extent to which actors have formed networks and how these processes have played a role in the structuration and uptake of practices and associated technologies.

Together with the analysis of niche processes, the case studies investigate the roles played by intermediaries and the way decision making is undertaken. The case studies also reflect on i) the tensions that have marked the process and ii) how the stories are resolved, if they are at all, or at least how these two socio-technical change processes stand at the moment and on iii) the perspectives with respect to their future development.

5. Solar PV Off-Grid Rural Electrification in Central and Northern Chile

5.1 Introduction to the chapter

Solar Photovoltaic (PV) technology and wind systems were the first options to be evaluated and implemented for rural electrification purposes in Chile. This chapter focuses on Solar Photovoltaic (PV) technology. Despite some failures experienced in the first executed projects, which lead to poor service provision or unreliability of supply, and consequently, to a perceived eroded willingness to pay for and to adopt PV systems, the technology has become widely diffused in several regions with the largest electrification deficits[34]. Initially devised for sunny northern regions, some projects have been executed even in southern regions where other renewable energy resources, such as wind or streams and rivers with hydroelectric potential, had seemed to be a preferable option.

The large majority of PV systems installed in the country are solar home systems (SHS) supplying limited amounts of electricity to individual households. The size of those systems varies from some tens of watts (of installed capacity) to one or two hundred watts-peak in the north (or its equivalent electricity generation potential for southern regions). There are also more robust systems supplying electricity to community or public buildings such as schools, rural clinics or community centres, although these systems have been promoted more vigorously only since the launch of the Energisation Programme (PE) in 2010 when the PER was closed, and therefore account for a minority of the executed projects. In recent years hybrid PV-fuel systems have been developed and there is record of two rural villages being entirely supplied through PV mini-grids in northern Chile (Alvial-Palavicino et al., 2011, Hidalgo, 2006). There are also some larger PV systems which support pumping and irrigation in smallholders' agriculture[35].

[34] Electrification deficit refers to the difference between the actual rural electrification rate (as a percentage of rural households connected to any form of electricity service) and the rural electrification target defined by the PER. Electrification rates, and therefore deficits, are normally calculated at national, regional and council scales.

[35] Information about PV projects has been collected from the Ministry of Energy, the GEF Programme, independent developers, personal conversations with interviewees and field visits to projects' sites. A complete database of projects has thus been assembled and is presented in the subsequent sections of this chapter.

5.2 Uncoordinated flashes: today's light is tomorrow's darkness

Several SHS projects had already been implemented in the central and northern regions of the country before the inauguration of the PER (1994) and in some cases remained in use until the launch of the GEF programme in 2001.These scattered and uncoordinated interventions, mainly executed in the framework of international cooperation projects, are difficult to track due to a lack of official records or literature and because many of these projects were executed in absence of management schemes and operational support. This means that only a few years later most of the PV systems were no longer working or that part of their equipment had been altered or replaced by underperforming spare parts (mainly storage units which are replaced by automobile short cycle batteries and conventional incandescent lights).

McAllister and Waddle (2007) report on a SHS project in El Maule region, Stevens (2002) reports on more than 200 SHS schemes in the central Bío-Bío and northern Antofagasta regions and Schmidt (2002) reports on PV systems installed in the early 1990s in rural schools and villages in the Chilean Altiplano (high-plateau), in the Tarapacá region. Additionally, there is an estimate of 1500 SHS installed in a number of initiatives prior to 2001 in the Coquimbo region (Poch Ambiental, 2009, Poch Ambiental, 2011). Most of the interventions were funded by international aid or bilateral cooperation and implemented with very limited local (user) participation and without coordination between institutional actors. Technical problems, such as the use of low quality inverters or charge regulators, or the lack of adequate maintenance and replacement of key parts led to malfunctioning and underperforming equipment which eroded the quality of electricity service as well as trust in PV technology (UNDP, 2001, Interview 36, Interview 32, Interview 40, Interview 4, Interview 7).

These technical problems were internalised by planners and government officials in the form of a lack of supporting models (including delivery, business, institutional and governance factors) to guarantee adequate operation, regular maintenance and the timely replacement of batteries and other control equipment. This reflection led to reconsideration of the policy and support mechanisms in place for RETs, but particularly for SHS.

A typical SHS project normally involved some tens of households in a particular area of a rural council. Some of these families live in very small villages or hamlets and many of them live in isolation and far away from each other. Rural population in these areas tends to rely on subsistence farming and shepherding, artisanal fishing, small-scale mining or other artisanal work. It is rare to find projects larger than 100 households in a defined rural area, but some projects were linked to each other by a very informal form of institutional networking, such as in the case of the nearly 1,500 SHS installed in the Coquimbo region in the 1990s. Although no formal supporting mechanisms and institutional arrangements for off-grid rural electrification were in place until the first years of PER implementation, regional and local authorities were aware of the SHS projects being implemented and of the potential political and financial responsibility they would have to assume if projects failed.

Operation was regularly left in hands of users although training and guidance was not provided on a regular basis (and may not even have been provided at the moment the equipment was installed). Maintenance responsibility was somehow ignored or project funders and implementers relied on the supposed municipal capacity to oversee projects and for some form of community self-organisation to be put in place for collection of fees, maintenance and replacement of key equipment and so on. The rule of thumb was that something had to be done to ensure a reliable electricity service (normally at 12V DC for both lighting and connection of small radios or B/W TV sets), but nothing was actually implemented.

Most projects failed in the years following installation. This was mainly due to the cumulative effect of low quality charge regulators (normally by-passed when they had broken down), the use of inefficient incandescent lights and the connection of additional appliances not designed for small 12V SHSs, coupled with a lack of technical capacities in the emerging networks of actors working in RET rural electrification. These situations affected the life cycle of batteries which rapidly reached a permanent discharge (or were replaced by used automobile batteries). SHSs became useless and PV modules became a nice piece of home decoration on the roof or at the front door of poor rural households. By the year 2002, when fieldwork data collection for a new SHS project in Coquimbo (discussed below) was being conducted, most of the 1,500 SHS projects installed in the region had been altered and were malfunctioning or not working at all (Canales, 2011a, Interview 36, Interview 3, Interview 40).

In this early phase of PV dissemination, intermediary action was primarily undertaken by project champions (e.g NGOs, politicians) working on a project-by-project basis. Their intermediary work consisted mainly of financial and technical assistance in the form of system design, implementation and the channelling of up-front funding for hardware and equipment transfer. The circumstantial involvement of intermediaries in PV projects implied that long term commitments were unlikely and that follow up activities and performance assessments were inexistent.

Expectations about the potential of PV technology lacked comprehensive technology needs assessments, resulting in a poor articulation between needs and options and a vision shared by only a few unconnected actors. This basic and broad idea about the possible future of PV technology was still confined to a few supporters, who were not connected in networks. The initial experimentation with PV technology, characterised by the implementation of piecemeal interventions, entailed learning about what to do with technology, but lessons were neither properly codified nor systematised and thus did not lead to adaptations in the social or (low) technological contexts in which projects were being implemented.

5.3 Connecting actors, lighting expectations: The Pivotal Role of the Coquimbo PV Project

With the start of the GEF programme at the beginning of 2002, priority was given to the development of a large scale demonstration PV project in Coquimbo. At that point (i.e. before the 2002 national census), there were an estimated 6,000 rural households lacking access to electricity in the extremely isolated and dispersed localities of the region, as well as the households with malfunctioning SHSs already mentioned. In February 2002 a dedicated team from the GEF programme started an extensive field campaign which lasted for almost a year. Fieldwork aimed at visiting all those rural families without electricity so as to promote the project and gather the socio-cultural and technical data needed to design and assess the new project. While the GEF fieldwork team went to the country, where they worked side by side with municipal staff, the GEF directive team regularly visited municipal and regional authorities to raise awareness, empower regional actors and consult on and negotiate how to best implement such a large scale demonstration project.

By the start of 2003 a regional SHS project had been designed for 3,100 rural households, community centres, schools and medical centres in Coquimbo. As the 6,000 households target could not be reached in that region alone, the GEF programme decided to extend field work activities to other regions in central and northern Chile where several hundred rural families lacked access to electricity and conventional grid extension had been assessed as technically and economically unviable. Following the field work in Coquimbo, the identification of beneficiaries and techno-economic assessments were carried out in Atacama (500 hundred rural households), Antofagasta (200 households), Valparaíso (80 households), Maule (500 households) and Bío-Bío (560 households) regions between 2003 and 2005 (Canales, 2011a, GEF, 2003, 2004, 2005, 2006, 2007).

For the Coquimbo PV project, an improved technical design was put together and a management model was proposed (see more details below). From a technical point of view, the new design included maintenance-free sealed solar batteries, standardised electrical wiring, a sealed protection cabinet for the charge controller and other protection measures. The development of this design was carried out alongside the elaboration of technical standards for solar systems (and other RET systems). It was thus taken as an input in the cost benefit analysis undertaken in accordance with MIDEPLAN's methodology, which had been modified to include financial and economic assessment of renewable energy projects. In 2004, the Coquimbo PV project was finally granted approval from MIDEPLAN and CNE and so responsibility for execution was transferred to regional and local governments, as established in the PER project cycle guidelines (Government of Chile, 2005, MIDEPLAN, 2007). The Regional Government of Coquimbo assumed the leadership and undertook all responsibilities in the bidding call carried out later that year.

During the design and development of the Coquimbo project, several measures were taken to overcome the perceived barriers faced by RET projects in rural electrification, which can be described as a mix of socio-technical factors. The improved technical design attempted to match rural people's practices and needs, supply a still basic but improved quality of electricity service, and avoid users' intervention in SHSs, and use high quality equipment. An additional notable feature of the project was that it included not only the provision of hardware but also the training of users and a mandatory business and delivery model (or management scheme as it is normally called in RET rural electrification in Chile) in which operation and maintenance was guaranteed for a period of 10 years. All these features flowed from consideration of socio-cultural and institutional issues and discussion between central authorities and their regional and municipal counterparts or stakeholders.

The management scheme selected was chosen from among a number of different delivery models which had been designed, assessed and finally deliberated. Three operational and maintenance options were proposed to fit different sizes of projects. These varied from i) projects in which users organisations would be in charge of managing and maintaining SHS, ii) municipal supported schemes in which users and local authorities would collaborate to operate and maintain the systems, to iii) privately managed projects in which the company supplying and installing SHS would be in charge of maintenance and operation in a fee-for-service approach (GEF, 2005, Poch Ambiental, 2009, Interview 36, Interview 7). The discussion of the management model was an iterative process in which different actors took part (mainly from the public sector but with the influence of private actors as well).

These models involved differences in cost, organisational arrangements and practicalities. These included the likelihood of engaging a private company in the maintenance of small projects involving few dispersed poor rural households, the ability of isolated rural communities to access renewable electricity service markets, to contract maintenance or replace high quality, apparently complex electronic equipment and batteries. However, the most important difference between models was related to different visions of society, approaches to service delivery and the political viability of actual implementation.

User-led models faced opposition from central government officials who considered that the rural poor were unable to correctly operate and maintain SHS and that previous projects had failed because of local communities' lack of relevant abilities (Interview 17). Models based around municipal leadership but with community involvement seemed to have the right combination of local participation and commitment from local authorities, who are the most direct gateway to public institutions and government officials. This model, however, lacked both the particular mechanisms to enhance municipal capacities and knowledge about RETs and, most importantly, the financial and staff resources to implement such schemes (Interview 14). Private led models were more expensive, because their design involved setting up offices, hiring personnel and making equipment available to provide maintenance services over a long term. But in reality private managed schemes transferred public responsibility to a private firm, which would offer a service according to contractual obligations and would charge a fee to recover costs without political interference and bureaucracy (Interview 14, Interview 36).

Furthermore, a privately managed model would better accommodate existing practices, structures and rules in the dominant rural electrification regime, something which has been extensively discussed in chapter 4. As for central and regional authorities involved in decision-making in the Coquimbo PV project, and given that the main regional distribution utility (CONAFE) had tacitly express interest in becoming engaged in the project (Interview 14, Interview 36, Interview 15), policymakers preferred to implement a private delivery model for this large scale project. In that context, issues framing the problem-solution duality were transformed into a discussion of the highest fee policymakers would accept as adequate for the provision of rural electric service and which rural users would be willing to pay[36]. To make SHS projects financially viable, the management model had to evaluate cost recovery tariffs (at least for maintenance and operation) but those tariffs were too high (particularly in the case of private models). Lower tariffs would imply a risk of worsening the quality of service or lack of interest from electricity companies. In larger projects, economies of scale could be achieved so fees might be reduced to levels similar to those of existing expenditure on inefficient lighting, such as candles, kerosene or gas lamps. In the case of the Coquimbo PV project, non-electrified rural families were spending as much as CLP 6,000 (circa US$12) per month or more on lighting. However, many of these families did not really spend money on candles or torch batteries, but bartered their own produce (generally self made goat cheese) for energy sources with merchants who made their living trading goods in the rural areas they visited in vans or small trucks (Poch Ambiental, 2009, Interview 3).

These local economic networks and practices were not evaluated, or may have been neglected, in the decision making process. On the contrary, given the economies of scale in the Coquimbo PV project and the potential to incorporate the existing 1,500 SHS installed in the region through a retrofitting project, a privately managed scheme was selected. The operational cost of such private models was higher than any other scheme. Cost recovery monthly tariffs were estimated between CLP 10,000 and CLP 12,000 (circa US$20-24)[37].

This electricity service (for as little as the 13 kWh per month that the SHS would provide) was indeed apparently more expensive than what the rural families were already spending on extremely low quality lighting, but they might have been willing to pay more for a reliable and high quality electricity service. However, from a policymaking

[36] Electricity tariffs for non-regulated residential clients in isolated electricity systems (i.e. those not serviced by distribution utilities or cooperatives through grid service) are defined by agreement between the municipality and the service provider. The tariff has to be sufficient to guarantee replacement of parts and equipment with a life cycle shorter than the project estimated duration plus operational and maintenance costs, so quality of service and system performance is guaranteed over the project life.

[37] The tariff would recover maintenance and operational costs, since equipment was being funded by a state subsidy (FNDR).

perspective, charging higher bills to extremely poor rural citizens was contested since grid-connected rural households in Coquimbo were paying about a third of the estimated SHS fee for more abundant and all purpose electricity (around 30-50 kWh per month at 220V).

These differences triggered a discussion of equity and the social and political implications of an unbalanced price of electricity within a given locality. For the first time since the liberalisation of the energy sector, a subsidy for electricity consumption was considered and finally approved by the parliament. The subsidy was to be given to rural users of RET projects executed within the framework of the PER. The rationale behind the subsidy was that RET rural customers should pay the same price per kWh as the nearby grid-connected customers who were paying regulated tariffs. In the discussion and approval of the law as finally drafted, the subsidy was to apply to all off-grid electrification systems, regardless of the technology involved (i.e. either RET or conventional fuel). This has had some very important implications that will be discussed later in the thesis, as non-RET off grid rural electrification would also be benefited with a supporting mechanism originally intended to provide protection for sustainable technology at a niche level.

In the case of the PV Coquimbo project, rural users pay about 25% of the estimated (cost recovery) tariff (circa US$6), while the remaining 75% (circa US$18) is covered by the consumption subsidy the Regional Government transfers to the company in charge of the maintenance model on the condition that users pay their share and receive the agreed service[38].

As all these developments began to come to a head, an international bid was announced by the Regional Government and the UNDP in the first months of 2005. CONAFE – the main local electricity distribution company - was selected to supply the equipment and maintain the systems. Between 2005 and 2007 more than 3,000 SHSs were installed in households and community, social and public service buildings throughout the region and have since been maintained by CONAFE SER (a Renewable Energy Services branch created by CONAFE with the aim of expanding its position in renewable energy in rural areas).

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[38] The consumption subsidy, which can be considered as an adapted version of the feed-in-tariff model, comes to about US$650,000 per year for the 3,000 SHS rural users in the Coquimbo region. This is a direct transfer from Regional Government funds to the utility company providing the service (source: CNE 2004. Propuesta de Subsidio al Consumo Eléctrico en Localidades Aisladas. *In:* RURAL ELECTRIFICATION UNIT (ed.). Santiago.).

Electrification of rural schools and medical centres had originally been planned in the framework of the same project but in the end these were not included as the system requirements for fulfilling their users' demand were quite different. Coordination problems between the Regional Government and the Ministries of Health and Education, which should have been in charge of those systems as part of their responsibilities in rural service delivery, also featured in the decision to implement a different intervention for such facilities. A new project was soon designed and finally executed in 2009-2010. In this case a different firm, TECNORED, was selected to provide the equipment and install PV systems, but maintenance and support for operation was not included in the contract, so it is not yet clear who will be in charge of the replacement of required parts during the operation of the project.

An important determinant of success in the Coquimbo PV project can be attributed to the spread of commitment between different types of actor. Government institutions were aligned at the regional and central scale through political mobilisation in which PER and ministerial authorities engaged with regional and municipal authorities, and so a political decision was made to support mid-level government officials through the long project development cycle. That support gave the GEF directive team a clear counterpart with whom to communicate. These regional actors were important intermediaries between centralised and local public institutions and between public and private actors during the development phase.

On the other hand, CONAFE was engaged from the beginning in the PV project. Once the GEF programme was designed, CONAFE showed willingness to participate in a large scale SHS project. They openly disclosed their strategic plans for rural electrification and contributed to deciding in which areas grid extension was feasible and in which off-grid alternatives were more appropriate. From the beginning CONAFE knew that any project would be implemented through a competitive and open process, so they developed the internal capacity to prepare themselves for the challenges of RETs rural electrification. CONAFE SER was formally registered and staffed with a mix of experienced technical professionals and young graduates with less structured practices and more willingness to innovate and learn in a new domain. From a strategic perspective, CONAFE SER was established with the expectation of becoming a dominant RET actor in both rural electrification and grid-connected RETs in urban areas. Such a domain did not exist at that point in Chile, but it was expected that one would be regulated in the not very distant future.

A crucial change in intermediary action during this phase of PV diffusion is the involvement of the GEF programme in the rural electrification scene in Chile. The role played by the GEF team was still a bilateral type of technical, managerial and political mediation, which brought together several actors working in different parts of the institutional framework (such as private sector companies, regional and local authorities and rural communities). In this process, the functions undertaken in the intermediary action started moving from technological and managerial areas to broader and systemic roles such as awareness raising, cultural articulation of technological possibilities and societal needs or the identification of key issues in the policymaking process.

During the implementation of these larger PV projects, expectations began to be shared by actors at several scales of action, including regional government officials and authorities, council mayors and private actors (particularly top level directors at CONAFE, the regional distribution utility in Coquimbo). Issues around PV moved from general ideas about the potential of the technology to managerial challenges and the question of the sustainable, long term operation of SHSs. Networks in Coquimbo expanded into a diverse set of actors, including incumbents and newcomers. Important resource commitments were made by the regional government through the staffing of a relevant rural electrification technical unit (UTER) and by the creation of a specific branch of the distribution utility to deal with all RET projects (CONAFE SER). Another important factor was the engagement of many municipal authorities, who committed local council human resources to undertaking field surveys and promoting awareness amongst rural families, work jointly carried out with the GEF field extension team.

Additionally, much progress was achieved in terms of knowledge. Learning was fundamentally technical in this phase, concerned with improving PV technology know-how. Workshops, design courses and visits to similar projects (particularly a visit by CNE and GEF Programme staff to a World Bank's SHSs project in Salta, Argentina) led to increased knowledge of the technology and greater awareness of the challenges in project implementation and long term operation. Although important, however, learning was kept at central scale and know-how did not get transferred to the regional or local scale (Poch Ambiental, 2011).

5.4 Replicating success or repeating homogeneous models? The emergence of routines and practices around PV electrification

The project development process in Coquimbo led to the emergence of routines and design practices that were then replicated in different regions. The first of those practices to become tacitly institutionalised at the CNE was the fieldwork methodology in which a GEF team covered rural areas in a region extensively to identify non-electrified beneficiaries and collect data to design and assess projects. One implication of this method was the engagement of municipal and regional actors, mainly mid-level government officials. CNE and GEF staff were able to connect with municipal and regional authorities in a smoother way than was normally the case, fostering relationships and communications between authorities at different scales, from central government ministries to regional or municipal authorities traditionally being very formal in nature. Those key intermediaries were naturally different in each region and their level of engagement affected level of the political commitment to rural electrification at a decentralised scale that emerged in many regions of central-northern Chile.

Initially, fieldwork was replicated in northern regions from Coquimbo to the Atacama Desert, as agreements were reached between the CNE, the GEF Programme and regional and local authorities. The Atacama, Antofagasta and Tarapacá regions followed Coquimbo, and then fieldwork was extended to the central regions of El Maule, Bio-Bio and O'Higgins. Following the methods developed at the CNE and at the GEF programme for the Coquimbo PV project, needs assessments, option analysis and technical designs were undertaken and several PV projects were thus developed. From 2003 to 2007 a pipeline of 48 off-grid rural electrification PV projects was assembled. Of these, 15 have already been executed, many projects have been assessed in accordance to MIDEPLAN methodologies and some others are still at a preliminary design stage. In this phase of replication, the GEF Programme directive team acted as a key intermediary which initially raised awareness about the benefits of RET in rural electrification amongst regional and municipal authorities and provided financial and technical support to identify and develop the projects. The GEF programme also funded users' training in RET operation and covered part of the investment costs, normally about 10% of the required capital subsidy. This incremental cost of the technology compared to grid extension had been identified as a key financial barrier to the uptake of RET in rural electrification and was one of the reasons underlying the grant from the GEF Secretariat.

The centralised support for the Coquimbo PV Project, together with its large scale, resulted in the adoption of a more centralised delivery model managed by the private distribution company that already concentrated most of the electricity market in Coquimbo. However, for smaller projects, support from the private sector was not obvious and the roles played by regional and municipal authorities affected the degree of smoothness of project implementation. Some regions executed projects at a rapid pace and others faced pitfalls and delays. This had direct implications for the management schemes that have been applied to the operation and maintenance of projects.

For instance, the Atacama PV project, which involved around 500 SHSs and which was developed by replicating the methods and designs a year after the one in Coquimbo, did not find the same political support at the regional level. Regional authorities did not commit their own resources (in the form of staff and time) to the development of the project and the GEF programme team found themselves carrying out activities without the same deep interaction they had experienced in Coquimbo (Interview 4, Interview 36, Interview 9). As a result, even though the Atacama PV project had been granted approval and FNDR funding in 2004, the Regional Government was unable to carry out a successful international bidding until 2008 (Interview 36, Interview 9).

The bid submitted by CONAFE in Atacama was not successful. Instead, SICE Chile, a Spanish firm with experience in telecommunications, transport control and tolling systems in Chile and grid-connected PV in Spain, was selected. The firm had an engineering department based in Madrid which developed all designs according to the technical specifications of the brief. The technological capacities for this project were not really transferred to the country and all technical knowledge remained at the European headquarters. At the time that the fieldwork was being undertaken for this research, SICE Chile was executing the works in Atacama and most of the SHSs had been installed. Users received a training course and a leaflet with a description of the system and basic operational information. SICE Chile was requested to provide maintenance for 10 years, replicating the requirements of the Coquimbo project. A subsidised tariff was also set in the case of the Atacama project.

However successful the installation of the Atacama PV project, some contested issues remain about the process. Why was the time-lag from identification and development to actual implementation so long? Cross learning and lessons sharing never took place at a regional scale. Several attempts to implement visits to the Coquimbo project and visits from the actors involved in project implementation from Coquimbo to Atacama did not take place (Interview 9). Regional actors did not become fully engaged so commitments to the project were low, representing something more like an imposition from the PER rather than a local/regional option. Deep interaction between public and private sectors never featured although this was a crucial factor explaining the long-term support experienced in Coquimbo. Finally, as in the case of the Coquimbo PV project, communities never had a voice in the design or the delivery model being planned for the project. Although it is too early to draw conclusions about the results of the project implementation and operation, it seems that the size of this project creates sufficient scope to implement a private led model, although the capacities of a firm with no experience in service delivery in rural areas is uncertain and might represent a risk for the long term operational sustainability of the project. In fact, the executives of SICE Chile affirm that for them the Atacama PV project was an opportunity they saw to enter the renewable energy market (more particularly the PV sector) that was thought to be very likely to emerge in different domains, such as utility scale electricity generation and electricity provision for the telecommunications and mining sectors (Interview 10).

Following the practices in the Atacama PV project, SICE Chile was also selected to provide the equipment and user training in an additional SHS project in the southern Aysén region, in which 90 SHS were installed. This project did not, however, involve any maintenance or operational support from the firm. The systems in the Aysén projects were bigger in installed capacity (PV modules and batteries), a response to the low radiation levels and poor weather of the southern regions of the country. Although the electricity service level was improved to ensure reliable supply, the systems' design is still limited to servicing basic electricity needs at 12 V DC for residential uses, supplying lighting and electricity to connect small B/W TV sets and radios.

Apart from the two relatively large scale PV projects in the Coquimbo and Atacama regions, most of the initiatives in the GEF portfolio are smaller projects. These projects normally involved tens of households in a particular geographical area, so the actors involved in the design, promotion and deliberations about project implementation moved more to the local scale. Council mayors, municipal staff and even local communities started to become more relevant to how projects were planned and executed. For these reasons it is important to analyse projects that have been initiated following the same practices established by the GEF programme for beneficiaries' identification and project development support, but that have ended up implementing radically different management and participatory models.

One of these instances is the electrification of isolated villages and hamlets in San Pedro de Atacama, a rural municipality in the Atacama Desert in the northern Antofagasta region. The town's electricity system remains isolated from the Great Northern Interconnected System (SING), but is not really an off-grid electricity system like the majority of those discussed in this investigation. The local electricity system is currently powered by gas and diesel fired generators and covers the town of San Pedro de Atacama, the village of Toconao and some hamlets close to San Pedro (called Ayllus in Quechua or Kunza, the local indigenous languages). This electricity system grew out of the initiative of the San Pedro de Atacama Electricity Cooperative (CESPA), which is formed by a majority of indigenous 'Atacameños' people. CESPA has a close relationship with the municipality and the local authorities. Most of CESPA's investments have been implemented with the use of public funds, for which the municipality plays a very important role as intermediary with respect to the regional and centralised institutional apparatus. Currently, most of the generation and distribution equipment is owned by the municipality, but administered in the form of *commodate*[39] by CESPA.

San Pedro's electricity system fulfils the requirements of legislation and regulations in the same way as any other electricity cooperative or distribution utility; however, CESPA's operations are geographically limited and small in terms of installed capacity. Although a regime actor, it does not have as much influence or as strong a position of power as other big utilities, which have operations in several regions and many subsidiaries and thus operate a *de facto* vertically integrated sector.

CESPA's limits of capacity, literally electrical, but also technical and managerial, had the result that many small villages and dispersed rural families in the San Pedro de Atacama municipal area were not served by electricity service until the implementation of the PER and the GEF programme. For those settlements, the municipal strategy was to install off-grid RET systems covering a fairly diverse range of technological options. SHSs have been installed for isolated rural households and RET-based mini-grids have been preferred in far-off villages. There are three micro-hydro plants (in Talabre, Río Grande and Socaire) and a hybrid PV-diesel mini-grid in Camar. These systems supply electricity

[39] A *commodate* refers to a free concession of anything movable or immovable, for a certain period of time after which it must be restored to the individual or entity that lent it: what is transferred is possession without ownership.

to tens of rural households, shops and other public service buildings in each village. Because these projects are similar in terms of delivery and maintenance models to the technologies being discussed in this thesis (the focus of the thesis is on the solar PV systems, i.e. the PV-diesel mini-grid in Camar and disperse SHS), during field work one of the micro hydro plants (in Río Grande) was visited so as to compare users' experience and management models.

The case of San Pedro de Atacama is thus a good example of diverse experiences. In every project, the role of the municipality has been crucial in i) taking control and ownership over decision-making processes; ii) promoting a more participatory approach in which users' organisations are in control of system operations, basic maintenance and management, including tariffs collection at the village scale; and iii) allowing for diversity in terms of models. The municipality had technical and political support from the GEF programme and the PER authorities from the beginning of those programmes, so the same practices for project identification, appraisal and development were replicated and a determined commitment from centralised and regional authorities was maintained over several years of project development and execution.

Moreover, the municipality engaged additional actors in the development of RETs projects. Initially, a PV mini-grid had been planned for the village of Machuca and SHS for the dispersed households in the area, but finally, given the low demand profile over the year (the village is not completely inhabited during winter), SHSs were installed in all households around and in Machuca. This particular project was developed with the financial and technical support of the Small Grant Programme (SGP), a second GEF programme operating in Chile, which had a focus on more participatory approaches, capacity development and empowerment of rural communities.

In fact, the Machuca community was the main actor behind the initiation of the project. A local community-based organisation applied for funds and took control over decisions and the development process in coordination with the municipality. A second project, the Camar PV-diesel mini-grid, was developed with the support of the GEF programme, but the University of Chile was also involved, through the municipality, in the design of the generation and distribution system. An engineering student did his thesis by looking at local electricity needs, estimating future demand and designing the RET system (Hidalgo, 2006). The thesis was then used by the municipality to apply for FNDR funds for project execution. Finally, for the micro hydro projects, the PER and the GEF programme supported the project development phases and provided funds for technical designs.

The particular feature of all these off-grid projects in San Pedro de Atacama is that village users' organisations are in charge of project operation, and normally a villager has been trained as the plant operator, while the municipality is in charge of regular maintenance. For all these off-grid systems, the municipality has a contract with a small electrical company which also provides services to CESPA. Although not fully cost-recovery, tariffs have been set and are collected by users' organisations and regular interaction is maintained between these committees and the municipality. Through these instances of off-grid RET rural electrification the sense of a cohesive network of actors cooperating and adapting practises to the local reality emerges as a key determinant of success in technological dissemination. Additionally, as relevant intermediaries, municipal officials have enhanced their planning and managerial capacities through training courses and are now able to develop projects by themselves and follow the procedures and rules of FNDR funding and MIDEPLAN assessment methodologies.

Another example of off-grid PV rural electrification described in detail in this section is the case of Empedrado, a rural municipality located in a poor area dominated by forest plantations belonging to the pulp, paper and timber industries in central Chile. As forest activities expanded in central and southern Chile over the last 30 years, small farmers and agricultural activities have been reduced, exposing subsistence farmers to higher risks with the result that people have been forced to move to towns and urban centres. Empedrado's rural population shrank by 25.9% between 1992 and 2002 to 1,726 inhabitants and 73.3% (or 37,630 hectares) of the entire municipal land area is estimated to be covered by forest plantations (Municipalidad de Empedrado, 2008).

Given this reality, traditional grid extension faced two main inhibiting factors. Firstly, distribution utilities showed no interest in expanding electricity service to low populated poor rural areas where load factors and return on investments are extremely insignificant. Secondly, landowners, now investors with interests or rents from forestry plantations, obstructed planning permission procedures or simply opposed the construction of electricity lines through their properties. By 2002 rural access to electricity was 68%, the lowest electrification level in El Maule region (Poch Ambiental, 2009).

Against this backdrop, municipal staff and authorities welcomed the GEF programme initiative. In 2003, fieldwork and supporting activities were implemented to develop one SHS project for 21 rural families, and municipal staff were trained in project development activities and RET general knowledge. The first project was implemented in 2006 and, following this experience, the municipal staff themselves started developing a second project for 44 additional families. Both projects had been implemented by 2008 and new initiatives were being explored by interested professionals who worked for the municipality. These included a PV water pumping system, a pilot bio-digester and a biomass (sawdust) heating system, which have been installed locally in the last 5 years (see next section).

For the two SHS projects, an operational model in which users' organisations would have to create electrification committees, charge monthly tariffs and receive municipal support for expert technical capacity was attempted, following guidelines and advice from the GEF programme. However, as municipal staff pointed out during fieldwork interviews, maintenance is somehow undefined and users request the support of the municipality in case of operational problems (Interview 39). Interviewees think that the management model did not match local economic practices and that a monthly tariff being charged to save resources for future battery replacement was unpractical in an impoverished agrarian community. As the projects are still manageable and involve a reduced number of families, municipal authorities feel confident they will be able to provide support and access to funding for the future reinvestments (e.g. batteries, charge controllers) needed for SHS over the projects' life cycle (Interview 39).

As in the case of San Pedro de Atacama, local authorities and municipal staff in Empedrado played a key role in promoting and advocating the use of RETs. An important feature here was the development of local capacities to manage a growing number of initiatives. The capabilities thus developed are not really technological but at least some knowledge about RETs has been transferred, which includes enhanced ability to generate project proposals that are eligible for public funding. An important element in the development of RET projects in Empedrado (and also in many other local contexts) is that trajectories of development have been progressively initiated from the local scale (in this case the local municipality; in other instances from community organisations), and are not imposed by central or regional authorities. This is an important feature observed during fieldwork and commented on over and over again by interviewees. The consequence of these new practices is that the approach to project development has moved from centralised top-down models to more participatory and decentralised bottom-up schemes in which local communities and council staff and authorities get involved from the very beginning of project design and implementation.

Complementing the projects already analysed in this section, there is an ample portfolio of executed or developed PV projects in central and northern Chile (and also some projects implemented in southern regions). Table 5.1 shows the complete list of PV projects, including experiences consisting of SHS and some hybrid PV-diesel and PV-wind-diesel stand alone systems or mini-grids. Most of the projects have been identified, developed or supported by the GEF Programme, although some initiatives are still being developed by independent institutions or financed by private firms, such as the case of Collahuasi Mining Company and Endesa Eco. These will be analysed in the next section due to the inclusion of additional application domains and energy uses, which represents a change in expectations and further articulation between needs and options.

In the phase of PV dissemination analysed in this section (i.e. replication of local initiatives), the scope of intermediary action expanded and was undertaken at an increasingly systemic level. This included the development and application of technical standards, needs assessments in an extended territory which allowed the compilation of a large project portfolio, the engagement of stakeholders in many regions and rural councils in the country and the consideration of follow up activities and impact evaluations, including the implementation of various management models at a decentralised and centralised scale.

Expectations and visions with respect to PV futures started to become more specific, particularly in terms of the management models that could work better in particular rural contexts. The most relevant projects (in terms of their geographical scope and size) implemented centralised models whereas others preferred more decentralised approaches that gave greater importance to municipal support in the provision of maintenance and operation. The emergence of a large portfolio of projects consequently redistributed the scope of action of regional and localised networks, with the increased participation of private actors (such as distribution utilities and cooperatives, technology providers, technicians and even users' groups, particularly in those regions that favoured more decentralised approaches of electricity provision).

Cross fertilisation between projects in different regions was still limited, a factor which impeded the ability of networks to strengthen their linkages. Learning in this phase was mainly about i) how to manage rural electrification and ii) what can and cannot be achieved with SHSs in terms of domains of application and fulfilment of societal needs. This is very important since learning has started to become more reflexive and to include considerations about the efficacy and effectiveness of rural electrification policy. Although important, those policy discussions and feedbacks that might have adapted technological practices and policy were eminently a central government matter, which additionally increased dependency on central actors, mainly CNE and GEF programme support to identify, develop and finance projects.

Table 5.1: Complete Database of PV Rural Electrification Projects in Chile (2001-2012). Sources: (Ministerio de Energía, 2010, Canales, 2011a, Poch Ambiental, 2009) and author field research.

ID	Region	Council	Name	Tech, Type	Nº of Families/ beneficiaries	Installed capacity (KW)	Total Investment (US$)	Implemented (EXEC)/ in pipeline (FNDR)/ Study only	Execution Date
1	XV	Arica	Chaca Hybrid Project	HIB (PV-diesel)	25		60,000	FNDR	
2	XV	Reg, Arica & Parinacota	PV Electrification: Rural Schools and Health Clinics	PV	11	20	574,468	EXEC	2011
3	XV	Camarones	PV Camarones	PV	50		113,122	FNDR	
4	XV	Putre	PV Putre	PV	76		80,000	FNDR	
5	I	Camiña	Nama Hybrid Project	HIB (PV-diesel)	28		50,000	FNDR	
6	I	Iquique	San Marcos Hybrid Project	HIB (PV-diesel)	70		300,000	FNDR	
7	I	Huara	Sibaya Hybrid Project	HIB (PV-diesel)	40		60,000	STUDY	
8	I	Huara	Achacagua Hybrid Project	HIB (PV-diesel)	35		50,000	FNDR	
9	I	Pozo Almonte	Huatacondo Mini-grid hybrid proj,	HIB (PV-wind-diesel)	80	23	425,532	EXEC	2010
10	I	Reg, Tarapacá	PV Electrification: Rural Schools and Health Clinics	PV	13	25	659,574	EXEC	2011
11	I	Pica	PV Pica	PV	6		10,000	FNDR	
12	I	Huara	PV Huara	PV	16		20,000	FNDR	
13	I	Colchane	PV Colchane	PV	21		25,000	FNDR	
14	I	Pozo Almonte	PV water pumping Pozo Almonte	PV	3	3	100,000	EXEC	2010
15	I	Pica	PV Salar del Huasco	PV		n/i		EXEC	2003
16	II	Ollague	Ollague Hybrid Project	HIB (PV-diesel)	80		500,000	FNDR	
17	II	SPA	Camar Hybrid Project	HIB (PV-diesel)	22	10	218,577	EXEC	2008
18	II	Calama	PV Calama	PV	40		63,462	FNDR	
19	II	Reg. Antof.	PV Electrification: Rural Schools and Health Clinics	PV	11	29	787,234	EXEC	2011
20	II	SPA	PV San Pedro	PV	26	18	96,662	EXEC	2006
21	II	Prov, Tocopilla	PV Province of Tocopilla	PV	11		11,000	FNDR	
22	II	Ollague	PV Ollague & Puquios	PV	26	8	30,000	EXEC	2006
23	II	SPA	PV Machuca	PV	23	10	20,000	EXEC	2006
24	II	SPA	PV School E-26 San Pedro de Atacama	PV		5,8		EXEC	2010
25	III	Huasco	Carrizal Bajo Hybrid Project	HIB (PV-diesel)	100		750,000	FNDR	
26	III	Chañaral	PV Caleta Pan de Azucar	PV	20	2	100,000	EXEC	2010

ID	Region	Council	Name	Tech, Type	Nº of Families/ beneficiaries	Installed capacity (KW)	Total Investment (US$)	Implemented (EXEC)/ in pipeline (FNDR)/ Study only	Execution Date
27	III	Reg, Atacama	PV Region of Atacama	PV	462	46	1,439,000	EXEC	2011
28	III	Reg, Atacama	PV existing systems Atacama	PV	200		250,000	FNDR	
29	IV	La Serena	Almirante Latorre Hybrid Project	HIB (PV-diesel)	70		250,000	FNDR	
30	IV	La Higuera	Los Morros Hybrid Project	HIB (PV-diesel)	42		194,000	FNDR	
31	IV	Canela	Electrification Totoral Rural School, Canela	HIB (PV-wind-diesel)	10	3	37,000	EXEC	2008
32	IV	Reg, Coquimbo	PV Region of Coquimbo, rural households	PV	3,064	383	7,400,000	EXEC	2006
33	IV	Reg, Coquimbo	PV Electrification: Rural Schools and Health Clinics	PV	34	78	2,300,000	EXEC	2011
34	IV	Reg, Coquimbo	PV existing systems Coquimbo	PV	1,500		1,500,000	FNDR	
35	IV	Reg, Coquimbo	PV water pumping Coquimbo	PV	4	2	84,000	EXEC	2008
36	V	Petorca	PV Petorca	PV	38	5	171,000	EXEC	2006
37	VI	REG	PV O'Higgins coast sector	PV	30	8	245,650	EXEC	2009
38	VI	Reg, O'Higgins	PV Region of O'Higgins	PV	200		180,000	FNDR	
39	VII	REG	PV Region of El Maule	PV	365		600,000	FNDR	
40	VII	Empedrado	PV Empedrado I (Provoste)	PV	21	5	88,600	EXEC	2006
41	VII	Empedrado	PV Empedrado II	PV	44	10	157,648	EXEC	2007
42	VII	Empedrado	PV water pumping Empedrado	PV	1	0,5	21000	EXEC	2007
43	VII	Colbún	PV El Melado	PV	21	5	45,000	EXEC	2006
44	VIII	Prov, Arauco	PV Arauco	PV	238		664,089	FNDR	
45	VIII	Prov, Bio Bio	PV Bio Bio	PV	164		170,000	FNDR	
46	VIII	Prov, Ñuble	PV Ñuble	PV	164		170,000	FNDR	
47	XIV		PV Tres Chiflones	PV	41	13	370,153	EXEC	2011
48	X	Futaleufú	PV Futalefú	PV	223		300,000	FNDR	
49	XI	PROV	PV Cochrane	PV	63		70,000	FNDR	
50	XI	Prov, Cap, Prat	PV Capitán Prat (Cochane, Tortel & Villa O'Higgins)	PV	90	46	1,834,499	EXEC	2010
51	XI	Prov, Cap, Prat	PV Capitan Prat II	PV	120		788,200	FNDR	
52	XI	Cisnes	PV Isla Toto	PV	n/a			EXEC	2006
53	NAC	NAC	Solar PV Irrigation National Programme	PV		255	2,200,000	EXEC	2013
54	NAC	NAC	Solar PV Irrigation several rural Municipalities	PV	32	3,5	672,000	EXEC	2012
				TOTAL	**8,074**	**1,017**	**27,306,470**		

5.5 Up-scaling local niche practices to a more stable level? Opening up new domains and the involvement of new actors (uncertain diversity)

After several years of work, the GEF programme had managed to promote and develop a wide portfolio of solar PV projects throughout the country. By 2011, out of 116 identified, designed or executed rural electrification projects funded in the framework of the PER or by independent parties, 54 were SHS or PV mini-grids[40]. The most significant and earliest executed experiences have been described in the previous section. Together with those projects, all SHS interventions demonstrated that the technology was suitable for rural communities and that despite differences in how projects had been initiated (i.e. the direction of development that trajectories have followed) or how diverse management models have been implemented (private, municipal or community managed models), solar PV rural electrification is currently a relatively successful set of local experiences. Pilot and demonstration projects yielded learning that has been replicated throughout a vast territory of the country and technological practices around PV rural electrification started to become increasingly embedded into a wider group of actors and institutions. Success in PV dissemination can be assessed as a positive outcome for off-grid rural electrification, particularly from the perspective of centralised policy makers measuring progress by the achievement of electrification targets.

However, a different history could have been perceived by rural communities using SHSs. The benefits of basic electrification were substantial compared to the situation before projects were executed. Several RET rural electrification projects impact evaluations have been conducted and they suggest a general consensus about the positive impact of these projects in terms of i) greater free/disposable time, ii) improved quality of life (better studying and household conditions), iii) access to communications and information and, in some instances, iv) improved productivity potential and income generation from irrigated agriculture (Canales, 2011a, DICTUC, 2012, Universidad de Chile, 2013). Nonetheless, as SHS fulfilled only basic needs (lighting, radio and small TV sets), new demands and needs arose from both users and planners. While SHS installations offered radically new ways of using energy, they only dealt with basic lighting and communication needs, but were too small to support other productive or commercial activities (Poch Ambiental, 2011, Ingematik, 2009).

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[40] The remaining projects are micro hydro plants or hybrid wind-fuel projects. Small wind power projects have been designed and are currently being executed. Mini or micro hydro projects do not fall within the scope of this thesis. The subsequent chapter offers a detailed account of the dynamics, tensions and pathways followed in the wind case.

So how can it be determined when a process of increased dissemination of a technology has become embedded into a broad socio-technical system? In this subsection, the concept of the scaling up of local experiences is explored. To that end, scaled up interventions are considered here from two angles: an individual (or horizontal) and a societal (or vertical) perspective. For the former view, scaling up PV projects is seen in terms of attempts to match system design to local demands, or the ability of an off-grid system to match users' needs beyond their basic residential lighting requirements. On the other hand, a societal/vertical perspective sees scaling up as the ability of an experience to transcend the local scale and expand its embeddedness in society. Institutional stability, interconnection of actors, political visibility, power relationships and market structures are all elements of this societal scaling up process.

Scaling up happens from both perspectives, new projects are devised to better address societal needs, so from a more local perspective, individuals' experiences explore new application domains that satisfy additional energy needs and demands, such as electrification of services beyond the residential sphere (e.g. social activities in community centres, public services needs in schools, and health centres, or electrification of productive and commercial activities). This is a horizontal scaling up because new local practices emerge in which knowledge and rules still refer and are applied to local contexts. From a societal perspective, a vertical scaling up occurs through the development of new energy policies, the expansion of networks of actors and institutions dealing with electricity provision and the involvement of new intermediary organisations acting at a system level and new delivery models of access to rural electricity. From this perspective, knowledge and rules transcend the local context and therefore refer and are applied to a more abstract and global context.

The evidence investigated in the off-grid PV rural electricity sector (mainly from interviews and records from the GEF programme and the Ministry of Energy) shows that the first experiences of scaled up interventions were in the design of electrification projects for rural schools and medical centres. Such projects have been designed and are now being installed in the regions of Coquimbo, Antofagasta, Tarapacá and Arica-Parinacota, initially in the framework of the PER and now as part of the Rural and Social Access to Energy Programme (PERyS) at the Ministry of Energy.

Additionally, productive uses of energy were supported by pilot PV water pumping projects in Empedrado (a rural council already engaged in the implementation of SHSs), Coquimbo, Antofagasta and Tarapacá. As these PV water pumping projects have demonstrated their economic and technical feasibility, new actors have entered the network around PV. Originally, all projects were developed from a centralised scale, with key support from the GEF programme. From 2005 onwards, new institutional and private actors have become involved in PV off-grid dissemination. FOSIS (Solidarity and Social Investment Fund) and INDAP (National Institute for Agriculture Development), two key government social policy delivery institutions, started to evaluate the use of PV in their assistance programmes, particularly in water pumping and irrigation projects and rural electrification interventions. These projects are normally developed and executed by bilateral intermediaries and have often lacked adequate technical designs as intermediaries' skills generally relate to social interaction and organisational matters but not to the technical particularities of RETs (Interview 35).

Other actors involved in the dissemination of RETs at this stage were research institutions and the CSR units of private companies. A notable example is the case of the Huatacondo project in the northern Tarapacá region. Led by the Energy Centre of the University of Chile and financed by Doña Inés de Collahuasi (a mining corporation), the project comprises a hybrid PV-wind-fuel system connected to a smart mini-grid supplying electricity to the entire village (around 80 households). This initiative differs from those executed under the PER both in terms of the assessment methods and project finance. Community participation has also been crucial throughout the development process.

The University of Chile aimed to develop part of the technology and is using this demonstration project as a real world experiment. The Energy Centre developed a control and dispatch system that makes it possible to predict demand for and availability of solar radiation and wind in advance. Those inputs permit the generation of a dispatch forecast which is reflected in a sort of smart meter installed in households. This in turn enables community members to make consumption decisions, such as laundry or productive uses of electricity, on the basis of information about the amount of energy available as predicted by the model. The aforementioned systems have strengthened user participation during project implementation and operation. As a result, users have changed their energy consumption patterns thus generating efficiency gains. They also control and operate the generation system in coordination with the Energy Centre at the University of Chile. The active involvement of users was a crucial element of this project. Community members have participated in the design and in all decisions around the project, so they became very empowered from the beginning (Alvial-Palavicino et al., 2011).

Two additional examples of joint corporate-research entities collaboration are the first pilot projects of grid-connected PV systems. The first case is one undertaken jointly by the University of Antofagasta and Juwi SOLAR (a German renewable energy company that plans, develops, builds and operates energy utility plants). The project has the support of the Ministry of Energy and the Regional Government of Antofagasta, who are testing the performance of thin film and polycrystalline PV modules connected to the local grid in the primary school of San Pedro de Atacama (and in an additional laboratory at the faculty of Engineering at the University main campus in Antofagasta). This project benefits from the somewhat unstable regime conditions (Interview 31) of the cooperative-managed electricity system in San Pedro de Atacama (an electricity generation and distribution system which suffers from excess demand), which is isolated from the main transmission system in northern Chile and has gained support from incumbent actors (e.g. cooperative management unit, Ministry of Energy).

The second pilot project has been entirely developed by CONAFE in Coquimbo using its own internal research capabilities. Since their involvement in the SHS project in the region, the company has been operating and monitoring a small PV system connected to its own distribution grid, to assess performance, gain experience and develop technological knowledge in a potential large scale business the company foresees in a not too distant future (i.e. grid connected distributed generation with renewable energy[41]) (Interview 32, Interview 13).

These two projects have been implemented outside the formal scope of the RET Rural Electrification policy since they are aimed at providing grid connected electricity in already electrified distribution networks. However, these experiences are important to understanding how niche actors (e.g. CONAFE, the Regional Government of Antofagasta, the Ministry of Energy, etc.) play a role in linking niche and regime activity and how new domains of application are sought, and in doing so how the niche space expands and niche experiences proliferate.

[41] A new law enabling distributed electricity generation was enacted on 20 March 2012. The so called 'Net Metering' Act considers RETs and co-generation units of an installed capacity up to 100KW to be connected to distribution grids so as to trade surpluses of electricity generation with the distribution utility. The technical regulation defining economic and technical aspects, such as the price to be paid to generators, the standards to be complied with and so on are still under negotiation at the time of writing.

From a societal perspective the scaling up phase has been characterised by the development of an adapted access to energy policy in rural areas that evaluates new energy services or the application of PV technology to new domains (such as productive activities), and support for public services beyond the residential space (such as education and health provision). This new policy framework is a result of learning, the development of expectations and new networks around access to energy in rural areas.

The former PER formally ended in 2010 when two different governmental programmes were created, one at the Ministry of Energy and another at SUBDERE. The PER represented a governmental policy for more than 15 years (1994-2010), but had answered to presidential imperatives. In February 2010, the Ministry of Energy was formally created, replacing most of the planning and policy roles formerly played by the National Energy Commission (CNE). The Rural Electrification Department at the CNE was replaced (and its role enhanced) by the Energy Access and Equity Division (DAEE) at the Ministry. At this ministerial unit the Rural and Social Access to Energy Programme (PERyS, *Programa de Energización Rural y Social*) was then created in 2010. During its implementation period, the Rural Electrification Programme (PER) had been co-executed between SUBDERE and the CNE, but growing conflicts over authority and decision-making powers had contributed to tensions and a lack of cohesive cooperation between the institutions (Interview 36, Interview 15, Interview 38). The separation of roles and the emergence of a new institutionalisation in the energy sector were then used as a good reason to create a new programme in SUBDERE, in collaboration with, but not in subordination to, the Ministry of Energy. This new programme was called Rural Energisation Programme (PE, *Programa de Energización Rural*).

The PER evolved during 15 years: it improved the application of an assessment methodology for RETs projects (MIDEPLAN methodology) and built a decentralised institutional structure (including rural electrification technical units at regional governments and financing sources clearly defined). That level of structuration and institutional stability was somehow under-evaluated in the creation of the PERyS and the PE, which lacked clear assessment methods and implementing institutions.

From an evolutionary perspective, these tensions might represent a decreased level of stability at a global niche level, but they have also opened up new applications domains. From both a policy and a practical perspective, the two programmes have contributed to expanding experimental space, providing protection of and support for new technological applications, innovative financing and market structures, generating new user practices, developing new technological capabilities and therefore enhancing the possibilities of PV electrification in rural areas.

Despite the challenges of creating fresh rules and stability in the new governmental programmes, the adapted policy framework now responds better to rural energy demands and needs. Policy learning has, however, been limited and kept at the centralised scale (Interview 12, Interview 14). Instead of transferring responsibilities to those regional and municipal actors that had created the capabilities to manage off-grid PV projects, the programmes are now developing pilot projects in the newly identified domains (such as RET powered irrigation, electrification of schools and medical centres, and so on). Rather than creating improved institutional coordination, the two programmes are now operating as separate policies. Instead of providing support for the already operational companies that had been involved in rural electrification projects under the PER, the PERyS is undertaking all development and execution activities and the PE still lacks the adequate methodologies for assessing projects as laid down by MIDEPLAN guidelines. These two ‘access to energy’ programmes have been developed mainly around technological provision and seem to be quite disconnected from previous experience.

The last phase identified in the dissemination of PV technology has been characterised by the adaptation and displacement of intermediary action. Specifically, the Ministry of Energy has institutionalised many roles formerly performed by the GEF Programme (which was in its final implementation period) through the active work of ministerial staff in the following areas: awareness raising, technical and financial support, policy coordination, articulation of needs and options and the opening up of new domains (e.g. electrification of schools and rural clinics, application of PV in agriculture and irrigation, etc), stimulation of experimentation and inclusion of additional elements of the innovation system (such as the implementation of applied research with engagement of universities). All these tasks are more aligned to systemic functions played by intermediary institutions. The growth of experimental space also led to new institutions becoming involved in the use and diffusion of PV (e.g. INDAP through support to innovation in small scale agriculture and FOSIS in SHSs rural electrification). These institutions continued developing more traditional, bilateral intermediation, in which technology, finance and managerial support were provided. Regional and municipal actors have also improved their capacities to coordinate and manage RET projects. For instance, technical and methodological training courses have been implemented, so local and regional governmental staff are now better equipped with the skills and knowledge to initiate and develop RET rural energy projects.

Policy adaptation is understood as the realisation of a type of reflexive learning (although it was mainly kept at centralised scale). The creation of the PE and PERyS, together with sectoral programmes for PV irrigation at INDAP, and the engagement of a broader set of actors at the regional scale show how networks have both expanded and deepened. The emergence of many projects in several regions, for both residential rural electrification and other productive uses of energy, have impacted on the nature of decision-making, transforming the process into a more distributed array of issues to be settled and decisions to be made by different groups of stakeholders acting at different scales.

Project implementation decisions have also been influenced by the development of expectations, which became specific about what was possible in terms of socio-technical practices: i) what domains (off grid electrification, mini-grid development, productive uses of PV energy); ii) which type of governance arrangements (private delivery models, communities involved in implementation and use, local council roles in supporting technology dissemination); and iii) what roles different actors and institutions could play (support from universities, strengthened relationships between communities and local authorities, technical and financial support from the State, long term operation and maintenance with private sector engagement). However, this increasingly widely distributed and displaced nature of the decision-making process has not been accompanied by the establishment of rules and institutionalisation of PV diffusion practices. The distribution of decision making has been observed mainly in projects being implemented outside the PER (such as the Huatacondo mini-grid, PV irrigation, and local scale driven SHSs projects). The evolution of reflexive learning has been mainly a matter for central institutions and has not formally permeated into empowerment arrangements for societal groups outside the governmental authority circles.

5.6 Chapter Conclusions

This chapter has presented the first case study of the thesis. It tells the story of PV diffusion in rural electrification in Chile over the last two decades and has been constructed around an aggregation narrative that starts with the implementation of several projects supplying electricity with SHSs for basic electricity uses, executed prior to the launch of the PER (1994). These projects were characterised by a lack of coordination between actors, the absence of policy guidance and a dearth of know-how and skills to operate and maintain the technology.

More comprehensive PV dissemination was triggered by the development of a demonstration project in Coquimbo, whose main features have been described as: i) extensive needs assessment involving both policy makers and rural communities; ii) the engagement of decentralised authorities and governmental officers (at regional and municipal scale); iii) the implementation of an awareness strategy amongst regional policy makers and rural families and the inclusion of management schemes (delivery model) for the project so as to ensure adequate hardware provision and long-term operation and maintenance.

The abovementioned strategy allowed the generation of a reflexive analysis of the technological capabilities needed to sustain an emerging technological change trajectory. In the case of the Coquimbo PV project, this resulted in a more incremental model aligned with the managerial practices and political-institutional structures of incumbent actors (distribution utilities, central and regional public authorities and governmental staff) taking responsibility for rural electrification. The project was implemented and is being operated by COANFE (the main distribution utility in the Coquimbo region), a factor which also means that incumbent actors are playing new intermediary roles, that actors' commitments are spread throughout a relatively broad set of institutions and that through those processes visions have been aligned at different scales, facilitating convergence in decision making.

The development and subsequent implementation of the Coquimbo PV project was pivotal in establishing a set of emergent socio-technical practices, design heuristics, assessment criteria and tacit rules around the project implementation cycle. Several projects in different regions replicated the same practices and many were implemented in subsequent years. However, the level of engagement at regional and local scale has not replicated the way in which the Coquimbo PV Project was implemented, consequently affecting the diversity of the networks around individual projects and how learning has or has not been spread. Most of the knowledge generated has been retained at a centralised scale.

Additionally, management schemes and governance arrangements have also been very diverse, something which results from particular local conditions, the commitment of regional and local authorities and the engagement of community leaders. One particular factor affecting the managerial and operational approach applied has been the depth of commitment of intermediary actors such as municipal authorities, local leaders and directors of energy service firms. At this stage of replication, intermediary action was important at the local (project) scale but did not encompass system change and comprehensive systemic support.

Finally, a scaling up phase has been identified from two perspectives. In an individual scale up, improved technological designs allowed for a better match between users' needs and technological solutions. In such cases, local intermediation is very important. From a more systemic viewpoint, societal scaling up takes place when an increased embeddedness of access to electricity policy and practice reach wider networks and RETs find new domains of application. This implies that new methods and assessment criteria, wider networks and knowledge are spread throughout various scales. In such cases, intermediary action seems to be more important at system level rather than in local spaces.

The next chapter tells the story of small scale wind-power development and diffusion in small islands and villages in southern Chile, focusing on the implementation of wind projects in Chiloé. As will be shown, the trajectory has been quite different to that of PV dissemination in central and northern Chile and wind-power mini-grid development has achieved very limited acceptance and socio-technical diffusion is still extremely restricted.

6. Wind Powered Mini-Grids for Rural Electrification in Southern Chile

6.1 Introduction to the chapter

Small scale wind power attracted the attention of practitioners and policy makers from the very beginning of the rural electrification policy in the 1990s. Few projects executed prior the launch of the PER in 1994 sustained emerging expectations or obtained the commitment of robust political support for mini-grid development in isolated villages throughout the country. It was the combination of a pilot project in the Chiloé Archipelago – the Tac Island wind project - and the hope of complementing electricity service provision with wind turbines in existing diesel gen sets connected to mini-grids in dozens of small villages, which put wind-based mini-grids on the agenda of rural electrification in Chile towards the turn of the millennium (Duhart, 2009). Small scale hybrid wind-fuel systems had the potential benefit of improving the electricity service while reducing fuel costs (UNDP, 2001, Interview 7, Interview 36).

Initially devised for the windy southern regions of the country, resource monitoring campaigns were extended to several other areas, such as fishing villages along the Pacific coast and mountain valleys in the Andes, places where good wind potential was expected, but accurate resource measures have not been collected (GEF, 2005, 2006, 2007). Potential resource data, on the one hand, and socio-cultural assessments, on the other, fed into project development processes and technological designs that articulated needs and options. A portfolio of projects was prepared and submitted with the aim of obtaining state subsidies in the framework of the PER and the FNDR (Canales, 2011a, Poch Ambiental, 2009).

However, after years of efforts, only a few wind turbines continue to power rural communities in the country. Most of the wind systems installed are stand alone turbines connected to batteries and only one mini-grid was built within the framework of the PER before it ended in 2010 (Canales, 2011a). The lack of institutional support and poorly developed technological capabilities for wind based rural electrification have shifted the attention of technology providers to different sectors, such as telecommunications and productive activities in the mining and salmon farming industries (Poch Ambiental, 2009, Interview 36, Interview 1, Interview 21, Interview 19).

Only in recent years have a few more small scale wind electrification projects begun to receive increased support[42] and might turn the weather-vane in the right direction, improving the access to energy position of non-electrified communities that still lack a reliable electricity service[43].

6.2 Uncoordinated winds

The first wind-based electricity systems for rural electrification were installed in southern Chile in the late 1990s. These interventions aimed to provide electricity to remote villages through mini-grids or through stand alone wind turbines in schools or rural clinics. Three pilot projects in Puaucho, Isla Nahuehuapi and Villa Las Araucarias, in the Araucanía region, were initiated in 1997, supplying electricity to 26 rural households, three schools, two clinics and a church (Forcano, 2003). As in the case of solar PV, little is known about the current state of those projects. One reason for this lack of information is that regional authorities, who initially supported the projects in Araucanía, soon decided to focus on grid extension due to the difficulties experienced in maintaining and operating RET systems. Technical problems are often mentioned as the main reason for low expectations about wind power (Interview 1, Interview 14, Interview 21). However, the absence of supporting mechanisms for RET development also accounts for the unstructured and unconnected nature of the networks of actors and therefore the difficulties in capturing lessons which could feed into management and learning around those projects (Interview 36, Interview 15).

In other southern regions, universities have played an important role in the development and implementation of wind projects. For example, over the last couple of decades in the very southern Magallanes region, the University of Magallanes (UMAG) has implemented some wind energy projects for the electrification of rural schools and ranches (Kunstmann and Mancilla, 2002) and the University of Chile (UCh) executed another wind energy project to electrify a rural school and few households in Hualaihué, in Los Lagos region (Muñoz, 2002). Other small scale wind projects which were executed

[42] Nine additional wind powered mini-grid projects originally planned to be implemented between 2005 and 2009 (Quenu and Tabón Islands and the Desertores Archipelago wind projects) have been under execution since 2012. These projects are described in the subsequent sections of the chapter.

[43] Information about Wind projects has been collected from the Ministry of Energy, GEF Programme, independent developers, personal conversations with interviewees and field visits to project sites. A complete database of projects has thus been assembled and is presented in the subsequent sections of this chapter.

in the 1990s have suffered a similar fate to that of the first PV initiatives of the central and northern regions of the country. While good wind resources do exist, there was uncertainty about seasonal patterns and, more crucially, about the socio-cultural characteristics of energy demand in rural villages. Most of the wind systems have been left without adequate monitoring and maintenance and are no longer providing electricity (Interview 19, Interview 16).

These first experiences, however, prepared the ground for further interest in wind powered rural electrification. As in the case of solar PV in the central-northern regions of the country, at the start of the PER in 1994, special political priority was given to the electrification of the Chiloé Archipelago in the Los Lagos region. Wind powered mini-grids were meant to revolutionise the way rural electrification was planned in a territory dominated by tough winters, isolated and unconnected islands and a strong local culture – the 'Chilotes' - closely tied to fishing, forestry and with a rich mythology and cultural heritage. Formed by the Great Chiloé Island and a cluster of more than 40 smaller islands, the Chiloé Archipelago was home to more than 3,500 families, all of whom lacked access to electricity. In most cases conventional grid extension was considered technically unfeasible given that the national grid had just been connected to the Great Chiloé Island and the majority of the smaller islands in the archipelago were far away from existing electricity lines. Wind-based systems and other RETs (such as biomass small scale power plants) were then thought of as a promising alternative if implemented in close interaction with local community organisations (Interview 14, Interview 15, Interview 19).

As in the early phase of PV diffusion in rural electrification, wind power development was the result of intermediaries working on a project-by-project basis. Their work consisted mainly in technical assistance for the design and implementation of projects. Project champions channelled international cooperation funding, which was used for hardware and equipment provision. Once executed, however, interventions were left in the hands of users who lacked the capabilities to operate, maintain and follow up projects so as to ensure adequate performance (Interview 15, Interview 16).

Expectations about wind technology were often vague and primarily held by individuals working at universities and NGOs. The result was that needs assessments were too general and technology driven, resulting in a poor articulation between societal needs and technological options (Interview 36, Interview 14, Interview 16). As projects were executed by universities or NGOs working separately and even in completely different regions, expectations were not shared between actors and networks did not appear at this stage. Learning was not codified and project developers were primarily learning what to do with the technology (Interview 16).

6.3 Piloting Wind-based mini-grid in Chiloé islands: Is anyone on charge?

The regional electrification strategy in Los Lagos evaluated grid extension to mainland non electrified areas and off-grid RET based systems in isolated territories and far off villages. With the support of the NREL (US National Renewable Energy Laboratory) the PER carried out a preliminary assessment of wind resources and a wind map was assembled for Chiloé. A field survey complemented the wind assessment with socio-cultural data and so a pilot project was designed to electrify Tac Island with a wind-diesel mini-grid. This was considered as a flagship for the electrification of another 32 islands in the archipelago.

The Tac Island electrification project was implemented between 1999 and 2000 through a partnership between CNE, NREL, DOE (US Department of Energy) and SAESA (the main regional electricity distribution company). It consisted of a hybrid wind-diesel generation unit (15 kW wind turbines and 12 kW diesel gen set), 2100 Ah batteries, inverters and control equipment and a 13 km single phase distribution grid. The system provided 220V electricity 24 hr a day to 72 rural households, one school, a community centre and the rural clinic (Stevens, 2001).

The system was successful in providing electricity during the first year. Users realised savings in energy costs (compared to inefficient candles, LPG lights and small stand alone gen sets) but electricity prices remained higher than regulated tariffs in the grid connected areas of Chiloé. Electricity demand increased steeply due to the use of refrigerators, additional lights, washing machines and other electrical appliances. The use pattern and characteristics of the new electrical appliances also caused technical problems in the generation and distribution system due to a low power factor in a single phase grid[44]. The increased electricity demand experienced implied that the penetration

[44] Power factor is the percentage of electricity that is being used to do useful work. In electric systems there are different types of loads (e.g. resistive and reactive). Examples of resistive loads are heaters or incandescent lamps, which do not affect the power factor. Examples of reactive loads are inductors or capacitors (electric motors, cooking stoves, lamp ballasts, etc.) and not all the electrical energy stored in the load is able to do useful work because there is a time difference between the electric current and the voltage waveforms. Some of the electrical energy is required for magnetization of items. The presence of these types of loads (or appliances) in an electric system reduce the power factor. A low power factor implies that more electricity is lost,

of wind generation was lower than originally estimated. The diesel back-up gen set was then used as a primary generation unit to fully charge the battery bank for peak evening hours and wind electricity was spilled over in periods of low demand (Stevens, 2001, Nelson et al., 2002).

SAESA had signed a 10 year maintenance contract that was outsourced to Wireless Energy, a RET provider based in the Los Lagos region, which had been involved in the project since its inception as technology provider and installer. A huge effort was made to ensure the system was adequately maintained, but due to the difficulty of reaching the island in winter, persistent failures and operational stress led to the breakdown of the bank of batteries, control unit and wind turbines. The system currently continues to supply electricity but only with a diesel generator supplying the mini-grid (Interview 19, Interview 25, Interview 51).

Technical problems were quickly identified by Wireless Energy and described in monitoring reports (Stevens, 2001). As this was a pilot project, it should have been assumed that some problems and difficulties might arise and that concerted follow up support would be needed. However, the fact that the project was designed and financed mainly through international cooperation and FNDR state subsidies made it difficult to invest additional resources to overcome emerging technological and operational failures (Interview 19). International support from NREL and DOE consisted of technical cooperation for the design of the electricity system, including studies at the project development stage. Once the project had been executed, however, their support turned into replication and scaling up activities, but insufficient follow up, monitoring and operational support was provided (Interview 4, Interview 15, Interview 36).

As private entities, SAESA and Wireless Energy restricted their involvement to their contractual responsibilities, i.e. to ensuring electricity provision regardless of the power generation technology in question and providing the stipulated maintenance on the contract. None of the actors involved had envisaged that the RET components would break down. Government institutions, particularly the CNE and the Regional Government followed their functions and practices as if the Tac Island project were any other rural electrification experience, so they relied on the distribution company to implement and operate the project and fulfil its contractual obligations.

higher current is drawn and excessive heat can damage the equipment. The power factor is then a measure of the efficiency of an electric system.

Technology development and innovation were somehow neglected. For instance, user involvement in innovation and niche activities did not feature as important, cooperation between private and public sectors was approached as a commercial relationship, testing and developing technologies was normally understood as a risky endeavour because potential problems or bad performance were seen as failure rather than as opportunities for learning and a way of improving new technologies (Interview 4, Interview 36). The understanding of technological change within the public institutions in charge of rural electrification was defective. Innovation policy was considered the mission of different institutions, to which rural electrification actors did not have a direct link (Interview 15, Interview 16).

All these dynamics reinforce the idea that the TAC Island project focused on hardware provision (normally referred to by interviewees as technologies already available in the market), but user involvement, network interaction and learning, all of which play key roles in technology diffusion, were under-considered or even neglected (Interview 36). Ironically, the project was highlighted and promoted in seminars and publications for many years after its execution and in spite of its unknown fate. The lack of coordination and information flows between SAESA and the relevant public institutions left the project unattended until it ended up operating with diesel alone as it does today, more than 10 years after its supposedly successful piloting (Interview 6, Interview 7, Interview 23).

Over the years, the perception developed that, because the Tac Island project had failed to provide electricity through renewable sources, wind technology was unsuitable for rural electrification in Chiloé. This perception influenced a diminishing support to RETs (Interview 20, Interview 21, Interview 27). The lack of buy-in on wind technology was primarily nurtured at the regional scale: SAESA never committed high level corporate support to small scale wind technology because the company had its own strategic plans in the rural electrification domain. These were based on grid expansion and diesel-based mini-grids in isolated areas and were impelled by two main factors. The first was the existence of a favourable contract agreement with COPEC, the main fuel distribution company in the country, owned by the same group that owned SAESA at that time[45] (Interview 1, Interview 6). The second was related to expectations concerning the future

[45] From 1995 COPEC controlled 93.88% of the ownership of SAESA. In 2001 the US giant PSGE Global Inc bought all the shares of SAESA owned by COPEC and took over control of the distribution utility. Source: www.saesa.cl/historia; http://www.bnamericas.com/news/energiaelectrica/PSEG_Concluye_Compra_de_Saesa;

interconnection of electricity systems in Chiloé islands in which the company hoped to reclaim capacity payments[46] for a subsidised investment in electricity generation. In other words, SAEASA was seizing on opportunities provided by the existing market structure, the institutional framework and their monopolistic position in the electricity distribution sector in Southern Chile. If wind power had been installed, they could not have taken advantage of these two comparative favourable conditions – namely state subsidies for infrastructure construction and capacity payments from the electricity market (Interview 1, Interview 6).

On the other hand, the Regional Government did not buy into the wind power rural electrification plans for Chiloé either. The agenda of the wind-based rural electrification of small islands was predominantly pushed by centralised governmental institutions, headed by the Rural Electrification Unit of the CNE and supported by the GEF programme. Central authorities faced sceptical regional actors who were unsupportive of CNE plans and who never assumed a pivotal role in facilitating the necessary local conditions, such as responsive and committed energy companies and positive expectations about wind power, translated, in turn, into long term political leadership and support (Interview 14, Interview 15, Interview 19, Interview 36).

At this stage, the emerging network of actors was primarily formed by centralised governmental institutions (CNE, MIDEPLAN) and international organisations (NREL, DOE-US). New actors from outside the rural electrification regime came to contribute to wind power development through the cooperation of the GEF Programme and the UNDP Chile office (also established in Santiago). However, their engagement came after the execution of the Tac Island project, so the ability of the network to work cohesively in adapting the system was low.

Alignment of expectations between international aid agencies and central government, on the one hand, and regional stakeholders from both public and private sectors, on the other hand, was never backed by concrete results from local experiences and never particularly specific, given that the only pilot project – the Tac Island wind-diesel mini

[46] Electricity generators in a liberalized market – such as the Chilean electricity market - receive economic gains (income) for the electricity they provide to the grid and for the installed capacity (power) available and ready to be dispatched when the system operator requests an instant injection. The latter form of payments are known as capacity payments and these are often higher for electric plants that can deliver electric output quickly (as the case of diesel generators). Because wind power output is dependent on the availability of wind resources and cannot be turned on and off upon the request of the system operator, these plants receive no or little payment for their installed capacity.

grid - was left without monitoring and evaluations. Only general commitments towards RET-based rural electrification featured in discussions between central authorities and regional actors (Interview 6, Interview 15). Locally driven participation and project development did not really happen, so learning could not become embedded at a local scale and conflicting strategic visions implied that the emerging network was marked by non-cohesive actors and even diverging interests between central, regional and local institutions (Interview 4, Interview 14, Interview 24, Interview 36). Moreover, the failure to manage and adapt the Tac Island project undermined expectations about the suitability of wind power to overcome rural electrification challenges in Chiloé. Second order learning was, therefore, absent and even counterproductive in technology development.

6.4 Not enough wind to take off: (De)institutionalising electrification, withdrawing support

Despite the silent decay of the Tac Island's hybrid wind mini-grid, while still in its 'renewable mode', the project generated high expectations amongst policy makers (mainly at the national scale but also within regional government) and attracted interest from additional international partners. Supplementing NREL support, the e7 Fund for Sustainable Energy Development, formed by a group of energy companies under the umbrella of the G7 countries, expressed willingness to contribute to the RET-based electrification of the Chiloé Archipelago through technical and financial support. Formal commitments were thus agreed between the government and the e7 Fund. The leadership role was assumed by the Rural Electrification Unit of the CNE – formally through the PER - and coordinated and executed with GEF programme support.

As the GEF programme annual reports show (GEF, 2003, 2004, 2005, 2006), a series of complementary activities were planned and executed in an attempt to obtain results at a quasi-system level. Advocacy meetings and awareness activities undertaken with both regional policy makers and private companies were combined with a wind monitoring campaign implemented in selected islands of the archipelago. During 2002 a technical workshop was held at the Federico Santa María University (USM) in Valparaíso. NREL experts trained local consultants, the technical staff of energy companies and regional government officers in wind monitoring campaigns. Following the workshop, the monitoring of wind resources was initiated in Chiloé for a period of 2 years.

Also in 2002, with the aim of improving public sector capacity to assess projects and to act as a counterpart to the wind experts, the regional officer in charge of rural electrification planning processes at MIDEPLAN attended a training course on RETs at NREL in USA (with a particular focus on wind technology). Additionally, a commercial mission to Australia brought together the CEO of Wireless Energy and the technical chief of the GEF programme to improve their knowledge of wind technology, new equipment and commercial practices in the small scale wind power market. Additional training sessions were organised both in the Los Lagos region and in Santiago on topics such as project cycle, basic knowledge about wind power, project assessment and design and use of modelling software for hybrid energy systems (HOMER, ViPOR and Hybrid 2, all developed by NREL).

By mid-2004 an extensive fieldwork campaign, similar to the one which had been implemented in the case of PV projects in the northern regions, was carried out in all islands of the archipelago. Fieldwork was done by a consultant who had previously worked at the Rural Electrification Unit of the CNE. That work fed into a project pipeline for 32 additional islands in Chiloé. Those projects were included in the official PER database managed by MIDEPLAN (Integrated Project Data Bank). Between 2004 and 2005, by means of technical support and financing, the GEF programme commissioned feasibility studies and techno-economic assessments and prepared all official documentation for the submission and approval of wind-based projects in the remote Chiloé islands.

However increasingly diminished support from the dominant distribution utility SAESA (which eventually turned into powerful opposition to the project) and a lack of high-level regional political commitment towards RETs led to the scope of the original project being reconsidered by regional authorities. Originally, 32 islands were to have been included in the project, but between 2004 and 2005 it was decided that more than 20 of those islands would be electrified through submarine grid extension (Interview 14, Interview 15, Interview 36). Although political, economic and technical grounds were given for this change, it is not clear whether sufficient evidence and studies existed to support such a decision.

Wind-based electrification initiatives were therefore regrouped as the Quenu and Tabón islands wind-diesel project (in the Calbuco council) and the Desertores Islands wind-diesel/gas project (a group of 7 small islands in Chaitén and Hualaihué councils). These two projects involved slightly more than 400 rural families (Poch Ambiental, 2009), a substantial decrease in numbers compared to the initial estimate of 3,500 rural families in the Chiloé Islands as a whole. A complete list of the hybrid wind-fuel projects remaining in the rural electrification pipeline in Chile is included in Table 6.1.

The absence of long term vision, weak regional networks and diminished political support soon led to both the e7 Fund for Sustainable Energy Development and NREL withdrawing from their engagement in the projects. By 2005 both international partners had provided technical support in wind resources monitoring campaigns and pre-investment studies. Their decision to end their support (Interview 15, Interview 36) was a result of two problems. First, there was no clear commitment on the part of regional government and private actors to implement the original plan of RET-based electrification of all Chiloé Islands. Second, the projects were not big enough to generate a minimum threshold of carbon emission reductions applicable as a programme of activities in the framework of the clean development mechanism (CDM).

This decision negatively affected expectations about small scale wind power in rural electrification at the regional scale. As the level of knowledge about RETs was still limited in the country, but more crucially within regional public institutions, the fact that two internationally renowned expert institutions had withdrawn their support was taken to mean that wind power was not the right technology (Interview 18, Interview 21). A negative impression of wind projects permeated the political bureau of the regional government and so political support diminished further. The reasons for the decision taken by NREL and e7 Fund were not, however, technical, but linked to the lack of clarity and the small size of the projects (Interview 14, Interview 15, Interview 36).

Despite the lack of response from regional authorities, the GEF programme continued to develop the activities according to its original work plan. In 2006 detailed designs and technical specifications for the Quenu and Tabón projects were commissioned from Lahmeyer International, a German engineering and consulting firm. In April 2007 all designs and tendering documents were handed over to the municipal and regional authorities. In 2008 designs, technical specifications and tendering documents were commissioned for the Desertores Islands project from Trama Tecno-Ambiental (TTA), a Spanish engineering and consultancy firm. Both projects had been assessed in accordance to MIDEPLAN's rural electrification methodology. By 2009 the Quenu and Tabón projects and, by 2010, the Desertores Islands project had both been granted technical recommendations (planning permission) from MIDEPLAN and funds had been made available in the form of investment subsidies from FNDR (Poch Ambiental, 2009).

In July 2009, after a public bid, the proposals for Quenu and Tabón were rejected on technical grounds as tenderers offered different wind turbines to those requested in the bidding specifications (GORE Los Lagos, 2009). Interviewees referred to the rigidity of technical specifications prepared more than two years in advance and said that the firms making the bids had evaluated ‘state-of-the-art’ wind technology which would have performed better under the wind regime of the islands (Interview 1, Interview 19, Interview 24). A second tender was also rejected in June 2011 because its financial proposals exceeded the budget allocated to the project (GORE Los Lagos, 2011). In light of the negative results for Quenu and Tabón, a first bid for the Desertores Islands project was unable to attract interest from sufficient proponents and had to be cancelled (Interview 18). At the time that fieldwork was being undertaken for this thesis the two projects were still in the regional pipeline. Negotiations between regional and central authorities had led to an instable agreement in which new public bids would be called but these new tenders would only request equipment and infrastructure provision, relegating operation and maintenance to the vanishing space of user responsibility.

In effect, the attempt to disseminate small scale wind power in Chiloé resulted in a downscaling experience. Although the project had been launched as an innovative and sustainable plan for off-grid rural electrification, two thirds of the islands initially considered were subsequently excluded from the wind power plans and reconsidered for submarine grid extension from the main grids of the Great Chiloé Island. However, as will be discussed in the next section, these islands did not become connected to the main grid but are now being electrified by stand alone diesel generators. Furthermore, the long period between the first proposal of the regional off-grid electrification strategy its final demise created fertile ground for political speculation and unfulfilled electoral promises, which was used in election after election, whether municipal, parliamentary or presidential (Interview 24, Interview 36).

The inability to execute these projects had consequences in terms of the expectations of rural communities and policy makers about wind power: “small scale wind turbines were not suitable for Chiloé” began to be the perceived wisdom (Interview 4, Interview 21). Fed by this not very promising outlook, regional authorities started to demand that their technical staff articulate new options for Chiloé’s rural electrification and so regional government officials had to negotiate with distribution companies which easily co-opted struggling public servants (Interview 6, Interview 19).

The result of the series of events described above impacted on cognitive and normative dimensions. Regime actors imposed their vision and turned other actor's beliefs into negative attitudes towards small scale wind power and the overall institutional framework that supported RET-based rural electrification started to crumble as project execution decisions, once negotiated and agreed, where bypassed by regional authorities. Municipal authorities then demanded solutions to the electricity access problem of their constituencies, with the result that new options and means of financing had to be considered (Interview 25).

Table 6.1: Complete Database of Rural Wind Electrification Projects in Chile (2001-2012). Sources: (Ministerio de Energía, 2010, Canales, 2011a, Poch Ambiental, 2009) and author's field research.

ID	Region	Council	Project Name	Tech. Type	Nº of Families/ beneficiaries	Installed capacity (KW)	Total Investment (US$)	Implemented (EXEC)/ in pipeline (FNDR)	Execution Date
1	I	Colchane	Colchane Hybrid Project	HIB (wind-diesel)	40		300,000	FNDR	
2	II	Calama	Cupo Hybrid Project	HIB (wind-diesel)	12	11	50,000	EXEC	2007
3	IV	Ovalle	Caleta Talcaruca Hybrid Project	HIB (wind-diesel)	10		100,000	FNDR	
4	IV	Ovalle	Caleta Totoral Hybrid Project	HIB (wind-diesel)	10		100,000	FNDR	
5	V	Juan Fernández	Juan Fernández Island Hybrid Project	HIB (wind-diesel)	300		2,000,000	FNDR	
6	X	Queilén	Acuy Island Hybrid Project	HIB (wind-diesel)	22		140,000	FNDR	
7	X	Calbuco	Chaullin Island Hybrid Project	HIB (wind-diesel)	26		140,000	FNDR	
8	X	Quemchi	Teuquelin Island Hybrid Project	HIB (wind-diesel)	11		50,000	FNDR	
9	X	Calbuco	Tabon Island Hybrid Project	HIB (wind-diesel)	131	54	1,000,000	EXEC	2012
10	X	Calbuco	Quenu Island Hybrid Project	HIB (wind-diesel)	46	18	760,000	EXEC	2012
11	X	Quemchi	Tac Island Hybrid Project	HIB (wind-diesel)	82	30		EXEC	2000
12	X	Chonchi	Chonchi Wind Project	HIB (wind-diesel)				EXEC	2003
13	X		Rahue-La Montaña Wind Project	HIB (wind-diesel)				EXEC	2003
14	X	Chaitén	Auteni Island Hybrid Project (Desertores)	HIB (wind-diesel)	25	43	4,550,000	EXEC	2012
15	X	Hualaihué	Llanchid Island Hybrid Project (Desertores)	HIB (wind-diesel)	19	11		EXEC	2012
16	X	Chaitén	Chuit Island Hybrid Project (Desertores)	HIB (wind-diesel)	35	25		EXEC	2012
17	X	Chaitén	Imerquiña Island Hybrid Project (Desertores)	HIB (wind-diesel)	6	6		EXEC	2012
18	X	Chaitén	Nayahue Island Hybrid Project (Desertores)	HIB (wind-diesel)	31			EXEC	2012
19	X	Chaitén	Talcan Island Hybrid Project (Desertores)	HIB (wind-diesel)	48	24		EXEC	2012
20	X	Chaitén	Chulin Island Hybrid Project (Desertores)	HIB (wind-diesel)	50	43		EXEC	2012
21	XI		Puesto Viejo Police Station Hybrid Project	HIB (wind-diesel)	5	3	25,000	EXEC	2007
22	XII	Pto, Natales	Villa Renovales Hybrid Project	HIB (wind-diesel)	12		64,000	FNDR	
23	XII	Laguna Blanca	Villa Tehuelche Hybrid Project	HIB (wind-diesel)	50		238,000	EXEC	1995
				TOTAL	**971**	**268**	**9,517,000**		

The sense of urgency and perceived lack of alternatives created the ideal conditions for the search for piecemeal solutions. Rural electrification projects started to be conceived increasingly outside of the efforts to institutionalise practices around RET-based rural electrification. In the case of the few remaining wind projects, if it was too difficult to attract interest from companies to supply equipment and sign a maintenance contract over a period of 10 years, new calls would only include provision and installation of equipment. If RETs were not the distribution companies' favourite option, regional authorities would accept any technology proposed by the incumbent firms, including diesel-based electrification. If the prices charged by incumbent companies were too high, regional authorities would have little capacity, or willingness, to negotiate, given the need to reach electrification targets. Electrification planning and decision making started to be an eminently political issue and less a technically informed process. Authorities and advisors inexperienced in technical and scientific issues (such as particular technologies, social contexts and community needs) opted out from wind-based electrification. Only Quenu and Tabón and the Desertores Islands projects were kept in the pipeline as a concession to central authorities given the expected outcomes of the GEF programme (Interview 19, Interview 20, Interview 21, Interview 24, Interview 36).

The overall dis-institutionalisation of rural electrification in the Los Lagos region had the following consequences. By 2010, rural electrification projects for the remaining islands, now taking the form of submarine grid extension, were being implemented by local councils through a mix of stand-alone and mini-grid diesel gen sets in the absence of clear standards and outside the framework of the PER. That is to say, the implementation of these projects was taking place without the use of official assessment and selection criteria or through alternative funding mechanisms provided by sectoral institutions for which assessment guidelines, standards and procedures for state investment in electrification projects were less strict or neglected. (Interview 18, Interview 19, Interview 25). After years of promises, rural communities were demanding solutions via their most accessible gateway to the public sector: the municipal authorities (Interview 24). Local council mayors had to find new sources of public finance to implement electrification projects. In doing so, they had to adapt electrification projects to other ministries' infrastructure programmes, such as the Neighbourhood Improvement Programme of the Housing Ministry, which had never been intended to fund electrification projects but rather infrastructure in villages (Interview 21, Interview 25).

Not surprisingly, these programmes did not consider technical assistance for RETs or rural electrification, so although projects provided electricity to rural communities they did not even meet PER technical and safety standards. Projects did, however, benefit from some RET-linked protection measures. For example, a consumption subsidy was considered for all diesel projects. Regional authorities and mid-level officials lobbied to apply the same rationale behind the operational subsidy to SHS in Coquimbo region to all off-grid projects (not only RET-based). They argued that regardless of the electricity generation source, off-grid rural consumers would be hit by higher electricity tariffs, so the consumption subsidy should be approved on the grounds of social inclusion (Interview 12, Interview 20, Interview 38).

In fact the subsidy is decided (and normally approved) by the Parliament on an annual basis, when the provision of funds to be distributed to Regional Governments is included in the Budget. These funds are negotiated directly between regional authorities and ministries (Treasury and Interior Ministry) and there is no incentive or reason for other authorities (from other regions or different ministries, such as the Ministry of Energy) to oppose such subsidies (which are counterproductive from a sustainability perspective). This is because the regions might recall the reasons for additional funds in potential future projects and the Ministry of Energy is, in the end, seeking to achieve electrification targets rather than RET diffusion (Interview 21, Interview 36, Interview 38). Rural municipalities which have implemented electrification projects regardless of the source of finance and the type of electricity generation technology simply applied consumption subsidies to pay for fuel (Interview 18, Interview 25).

This phase of wind power dissemination was marked by the attempt by the central authorities to undertake systemic intermediary functions, including needs assessments and the connection of actors through conferences, workshops and technical missions and courses. The engagement of international cooperation actors (NREL, e7 Fund) helped improve the visibility of small scale wind power for the national authorities. However such top level relationships did not permeate to the local and regional decision making arena. Additionally, rural communities and R&D actors were never considered in formal mechanisms for project development and execution, so the rigidity and non-adaptive institutional structure of the rural electrification regional strategy meant that experimentation was not stimulated.

Misaligned visions with respect to the role of wind power in rural electrification are an important factor explaining why expectations grew and then declined. The changing nature of visions also impacted on the expansion and sudden contraction of the network of wind supporters and the self exclusion of incumbent actors from the rural electrification regime in the Los Lagos region. Against this backdrop, decision making became trapped within regional authority circles, and the action of the latter was influenced by the narrow range of possibilities offered by powerful actors such as the dominant distribution utility in the southern regions.

That not very promising scenario made it impossible to internalise lessons from previous experience: the Tac Island project results did not feed into new management models or the consideration of socio-cultural factors. Those localised lessons from Tac were not heard, implying that it was difficult to embed socio-political capital in different arenas. What the experience shows is that networks broke down and expectations turned into parallel plans for the electrification of Chiloé islands outside the PER framework, with the result that diesel gen-sets started to be considered and installed in several locations. Finally, protection measures originally devised for RET development (subsidies for operation of off-grid RET systems) were applied to support the operation of those gen-sets.

6.5 Pilot projects again: The consolation prize?

Between 2009 and 2011, negotiations on the conditions under which the Quenu, Tabón and the Desertores Islands projects would be executed took place between the Ministry of Energy and the Regional Government. During that period there was a significant change in the Chilean political landscape. In 2010 a new right-wing government took office after 20 years of centre-left wing leadership of the '*Concertación*' coalition. Most of the technical staff and authorities at the Rural Electrification Unit (former PER, now DAEE) of the Ministry of Energy were confirmed in their positions but important changes happened at the Regional Government level, in which the new designed '*Intendente*'[47] brought in a new team of advisors and a different approach to rural electrification policy. Some technical staff at the regional government were confirmed in their positions but the UTER officer in charge[48] was removed.

All these changes implied that network building, learning and trust had to be recreated from scratch (Interview 36, Interview 38). Positively, this created the opportunity to establish a new agenda in which the powerful stabilising forces of incumbent actors, including distribution utilities and policy makers, could have been eroded. However, the political ability of the central authorities was limited in opening up opportunities for RET-based rural electrification. The regional strategy therefore tuned-in better with a market vision promoted by the

[47] 'Intendente Regional' or head of the Regional Government is the highest political authority at the regional scale. The position is designated by the President of the Republic.

[48] UTER stands for Technical Rural Electrification Units, which were established in several Regional Governments to manage the rural electrification process in coordination with central and regional authorities.

incumbent distribution utilities and a relaxed approach regarding technology choices, which in practice meant that non-standardised diesel-based projects filled the off-grid rural electrification pipeline (Interview 18, Interview 21, Interview 27, Interview 36).

As part of the negotiations, the Ministry of Energy and the GEF Programme started to define a new cooperation framework in which the GEF programme would reallocate some of its funds to leverage public investment for the implementation of the few wind-based projects that were still in the rural electrification pipeline for the Chiloé Islands. Although agreement was never reached, key informants affirmed that the negotiations generated political momentum at the central scale, so the Ministry of Energy obtained high level political support from the General Secretary of the Presidency and the Ministry of the Interior (the two most prominent political Ministries) for the completion of the wind-based mini-grid projects in Chiloé (Interview 12, Interview 17, Interview 36). This is one of the reasons why, regardless the lack of support at regional scale, the GEF programme and the Ministry of Energy were able to sustain the commitment to go ahead with the RET-based electrification of the 9 islands in the rural councils of Calbuco (Quenu and Tabón), Chaitén and Hualaihué (Desertores Islands).

Despite the regional government's change of approach to RET-based rural electrification, many council mayors responded to demands from their constituencies to fulfil promises about access to electricity in rural areas by starting to negotiate directly with the Ministry of Energy as an alternative path to agreement on project implementation. This local councils lobby resounded at the Ministries cabinets in Santiago with the result that central authorities mandated to their regional counterparts the electrification of Quenu, Tabón and Desertores Islands with wind-based systems. Additional financial resources from central sources (Ministry of Energy and SUBDERE) were allocated to the Regional Government to call new public tenders[49].

At this point, RET-based projects had ceased to be a fundamental part of the regional electrification strategy, and had become, rather, a number of initiatives in the process of becoming a nightmare which it was felt had to be completed (Interview 12, Interview 20, Interview 36). Development and implementation of projects were not flowing through a cohesive network of actors at different scales and from different sectors, but through a top-down authority line. More importantly, in the opinion of some of the interviewees, projects became a problem to be got rid of rather than a solution to local needs to be co-produced

[49] The construction of a bridge between the Great Chiloé Island and the mainland was cancelled and as a trade-off an infrastructure plan for Chiloé was launched. The so-called Chiloé Plan included rural electrification, and the remaining wind-based projects were therefore incorporated into this centralised budgetary allocation.

between local, regional and national actors (Interview 4, Interview 21, Interview 24, Interview 36).

The aforementioned dynamics suggest that the execution of rural electrification projects in Chiloé has been driven in recent years by the imperative to achieve political objectives and electrification targets. These, however, are not fully aligned with the new policies and motivations behind access to energy, a process already co-evolving in many other regions of the country, as shown in the case of productive uses of PV projects in northern regions or through the creation of broader access to energy programmes at SUBDERE and the Ministry of Energy. By contrast these few RET projects did not fully articulate social and productive needs at the local scale, but focused only on basic residential electrification. The opportunity to integrate productive uses of energy and non-electricity energy services was neglected in the electrification of the remote islands of the Chiloé Archipelago (Interview 18, Interview 19).

But more importantly, during the long years which passed between the development of draft plans and the production of detailed project designs, a crucial issue emerged as a condition for the success of technology uptake. This is the engagement of community organisations in the management and operation of projects. Lessons from previous experiences (such as the Tac Island and other RETs projects elsewhere) did not permeate new projects designs. This could be the result of the lack of monitoring and evaluation of implemented initiatives, and so is a great missed opportunity of taking advantage of one of the strengths of Chilote's culture: namely their self organisation and local governance capacity (Interview 19, Interview 24, Interview 51).

An example of other social practices is useful to understand this particular feature of the local culture in Chiloé. Extremely isolated island communities are used to the close bonds of their own community networks. Local leaders play important roles as intermediaries between public service provision and societal needs at the local level (Interview 18, Interview 24). But a remarkable cultural feature is the '*minga'*, a collective project with community benefits or a community volunteering work that helps some members of that community. An example of a 'minga' is the physical moving of an entire house (and the family) from one location (e.g. an island) to a different one (e.g. another island or a different place in the same island), a process carried out by an entire community, which takes the house through the sea to its new place. Consequently, local community engagement could have been considered a natural step in the project implementation cycle and therefore electricity cooperatives were thought to be the right mechanism (Interview 14, Interview 36). The GEF Programme indeed supported the creation of several cooperatives through legal analysis and advice, but over the years these entities have not played a role in the decision making or the management of electricity services at the local scale (Interview 4, Interview 36).

However, the absence of regional support for the implementation of more decentralised, bottom-up approaches to energy provision favoured traditional commercial relationships between energy companies and rural customers (Interview 21). Distribution utilities managed to define the direction (technological options) and the scope (particular locations and villages) of rural electrification planning in Los Lagos. Wind mini-grids were kept in the regional pipeline as a concession to the dominant regime actors and were ultimately left as pilot projects to be implemented by the Regional Government through public biddings (Interview 12, Interview 20, Interview 21). The result is that the opportunity to better articulate community needs and technological options (for instance for productive uses of energy) was somehow missed.

Replication and scaled-up interventions were not achieved in Chiloé. The lack of a cohesive network of actors meant that lessons from previous experiences have not been learnt; expectations have changed and have even been contradictory over time; knowledge has not been transferred to the local space and so those RET projects still in the pipeline (Quenu, Tabón and Desertores Islands) were conceived as new pilot experiences (i.e. the wind-based mini-grids have not benefited from replication of practices but are understood as new and separate interventions). Rural families are finally being connected to electricity service provision through hybrid RET systems in some of the Chiloé islands. However, the long period between project identification, development and implementation has generated doubts about the extent to which users' needs, the engagement of rural communities and governance arrangements match technological options and institutional capacities to manage such systems. Additionally, the changing nature of political visions and rural electrification regional strategy has entailed a lack of reflexive co-construction and articulation of the problem-solution issue, achieving only a limited scaling up from a societal perspective (also referred to as societal scale-up in chapter 5).

In the first two quarters of 2012 both wind-based projects in Calbuco (Quenu and Tabón Islands)[50] and Desertores[51] were commissioned and are currently – at the time of writing up this thesis - being implemented[52]. The only aspect of the contractual obligations actually

[50] GORE Los Lagos Press release. http://www.goreloslagos.cl/sala_prensa/noticias_det/434
[51] Ministry of Energy Press release:
http://www.minenergia.gob.cl/ministerio/noticias/generales/ministro-alvarez-lanzo-proyecto-de.html
[52] The Quenu and Tabón projects were inaugurated in May 2013 and the Desertores Islands project was under execution at the same time (http://www.subdere.cl/sala-de-prensa/subdere-inaugura-electrificaci%C3%B3n-rural-para-la-isla-tab%C3%B3n-en-la-regi%C3%B3n-de-los-lagos)

decided so far relate to the provision of maintenance, leaving the real capacity to deal with operational challenges still somehow unclear. The extent to which lessons from previous projects are being taken into account is doubtful. Wireless Energy, the very firm that provided the equipment for the Tac Island project, is designing and building the electricity systems in the Desertores Islands and is responsible for providing maintenance during the first 10 years of subsidised operations[53] (Interview 18, Interview 19, Interview 21). In Quenu and Tabón only equipment provision was considered in the tender and the Calbuco council has the responsibility of supporting local electrification committees to ensure adequate operation and maintenance (Interview 18, Interview 51).

The last phase of dissemination of small scale wind power in Chiloé was characterised by the displacement of decision making from arenas focused on solving societal needs to a direct negotiation between central and regional authorities. Intermediary action became a bilateral negotiation between stakeholders and the importance of connecting producers and users of technology was forgotten. The narrow set of actors involved in deciding the fate of the few remaining wind projects in Chiloé can be understood as a factor affecting the extent to which the adaptation of practices and technology has been addressed. The problem has been that the rigidity of rules (institutional, cognitive and technological) hindered the possibility of stimulating experimentation and variety.

Expectations in this phase were shared by only few actors, mainly central and local authorities and some technology providers. This left a gap in the intermediation at regional scale, where most decisions should have been taken in this stage of project implementation. RET-based rural electrification visions and strategies were often contradictory and contested between these actors, so non-cohesive networks were easily co-opted by incumbents' interests. Commitments from regional actors were shallow and not backed by concrete plans and implementing strategies. Finally, as has mentioned in several parts of the wind power journey, lessons from previous experiences were regularly disregarded, particularly learning about management models, user involvement and the creation of socio-political capital that might have empowered local electric cooperatives to manage their own decentralised electricity systems.

[53] Together with the FNDR subsidy for infrastructure provision, an additional annual CLP123 million (circa USD250,000) was agreed as a subsidy to user's tariff (http://www.datossur.cl/index.php?option=com_content&view=article&id=5309:islas-desertores-inician-obras-de-electrificacion-en-siete-islas&catid=37:local&Itemid=127).

6.6 Chapter Conclusions

This chapter has presented the second case study of the thesis. It tells the story of wind power diffusion in rural electrification in the southern Chiloé Archipelago over the last two decades. The empirical account has been constructed through a narrative that looks at the development of small scale mini-grids using a mix of wind resources and traditional fuels. As in the other case study (PV), different phases of socio-technical dissemination have been identified in an historical account of developed and executed projects in the framework of the PER in Chile.

The first stage was marked by the execution of small-scale wind pilot projects supplying electricity to rural schools, community centres and households in southern regions by local authorities and universities interested in supporting technology development for rural communities. Given the lack of institutional embeddedness and support for operational challenges, most wind turbines broke down and expectations turned towards grid extension.

In a subsequent phase aiming at demonstrating the viability of small-scale wind systems, the Tac Island pilot project was implemented at the beginning of the PER in one of the islands of the Chiloé Archipelago. To overcome the perceived barriers to wind power dissemination, the central government reached a cooperation agreement with NREL and obtained the international cooperation from the US (through the Department of Energy) to provide technical assistance in the development and execution of the project. The initial engagement strategy involved bringing together regional authorities, the major distribution utility in the region of Los Lagos (SAESA) and a technology provider (Wireless Energy, a locally based RET firm owned by an American citizen). A needs assessment and a wind monitoring campaign were implemented, and the international actors provided their technical expertise in analysing all the data gathered and in designing the electricity generation plant and mini-grid.

Once the pilot project was executed, however, local and regional support began to diminish so follow up activities were never planned. The operational scheme (a local operator and the technology provider in charge of maintenance through a contract with SAESA) proved to be impractical given the difficulty of reaching the island during winter and in periods of poor weather. Lack of local know-how prevented the anticipation of technical problems and the provision of adequate maintenance. Moreover, low local engagement from community members resulted in misuse of electrical appliances, a steep growth in demand and a badly managed electricity generation system. After two years of operations the wind components of the system had broken down.

The failure of the distribution utility and the regional government to seriously buy into this project specifically or small scale wind power more generally meant that expectations were not backed by concrete commitments and ongoing support. Claimed as a success at the beginning, the pilot experience in Tac Island failed in the end to demonstrate the viability of the technology because the electricity system started to run only on diesel and demanded very expensive tariffs to ensure cost recovery operations.

However, as a pilot project, the Tac Islad project had been devised as a flagship for the electrification of an additional 32 remote islands in the Chiloé Archipelago, something which would have constituted the greatest set of mini-grid projects ever developed in the country. The GEF programme started to support the plan and the e7 Fund became involved through technical expertise and financial aid. The strategy included quasi-system level supporting activities: training and knowledge development, awareness campaigns amongst authorities and rural communities, networking and advocacy amongst firms and regional authorities, fieldwork with communities and wind monitoring campaigns, project designs and technological and commercial visits to more developed markets.

This space of protection was advocated and pushed forward mainly by central government authorities (National Energy Commission) and the GEF programme, also based in Santiago. The lack of regional buy in mentioned in the case of the Tac Island project, coupled with the lack of interest and tacit opposition played by SAESA generated pressure on regional authorities whose priorities began to diverge from the original plan. This resulted in a change to the regional electrification strategy so as to favour submarine grid extension to those islands closer to the Great Chiloé Island, which had itself only recently been connected to the national grid.

Most of the support committed by international and regional institutions vanished over the following years and the change of strategy resulted in a lack of stable political support, so municipal authorities found themselves void of possible solutions to demands made by community leaders. Alternative means of executing electrification projects were thus sought and what were supposed to have been grid extension projects became a myriad of diesel gen sets installed in rural homes or non-standardised mini-grids developed outside the rural electrification institutional framework. The latter would have ensured adequate assessment criteria, project development methods and focused funding mechanisms, amongst other rules and practices, but outside its framework these were lacking.

The overall dis-institutionalisation of the early and emergent support for RET-based rural electrification was further eroded by the misuse of other protection measures. This includes the newly approved subsidy to RET rural electrification consumption, which was counterproductively provided to diesel generating technology in rural contexts.

Against the backdrop of pervasive forces frustrating the implementation of RET-based rural electrification projects in Los Lagos and Chiloé, but more crucially, in opposition to stabilising pressures in favour of traditional actors' roles and practices in rural electrification, the few wind-based mini-grids that remained in the project pipeline (Desertores, Quenu and Tabón Islands) continued to be pushed forward by the GEF programme and the central authorities at the Ministry of Energy.

Changes in the political landscape in 2010 forced the rebuilding of networks, strengthening of expectations around small scale wind power and advocating access to electricity policies launched more than 10 years earlier at the central scale. These visions and political imperatives found little support in regional government circles, but political negotiations allowed the few remaining wind-based projects to be kept in the regional electrification pipeline. Once devised as transforming initiatives, these nine small scale wind mini-grids are currently under implementation as pilot interventions, in which none of the pitfalls and difficulties from previous experience have been internalized as learning, for which local participation has been negligible and technological knowledge and skills for adequate management schemes have been irrelevant.

The next chapter presents a discussion in which both case studies are compared and linked to the theoretical framework used in this thesis.

7. Discussion

7.1 Introduction to the chapter

The previous two chapters presented the case studies that form the basis of the empirical analysis of this thesis. The cases are constructed from aggregations of two sets of decentralised rural electrification projects using PV and wind-based power systems in central-northern and southern Chile respectively. This chapter discusses the results of the cases in order to answer the research questions guiding the thesis. Before doing so, however, it is first worth revisiting these questions. The overarching research question looks at the development rural electrification projects in Chile with the aim of understanding **how PV and wind off-grid renewable electricity has been developed in rural Chile, exploring the factors that have driven or constrained this process.**

A first approximation to an answer to this question is presented in section 7.2 which contains a brief empirical summary of findings of the case studies. The two cases are combined in an historical recapitulation that starts with the early development of unconnected projects which led to the founding of a national off-grid rural electrification RETs programme. This section focuses on similarities and differences in the processes within PV and wind projects, something which resulted in different socio-technical trajectories. The discussion highlights the main outcomes of PV and wind rural electrification diffusion by comparing the total number of projects within each aggregation of technological solutions, the domains of application, particular features of each technology configuration and their related socio-institutional contexts, identifying which actors have been involved and the types of delivery models identified in the development and implementation of projects.

Building on this summary of results, the three sub-questions posited in chapter 2 are then explored. These look at particular empirical and theoretical issues affecting the success and/or failure of the diffusion of new technologies and the interaction of new socio-technical practices with dominant rules and technologies.

The first of these sub-questions seeks to understand **how and why PV and wind trajectories have been different**. The discussion analyses SNM internal processes (i.e. expectations, learning and networks) and how these have affected the trajectories in each niche (PV and wind). In addition to a viewpoint from within the niche, the discussion attempts to shed light on the particular features of the aggregation activity, as a way to extend the analysis from the local niche perspective towards a systemic or cosmopolitan level. Intermediaries' roles are discussed in relation to their function in augmenting a cosmopolitan level of knowledge and practices, which determines whether a global niche has emerged and particular trajectories have been defined. This discussion is presented in section 7.3.

The second of these sub-questions was formulated to critically discuss the suitability of the SNM framework to analyse the diffusion of radical innovations in developing country contexts. It asks about the **extent to which the SNM helps explain differences in socio-technical trajectories at the niche level and whether the theoretical propositions take into account particular developing country contextual conditions.** Section 7.4 discusses the limitations of SNM theories and identifies gaps. Based on the theoretical assessment of gaps presented in Chapter 2, this section elaborates on how decision making has evolved for each niche, the roles played by key actors and the mechanisms of negotiation, coordination and deliberation that affect how project decisions are made. Particular attention is given to those mechanisms that are important to the technological and social embedding of niche practices in the construction of a global niche level. Intermediary action is considered from a supra/extra institutional context in which decisions are made (i.e. beyond practices, rules and processes defined within the rural electrification institutional framework). In this way, intermediary action is placed and understood as a political activity.

An answer to the third sub-question is explored in section 7.5: **What impact has the development of off-grid renewable energy niches had on the Chilean rural electrification regime?** To answer to this question a critical discussion is offered of how protection has been developed both in niche and regime contexts. By looking at protection measures, the discussion assesses whether these have enabled or constrained the development of niche activities. Additionally, the way rural electrification has been implemented is assessed through an analysis of the evolution of the stabilisation, structuration and expansion of domains of application in niches. This discussion looks particularly at the extent to which PV projects have been scaled up and wind projects have faced obstacles to the achievement of more than a limited form of replicability.

Finally, to permit understanding of the implications for public policy implementation, a discussion of the critical **roles played by governmental and private sector actors in RET innovation for rural electrification** is presented in section 7.6.

7.2 Summary of case studies' findings: PV and wind off-grid rural renewable electricity in Chile

The Rural Electrification Programme (PER) was launched in 1994 as a predominantly social policy aiming to increase access to residential electricity services in rural areas. Until 1999, the programme was successful in meeting electrification targets, defined as the percentage of rural families in a particular geographical areas covered by any type of electricity service, such as grid connected electricity or through off-grid electricity generators – both fossil fuelled or renewable. Nearly all electrification during that initial period was done through grid extension from urban centres to rural areas. One of the main determinants of progress was the committed engagement of the government at different scales, from national institutions providing guidance, setting policy objectives and methodological approaches, to a decentralised and local delivery of state subsidies through the FNDR to cover a large part of the rural electrification infrastructure costs.

By the arrival of the millennium, however, the costs of conventional grid extension were rising. A result of the low levels of demand in isolated rural areas and growing distances to existing grids, coupled with the inability to adjust the institutional framework to radically different socio-cultural practices in rural areas (such as off-grid solutions based on RETs), this was undermining the scope and scale of rural electrification progress. The combined effect of these factors created the need for new ways of approaching rural electrification in isolated villages and settlements. To that end, the relevant entities dealing with rural electrification (mainly CNE, SUBDERE and MIDEPLAN) and independent institutions (such as NGOs and universities) started to seek international assistance so as to raise funds and attract technical support. Few bilateral cooperation projects were executed in the first years of the PER, in which aid was given to particular projects. The experiences of the wind-based electrification of the Tac Island in the Chiloé Archipelago (supported by NREL and US DoE), the very localised support given by the Japanese government in a few southern villages (wind and hydro projects funded through JICA) and the Spanish government funded SHS projects in several settlements in Coquimbo, have been highlighted. Although disconnected from each other, these first RET projects prepared the way for further interest in RETs rural electrification in Chile.

A more programmatic approach was driven by the CNE - formally in charge of PER execution - with the support of international cooperation from the GEF to implement a programme within the framework of the rural electrification policy, which focused on overcoming the barriers to RET use in off-grid rural electrification. This programme clearly opened up a new perspective in the rural electrification political agenda. By 2001, at the start of the GEF programme, knowledge about small scale RETs was limited and only a handful of projects had been executed and this had been done without formal supporting mechanisms and clear protection. This implied that the embeddedness of RETs in rural electrification policy was almost non-existent. Attempting to achieve results at a system level, the GEF programme defined an implementation strategy that involved technological knowledge development, extensive socio-economic assessments of rural communities lacking access to electricity, project development support, institutional strengthening, decentralised engagement of actors and experimentation with RETs through the execution of demonstration projects.

Priority was given to the development of RET-based projects in the regions with the greatest deficits in access to electricity: the Coquimbo Region in central-northern Chile and the Chiloé Archipelago in Los Lagos Region. In those two regions there were previous experiences of RET-based rural electrification: 1500 families using SHS in Coquimbo and the Tac Island community using a hybrid wind-diesel mini-grid. These two technologies guided the structure of the two case studies undertaken in this thesis: Solar PV projects in central and northern Chile and wind-based min-grids in the Chiloé Archipelago. The dynamics of socio-technical development have been analysed through a historical account, paying particular attention to processes of project development, engagement of actors (institutional agents from a variety of scales, private energy companies, research institutions, NGOs, RET providers and users), delivery and operational models, financing schemes, technological configurations and domains of applications, amongst other things.

7.2.1 Cross-comparison in PV and wind diffusion stages

The empirical account of PV and wind rural electrification diffusion has identified different phases that led to the relative structuration of practices within each aggregation of projects[54]. In the PV case, since 2000, out of 54 solar PV identified projects, 27 have been implemented involving more than 5,500 families. The analysis has found that the dissemination of PV projects experienced the following path of development:

1. Uncoordinated flashes, in which many projects were developed and implemented before offering specific support to RETs within the PER had been considered. These projects tended to fail after only a few years, due mainly to technical problems and a lack of O&M support.

[54] Structuration is seen as the process of increasing constraining factors (actors, markets, cognitive structures) and the generation of rules around socio-technical practices.

2. Connecting actors and lighting expectations, a subsequent phase characterised by the more comprehensive and coordinated support offered within the framework of the development of the Coquimbo demonstration PV Project. In this phase, assessment and design routines were created inside the GEF programme. This stage is marked by a more reflexive analysis of the operational models and governance arrangements needed to sustain projects in the long term. This emerging structuration led to some institutionalisation of practices, easing the replication of routines in subsequent projects in different locations.
3. Replication of emerging practices was the main characteristic of a stage that experienced the appearance of a dominant design for SHS and the first PV-based mini-grids. There was a generalisation of practices and knowledge, and lessons were spread amongst various scales and different types of actors. Protection and supporting measures– such as an operational subsidy for PV systems, and both the formal and tacit engagement of distribution companies, local authorities and rural communities – were institutionalised. At this stage lessons began to feed back into policy, leading to an adaptation of strategies and approaches to PV rural energy access.
4. A final stage marked by new domains of application and the emergence of new energy needs was opened up. After a large number of projects led by the GEF programme had been implemented, productive uses of energy were considered in the framework of access to modern energy services in rural areas (e.g. water pumping, electrification of schools and clinics) and new institutions were engaged in policy and practice. These were mainly newcomers to the rural electrification regime, such as institutional actors (INDAP, FOSIS), universities and CSR departments of private firms.

In the wind case, from the year 2000 onwards, 23 small scale wind projects were designed, 6 were implemented and 9 wind-based mini-grids are currently being constructed. The executed projects involve 540 rural families. The analysis found that dissemination of wind projects experienced the following path of development:

1. Uncoordinated wind projects. A stage characterised by the implementation of projects in different southern locations (Araucanía and Chiloé) in which hardware (equipment) alone was provided but not enough attention was given to the technological development of O&M skills, training, or to project management, which led to malfunctioning equipment and failure of projects.

2. However, as wind technology seemed to be a promising option, the Tac Island Wind project was implemented in Chiloé with the support of international institutions (NREL, e7 Fund, US-DoE). This pilot project was designed to be a flagship for the implementation of a broader small scale wind power plan in 32 islands. However, there was not enough local/regional support from either public or private sector institutions. Lack of local buy-in implied that experience and knowledge were not linked to the local scale, with the result that neither local practices nor more general rules to support wind energy were developed. Rural communities and local authorities were not involved in project design and implementation.

3. In the absence of a coordinated policy strategy shared by national and regional government institutions, rural electrification in Chiloé - and more generally in Los Lagos region - started to show signs of weaker structuration. This equivocal institutional platform for rural electrification suffered the withdrawal of formal support for RETs and the search for divergent (and even contradictory) approaches that mixed diesel based off-grid electrification and grid extension. Protection was not only provided for renewables, but also for fossil fuel off grid technologies, something which further eroded and undermined wind-based mini-grid development in Chiloé. Due to their interest in grid extension and diesel-based generation, distribution utilities exerted pressure and opposed RETs, limiting the extent to which wind projects could have been considered. Additionally, international actors withdrew from their engagement, citing the lack of clear governance and policy support.

4. However, persistence and the respect for agreements made by the central government kept wind-based rural electrification in Chiloé on the agenda. Of 32 initial islands, however, only 10 were included in a new plan. The GEF programme and central ministries continued to develop a few wind interventions in the most remote islands of the Chiloé Archipelago. However, these projects too were designed as pilot exercises, with the result that experiences, lessons and practices developed in the few wind projects implemented in southern Chile did not feed into new ones. Learning was non-existent and it looked as if the technological pathway was being started again without clear prospects for an inclusive, coordinated approach amongst the different actors and sectors involved.

7.3 Understanding PV and Wind Trajectories: a critical cross-examination of Internal Niche Processes

7.3.1 Voicing, Shaping and Empowering Actors' Expectations?

The aligning of expectations has been important in understanding how both PV and wind rural electrification projects have been identified, developed, implemented and, in the process, how different trajectories have emerged in each case. As suggested by earlier research (Raven, 2005), the analysis of the cases shows that at the beginning of the PV and wind development trajectories in Chile, visions relating to the desirability of these technological options were **general and particularly fragmented**. Actors promoting the first off-grid projects were NGOs, technical research groups at some universities, local government institutions and people not connected to the rural electrification regime. Although positive attitudes dominated these first efforts, the interventions were executed as localised projects that remained at that scale, and thus expectations about technological options remained contextualised, general and fragmented. As the projects were not linked up and were characterised by the provision of hardware alone, only general promises about technology performance guided broad expectations. However, most projects failed from a technological performance perspective: wind turbines broke down or batteries and charge regulators in SHS were inadequately maintained, so PV systems stopped providing useful electricity services.

With the start of the PER, more stable institutional support was given to small scale PV and wind power. Both technologies were considered in the emerging strategies of the Rural Electrification Programme. In the wind case, the implementation of the Tac Island pilot project defined a particular direction of development: wind power could be used in combination with conventional diesel generators (gen-sets) to deliver electricity services in small villages through mini-grids. In the PV case, the potential of SHS (i.e. PV systems at each point of demand, not connected to a small grid) was seen as the only electrification solution for thousands of scattered rural households throughout the central-northern regions. This seems to be a defining feature explaining how expectations were shaped afterwards.

First, PV projects were identified as a promising technological solution for a vast geographical area covering several regions which is why more actors became engaged in deliberation about how PV rural electrification could be implemented. These actors varied from dozens of municipal authorities (such as council mayors and planning officers), to several regional governments authorities and staff (such as the Head of Government in each region, officers from UTERs, SUBDERE, sub-regional or provincial authorities), members of the parliament (from many regions, but particularly in Coquimbo), a number of distribution companies (for example CONAFE in Coquimbo and other regions), and technology providers and consultants.

Conversely, wind-based mini-grids were mainly envisaged as a solution in a more confined geographical area (such as the small islands in the Chiloé Archipelago), so fewer actors were identified and engaged. Institutionally, only one regional government and a handful of municipalities were in charge of wind-based rural electrification in Chiloé, meaning that a reduced number of authorities and public officers were involved in discussions about electrification plans. From the private sector, SAESA - the biggest distribution utility in south - was a powerful rural electrification regime actor. In fact, their monopolistic position was highly influential in the definition of the agenda. The company initially supported wind projects but later opposed them on the grounds of the supposed techno-economic unfeasibility of projects. It has been shown how, in the Tac Island Pilot project, SAESA backed the project's development as a compromise with regional policy-makers and international aid actors so as to secure its monopolistic power in the region (see a detailed description of these events in chapter 6).

The above discussion shows the extent to which **PV was naturally more protected than wind**. Grid extension was technically and economically unfeasible for the very disperse settlements in northern regions and solar radiation was more appropriate and more predictable, making PV the best and the only solution. Wind power, by contrast, competed with diesel-generation to supply mini-grids in Chiloé and wind resources required long and costly monitoring campaigns to assess project feasibility. This implied that wind power was not the only option for rural electrification in Chiloé.

Additionally, the network of PV supporters grew more rapidly than the smaller network of wind supporters. This created an unequal level of interest in PV and wind respectively: expectations with respect to solar energy **became shared by many actors across different sectors** (public, private, academia at different scales) and the role played by **incumbent actors was critically helpful in voicing the PV option**[55]. A good example would be the private utility, CONAFE, backing PV electrification while the public authorities played a regime role as planner and implementers of rural electrification. By contrast, expectations in wind energy had to be

[55] The engagement of incumbents in niche development is often frowned upon in transition studies (see for example Hoogma et al., 2002). This is due to the risk of reducing the radical and transformational potential of niche innovation. However, this study highlights the importance for socio-institutional embedding of niche innovations in developing country contexts. In this regard incumbents can have a critical role in enhancing the more socio dimension (in contrast to the more technical one) of niche innovations. The characteristics of incumbent functions and roles played in the dynamics of niche embedding are further discussed in this section and in the conclusions of the thesis.

sustained in the face of **ambivalent and lower levels of support**. For example, SAESA initially showed willingness to participate in wind diffusion in Tac Island, but later withdrew its support for the further use of wind, affecting negatively the willingness of the public authorities to back the plans for winds power in Chiloé.

In summary, the analysis of the case studies shows that expectations have been affected by **the extent to which i) a particular technology was more protected and ii) the expectations were anchored in a broader space (both in the geographical sense and the sense of actors and institutions linked to local contexts**).

Secondly, the way **expectations guided specific directions of development** (Raven, 2005) is discussed. To address this particular mechanism in the development of expectations, the analysis looks first at how electricity needs have been matched to technological options at the local level (i.e. particular projects addressing electrification needs); it then looks at a more de-contextualised level, by assessing how RET rural electrification has been institutionalised into policies at centralised and regional scales. The analysis of the PV niche shows that most projects, and particularly those executed at the beginning of the experimentation with PV (prior to the implementations of the GEF programme and those developed in the initial years of GEF support), targeted isolated rural households that previously did not have any sort of electricity service and rural dwellers who had a very basic and low level of energy consumption (mainly through candles and kerosene lamps). The technological solution provided (SHS at 12 volts DC) was sufficient to greatly improve their energy needs. Subsequently, after several SHS projects had been executed in many regions, more robust PV systems were considered as an option for rural electrification. Some mini-grids were developed (e.g the villages of Camar in Antofagasta in 2005 and Huatacondo in Tarapacá in 2010, both at 220 volts AC), and other types of PV systems were included to provide electricity services to rural schools, clinics and water pumping to promote agriculture in northern regions of the country. Some were connected to DC loads – pumping stations - and others to 220 volt AC loads. Although the technological solutions developed can be considered as a radical innovation in rural electrification (since the service was provided off-grid and with a completely different technology to centralised generation distributed through grid extensions,) **technological development within the PV niche was progressive and incremental. It progressed from less complex systems at the point of consumption to more complex systems connected to isolated mini-grids that could supply more robust power equipment, and provide greater amounts of capacity and energy to schools, rural clinics and productive uses.**

The analysis of projects in the wind niche shows that although a few projects were executed through bilateral aid to provide electricity to single rural households, most projects executed at the beginning of the PER were technically more complex. Such projects involved either more robust technological configurations (in some rural schools in Araucanía, for example, which needed greater installed capacity) or wind-powered mini-grids that needed diesel back-up. From a technological perspective, managing an isolated mini-grid demanded higher technological capabilities than could be built at the local scale. To a great extent, this explains why in the Tac Island wind turbines and control equipment broke down in the first years of operation. From a societal perspective, accessing electricity through mini-grids was a closer alternative to grid extension so electricity consumption increased to a greater extent than in those basic systems which provided electricity to a single household. For example, a rural family becoming able to connect electrical equipment to an AC distribution network (even though the network is a wind-powered mini-grid) is not the same as using electricity generated at the point of consumption (normally DC loads) and stored in batteries.

Although wind-based mini-grids are radical in nature, the rural electrification solution appears to be more incremental compared to grid extension and there has been little technological development within the wind niche. In other words, there has been a lack of progressive adaptation of wind systems to better suit users' needs such as home appliances beyond lighting, productive uses of energy like tools for timber workshops or refrigeration of fishing production. Consumption patterns can be explained on the grounds of low local participation and the insufficient training of users. This demands greater engagement on the part of a whole network of actors interacting in the deployment and operation of technological systems, something which at the early years of RET rural electrification policy was still very narrow, both in the PV and wind cases.

Differences between the PV and the wind cases can also be distinguished when the issue of directions of technological development is looked at from a more general perspective. Once the GEF programme was launched, RETs were treated with neutrality (i.e. there were no explicit tendency to support one technology rather than other, with the exception of the particular support for assess wind resources in rural areas). However, when differences that emerged in implementation are explored, a wider and multi sector support for PV can be detected that is not also observed in the case of wind.

From a policy perspective, the initial trajectories of both PV and wind were driven by national-level policies and processes, with the Ministry of Energy (formerly the National Energy Commission) taking an active role and with the GEF programme directive team raising awareness amongst regional and municipal authorities throughout the country. PV support focused on the implementation of a demonstration project in Coquimbo, and then expanded geographically to several central and northern regions. Wind powered mini-grids were initially supported by national Ministries and promoted at the regional scale (in Los Lagos region) with the cooperation of NREL and US-DoE. However the analysis suggests that in the case of PV projects, many regions and rural councils developed their own rural electrification plans that considered both grid extension where feasible and PV projects (mainly SHS) in off-grid contexts that were jointly assessed and agreed between regional, local and national authorities and distribution companies (such as the case of CONAFE in Coquimbo).

In the wind case, the regional government of Los Lagos acted erratically in the development of a regional rural electrification strategy. Initially it showed willingness to develop wind projects in all the Chiloé Islands, but then withdrew support for the RET option in favour of submarine grid extensions and finally promoted diesel gen-set deployment in rural households to meet rural electrification targets. If at all strategically managed, the policy strategy in Chiloé was less inclusive that the processes followed in other regions. Regional authorities were ineffective in interaction with rural councils and did not develop a conducive relationship with distribution utilities.

In sum, the policy approach in the PV case resulted in a **widening of support mechanisms for diverse domains of application**. This included project development support, guidelines for the assessment of projects, and in later years consideration of more robust projects and productive uses of energy, such as the explicit consideration of PV within PERyS and the Energisation Programme, and specific agreements between the Ministry of Energy and several executing institutions for the implementation of PV projects in several regions of the country. By contrast, the wind case suffered from a **diminishing level of support from the regional scale, which affected negatively the later consideration of wind in the new policy framings** (e.g. neither PERyS nor the Energisation Programme have included wind projects in their pipelines) and the absence of new wind projects developed after the end of the GEF programme through specific agreements between the Ministry of Energy and other executing institutions.

Thirdly, as SNM theoretical insights suggest, **results from experimentation affect the development of expectations** (Raven, 2005); however, the nature of projects' results has not been critically unpacked. In the cases analysed, experimentation is looked at through the lens of real life rural electrification projects and their results are assessed more from the viewpoint of deployment of electricity services in rural communities than the development of particular technologies (such as PV and wind energy technologies). Project results can be assessed against the performance of the technology, or in other words, how a particular technological configuration works for the purposes it has been designed. Here the analysis looks at the provision of electricity in rural contexts, taking into account residential needs (the initial scope of the PER) and formerly productive uses of energy (in schools, clinics, agriculture and so on). Most RET projects implemented before and during the first years of the PER failed to provide electricity services after some years of operation. For example, batteries and charge regulators failed in SHS, wind turbines and control equipment broke down in adverse weather conditions, mini-grids suffered of lack of operational control.

However, from the evidence presented in the thesis, the extent to which results are claimed as successes or failures does not depend solely on technology performance given the technical characteristics of 'hardware', but on the extent to which institutional support and soft rules are developed alongside technology provision. This has been described elsewhere as 'software' and 'orgware' (Dobrov, 1979, IIASA, 2007) and is translated here as the way a particular project or group of projects develops an operational model to ensure long term operation, maintenance and adaptation to new societal needs. The literature suggests that if backed by concrete results, higher quality expectations are achieved (see for example Raven, 2005). But project results vary and depend on, for example, the extent to which there are mechanisms in place that institutionally create the conditions for the transfer of operational responsibilities from project identification and design to long term use of technology. In the case of RET rural electrification, the above discussion is exemplified by the O&M models designed, discussed, negotiated and agreed amongst several scales of decision-making that play a role in their final implementation. Consequently, the quality of expectations varies with how projects achieve their results.

In the case of PV, projects were initially executed without any definition of the rules needed to operate SHS. As new projects were developed, particularly through the development of the Coquimbo PV demonstration project, different models were proposed, assessed and deliberated, taking into consideration the particular contextual conditions of each project. In larger projects, such as Coquimbo and Atacama SHS projects, private companies were engaged in both hardware provision and O&M responsibilities for long periods (for example, for a period of 10 years after hardware provision). In smaller projects, mixed models have been applied, so rural councils and communities share O&M responsibilities, alongside technical assistance and training from equipment suppliers. Not all PV projects have implemented effective software measures, but there is varied evidence from different types of models, which have added diversity to the PV niche trajectory and have impacted on the way new projects are initiated and in doing so have opened up possibilities for new points of departure in socio-technical development.

In this sense, new institutions and actors have become engaged in project development and implementation, and in doing so have reinforced expectations about PV as a feasible option for rural electrification. This is illustrated by the case of productive uses of energy supported by the Ministry of Agriculture, or the Ministry of Education funding for PV projects in schools, the active role of the councils of San Pedro de Atacama and Empedrado as initiators of municipal staff, and the role of independent actors like universities fostering projects such as the PV Huatacondo mini-grid. The diversity of actors involved also impacted on the operational models adopted. This diversity of models is the result of a more inclusive approach to PV electrification, in which not only do private companies have a crucial role in the managing of technological systems, but also local actors (such as municipal staff and users) and non-for-profit institutions (such as research centres), have a role in implementing and developing projects.

In the case of wind, the first projects followed a similar approach to those early executed PV initiatives: interventions focused on hardware provision without any measures to ensure adequate operation and maintenance. Subsequent projects considered the engagement of regime actors in managing the initiatives (e.g. SAESA in the Tac Island pilot project, who outsourced maintenance to Wireless Energy). However, after experiencing problems and the effective implementation of an O&M model in Tac failed, actors promoting the development of new projects considered the implementation of more robust management models, such as the creation of rural electric cooperatives in island villages. But this approach was mainly pushed by centralised authorities at the Ministry of Energy and the GEF programme and did not find regional support to effectively implement and support such cooperatives. The result was that the few small-scale wind projects that remained in the pipeline did not ensure the implementation of any type of software measures or the creation of institutional arrangements to oversee and maintain projects appropriately.

Finally, the discussion of how expectations are shaped (Hoogma, 2000) is considered from a perspective that takes into account **the empowerment of actors carrying future visions and expectations** about how promising a technology can be. The analysis of the cases suggests that for expectations to become **robust, specific and of high quality** (the three dimensions discussed previously) they have to be carried by particular actors that connect particular interests and hopes associated with particular technological contexts, such as localised projects, and who are able to mobilise support at a systemic level. Such actors initially raise awareness and develop localised visions, such as regional or municipal electrification plans and also help to create the capacity to assess, design and make decisions about project implementation (including hardware provision, soft rules definition and institutional arrangements that enable the fruitful management of technological systems). A key **'carrying actor'** identified in the diffusion of RETs in rural electrification was the GEF programme directive team, formed by Ministry of Energy authorities and a group of highly skilled national professionals with proven experience in regime contexts. The role of this team was particularly important in **spreading expectations at a decentralised scale**, increasing interest in and expectations about RETs in regional and local circles. But what are the particular features that can explain how expectations became more positive in the PV case than in the wind case?

The analysis of projects suggests that expectations initially carried by a national institution were transferred towards more decentralised institutions in the PV case, such as regional government authorities taking responsibility and the initiative in the further development of projects and who played important roles in re-contextualising practices for the emergence of diverse operational and delivery models. The wind case suggests that expectations were initially carried by international actors who were unable to connect proactively and efficiently with local actors (the case of NREL and US-DoE cooperation in the Tac Island project) and that the later involvement of the GEF programme directive team was ineffective in transferring expectations to the local (or regional) space. In other words, regional and municipal authorities did not share the expectations carried by national institutions and opted out from wind development in favour of more traditional models of rural electrification delivery. From a theoretical perspective, the findings of this research agree with previous SNM literature in arguing that the way that shared expectations between broad and diverse actors is a key feature of the process. However, this thesis contributes to the literature by identifying the different roles and scales of action of those actors who carry expectations, whose capacity to connect national visions to specific local contexts helps to explain the further development and implementation of projects and the emergence of additional domains of application.

7.3.2 Network building in PV and Wind Niches

In the SNM approach, the role of network building support is considered fundamental. Scholars in the field have suggested that a **diverse range** of actors are required, including, for example, technology producers and users, investors, policy-makers, regulators, technology advocates and other interested social groups (Geels and Raven, 2007). Additionally, the configuration of networks should be **broad**, including traditional (regime) actors and newcomers (niche actors) (Schot and Geels, 2008, Raven, 2005, Kemp et al., 1998) and they should rely on clear commitments and **resources** from these actors. However, the network concept has not been systematically interrogated in order to understand what factors and events facilitate the emergence of networks behind an innovation process. In other words, to what extent can the involvement of a broad and diverse group of actors be considered as a network supporting and developing new socio-technical practices? How do these actors interact beyond their own interests so as to work cohesively and collectively towards a common end? If a broad set of actors interact in a network, how do their potentially divergent interests affect whether the niche is established successfully?

From the evidence analysed, links in the PER institutional architecture attempted to promote a decentralised approach in which communities, local and regional authorities, national policy making bodies and private sector companies play their roles in the identification, design and implementation of rural electrification projects. However, formal rules translated into policy guidelines have been critically questioned by the very actors that should interact in the electrification process (Interview 11, Interview 15, Interview 36, Interview 39). Key interviewees have stated that although communities are considered to be the starting point in the identification of a rural electrification project (both grid extension and off-grid interventions), there are no clear mechanisms for engaging them in the decision making process. Moreover, when RET projects were designed, these were only considered once the grid extension option had been discarded because projects were too expensive or technically unfeasible. In those cases, the great majority of PV and wind projects have been initiated and pushed forward in an eminently centralised way and through links that initially included GEF programme actors, authorities at the Ministry of Energy and then were carried to the regional or municipal scale.

The cases show that the breadth and diversity of a network depend not only on the quantity of actors interacting, but also on the context they come from (either niche or regime settings). An important contribution of this thesis that complements previous SNM research is the argument that building wide ranging networks depends to a great extent on the ability of the policy making architecture and implementation strategy **to strengthen regional and local teams and on the importance of local communities being engaged in the decision making process** in both the implementation and long term operation of a rural electrification project. This characteristic of networks is important because institutional arrangements - and therefore the networks implementing those arrangements that define responsibilities and roles in several phases of a project - are deployed at different scales when new socio-technical practices are diffused. The importance of network scale (e.g. local or regional) is twofold. First, they are the local ground from which a global or cosmopolitan level of niche rules can emerge. (Such rules answer the questions which management models could be implemented in a particular local context, which capacities exist amongst actors and which are required to be constructed or strengthened and so on.) Second, local networks are the vehicle which translate knowledge and guidance that comes from a generic, global level (generally from national institutions driving RET rural electrification) into the practical realities of localised, specific rural electrification projects which need to build new socio-technical practices. In other words, the analysis of PV and wind projects confirms that networks need to be **as diverse and broad as possible, but that to be effective, they have to be able to act in a decentralised way that takes into account particular contextual conditions and the micro-institutional capacities** of communities, policymakers and technology actors at the local level.

The PV case shows how those projects that have been more successful (in terms of smoother and more inclusive decision-making process, operational strength and socio-technical embeddedness), have effectively implemented networks at several scales:

i) the PV Coquimbo project is to a great extent the result of cooperation between the GEF programme, CONAFE, the regional government and 15 rural municipalities;

ii) PV projects in San Pedro de Atacama are characterised by the engagement of users in both the negotiation and implementation of delivery and management models, the active participation of the Municipality and a network of technicians that support the operation and maintenance of local projects;

iii) PV projects in Empedrado have been driven by the initiative of the local council, including interested and persistent staff who have supported and undertaken advocacy for projects of different kinds (SHS, PV water pumping and other RETs) and linked up with the GEF programme and the Ministry of Energy;

iv) the Huatacondo PV mini-grid, although developed independently by the University of Chile, gave priority to long term interaction with the local community in the design, decision-making process and operation of the project and generated links with municipal and regional authorities that strengthened the relationships between the funding source (Collahuasi Mining Corporation), the Energy Centre at the University of Chile and the local community.

By contrast, the wind case shows that initial interactions between actors were carried out through a centralised model in which the Ministry of Energy entered into partnerships with international organisations (US-DoE and NREL) but was ineffective in developing links with regional and municipal authorities. Regional government plans were unstable and unpredictable, initially favouring wind based mini-grid electrification for islands, then supporting submarine grid extensions and later accepting diesel based rural electrification in Chiloé. Moreover, the UTER – the main technical support body for rural electrification at the regional scale - lacked a clear role in decision-making processes and was in fact influenced by the interests of the main distribution utility in the region (SAESA). In the case of the few wind projects that are under execution in Chiloé, the driving force behind project implementation decisions has been a centralised commitment to fund rural infrastructure projects after the failure of the Chacao Bridge in 2006 and the implementation of the Chiloé Plan, which considered (amongst several options) financial support for rural electrification in remote islands (some with wind, most with diesel). The evidence shows that networks with decentralised capacity have not been strengthened at the regional scale and that local actors have not had a voice in strategic planning or decision-making processes.

A second characteristic of a network is the level of **resources and commitments** that actors contribute, or what scholars have called its deepness (Schot and Geels, 2008). What are the types of resources and commitments that have been contributed to the emerging networks? Here the analysis suggests a differentiation between formal and tacit commitments. Formal resources and pledges can be associated with financial support in the form of subsidies, investment flows or funding for the design, development, implementation and operation of a rural electrification project (or several projects, as in the case of the GEF programme support). Formal commitments are also the effect or result of policy endurance, e.g. long term political support translated into clear rural electrification plans and programmes. Operational structures, such as technological capacity building platforms, technical teams at companies providing electricity services or government units in charge of managing rural electrification at national and local scales, are examples of formal structures providing stability to niche activities.

In addition, tacit commitments and resources that have effects of a cognitive and symbolic nature can also be identified. The way trust is built and maintained amongst actors and how resources are distributed and allocated - and in doing so how actors are able to participate in decision-making processes – can be elaborated. Networks in which actors demonstrate willingness to participate are more likely to develop collaborative attitudes and formal resources and commitments. However, those formal pledges are backed by more tacit commitments that nurture the emergence of deeper relationships. The emergence of trust is a concerted process in which all actors demonstrate interest and their resources are contributed to a common or public cause.

In the wind case, formal resources were contributed by both the central government (through the FNDR budget as capital subsidies for wind based mini-grids in Chiloè) and the US government for the implementation of the Tac Island pilot project. Additionally, the GEF programme invested their own budget in project designs, capacity building activities and investment grants to partially cover project costs. However, once additional funds from the FNDR had been allocated to the regional government to finance wind projects, the budget was re-allocated by regional authorities to implement post-crisis employment programmes. Although the regional council had the right to redirect funding to regional priorities, the lack of alignment between rural electrification plans at the regional and national scales and the emergence of other political priorities eroded the trust between institutional actors at different levels, an example of how tacit and formal commitments mutually interact. Additionally, although initial formal commitments were expressed (e.g. from SAESA and the regional government in the context of the Tac Island pilot project) those promises were not kept once replication and scaling-up plans were developed, implying that tacit trust was not particularly durable when it was put to the test. Regional electrification plans were changed from the promotion of wind based mini-grids on islands to a strategy that supported submarine grid extension (which in fact did not lead to investment in practice) and finally shifted to a mix of diesel based electricity generation interventions funded though several sources and management models not embedded in the rural electrification policy.

At a much lower and localised scale, trust has also to be built between communities and the local authorities that are intended to participate in the design, development and implementation of rural electrification projects. During project development activities, the GEF programme supported the creation of RET-based rural electrification cooperatives (for wind based mini-grids and micro-hydro projects) in an attempt to develop local capacity to manage such projects. However, those cooperatives were not considered in the final design and implementation of projects and, more importantly, these local organisations were not included in decision-making, which resulted in the diminishing capacity of local communities to participate in the political process of taking control over possible solutions to energy needs affecting those communities. The concomitant effect of a weak, shallow network finally eroded trust amongst policy makers, communities and technology actors at several scales.

In the PV case, formal resources were also contributed from centralised institutions (such as FNDR investment subsidies for project implementation) and the GEF programme, which substantially supported project designs, capacity building and training activities. Nonetheless, those formal resources contributed by the state within the PV niche were not significantly different from public sector commitments to the wind projects. The differences can be found in those formal contributions made by other actors, such as the commitments made by CONAFE, in which the company created a subsidiary in charge of renewable energy development (particularly solar PV) in rural areas (registered as CONAFE SER), or the commitment of mining companies and universities to implement innovative applications of PV in mini-grids (such as the Collahuasi Mining Company and the Energy Centre at the University of Chile). The difference is that private sector companies formally committed their participation to the development of the PV niche and thus diversified the number and sources of formal commitments.

But those formal resources were also backed by tacit commitments that strengthened the networks through the construction of lasting relationships and trust amongst actors. These tacit commitments are also found in the form of the long-term support of regional and municipal authorities for PV development, initially through the implementation of PV projects for rural residential electrification, but later on through the development of PV electrification in schools and rural clinics and productive applications, such as PV pumping systems for agriculture irrigation. In other words, **the combination of formal and tacit commitments have reinforced a deep and enduring network of actors adapting and implementing long term rural electrification policies and projects based on PV systems** in central and northern Chile. Moreover, **tacit and formal commitments appeared to interact in a mutually reinforcing relationship**, i.e. with greater tacit commitment came greater resource commitment, leading to a symbiotic relationship within the network of actors (something that is further explored in the next section).

In addition to offering evidence for the support given by a variety of actors to policies favouring PV rural electrification, the analysis of the PV case has also shown how rural communities have been able to participate in some key projects. For example, in San Pedro de Atacama, through deep interaction between rural communities and the local council, and through local networks linking to regional and national authorities, rural inhabitants have played a decisive role in demanding and then implementing PV projects. Organised communities were active in designing projects and implementing management models that are now responding to operational challenges such as tariff schemes and maintenance activities in Camar and other villages in San Pedro de Atacama. In Hutacondo, the PV mini-grid was designed and built with the active involvement of the local community and a local committee is in charge of monitoring the performance of the system which feeds back and guides consumption decisions and the use of electric equipment in the rural village. In the case of the Empedrado council, the empirical analysis has highlighted how local municipal staff played a leading role in defining electrification plans and strategies at the local scale and how different types of PV applications have been implemented, including SHS projects, PV pumping stations and community workshops on the design and construction of biogas and solar systems.

Although not all PV projects have implemented the same participatory models, the evidence suggests that it is in those **projects in which greater active community participation has been promoted, that more complex systems, embracing organisational and technical issues, have been implemented. In those cases, trust has been strengthened through the capacity of local authorities and rural dwellers to become engaged in decision-making processes.**

Finally, theory suggests that when resources are available, regular interaction amongst actors can be sought (Raven, 2005). It is clear that interaction is a critical activity that leads to network deepness and therefore should depend on both formal and tacit resources and commitments. But interaction does not depend solely on the availability of resources. The extent to which actors generate links and relationships, whether they contribute their resources and commitments and get engaged in niche construction, depends on their ability to influence the agenda and decision making processes and on the roles that actors deploy in networks. In other words, **interaction can be understood as a result of the empowerment that actors obtain in contributing to the network**.

Moreover, actors interact on formal and informal or tacit platforms. These platforms have been considered from the perspective of knowledge exchange (e.g. conferences, seminars) or shared interest (e.g. industry associations, NGOs or community groups) (see for example Geels and Schot, 2007, Geels and Deuten, 2006, Kemp et al., 1998). Although these types of platforms can be important and have been promoted in RET rural electrification in Chile, mainly through the support of the GEF programme for the execution of technical workshops, conferences and courses, regular interaction in RET diffusion in Chile has been limited. **Most of the interaction has happened in the context of decision making processes for specific projects, and mainly during the development and project design phases.** Once projects have been granted approval or when projects have been executed, interaction between actors has been reduced and only formal commitments to operation and maintenance have been kept.

A notable feature of the PV and wind cases is that **formal and informal resources, commitment and interaction platforms have been more readily available when regime actors support niche activities**. This has been the case for CONAFE and its subsidiary CONAFE SER and the active participation of some key regional and municipal authorities. These actors have been important in translating and implementing regime practices such as traditional rural electrification policies (e.g. grid extension), but have also supported RET projects in the long run. The long-term commitment of the Ministry of Energy is another example of niche support (through the institutional space opened up for the GEF programme) and implementation of mainstream practice (through regime reproduction in grid extension). In other words, the analysis of the cases suggests that **for niche networks to be deep and to have the capacity to commit resources in the long term, the engagement of regime actors seems to be important. But the way regime actors commit themselves most effectively to networks seems to be in the form of factions of niche advocates (or 'outsiders') who come from 'inside' regime contexts**.

7.3.3 Learning as a process of policy development

Learning is the third critical process theorised as acting at the niche level. This explains how technologies and practices are developed, stabilised and structured. Learning influences a progressive departure from localised and contextualised knowledge to a more generic level at which a global niche emerges. As has been argued in SNM research, for effective niche creation learning should include **both techno-economic knowledge and a more reflexive generation of knowledge**. This has been categorised as **broad and reflexive learning**, or in other words, first and second order dimensions of learning.

The analysis of the PV and wind cases shows that different types of learning have been achieved in the niche structuring dynamics of the RETs rural electrification process. Initially, techno-economic learning was associated with project assessment (solar and wind resource assessments, socio-cultural dimensions of rural communities affecting economic assessments, energy use patterns and so on) and design routines that structured the emergence of dominant technical designs of PV and wind-based systems. A significant difference in how techno-economic learning was internalised and adopted in each niche is the effect of whose actors carried out project assessment activities and how coordinated action was achieved by the PER/GEF programme. In the PV case most of the project assessment and design activities were carried out by an internal team of consultants working at the Ministry of Energy in the framework of the GEF programme work plan, whereas in the wind case most assessment and design activities were outsourced. A detailed discussion is presented below.

In the PV case, from the beginning of the GEF programme most projects were developed by an internal team of consultants that became part of GEF staff. These consultants were trained by expert engineers who had previously implemented PV project in rural communities, so they were able to develop skills in the application of assessment and design techniques and learn how to use RET design software such as HOMER and Hybrid-2, developed by NREL. That way, techno-economic capacity was acquired by long-term contracted staff seconded to the Ministry of Energy: design and assessment heuristics were developed and replicated by the same teams of engineers and consultants who initially worked on the Coquimbo PV project and then applied their knowledge to dozens of projects in several regions and rural councils in central-northern Chile. Assessment and design activities were translated into procedures, guidelines and project document templates that could be taken up by external teams of consultants, engineers or even municipal staff (not necessarily trained in technical aspects of PV design, as in the case of the Empedrado PV projects) and applied to the identification and assessment of PV projects.

Once more complex PV systems had been designed, such as the mini-grids in Huatacondo and Camar villages, the provision of electricity in rural schools and clinics or in the development of PV water pumping stations; universities, external engineers and other experts were contracted out. Only in the scaling up phase did independent actors play a leading role in the promotion of PV projects (such as the case of the Energy Centre at the University of Chile in the Huatacondo PV mini-grid). Techno-economic learning in the early stages of PV dissemination was developed within the institutions fostering PV projects. In that way, actors within the rural electrification institutional architecture were able to acquire the skills, translate them into formal and tacit knowledge and interact with other expert institutions as effective counterparts in project design and implementation when initiatives were promoted or developed by independent parties.

In the wind case, apart from the early developments of uncoordinated projects, the first signs of techno-economic learning are associated with the implementation of the Tac Island pilot intervention. Project assessment and design activities in this case were undertaken by NREL staff who travelled to Chiloé a few times and then carried out the analysis and initial designs in the US. Once the project has been conceptually designed, detail engineering designs were outsourced to Wireless Energy, a RET provider based in southern Chile. The company, owned by an American, had (and continues to have) excellent technical knowledge and skills to design and implement wind projects. However, actors making decisions about project implementation at the regional and national governmental departments did not have the skills and knowledge relevant to technological characteristics of wind-based mini-grids so techno-economic learning was not transferred into the institutions which were interacting in wind power development.

Although attempts were made to improve the technical capacities of regional government and ministerial staff (through technical visits to the US and Australia), so they would be better equipped to interact with engineers designing wind projects, these activities were not enough in themselves to strengthen the capacity of government institutions to assess and design wind projects when replication projects were planned. After the majority of Chiloé islands had been reconsidered for traditional grid or diesel electrification, the few wind projects in the pipeline were assessed and designed by consultancy firms based in Europe (Spain and Germany) or by the Wireless Energy. To sum up, techno-economic capacity in the wind case was not internalised in the network of actors interacting in a coordinated way to promote rural electrification in Chiloé, represented by national, regional and local governmental institutions, distribution utilities and some local firms. The skills and knowledge needed for wind development were kept in-house by one local company and by a variety of international organisations or companies.

The analysis of PV and wind projects suggests that techno-economic learning has been primarily associated with **'how to deal'** with technology and that knowledge, skills and practices can be transferred from one project to subsequent interventions in the same or a different geographical area. Based on the analysis of the cases, a key driver of successful replication, and therefore realisation of techno-economic learning, seems to be the way that knowledge becomes embedded into institutional practices and not dispersed amongst unconnected actors. **Although technical expertise can be better developed in firms and research institutions (due to R&D budgets or institutional missions), the leading role public institutions have played in rural electrification means that the capacity of 'institutional actors' to understand, apply and 'do' things with technology appears to be fundamental to broadening learning**.

A second dimension of learning which emerges from the PV and wind cases is linked to the **capacity to manage and coordinate the implementation of a portfolio of RET projects** in the framework of the rural electrification policy, i.e. management and coordination learning. As the evidence shows, the first wind and PV projects were executed without any policy guidance or coordinated interaction between actors. As time passed and more comprehensive action was promoted (e.g. through the implementation of pilot projects or the execution of the GEF programme), growing signs of coordination and management ability are identifiable. On the one hand, when projects started to be replicated, institutional actors placed overwhelming emphasis on a long-term approach to equipment operation. The first interventions, both in the PV and wind cases, had provided lessons about the importance of considering the operational challenges and software skills needed to maintain the technology. A lack of attention to these issues explains why many failures were experienced after few years of hardware provision.

For those reasons, during the development of the PV project pipeline from the Coquimbo project onwards, particular attention was given to the design of an operational model whose implementation was intended to ensure adequate maintenance and replacement of spare parts (such as batteries, charge regulators and inverters). Additionally, reliable and efficient lamps were used (and steps were taken to ensure that these would be available in the local market and be easy to replace). But more than the availability of customer service and electrical equipment, the challenge was to implement a model in such a way that different actors and institutions could interact in the long term. In the operational phase of projects, key responsibilities and leadership were transferred from those institutions in charge of assessing and designing projects (here the crucial role was at a centralised scale, for example the GEF programme and Ministry of Energy) to the regional governments and rural councils who would then be in charge of long term operation, thus decentralising responsibility in the process. Some projects considered outsourcing O&M activities to private companies (for example in the Coquimbo and Atacama PV projects) and other projects implemented models in which the municipality or a combination of municipal, rural communities and private actors were in charge of O&M (for example in Empedrado, San Pedro de Atacama and Huatacondo).

This type of learning framed the discussion about specific protection measures for off-grid RET projects, the most relevant being the subsidy to operate off-grid rural electrification systems, which is enacted by national law and included in the budget every year. The subsidy covers the difference between an estimated cost recovery tariff for RET projects and the regulated electricity tariff paid by rural customers in the nearby areas covered by the electricity grid. Funds are paid by the regional government to RET system operators.

Although in the case of wind based mini-grids, the same type of lessons were identified after the operational failure of the first pilot project in Tac Island, it can be asserted that learning was not realised because operational models were not put into practice in the few replication projects implemented from 2010 onwards. Management and coordination between actors from different scales in government (national, regional and municipal) or between public and private actors have been neither fruitful nor easily achieved. Particular interests have existed at different scales of government which support and implement contradictory approaches to rural electrification (off-grid RETs, submarine grid extensions, diesel based systems and so on), and ineffective attempts to engage private sector companies (such as electricity distribution utilities, LPG suppliers with existing customer service in Chiloé, RETs providers) in the operation and maintenance of wind based mini-grids.

Moreover, the application of the operational subsidy to fund the operation of diesel based systems in Chiloé (both individual gen-sets and diesel based mini-grids) was used contrary to the original spirit of the policy (support RETs in rural electrification). The existing political agenda and practice, thus, diverted the coordination and managerial efforts undertaken by relevant public institutions (mainly at the regional government scale) towards traditional approaches, practices and technologies to rural electrification (i.e. grid extension and diesel based systems).

The analysis suggests that, although fed by technical and economic issues, the type of learning discussed in the preceding paragraphs, (i.e. management and coordination learning) is different from the techno-economic learning was been discussed earlier. This is because the processes and activities involved in coordination and management are oriented to learning **'how to sustain'** projects rather than 'how to deal with' technology. This subtle difference is of critical importance because responsibilities and roles of actors are transferred from **'dealing with'** to **'sustaining'**, or in other words, from designing and implementing a project to operating and maintaining it in the long run.

Finally, a third dimension of learning that can be interpreted from the PV and wind cases is **policy learning**. The analysis has focused on this dimension as one type of reflexive or second order interpretation of the lessons internalised by experience in socio-technical diffusion (of off-grid RET projects) that feeds back into discussions about the **appropriateness, effectiveness and inclusiveness of the rural electrification process**[56]. As the cases show, the first interventions were executed without any type of policy framing or guidance, and led by independent institutions pursuing their own interests – which might have been legitimately aligned with the common good. Such interventions include, for example, universities testing and developing new technologies in real life contexts on the one hand, and, NGOs or political campaigns supporting interest groups and promoting sustainable development practices, on the other. Political agendas supporting better access to basic electricity service provision framed the design and implementation of the Rural Electrification Policy in the 1990s (the

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[56] It is acknowledged that second order learning is more than policy learning and indeed refers to the capacity to challenge and adjust framings, understand and question what a socio-technical configuration can achieve. The focus here is on a particular aspect of reflexive (second order) learning from what has been observed and analysed in the case studies.

PER), which focused on residential electrification. Results from policy implementation, translated into the achievement of rural electrification access targets (see Chapter 4 for a detailed discussion of how the PER defined thresholds of access to electricity in rural areas), allowed a better understanding of the reality of the energy needs and potential consumption patterns of rural dwellers. It thus fed policy discussions about new or emerging social needs and the need for alternative approaches that finally resulted in policy adaptations and changes.

The idea behind this dimension of learning is that a reflexive interpretation of experience brings about a questioning of **'how to transform'** (from a socio-technical perspective) realities of those in need of different and enhanced sources of energy. This reflexive interpretation of the policy approach underlying the PER was triggered during the implementation of the first projects supported by the GEF programme, in view of a number of energy needs that RET projects were not fulfilling, such as irrigation, heating, cooking, access to IT and communication services or other productive activities associated to particular rural geographies along the country. It was a study commissioned by the GEF programme in 2006 (Márquez et al., 2006) which first came up with the concept of 'rural energisation needs'. This expanded the idea of providing basic electricity services at the residential scale and considered a broader conceptualisation of energy needs (not limited to electrical lighting) in a particular rural area, considering current and future energy needs, their own local potential energy sources and socio-technical contexts.

From a policy perspective, between 2005 and 2010, the PER met its rural electrification targets. In 2010, two new policy programmes were launched: the PERyS at the Ministry of Energy and the Energisation Programme (PE) at SUDBERE[57]. As already mentioned, these two programmes extended the approach and considered a new set of domains of application: PV systems in residential uses linked to productive activities or PV in public service buildings; PV applications to support agriculture activities; other solar applications such as solar water heating or solar drying systems; biogas production; efficient firewood use and so on.

Neither the PERyS nor the Energisation Programme had considered wind projects in their pipeline. What can be inferred from previous experience with small scale wind interventions? Wind based projects in Chiloé were considered for the role of fulfilling electricity needs at a residential scale in small islander villages, i.e. through relatively simple and limited infrastructure in single-phase distribution networks at 220 Volts. These systems, however, are

[57] For a detailed description of both programmes see chapter 4. PERyS is Spanish acronym that stands for Social and Rural Energisation Programme.

not well suited to sustaining productive uses of electrical energy, such as electrical tools in workshops, water pumping systems, electrical motors or sawmills, so wind technology was not easily adapted for use in different domains of application.

These technological factors combined with the lack of consideration of users engaged in producing and using wind technology (for example through the involvement of rural electricity cooperatives or other local community organisations) suggests a lack of reflexive policy learning. The changing nature of rural electrification plans in Chiloé demonstrate that **without a long term and clear vision of the future, it is very difficult to realise learning because, as difficulties or pitfalls appear, changes in policy direction and approach to project delivery affect the persistence of niche activities.** In this sense, wind based rural electrification was never high on the regional agenda and was only pursued once the national government intervened (and injected fresh resources) in the framework of other political agendas arising at the regional scale. This is the case with the approval of a package of state resources for rural infrastructure (which amongst several programmes included the Chiloé rural electrification) as a trade off for the cancellation of the Chiloé Bridge from infrastructure plans at national scale.

7.4 Intermediary action in niche construction: the political nature of decisions in RET diffusion and the roles of systemic intermediaries as political advocates

Intermediaries have been identified as key players coordinating the interaction of other actors. This section analyses the extent to which intermediaries perform functions beyond niche processes, or in other words, how intermediary actions iterate between local and global levels. The discussion is important since intermediary action occurring at the community level has been highlighted in the literature as an additional mechanism influencing the emergence of a global or cosmopolitan niche level (Geels and Deuten, 2006). These scholars suggest that intermediaries' roles include monitoring various projects, aggregating lessons, translating or carrying them from one experiment to the next and circulating knowledge. When projects are aggregated and a global niche starts to emerge, intermediaries are placed at a different level, 'above' the networks of dedicated actors in local projects. These cosmopolitan or global intermediaries drive a process of reversal in which standardised rules start guiding activities and practices at the local level (Geels and Deuten, 2006) and not the other way round, from local to global levels.

Hence, the discussion here aims to identify those intermediaries, analysing the roles they play in different phases of socio-technical diffusion and how they intervene in the decision-making processes for RET rural electrification project implementation. To this end, intermediary action is looked at from a supra/extra institutional context beyond the established practices, rules and processes defined within the rural electrification institutional architecture through which decision-making settings are envisaged and designed. However, these settings are also influenced by additional forces beyond that institutional structure. In the setting up of decision-making, actors express their interests, mobilise resources and exert pressures on other actors. Decision-making settings are therefore expanded or constrained depending on the ability and power of certain groups of actors. Intermediaries acting at a systemic or cosmopolitan level mediate - and do not merely coordinate - the interaction in these settings. In doing so, intermediaries are placed as political actors advocating for certain directions in which decisions are made. In line with van Lente et al. (2003), intermediaries acting at a system level contribute to the transition in a strategic way. Nonetheless, while those authors consider that intermediaries' roles are linked to the management of systemic activity, the perspective of this thesis suggests that their involvement is more crucial than a managerial activity.

7.4.1 Intermediary action is carried out beyond strategic management of niches

In chapter 2 it has been argued that decision making is a political process in which different visions are confronted, the power positions of actors influence the direction and outcomes of deliberative processes, and the inclusion of certain groups and interests is mediated by the structure of institutions and participatory infrastructures. To contribute to the debate about the construction and strategic management of niche dynamics, the chapter discusses in detail how conflicts, power struggles and the politics of socio-technical change (focussing on dynamics at the local/global niche level) have developed and influenced the process and outcomes of PV and wind rural electrification in Chile.

Intermediaries do not only link niche actors at a more global level, but also bring in non niche actors, who do not necessarily belong to regime contexts. These actors can be considered as 'supra' niche-regime actors that are important in stabilising and structuring a cosmopolitan or systemic level of socio-technical practices. Based on the analysis of the cases, a number of system functions played by these intermediary actors can be suggested:

- Securing the political visibility of niche visions and emerging niche practices, so long-term support is committed and policy adaptation is enabled through reflexive learning.
- Translating local expectations into global or cosmopolitan expectations, so replication and scaling up of local practices or experimentation is facilitated because these non niche actors support specific projects with a broad reach.

- Creating the stability necessary for the existence of networks through support for the creation of networking infrastructures such as technology specific platforms or boards through which strategic plans and policies are constructed.
- Interpreting learning and supporting new policies and programmatic approaches or sustaining existing ones. This is achieved by securing financial resources to support infrastructure and equipment provision in particular projects, but also through resource commitments to funding programmatic activity supporting niche policy, such as long-term project operation or sector development.
- Arranging spaces and structures for the confrontation and resolution of power struggles between niche and regime actors.

The analysis of these functions performed by non niche actors suggests that global or systemic intermediaries are important not only in linking niche actors but also by making possible the inclusion of non niche actors who help generate the political momentum affecting (and protecting) niche construction. **Intermediaries are not necessarily political actors, but amongst their functions are those of facilitating and seeking political engagement, mobilising the building blocks to organise decision-making settings and bringing political actors in to the niche space.**

Who have these intermediaries been in the case of PV and wind rural electrification? The key systemic intermediary in the RET rural electrification process was the GEF programme. **As a quasi public entity it was driven by a public interest objective, but had the relative freedom to form links with bureaucratic institutions, private sector firms and international organisations. The GEF Programme design was directed towards system transformation with multi-scale and multi-sector impacts.** A crucial feature of the programme was the organisation and permanence of its directive team: nationally based staff, technically proficient, socially conscious and politically aware. They worked within centralised and international institutions (the Ministry of Energy and UNDP) and developed relationships with authorities and relevant public servants at regional and municipal scale. They also generated relationships and links with incumbent actors (from the regime) and newcomers in the rural electrification sector, particularly with private sector firms. The relational role they played with institutions in the public and private sectors included the engagement of key stakeholders and policymakers. These are mainly high and mid-level local and regional public sector authorities who are able to link up with other relevant authorities and non-niche actors, but who also represent a direct link with local contexts, so in their capacity these key stakeholders had the local knowledge needed to be effective and influential in decision-making process.

In the following pages, the roles played by the GEF programme as a systemic or cosmopolitan intermediary in the two cases analysed in the thesis is discussed. The way in which intermediation occurred within the niche space, i.e. from local to global niche levels, is looked at first, and then the analysis examines the intermediation functions that happened beyond the specific niche networks or spaces of action. As in preceding sections, the discussion starts with the PV case and then looks at the wind power case.

PV projects were supported by the GEF programme from an early stage. The strategy followed by the GEF directive team included an extensive awareness raising process that engaged local (municipal) and regional authorities, regime actors (distribution companies, public stakeholders and regulators) and rural communities. The results of this visioning and engagement process in the PV case allowed the structuring of locally bounded networks that emerged in several regions of the central-northern regions. Commitments and resources within those networks backed the development of socio-technical and economic assessments which fed into project technical designs. As these activities were carried out by an internal GEF programme engineering team with support from other network actors, their own programme was able to learn from local contexts so socio-technical options (PV projects) were closely aligned to local needs.

The experience and knowledge gained by the GEF programme through the study and design of several PV projects generated a more general, or de-contextualised level of knowledge that was translated and transferred back to local actors. These were mainly regional and local public sector actors who improved their own capacity to initiate projects (proposals, assessments and designs) and their ability to proactively interact in decision making about project implementation. The first projects were simple (SHSs meeting basic household electricity demand) and responded to low technical knowledge of rural communities (equipment was easy to operate and required low maintenance). Project replication in several regions sustained and reaffirmed the project development strategy. Only when the first demonstration projects had been executed, scaling up activities, which involved new application domains (or different energy services and types of users), were promoted and developed.

But the GEF programme did not only intermediate in project development phases. The GEF directive team also became engaged in the implementation strategy of several PV project in two ways. First, they fed in evidence from previous experience (for example, operational data from projects executed before GEF involvement in the PER which had been gathered in the development of new projects or based on monitoring and ex-post evaluations of their own projects). Second, they proposed diverse governance arrangements for the operational phase of projects (for example, with the analysis and assessment of operational and delivery models depending on contextual conditions of PV projects).

Complementing these advisory and analytical functions, one of the most relevant roles played by the GEF directive team was to bring in (and mediate with) non-niche actors in decision-making deliberations aimed at securing financial support and institutional structures to enable projects' execution. Amongst these actors the relevant authorities at the regional scale stand out. These were in charge of prioritising and approving public spending in a broad variety of sectors (not only rural electrification but all public investment at the regional scale). Additionally, the GEF team engaged supra niche-regime actors, such as members of the Chilean national parliament, who advocated further support for niche experimentation in the long term (such as the displacement of discussion about the need and suitability of operational subsidies for isolated rural PV projects). In this situation, the GEF programme supported technical and managerial activities, but more crucially, advised political discussion when decision-making issues were displaced between scales (from central to local administrations) and settings (from secretariats and national ministries to regional governments to parliamentary discussions or private sector settings in which their involvement was being defined).

Finally, as an additional point, the GEF programme followed up projects during the development and implementation phases and monitored/evaluated projects once executed with the result that learning enabled replication and scaling up. In sum, the systemic intermediation in **the PV case was characterised as an iterative process of socio-technical configuration that led to a symbiotic relationship between actors during development, design and implementation of localised projects**.

Wind projects in Chiloé were also supported by the GEF programme from an early stage. Following the strategy implemented in the Coquimbo PV project, the programme directive team engaged regional and local authorities in Los Lagos region and raised awareness about wind-based projects amongst regional scale public sector actors dealing with rural electrification and the main distribution utility, SAESA. Initially, a commonly shared vision was constructed and backed politically. This supported the engagement of additional international partners in the development of a regional portfolio of wind-based projects on more than 30 isolated islands in the archipelago. However, commitments and resources were contributed mainly from international actors, such as the GEF and the UNDP, the e7 Fund and NREL. Socio-technical assessments and basic engineering project designs were outsourced to national and international consultants, so knowledge and experience were not easily appropriated by niche actors or by the GEF programme as key systemic intermediary.

A pre-feasibility study carried out by the e7 Fund recommended the implementation of the portfolio but highlighted several implementation challenges, such as operational and logistical difficulties resulting from the wide dispersion of the islands, low levels of projected demand and rigid rules impeding the creation of additional protection measures for RET rural electrification (e.g. contracting procedures for project execution and the impossibility of creating cross subsidies to define a flat tariff for all islands). The study also recommend a focus on the definition of a clear implementation strategy led by the Chilean Government, because signs of a contradictory agenda that also considered submarine grid extension to some islands and diesel based electrification in others would undermine the aims of the initial plan for wind-based rural electrification in all islands of the archipelago (e7 fund, 2004). Consequently, the e7 concluded that their engagement in the implementation phase of an umbrella project (that would consider all islands) should be subject to further commitments and progress made by the Chilean government.

One additional and quite crucial factor undermining the progress in the Chiloé wind project was the persistent opposition of SAESA to participation in further wind projects and their explicit interest in developing a diesel-based portfolio of projects (e7 fund, 2004, Interview 6). As a result, in this preliminary project development phase, socio-technical options were still under-defined and not adapted to local island contexts. In the context of these unresolved issues, the GEF programme faced unsupportive regional and local stakeholders. Governance arrangements for project implementation and operation were kept off the agenda because disagreement about a shared vision was hampering the further development of a clear vision and plan. Altogether, the GEF programme and the Ministry of Energy authorities were unable to structure a locally bounded network to advance in the implementation of the wind-based rural electrification portfolio.

As there was no robust local support, the intermediary role played by the GEF failed to bring in non-niche actors and facilitate political discussions when conflicting issues emerged. These issues were displaced from the strict space of the niche (support and protection of wind project development) to other settings, such as regional level decision-making, international level support to RETs in developing countries or incumbent private sector networks putting pressure on the public agenda. The bumpy path of wind development meant that the national government and the GEF also failed to secure funding and supporting institutional structures at the regional scale to nurture and protect the wind power project portfolio.

However, the GEF programme continued to provide technical and managerial support to a small portion of the initial project portfolio. The few islands involved were the most remote in the region (Desertores islands, see chapter 6), with low populations and whose inhabitants were amongst the poorest rural inhabitants in Chiloé. The implementation of such projects was, therefore, a low priority for the regional government if they had to show progress in rural electrification outcomes. Increasing access to energy in the region to meet electrification targets would have been cheaper and would have had higher impact at the local level if they supported any type of technology, including diesel based electrification, in less remote islands. The GEF programme assumed a different role in the implementation of the Desertores islands project, changing from a systemic to a bilateral type of intermediation. They funded project development activities (wind monitoring, detailed engineering and designs, etc.) and interacted directly with the central government (Ministry of Energy). No further networking support was attempted at the regional level. This has been confirmed during interviews because all those actors who were originally engaged in the project said they did not know which was the key institution leading the project or what roles different actors were playing in the process. Little follow-up and monitoring of wind projects was undertaken in the Chiloé plan reducing the extent to which replication or scaling up was achieved.

In sum, **systemic intermediation in the wind case was characterised by discontinuities and non iterative processes of socio-technical configuration, which seem to have led to a parasitic relationship between actors during development, design and implementation of projects**.

7.5 Mainstreaming renewables in rural electrification? How do niches and regimes Interact, or “the battle for securing protection”.

This section discusses the agency and power positions of actors in influencing transitions (Smith et al., 2005), and the complexities of realising these structural changes in practice (Shove and Walker, 2007). In particular, the dynamic interaction and linking between niches and regimes as a politically underpinned process (Smith and Raven, 2012) is analysed. The contribution of the latter scholars is crucially relevant to theorising how protection is constructed and how actors deploy their power and capabilities to balance contested issues towards their own interests. In doing so, actors influence the extent to which different socio-technical options emerge, are confronted and legitimised.

The analysis of both cases (PV and wind) showed that **conflicts and contestation over niche alternatives emerged more decisively in those projects in which incumbent actors expressed little interest and were reluctant to support RET rural electrification** (e.g. the Chiloé wind projects, the Atacama PV project and many others still in the development pipeline which have not secure funding). These actors have mainly been electric distribution utilities but it is also clear that there are public sector institutions (both at national and regional scale) that have been partly supportive, but reluctant to commit funding, human resources or negotiating capabilities to advocate and protect RET projects.

Naturally, contested visions were more apparent in larger projects in which private firms would take the lead in implementing, operating and maintaining RET systems. According to the expectations of policy-makers, these would ideally be distribution companies which had grid-based commercial operations in the same or nearby geographical areas. For that reason, the significant differences between the Coquimbo PV project and the Chiloé wind plan implementation dynamics are particularly illustrative.

In central-northern Chile, CONAFE and its parent company CGE had become a powerful regime actor through integrated operations in generation, transmission and distribution of electricity. Over the last few years, CGE has kept a 40% market share of electricity distribution in Chile[58]. Particularly, CONAFE distributed electricity in the entire Coquimbo region. From the start of the GEF programme, the firm constructed a mutually beneficial relationship with the programme directive team and Ministry of Energy authorities (at that point in time still CNE). They disclosed strategic plans and provided techno-economic data and resources to help build an integrated (grid extension plus off-grid RET) rural electrification pipeline in Coquimbo and other northern regions. The company openly expressed their expectations of keeping their market share while serving the electricity needs of the majority of the rural inhabitants in Coquimbo. As the potential for grid extension growth was limited, they wanted to expand operations in the off-grid PV (potential) market. It has already been illustrated in previous chapters how they created a subsidiary (CONAFE SER) to develop and become market leaders in the small scale PV sector and so supported rural electrification projects in Coquimbo and other regions (such as Atacama and Antofagasta). As the rural electrification institutional structure was rigid in terms of the project development cycle, public bidding rules, contracting

[58] www.cge.cl/sectorelectrico/Paginas/SectorElectrico.aspx, retrieved on Jan 30th, 2014

procedures and project execution, they prepared themselves from the very beginning to gain the necessary experience to become engaged in as many projects as possible. Apart from collaborating in PV rural electrification, CONFE SER started piloting grid-connected PV at a distribution scale, expecting an additional market to be developed.

CONAFE benefited from this collaborative approach and exerted pressure (via negotiating with policymakers and disclosing their strategic plans and scenario analysis) for the creation of additional protection measures in off-grid rural electrification, such as the operational subsidy agreed in the framework of the Coquimbo PV project implementation. Finally, the firm was selected to build and maintain the Coquimbo PV project (3,000+ SHSs) and bid for projects in Atacama (400+ SHSs) and the electrification of schools and rural clinics in Coquimbo and other regions. But it is not only a question of CONAFE having benefited from support from public sources. They also committed their own resources to innovation in the PV niche by structuring internal teams and subsidiaries dedicated to R&D and piloting of projects. There was a constructive combination of experienced staff in rural electrification and young engineers with fresh knowledge in RETs who maintained a permanent link with the GEF programme. However, the relationship between the utility and the institutional apparatus, particularly at the regional scale, has not been permanent and has been limited to contractual obligations within the framework of the Coquimbo PV project. Under the PER institutional structure, roles and phases in project development and implementation are defined until a project is built and then the utility assumes the main responsibility for operation and maintenance; the government role is limited to the enforcement of contractual obligations and regulations.

In other words, **the consensus that RETs would need further protection during project operation was understood as financial support, but other types of intermediation and protection (such as ongoing monitoring, networks, policy feedback, joint R&D and so on) were not formally or explicitly provided. This is an example of a lack of second order learning, particularly amongst decentralised and regional networks. Where more innovative policy approaches and new application domains have been explored (such as the case of PV irrigation pumping), little coordination has been exploited between existing initiatives (rural electrification) and new programmes and institutions supporting RETs in rural areas.** These new application domains have been supported as unconnected pilot projects. For example, and paradoxically, regional scale public sector actors in charge of rural electrification (i.e. UTER staff) seemed not to know anything about PV pumping projects –(funded by the Ministry of Agriculture through INDAP) even if they were located in the same rural households that have

SHSs financed under the PER. This lack of interaction and coordination is due to a tendency of national scale institutions - like INDAP and the Ministry of Agriculture – to promote coordination only at the highest levels while ignoring on-the-ground collaboration with the Ministry of Energy and regional bodies.

In smaller PV projects (i.e. tens of rural households in a single municipal area), regime actors (electric distribution utilities) have not been actively involved in the development of the RET portfolio, a fact which means that conflicts and power pressures against or in favour of projects have been less apparent. The lack of willingness on the part of utilities to engage is related to the high transaction costs and risks involved in developing small RET rural electrification projects. In such cases, explicit and long term support from local council and regional government authorities helped support PV niche development. Paradigmatic cases are those of San Pedro de Atacama and Empedrado. There, protection was not only financial, but also related to the matching of local needs and socio-technical options, easing decision-making with respect to project implementation, and supporting operational models and capacity building amongst user organisations.

In Chiloé, on the other hand, contested visions and conflicting interests marked the development of the wind-based rural electrification portfolio from the start. SAESA became engaged in the implementation of the Tac island pilot project but soon after explicitly opposed governmental plans to expand small scale wind power on all the other islands of the archipelago. Conversely, they expressed interest in investing (and thereby benefiting from the generous state subsidies involved) in diesel based mini-grids. SAESA and all other subsidiaries of the SAESA Group had a significant market share in electricity distribution in all southern regions of the country, having become the most powerful regime actor in Los Lagos, Los Ríos, Araucanía and Aysén regions. The group had interests in all segments of the market (generation, transmission and distribution).

As mentioned in chapter 6, by the initial years of the PER and the GEF programme, SAESA was controlled by COPEC (in the oil and fuel sector), so through an interwoven network of firms they exerted pressure on relevant authorities at the national and regional scale to direct strategic plans towards 'mainstream' regime options (grid extension and diesel generation). **SAESA only participated in the wind niche network in Chiloé as a compromise so as to maintain their influence in larger investments (generation and distribution through electric grids). In fact, the relationship between SAESA and relevant public sector actors in the rural electrification arena was never mutually beneficial. SAESA was a passive participant who did not disclose their own strategic plans** (Interview 6) **and persistently displaced and attempted**

to organise alternative decision-making settings, avoiding commitments with RET actors, such as the GEF programme, the e7, NREL and regional or national policy-makers supporting wind-based electrification in Chiloé (Duhart, 2009, Interview 6, Interview 15).

Following the definitions of the MIDEPLAN methodologies, upon request from municipalities or the regional government, the distribution company budgeted and developed techno-economic assessment of rural electrification projects. In doing so, they were able to keep investment costs high enough for the most distant projects, making them unfeasible from a financial and economic perspective (Interview 6, Interview 19, Interview 21). In addition, arguing that rural electrification was more expensive in the region because its extreme isolation made it difficult to reach rural villages (e.g. through dense forests, on unconnected islands or across rivers and lakes), the firm was able to lobby for adaptations of the assessment methodologies (MIDEPLAN), which were finally changed and subsidy thresholds increased. **Those changes provided additional protection to regime options, such as grid extension or diesel based electrification, since grid extension projects became viable as increased investment subsidies led to financially attractive projects that otherwise would have been developed as RET alternatives**.

Little progress was being made in RET rural electrification in Chiloé and political priorities were unstable and changing. These considerations led public sector actors engaged in the PER at regional scale (UTER, technical staff in municipalities and regional government offices and sectoral – ministerial - regional authorities) to exert additional pressure to keep enough adaptable protection measures directed to niche support. Such measures included the operational subsidy initially negotiated in the Coquimbo PV project, something which was applied to any source of generation, including diesel off-grid projects. The fact that those supporting mechanisms were kept undefined (to be used in off-grid electrification regardless of whether the energy source was RET or not) was a result of their having been negotiated in different settings and in the face of different issues. For example: i) the Ministry of Energy proposed and drafted proposals in consideration of several opinions from regional and central actors, both niche and regime advocates; ii) regional authorities administered a rural electrification portfolio and they had to assign priorities and allocate funding; iii) regional authorities received funds from national sources (treasury and FNDR) to subsidise investment and operation of grid and off-grid projects; iv) local and regional private sector actors lobbied for their own interests and in this way influenced regional authorities' decisions. But the decision-making process was also heavily influenced by the need to achieve rural electrification targets, so in the end the persistent power of incumbent actors influenced project implementation decisions towards their interests (grid extension and diesel based off-grid generation).

After the rural electrification strategy in Chiloé turned towards submarine connection and diesel-based systems, those wind projects that remained in the pipeline, and which were being executed during 2013-2014 (such as the Desertores islands wind project) counted on different protection measures defined outside the rural electrification institutional framework. The GEF programme and the Ministry of Energy (on behalf the Chilean Government) had assumed a commitment to small-scale wind power development in Chiloé and as the GEF programme was to come to an end in 2010, there was an imperative to achieve results in that area. As negotiations at the regional scale were unfruitful, GEF and ministerial authorities organised alternative settings to approach the electrification of the few Desertores islands through wind systems: the authorities displaced the issue to the political cabinet at the national level and the electrification of this group of islands was included in a special package of funding being negotiated (and allocated) to the regional government to improve connectivity and infrastructure in Chiloé due to the decision of not to build a bridge between the Great Chiloé Island and mainland Chile. In other words, although funded through institutional channels also used in the PER (i.e. FNDR funding and MIDEPLAN methodologies), the electrification of Desertores islands was decided in alternative institutional settings (i.e. extra institutional arrangements outside the PER project cycle and decision-making architecture).

In summary, although the results are opposed (support for PV and opposition to wind power), in both cases incumbent private sector actors have played a crucial and influential role. These actors have influenced the creation of protection measures (to the benefit of both niche and regime options) through the use of what Hacker and Pierson (2002) and Fairfield (2010) have called instrumental power, i.e., via lobbying for particular socio-technical options or through formal and tacit agreements with the private sector. When existing rules, institutions and practices are less conducive to negotiation and deliberation, there can be additional power mechanisms operating in a supra or extra contextual form. For example, Cortés Terzi (2000) has coined the term *extra-institutional circuit of power* to refer to the 'de facto' capacity of actors to intervene in and influence decisions when maladapted institutions and inadequate political systems are unable to respond to (contemporary) social needs and demands. This extra-institutional setting, however, hinders the inclusive and democratic character of decision-making.

Finally, in order to answer the question about the impact that off-grid RET niches have had on the rural electrification regime, four crucial issues have to be revisited: i) the strategic nature of niche protection; ii) particular measures aimed at creating a protected space for innovation; iii) other measures that protect or support rural electrification but do not address niche development; and iv) the dynamics of structuration and stabilisation applied to the emergence of new application domains.

On the issue of whether protection for niche development has been strategically constructed, the analysis **detected that support for off-grid RET development has not formally differentiated between RET options. Apart from particular support for wind monitoring in Chiloé and other locations around the country and the development of specific voluntary technical standards in order to help guide project designs, formal support from the GEF programme and the Ministry of Energy have not considered the particularities of technologies and the social contexts in which particular RET options are more suitable.** Although 'ex-ante' definitions of the type of technology to be supported in a particular geographical area (which could be considered as 'picking a winner') can be observed, there has not been tailored or specific support or protection responding to the particular needs of any socio-technical options (e.g. low voltage and efficient electric appliances in SHSs, grid management and operational software capacity in mini-grids, remote monitoring and balance of systems in more robust and larger projects, and so on). Additionally, support and protection for RET rural electrification was given from the project development phase onwards, deliberately avoiding commitments and measures to enhance the R&D phases that occur before markets are created. The GEF programme and the PER explicitly considered only commercially available technologies to be used in rural contexts and did not support local R&D efforts to adapt and customise technologies to local contexts (with the sole exception of the Huatacondo PV mini-grid developed by the energy Centre of the University of Chile).

Regarding the issue of protection specifically created for niche development, the subsidy devised to cover increased cost recovery operation and maintenance fees, initially aimed at supporting RET systems, was finally applied to support any type of off-grid electricity technology. This included more mainstream regime options such as diesel-based generation. **The use of this measure to support both RET and fossil technologies has helped PV development in central-northern Chile but has constrained widespread diffusion of small scale wind power in Chiloé.** The role of institutional actors (primarily regional government and Ministry of Energy authorities) was decisive in influencing how the final draft of the law approving the subsidy became established. These actors, interested in achieving electrification targets (or obligations) at the regional scale, mobilised influence and means to make the law adaptable enough to cover any sort of energy source (not only RETs), and it was finally approved to support both niche and regime alternatives.

But more crucially, **the way the most pervasive rural electrification protection measure evolved (the FNDR investment subsidy) has created what is really a non-conducive space for RET diffusion.** The rationale behind the subsidy was to help fund projects that otherwise would not attract private actors (distribution utilities) to invest in rural electrification. If a particular project yielded a positive social (economic) NPV, based on cost-benefit analysis defined by MIDEPLAN's guidelines, but would not be privately viable (negative financial NPV), the state subsidised capital investments until a (private) breakeven point was reached. However, the MIDEPLAN assessment methodology enforced the consideration of grid extension projects as the condition of considering any other off-grid option (including both diesel and RET systems). In other words, the state did not provide particular niche (RET) protection and forced prior consideration of the grid extension option.

Moreover, as little progress towards rural electrification targets was being achieved in some regions (particularly Los Lagos region), changes in the assessment methodology and its guidelines introduced in 2007 (MIDEPLAN, 2007) heavily affected the extent to which RET projects would be supported[59]. If this had been implemented in a fair way so all technological options could have been considered on a level playing field, these changes would have benefited RET projects (with higher capital cost but lower O&M than the grid-extension alternative). However, as cost-benefit analysis was changed to a cost-effectiveness approach, and from that moment onwards only cost variables (investment and O&M) influenced project inclusion in the regional pipeline but no other factors were considered in the decision-making process (such as private and social benefits), regime protection was kept in place in the form of 'a priori' first right of refusal for grid extension projects. To limit public spending (in subsidies) and to avoid the monopolistic power of distribution utilities, investment thresholds (per connection cost) were defined on the basis of on the historic costs of rural electrification projects in that region inflated by acceptable cost increments given larger distances and more technical and logistical difficulties in project construction. In practice, these changes made a larger number of grid extension and diesel-based projects (financially) viable, so the original pipeline of wind projects in Chiloé was replaced by regime technologies.

[59] A new methodology was further adapted to consider RETs and productive uses of energy in Rural Electrification projects (MINISTERIO DE DESARROLLO SOCIAL 2013. Metodología de Formulación y Evaluación de Proyectos de Electrificación Rural. *In:* DIVISIÓN DE EVALUACIÓN SOCIAL DE INVERSIONES (ed.). Santiago.)

Finally, the issue of whether the emergence of niche practices (structuration) and socio-technical stabilisation affected how new application domains have emerged, and in doing so, rural electrification practice (particularly regime dynamics) has evolved in Chile, is discussed. The first thing worth highlighting is that in the PV niche, new application domains appeared in subsistence farming, electrification of schools and rural clinics and mini-grid development in the framework of the Rural Electrification Programme and its subsequent policy initiatives (PERyS and Energisation Programme). Grid-connected PV is also being developed, but no clear links between off-grid niche policy and regime (grid connected) practice is recognised[60].

The focus is on the use of off-grid RETs in other domains. It is important to note that **the emergence of these new domains has lacked the institutional coordination and replication of rules already developed in rural electrification**. Although these new PV applications responded to scaling up efforts initially supported by PER and GEF programme authorities and some rules and practices have been adapted (such as design heuristics and assessment methods), there has been a 'reinvention' of rules to develop new pilot projects (such as institutional coordination, private sector engagement and alternative funding sources amongst other practices).

The way the institutional framework has evolved, primarily the separation of the Energisation Programme (led by SUBDERE) and the PERyS (led by the Ministry of Energy), has affected the scope for knowledge transfer from previous experience and learning. Turning now to the other case study, niche practices in the small-scale wind power sector have achieved extremely limited structuration and stabilisation, affecting the way niches and regimes interact. Moreover, new application domains have not been explored and wind-based mini-grids still remain at a very localised scale. In other words, structuration and stabilisation of niche practices do not seem to have promoted niche growth. One reason for the inability to transfer niche practice might be that the knowledge and rules applied to off-grid rural electrification did not reach a sufficient level of generalisation and remained too focused on localised practice (development and implementation of residential scale electrification) and was not effectively adapted to include new needs and demands, such as productive uses of

[60] Although grid-connected RET is currently being supported in Chile, the analysis of its dynamics is beyond the scope of this thesis. However, as shown in previous chapters, CONAFE implemented grid-connected pilot projects in Coquimbo after experimenting in off-grid PV. This example shows that niche activities (off-grid PV) are not directly translated into radically new domains (grid-connected PV is subject to a completely different set of rules than off-grid systems under the Chilean electricity law and other institutional and social practices) but that knowledge and capacities acquired in off-grid PV has been used by incumbent actors to explore and expand application domains. The cases illustrated reaffirm that the regime actors are able to translate niche practice into the regime space, given their power and market position in the electricity distribution sector.

energy. **The analysis of these cases therefore reaffirms what Smith and Raven (2012) have suggested: that niche-regime interaction is a process of iteration between content and context, or technological performance at the niche level and wider rules, practices and societal needs (i.e. the regime).**

7.6 Public policy planning, governmental roles and private engagement in RET innovation.

The final issue discussed in this chapter is the role of different actors in promoting RET development in rural electrification and how niche construction has been enabled as an innovation process acting at a system level. The focus is on the process of public policy planning, the fundamental role the state has assumed in niche construction and how the private sector is crucially engaged to achieve policy goals within an innovation network.

One of the main strengths of the Rural Electrification Programme in Chile, and something which has been acknowledged internationally, was the persistent and long term government support in defining an agenda and implementing a national policy with clear decentralised roles (including regional governments, municipalities, distribution utilities and regulators) and stable sources of finance via specific provisions in the FNDR (McAllister and Waddle, 2007). Without the state guiding and funding the rural electrification process, progress would have not been so successful. It has been shown how access to electricity increased in rural areas from nearly 50% in the beginning of the 1990s to 96% in 2010.

However, the state relied primarily on existing technologies, dominant business models (aligned with the liberalised structure of the electricity market) and the crucial engagement of electric distribution utilities. To open up new domains (i.e. create a space for RETs in the rural electrification programme), the GEF Secretariat played a key role by funding a cooperation project that became a national programme aimed at removing barriers to renewable energy in rural electrification (the GEF programme). In other words, **contextual, general (or landscape) pressures coming from the international scale created a window of opportunity for RETs in a developing country context**. The interest in increasing the use of RETs in rural electrification received its impetus from the motive of mitigating climate change. This is important because international technical cooperation was crucial in diversifying the political agenda. This brought environmental and development goals into national debates and committed resources which were mobilised with a sufficient degree of independence and autonomy from bureaucratic institutional funding structures as to permit the emergence of a programme acting at a system level (or a cosmopolitan intermediary role) able to interact with and coordinate several sectors and institutions at different scales.

The state stepped into the development of specific programmes to promote the inclusion of RETs in rural electrification. Thus, the GEF programme was co-funded by the Chilean Government and institutional support was secured, mainly within the Ministry of Energy (formerly the National Energy Commission). **Governmental involvement was crucial in building networks in a space dominated by incumbent actors and institutions that lacked the vision, resources and knowledge to let a new technological space emerge naturally**. To do so, through the GEF programme (and in recent years in the framework of new policy initiatives), the state funded RET development through cash transfers (capital investment subsidies) to private sector companies to implement rural electrification projects. But the state also took on all pre-investment risks and invested in several other complementary activities: it identified and developed RET projects, assessed rural communities' needs and matched them to technological options, developed and adapted technological designs, accumulated knowledge and expertise, piloted technologies and delivery models, and created technical standards and design guidelines amongst many practices. For riskier projects (e.g. in small and extremely isolated rural communities) the state also assumed an active role in managing and operating the initiatives, overcoming challenges and creating additional protection mechanisms (through various institutional networks' scales). **In other words, as Mazzucato has argued, in developing new technological paradigms or 'missions', the state has played a critical role in creating markets, because the "private sector would not invest even if it had the resources"** (Mazzucato, 2013, p.24).

But the state had to bring in a number of other actors so as to be successful and effective in realising such visions (the gradual but radical increase in rural electrification access). The private sector has been an important player in the PER, primarily in the later commercialisation (or execution and operation) of RET options. Without the private sector, the state would have not been able to implement RET projects because, under the neoliberal Chilean constitution, it was not the role of state agencies to become provider of public services. Fulfilling its subsidiary role, the state engaged with the private sector in policy implementation and private sector firms adapted (or shielded) regime rules (market structures and models, infrastructural practices, user-producer relationships and so on) to enable (or hinder) RETs rural electrification in those areas where dominant technology was less likely to succeed.

In a small country with a highly concentrated electricity sector, it was neither easy nor natural to find private actors with the willingness and capacity to implement RET projects in poor rural areas. As has been thoroughly argued and exemplified in the thesis, **the PV niche achieved higher cosmopolitan levels because a symbiotic network of private and public institutions implemented projects in a vast geographical space. The wind niche, by contrast, was limited to a few pilot projects with very localised impact which impeded the emergence of a cohesive network of institutions that only collaborated in a parasitic relationship**. The engagement of incumbent firms in RET rural electrification (a dynamic observed mainly in the PV sector) was driven by expected opportunities and not by actually existing profits in that sector (Dosi et al., 1997). Because technological and market opportunities are projected to yield results in the long term, private sector commitment has to be patient and proactive in developing further those opportunities in the form of improving the reliability of technologies (ensuring operational performance of projects) and searching for new domains of application, such as productive uses of RETs, scaling up electricity services in non-residential markets and combining existing markets with new technological options (such as grid-connected PV).

8. Conclusions

8.1 Introduction

This chapter presents the conclusions of the thesis. Based on the analysis of the cases and the subsequent discussion presented in chapters 6, 7 and 8, the main findings of the thesis are summarised here. In doing so, the contributions of the research are emphasised in the following ways: empirically, theoretically and in terms of the implications for policy and practice. The empirical perspective emphasises the main findings from the analysis of the cases studied, including the extent to which these can be generalized for RET uptake for rural electrification. Theoretical contributions refer to findings that reinforce or confirm existing theory and, more importantly, those findings that suggest extensions, revisions and complementarities to existing theories. Policy and practice contributions highlight the implications of this research for practitioners involved in improving access to energy, and more generally, for the diffusion of RETs in developing country contexts. These concluding sections are followed by suggestions for areas for further research that can address any limitations of this thesis or additional areas that would be valuable to take further.

In concluding the thesis it is useful to return to the initial interest that framed the overall research, carried out between 2009 and 2013. The thesis has been concerned with the reasons underlying success and/or failure of diffusion of radical innovations. Off-grid RETs in rural electrification represent disruptive ways of fulfilling social demands and energy needs of rural communities. From the perspective of real life problems and based on the evidence of policy implementation in Chile, this thesis has reviewed a process that has fostered access to electricity in nearly all rural areas of the country over the last 20 years. Given the importance of the energy challenges faced globally, including access to and sustainable use of modern energy services, the particular cases analysed can shed light for policy action in many developing country contexts. But the social science approach taken in this research also shows that access to electricity is a complex process of socio-technical transformation at the heart of which lies inclusive innovation and development. It is hoped that this research will contribute to a better understanding of energy access challenges, the emergence and diffusion of RETs and the overall transformation of pervasive socio-technical practices requiring radical changes so as to build a sustainable and more inclusive future.

8.2 Empirical Contributions

This thesis has advanced knowledge about PV and wind diffusion in rural electrification in Chile, but it also allows a better understanding of RET uptake in general, in the context of access to energy in developing countries. The research has, therefore, made important contributions in terms of reviewing the processes through which RET socio-technical trajectories evolve, and hence the ways in which they might need to evolve on larger scales as a way to tackle the challenges of bringing modern energy services to millions of people – globally.

This thesis probably constitutes the most comprehensive empirical study of PV and wind rural electrification projects undertaken in Chile and it is the first doctoral thesis using a transitions and SNM approaches to investigate RETs diffusion in rural electrification in Latin America. As an important result, the study has probably mapped every Chilean small-scale PV and wind project (and also other RET projects that lie outside the scope of the analysis) in the rural electrification process (PER) and beyond, including early independent support for RET rural electrification projects and the subsequent implementation of other policies and programmes in the country.

Apart from these more general contributions, there are possibly 3 main empirical contributions made in this work. The first of these contributions is recognition of the importance of setting a vision shared at various scales (i.e. central, regional and local) and across several sectors (i.e. government, private sector and industry, civil society and rural communities, research institutions). The theoretical implications of expectations at the niche level are discussed below, so in this section the focus is put more on the empirical analysis of the cases.

When the construction of a vision is mentioned, it implies that access to electricity (rural electrification) is a social endeavour that requires credibility and strong public engagement, not only policy support (see also the discussion of policy and practice contributions). In this regard, Spath and Rohracher (2012) emphasise that “building up credibility is a crucial prerequisite for institutional embedding” (p. 462). RETs in rural electrification, and more generally radical energy innovations, need market development, but this is only one part of diffusion efforts. The analysis of the cases showed that the active involvement of different governmental institutions is a key driver of successful development and embedding of new socio-technical practices. But scale matters in how government institutions get engaged. The same authors suggest that regional and municipal policies provide the linking of niches and regimes (Spath and Rohracher, 2012), representing the intersection in which different visions are confronted and through which socio-institutional embedding occurs. This is due in part to the fact that within a general vision (expanding rural electrification access), competing socio-technical paradigms are often confronted, with the result that RET development and diffusion needs particular support including tailored and specific development of innovative capacity.

Secondly, from the cases it has been observed that the construction of these innovative capacities that allow the emergence of technological diffusion pathways is a continuous and incremental process. This started with the provision of RET equipment (hardware). It then continued with the generation of socio-technical knowledge which became anchored in local contexts. Finally, the process encompassed the development of an institutional infrastructure supporting RET development. It can be concluded that hardware, software and institutional embedding evolve dynamically in an iterative and ongoing process which sustains the development, adoption and diffusion of innovations that affect the extent to which experimentation, replication and scaling up are enabled.

Finally, the empirical analysis reinforces the idea that technological change (and particularly the emergence of new, radical technologies) is a path-dependent process. Previous experience, knowledge and institutional embedding affects the possibilities of the further development of these new socio-technical options and their being taken up in particular social contexts defining alternative socio-technical trajectories.

Having highlighted these three empirical areas in which this thesis is contributing, why has the construction of a PV niche been more successful than the wind niche? Technology seems to be important in understanding the uneven diffusion levels of PV and wind in rural electrification in Chile, but not only technology as hardware: knowledge about how to deal, sustain and transform technological options coupled with the social and institutional embedding of a particular technology are all interlocking determinants of niche construction. There are certainly technological development trends of international scale that support particularly the uptake of PV. Cost and performance improvements have been dramatic over the last decade, which impact technological diffusion of PV as a background factor. However, these (economic and technological) efficiency gains are not directly translated into local contexts where total costs of off-grid solutions are also composed by a series of other costs (such as labour costs, logistics, batteries and balance-of-systems).

Together with technological factors, the PV niche benefited from wider and diverse public engagement compared to the wind niche. The PV protected space also suffered less competition (and sometimes declared opposition) from alternative technological trajectories and options and it also gradually expanded an innovative space, thus creating better conditions for -incrementally - augmenting the possibilities of a – radically - different vision for the future of the PV technology compared to wind. In other words, the feasibility of a new configuration depends on technological feasibility and embedding, but also -and maybe more importantly- depends on matching institutions and practices which create the conditions for social and institutional embedding, an important contribution that Spath and Rohracher (2012) have also highlighted.

8.3 Theoretical Contributions

From a theoretical perspective, this thesis has sought to analyse the diffusion of two radical innovations of particular relevance in rural electrification efforts in a developing country context. In order to do so, it has operationalised an evolutionary perspective on socio-technical change, and in particular applied the Strategic Niche Management approach combined with literatures on intermediaries, power struggles and conflicts over decision making processes.

The first overall theoretical contribution of this research is that it has assessed the ability of SNM to explain the construction of niches in developing country contexts. To do so, niche processes within aggregations of PV and wind rural electrification projects in the Chilean Rural Electrification Programme have been analysed. The second overall theoretical contribution is that the SNM framework, with its considerations of agency, the systemic nature of intermediation and the consideration of a scalar conception of socio-technical trajectories, has been extended, in order to better understand the construction of niches and the dynamic interaction between niches and regimes affecting the extent to which wider regime shifts can happen. The following subsections draw conclusions from the analysis and discussion of the cases to stress where the findings of the research reinforce, complement or revise existing literature.

8.3.1 Contextualising SNM in RET research in developing countries.

This subsection draws on the main findings about how internal niche processes have evolved in the cases analysed and it proposes various extensions to early SNM theory. This thesis applies SNM theory in a new context which combines in itself several characteristics of a developing country, but also institutions, agents and localities that have evolved from a traditional ‘developing country’ typology (or stereotype) in the last couple of decades. In this regard, the selection of Chile as an umbrella case needs to be understood as an example that helps generalising the findings and contributions of this research (in relation to the application of SNM theory) to other developing countries facing similar access to energy challenges Chile started to tackle twenty years ago. It is important to note that rural electrification started when the country was still lacking several institutional capabilities, it was facing many social and political deficits and the democratic transition was in their early stages. Even today, the country exhibit many contrasts and contradictions in terms of social inclusion and spatial equity at several scales. While some areas or cities and their embedded relational networks can be compared to middle-income or advanced standards of development, most (if not all) localities and related networks where off-grid RET projects have been implemented exhibit complete 'developing country' characteristics.

These uneven contexts (and places) in which SNM theory has been applied are particularly relevant to understand (and also pose additional questions to) the multi-scalar dimension that niche development and socio-technical transition analyses are integrating in their frameworks, to address in a more nuanced way contextual dimensions of innovative embedding.

In the following sub-sections, particular findings of the application of the SNM framework in these uneven contexts are discussed and summarised.

8.3.1.1. Coupling and articulating expectations

During the development of a niche, expectations are supposed to evolve from general and fragmented visions towards more robust and commonly shared prospects about the future of a technology (Raven, 2005, Kemp et al., 1998, Schot and Geels, 2008). From the analysis of the cases it has been confirmed that expectations and visions were initially fostered by independent actors, and that government entities progressively internalised and promoted expectations about RETs with the result that these started to be shared by actors from a variety of sectors (public and private sector, academia and local communities). What has been found in the case studies is that when expectations became more robust, the process was characterised by the transfer of general visions and national level objectives (e.g. the development of a market for RETs in rural electrification) towards specific local contexts (e.g. the feasibility of implementing a private-led delivery model in a large-scale PV demonstration project in Coquimbo). The transfer from general to robust expectations is enhanced when those actors carrying the visions about technological possibilities have the capacity to mobilise resources from the particular local contexts in which new technologies are being promoted, thus enabling local actors to internalise and commit themselves to the development of projects. In other words, expectations become robust when these are anchored in particular contextual conditions (which include the geographical conception of space but also the relational notion of space including the networks of actors and institutions pertaining to those contexts, as suggested by Raven et al. (2012) and Coenen et al. (2012)).

The second characteristic of expectations is that they achieve greater specificity and they evolve in particular directions (Raven, 2005, Schot and Geels, 2008). This is an important contribution of earlier SNM research which has been corroborated in the uneven development of PV and wind rural electrification. PV was clearly conceived to provide basic although sufficient amounts of electricity in isolated and poor rural households in dozens of rural councils in central-northern Chile with a clear and defined aim. Wind-based mini-grids faced equivocal support from actors interacting at the level of regional strategy development and implementation. Two main contributions emerge in this respect. First, when the direction of development of a vision (or expectation about the desirability of a new technology) becomes socially embedded (i.e. there is an alignment or matching between needs and options) there are better prospects for additional domains of applications to emerge, reinforcing a particular direction of development. Secondly, if expectations are clearly backed by policy strategies (i.e. institutional embedding), they experience a progressive development, passing from simpler to more complex and robust technological systems and from centralised definition and control over visions towards a decentralised appropriation of those expectations.

Finally, the third characteristic of expectations alignment is that higher quality expectations are attained (i.e. expectations are more effective in being translated in projects) when they are backed by continuous experimentation and concrete results (Raven, 2005, Schot and Geels, 2008). Through the analysis of case studies, it has been shown how results affect the extent to which expectations increase credibility and quality. In this sense, experiments with technology (PV and wind rural electrification projects) have achieved better results only when technology is understood as a combination of equipment, knowledge and a supporting institutional architecture in which technological practices are embedded. It has been argued that in developing country contexts, marked by weak technological knowledge during early stages of technological diffusion, the development of soft rules, knowledge and an institutional platform in which technologies are put in service are key determinants of the successful functioning of technological systems (RET rural electrification projects). Moreover, the mutually dependent interaction and development of hardware, software and orgware (Dobrov, 1979, IIASA, 2007) sustains the spreading of expectations at a decentralised scale where projects results are finally perceived.

8.3.1.2. Social network cohesion

Building social networks supportive of niche development is a critical process explaining the success of new technologies. How actors interact in the development and diffusion of radical innovations has been extensively researched in SNM literature and this thesis has shown how these networks are formed and strengthened in the cases analysed. Through the analysis, the thesis has reinforced earlier suggestions of SNM scholars regarding the idea that cooperation between actors is not an easy undertaking (Kemp et al., 1998). Building networks of a diverse nature needs particular advocacy capacities to engage actors with competing or even opposed interests. Actors interacting in rural electrification vary from governmental institutions at several scales, private sector companies with an established presence in the electricity market (such as distribution utilities and electric cooperatives) or newcomers (such as RET providers and project developers), research institutions, NGOs, international cooperation organisations and, importantly, rural communities.

It has been found that public sector institutions have played the most important role in network building. Moreover, as a centralised social policy, rural electrification has been promoted, but has also been implemented by the committed and persistent activity of governmental institutions. The PER, beyond being a long-term policy framework, has been an umbrella platform on which socio-technical networks were constructed. This policy platform also provided the settings in which decision-making was undertaken. Rural electrification decisions are made at several scales (from centralised allocations of public funds, to regional or municipal prioritisation of projects and execution decisions; from public sector contributions in terms of state subsidies to private sector decisions to co-fund and implement projects). Therefore, a critical aspect of network building (and an important finding of this research) is that regional and local scale actors (including local rural communities) required strengthened capacities to participate in decision-making processes. In other words, for networks to be effective in supporting niche construction they need to be enabled to act with a decentralised capacity that takes into account particular context-specific conditions and micro-institutional capacities of local actors. The findings of the thesis reinforce Coenen et al. (2012) suggestion of ways to integrate space in transition analysis. These authors propose one building block of institutional thickness, understood as the governance arrangements between actors and institutions from one place compared to others to work collectively and support their activities with the inclusion of external agents.

Additionally, the thesis has contributed to theory development by analysing how broad networks are formed. SNM literature recognises that both incumbent (regime) actors and newcomers are important in niche construction (Schot and Geels, 2008, Raven, 2005, Kemp et al., 1998). Broader networks, i.e. those including both traditional (regime) and newcomer (niche) actors, were found in the PV case, but not in the wind case. The first suggestion from this finding is that broad networks are indeed important in fostering niche development and that the fact that the group of actors behind wind-based projects was narrow could explain the difficulties that niche had in emerging. However, it has also been found that the role played by incumbent actors is critical in supporting niche development. Particularly, what has been called "factions of outsiders" within incumbent actors has greatly contributed to sustain niche development. These groups of newcomers, who act within existing institutions more aligned with regime practices, have been key in opening up spaces of opportunity for considering radical innovations and actively supporting technology development and implementation of RETs projects. In doing so, they have been able to build opportunities with a system-level impact. These outsiders have been important at different scales and across sectors, including public and private institutions (e.g. the GEF programme team at the heart of the National Energy Commission and CONAFE SER as a subsidiary of an important distribution utility).

Finally, resource commitments are considered a determinant of how deep a network becomes (Schot and Geels, 2008). The analysis of case studies in this thesis has allowed a better understanding of the nature of commitments by distinguishing formal and informal resource contributions to the functioning of networks. Formal resources are associated with funding commitments, policy endurance, technical assistance to experiments and managerial support, amongst other things. Informal commitments refer to cognitive and symbolic resources contributing to trust building and empowerment of actors. Moreover, it has been found that these two types of commitments mutually interact in a process that reinforces and strengthens networks.

8.3.1.3. Learning in niche contexts

The diffusion of PV and wind technologies for rural electrification in Chile have been also characterised by learning processes. The findings of the cases confirm that learning has to be both broad and reflexive (Raven, 2005, Schot et al., 1996, Schot and Geels, 2008). Different dimensions of learning, which had not been explored in previous SNM research, have been unpacked. A first dimension is associated with the mainly techno-economic aspects of socio-technical practices, that is, the abilities, skills and knowledge that allow niche actors to learn 'how to deal' with technology. A second dimension of learning is linked to the capacity to manage and coordinate aggregations of projects (or experiments) that collectively improve learning capacity on 'how to sustain' the niche in the long term, thus enabling localised knowledge, expertise and technological capacities to be transferred from one project to subsequent ones. The third dimension of learning analysed in the cases is the capacity to transform realities (‘how to transform’), or in other words, how previous experience and socio-technical practices allow actors to reflexively interpret needs and adapt solutions to better tackle societal problems.

By unpacking learning through this deeper interpretation of different learning dimensions, the thesis provides a better understanding of the dynamic interaction between first and second order learning. First order learning is primarily associated with the accumulation of technical and economic experience and facts, while second order learning refers to the capacity to challenge meanings, frames and cognitive structures so as to redefine them. However, an important aspect found in the cases is that learning needs to be spread throughout the network of actors in order to be effective in stabilising and structuring dynamics within the niche. Here, the earlier findings regarding the key capacity of ‘institutional actors’ are reinforced. These actors deploy their capacity at several scales of action (national, regional and local) to understand, apply, adapt and create socio-technical practices. By doing so, localised experiments (or projects) can be ‘dealt with’, ‘sustained’ and produce feedback into the process of technology adoption to ‘transform’ technological trajectories. These trajectories not only deploy through different geographical scales, but also through relational dynamics within networks of actors and institutions, reinforcing the understanding of space and scales that has been recently conceptualised in the geography of socio-technical transitions research (e.g. Raven et al., 2012, Coenen et al., 2012).

8.3.2 Intermediary action as a political engagement process

One of the significant theoretical contributions of this thesis is that, building on early SNM and intermediaries’ literature, it has introduced an additional perspective from which to understand niche construction. This is its attempt to conceptualise intermediation processes at a global niche level. The SNM framework (see for example Kemp et al., 1998, Schot and Geels, 2008, Raven, 2005) has focused on the occurrence of internal niche processes that contribute to the emergence of such protected space in which new technologies are developed in real life contexts. The intermediaries literature, which links how new technologies increase their structuration and stability in a cosmopolitan niche level (Deuten, 2003, Geels and Deuten, 2006), and the roles played at a strategic or system level (van Lente et al., 2003) have focused on the emergence of abstract, decontextualised knowledge, rules and practices. Both literatures (SNM and intermediaries) approach the emergence and diffusion of radical innovations from evolutionary and cognitive perspectives. In contrast, by operationalising the intermediaries literature into the analysis of niche construction, this research has taken an approach that places intermediary action within an agency perspective, in which decision-making and power guide the analysis aimed at understanding how niches – and those process acting within protected spaces - are influenced by political dynamics.

As was noted in both the review of the literature and the discussion of case studies, Geels and Deuten (2006) had suggested that systemic intermediaries perform functions at the cosmopolitan niche level. The functions identified include: monitoring projects, aggregating and translating lessons from project to project and creating an abstract level of knowledge that guides practices at the local level, i.e. from global to local niche levels. The conceptual framework for this thesis proposed an extension to these theoretical insights in order to better capture the way intermediary action intervenes in decision-making processes that enable RET diffusion in rural electrification.

Based on the analysis of the cases, it has been suggested in this thesis that interaction in decision-making settings depends on the capacity and power of certain groups of actors. Systemic intermediaries mediate in the configuration of such settings, and they are, therefore, placed as political actors advocating certain directions in which decisions are made. The results of this thesis agree with the observation of van Lente et al. (2003) that systemic intermediaries play a strategic role in transitions. But the thesis also extends their view about the strategic management of these actors by proposing that intermediation overcomes managerial activity. How decision-making is configured in various settings is a crucial determinant of the construction of possible socio-technical trajectories. Intermediaries embody more strategic functions than coordination of actors and management of experiments at a system or cosmopolitan level. It has been found that systemic intermediaries are important in linking and involving both niche and non niche actors who interact in a political sphere affecting (and protecting) niche construction. Intermediaries facilitate and seek political engagement, mobilise resources and organise decision-making settings and bring in political actors to the niche space.

The analysis of case studies in PV and wind diffusion suggests two conclusions with respect to intermediary action. First, intermediary action is an additional process occurring within the niche, but it is different from traditional internal niche processes because it is placed as an encompassing process that links the dynamic interaction between expectations development, network formation and learning at several levels. Secondly, the importance of systemic intermediation lies beyond the managerial enterprise attributed to niche construction. In fact, system intermediaries engage in political activity, i.e. reflexive planning and contextualised implementation of new technologies aiming at challenging framings and modulating alternative socio-technical configurations.

An additional contribution of the thesis relates to understanding how the systemic intermediation process is able to iterate between decision-making settings and socio-technical configurations. The findings of the thesis suggest this is a continuous process of performance improvement, and one that takes into account technology equipment, rules and institutionalisation of practices. It has been found that when actors engaged in decision-making (including decentralised public sector institutions, private sector entities and rural communities) and they proactively interact in different stages of the diffusion process, networks of a symbiotic nature emerge supporting niche construction. On the contrary, when decision-making is constrained to a few actors and interaction is limited, parasitic relationships hinder the extent to which a global niche level is structured.

8.3.3 Niche-Regime Interaction

The final issue analysed and discussed in the thesis is how niches and regimes interact. Earlier research on SNM and transition theories had recognised the importance of the dynamic interaction between niches and regimes, but this is still an area which demands more systematic research. For instance, as noted in the literature review (Chapter 2), Schot and Geels (2008) argue that niches are necessary but not sufficient for transforming regimes, and Smith (2007) considers that the dynamic interaction between niches and regimes constitutes a challenge in current research. Suggestions come from different fields, such as the consideration of power and agency (Smith et al., 2005), constructivist approaches (Genus and Coles, 2008), and the politics of transitions (Shove and Walker, 2007). Geels (2010) acknowledges that business dynamics can offer a way forward to understanding how incumbent firms re-orientate and balance their interest to combine the relative advantage of existing technologies and new ones.

The dynamic interaction between RETs niches and the existing rural electrification regime in Chile was analysed through a more systemic consideration (i.e. beyond the scope of the firm) of decisions made to protect and/or destabilise niches and regimes. The first important finding of the research in this regard is that protection measures aiming to promote innovative activity in niches often come from regime contexts in the form of subsidies, assessment methods and guiding principles which are intended to increase access to electricity services in rural areas. In other words, niches have to compete with incumbent technologies under the same set of rules that have provided stability (and ongoing protection) to the dominant practice (rural electrification policy and practice). The neutral application of policy paradigms to RETs in the first instance led to conflicts and contestation about niche alternatives and more mainstream regime options (e.g. grid extension, diesel-based electrification).

In addition to existing protection in regime contexts, the decision to promote RET based electrification led the government to develop specific protection measures for niche alternatives. These measures consisted mainly of technical assistance in identifying, assessing and developing projects in areas where otherwise these would have not been developed. These soft measures (guidelines and practices for the development and submission of projects for State funding, technical standards, awareness campaigns and capacity development or training courses) were then transformed into hard supporting mechanisms, such as particular funding schemes to sustain RETs projects (e.g. subsidised operation of RET systems) or more explicit consideration of RETs in policy guidelines.

Protection measures for both regime and niche are discussed and settled in decision-making settings in which both niche and regime actors interact in an iterative and dynamic way. It has been found that issues (or conflicts, contested visions and interests) are articulated, discussed and resolved in a variety of settings which include elements from the niche and the regime. Issues get displaced through settings and there are additional power mechanisms operating in a supra or extra contextual form to influence decision making directions and outcomes. For example, incumbent actors have been able to displace issues to alternative decision-making settings in order to take advantage of emerging RET protection measures and re-adapt niche specific protection to support incumbent technology. This is done via lobbying and re-contextualisation of needs and options so non-RETs options are benefited by additional protection initially devised to support niche activity. In those local contexts in which competition between new and existing technological options is more acute (i.e. where RETs are not naturally protected and conventional electrification practice resists niche options), incumbent actors have been key in influencing decision-making and have applied pressure for the creation or adaptation of protection measures (to the benefit of both niche and regime options) through the use of their instrumental power (Hacker and Pierson, 2002, Fairfield, 2010).

The roles of government and private sector actors are crucial in influencing decision-making settings. Each has their own interests and contributes to both niche and regime development. Here the organisational and technological capacity of these actors to undertake niche development activities and improve the performance of new technologies has been crucial in the dynamic iteration with regime contexts, and in doing so, influencing decisions (on the implementation of niche experiments) and directions of development for new technologies. This dynamic interaction in decision-making settings explains in part the relative success of PV compared to wind diffusion. Government institutions at several scales and incumbent actors (CONAFE being the most prominent example) created and retained the internal capacity to undertake innovative activity in the PV niche, whereas wind-based electrification did not become embedded within institutional and organisational practices in the government and the private sector.

Additionally, the iterative and dynamic interaction of niche and regime actors in decision-making settings allowed or constrained the emergence of new domains of application for niche technologies. However, the lack of institutional coordination and replication of rules already developed in the rural electrification programme in new or adapted policy strategies (e.g. PERyS and Energisation Programme) constrained the extent to which incumbent actors supporting niche development (particularly in the PV case) became engaged in replication and scaling up efforts to enhance niche development. New contexts (including policy guidelines and decision-making settings) were created, focusing on the implementation of new experiments and not on the potential scaling up of niche practices to achieve structuration in different domains. The empirical findings show that iteration between content and context, as suggested by Smith and Raven (2012), was somehow lost when scaling up efforts were made and so niches experienced a limited ability to set a wider path of development.

8.4 Policy Contributions

This section briefly discusses the implications of this research for policy and practice. In doing so, the first important element to highlight is that the thesis has attempted to provide a systematic explanatory analysis of the diffusion of RETs in rural electrification from a social science perspective. The theoretical and methodological approaches come from evolutionary and constructivist disciplines in the field of socio-technical change. This is particularly important because, in doing so, the analysis starts from the understanding that the development, adaptation, use and diffusion of new technologies exceeds the technical and economic aspects so often regarded as the critical dimensions of energy policy and practice, and that the rural electrification enterprise is indeed part of an innovation process that deserves a socio-technical analysis to better capture the complexities involved.

The study has focused particularly on RETs (PV and wind based small scale electricity systems in rural areas), but as with any process of technology diffusion it has to be conceived of within a wider context in which dominant or traditional practice is so pervasive that the context itself is naturally part of the scope of the research (i.e. the rural electrification regime defines the scope of policy and practice but is also a subject of the research). RET diffusion in Rural Electrification has to be understood as a social enterprise in which multiple actors interacting beyond the space of liberalised electricity markets shape the possible trajectories of technology adoption, use and consumption of modern energy services. Supply and demand dynamics are only a part of the innovation process because needs and options are better conceptualised and resolved when complex technological, economic, socio-cultural and political processes are understood in a dynamic interdependence. In other words, the lack of access to electricity in rural areas of developing countries is not simply the result of market failures; however traditional policy approaches have relied on the ability of markets to expand access to electricity services whenever adequate incentives and regulations are provided by governments.

In this respect, the answer to the in-ability of markets to reach poor rural families with modern energy services has often been for the government to fulfil a subsidiary role and take overall responsibility over infrastructure and service provision in places where markets do not seem to work. Through dominant socio-technical practices, sustained through the provision of market-like instruments, the policy approach has been successful in reproducing dominant dynamics in non-remote and acceptably dense rural areas.

But in the last couple of decades, in often neglected and extremely isolated rural areas, the role of government not only in supporting but also in undertaking the rural electrification enterprise has been one of the key drivers and the engine of policy implementation that has paved the way for radical RETs innovations in rural electrification.

However, as the challenge is so acute and the pressure from mainstream practice so pervasive, one government alone could not have made any progress if it had not encountered a wide set of diverse actors from multiple sectors and with manifold visions to collectively implement policies and collaborate towards common aims. For these reasons, government institutions are crucial in leading access to energy innovation processes, but state ability is only effective when engagement from decentralised governmental institutions is achieved. Indeed, progress in the Rural Electrification Programme in the last two decades has clearly shown that the Chilean government led the process of long-term policy implementation. More successful RET diffusion has been achieved when national-scale government strategies have been translated into regional and local governmental institutions. This process has empowered regional authorities who have been able to define long-term strategies and as a result other local actors have committed their resources and become engaged in local-scale technology adaptation and diffusion.

Private sector companies have also been fundamental in constructing RETs niches in Chile. The balance between incumbent firms and newcomers in niche networks has overcome a tendency to focus too much on equipment provision (from technology providers) with the result that they have begun to work more cohesively in an interrelated process of needs and technology assessment, strategy and policy adaptation, project development, execution of projects (or experiments) and maintenance and operation of energy systems and equipment. More traditional (or incumbent) actors, such as electricity distribution utilities, can play a key role in widening and strengthening actors relationships, but these incumbent firms have to demonstrate –(tacitly and formally) their committed engagement in policy implementation. Incumbent firms, after all, can also oppose and hinder the development and diffusion of radical innovations. Governments need to promote and seek symbiotic relationships between actors by pursuing common goals, ensuring participation in deliberative processes and providing clear protection measures to specific technological options, targeted at the specific needs of contextualised socio-technical configurations.

But it is not only public-private partnerships that are important in realising visions and pursuing social goals (i.e. widespread access to modern electricity services in far-off and dispersed rural areas). Local communities are also fundamental in sustaining the process of technological transformation. Niche construction has to be embedded into local contexts in a process of iteration between general rules, knowledge and adaptation and adoption of socio-technical practices. Local communities, including rural families, local authorities and local social institutions (e.g. neighbourhood associations, rural schools, local productive networks), have to actively participate in the definition of options and take part in decision-making because through inclusive participation local networks and actors engage in the solution of energy demands and other societal problems. The evidence analysed in this thesis suggests that for RET diffusion to be successful it has to become embedded into wider societal problems and policy areas, which demand coordinated policies and strategies at several scales and sectors. Electricity access in rural areas is closely interlinked with other policy areas, such as education and health provision, improved productive capacity, communications and integration of rural areas into social life. Increased access to modern energy services cannot be addressed without considering wider development strategies aimed at improving living conditions of rural communities.

The complex relationships between rural electrification practice and more integral development policies reinforce the idea (sustained by the findings of this research) that political and cultural dimensions of the emergence of new technologies are extremely important in how finally policy strategies are socially constructed and how these factors affect the arrangement of settings and the outcomes of decision-making processes. Therefore, the consideration of political and cultural issues alongside technological, institutional and economic dimensions needs to be an integral part of developing country strategies of improving access to modern energy. These strategies have to recognise, anticipate and deal with diverging interests, conflicts and the power positions of actors that naturally arise in the process of transforming energy systems, because the challenge is “fundamentally cultural and political rather than technological” (Strauss et al., 2013, p. 10).

Through the analysis of RET diffusion cases the thesis has found that a decisive determinant of the successful emergence of niches is the ability to scale up policy and practice. This is done by linking broad societal needs together with diverse governance arrangements defining the provision, adoption and use of electricity services in an iterative process of replication, expansion and contextualisation of socio-technical practices. Together with equipment provision, the social construction of knowledge and institutions (rules) has to be promoted. Software and orgware capacity is not the same as training and rigid institutional structures. Knowledge must be accumulated and institutional stability provided through governance dynamics that are the result of deep and ongoing interaction and commitment of actors, not only by governmental entities (central, regional or local), but a diverse set of institutions and social groups.

These dynamics are particularly context-specific: different RETs represent diverse potentials and options in different contexts (including completely different geographical areas in Chile, uneven cultural dynamics, political relationships and environmental factors). For these reasons, particular supporting and protection measures have to be developed and put in practice depending on the context in which new technologies are being implemented.

Linked to these implications for policy and practice, the thesis suggests that these protection measures have to consider as many elements as possible within the innovation milieu, from knowledge development, to governance construction, market creation, and operational and maintenance support in a long-term endeavour. If visions of future socio-technical configurations that decisively integrate RETs in developing countries are to be an integral part of their development plans, technology (including equipment and wider socio-technical practices) needs to be adapted to local conditions and therefore more R&D efforts have to be conducted at the national, regional and local scale. Applied R&D in rural electrification is an extremely neglected part of the innovation process in Chile and it seems important that specific support is provided to local actors to integrate and produce new knowledge that can be better applied to tackle societal energy needs.

8.5 Limitations of the thesis and areas that require further research

This thesis has undertaken a systematic and comprehensive study of the diffusion of PV and wind rural electrification projects within niches in Chile, but these spaces exhibit relatively natural protection and are limited in size and scope. Although the thesis has to some extent generalised the analysis and findings of this research, the analysis is constrained to very particular contextual conditions that are neither automatically nor easily translated into different developing country contexts. There are still some 34 million people in Latin America and more than 1.3 billion globally without access to electricity. Most of these live in rural areas where RETs can be the only or best solution to their energy needs. More research is therefore needed to understand the determinants of diffusion of radical innovation in such contexts and evolutionary and constructivist approaches can help to integrate into a robust conceptual framework many of the complexities underlying sustainable energy transitions.

The findings of the research reiterate many research challenges posited by scholars who have demanded a better consideration of the politics of radical technology and sustainable innovation (Smith et al., 2005, Baker et al., 2014, Meadowcroft, 2011). Although the theoretical and methodological frameworks have integrated a nuanced consideration of agency, power struggles and decision-making in conflicting settings, there is still much room to "develop a politically oriented literature on sustainability transitions" (Meadowcroft, 2011, p. 70), that takes into account the inter-relationships between evolutionary approaches and political science and constructivist approaches in the study of the emergence of radical innovations.

Building on these suggestions, the study of RETs in grid connected systems offers great potential to improve understanding of the dynamic interaction between niches and regimes. Since this thesis was formally proposed (2009) much progress has been made in Chile and elsewhere with respect to the development and integration of RETs, particularly PV, into existing electricity systems, in both utility scale generation plants and distributed generation. Both cases (large scale PV plants and distributed grid-connected PV generation) need further research to improve understanding of niche development, scaling-up efforts and niche-regime interaction. These cases also present particularities in terms of potential barriers, conflicts and possible trajectories of niche development and regime transformation. Grid-connected small scale RETs, however, represent a more radical innovation in electricity systems in developing country contexts, where distributed generation is virtually non-existent. Community energy efforts and innovative financing models offer great potential for both policy/practice and research, so these two areas are also suggested for further development in future research.

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Annexes

Annex 1: PV and Wind Rural Electrification Projects in Chile

ID	Region	Council	Name	Tech. Type	Nº of connections	Nº SHS executed projects	Installed capacity (KW)	Total Investment (US$)	Implemented/ in pipeline (FNDR)/ Study only	Execution Date	Management Scheme	Executor/Contractor	Financed by	Developer
1	XV	Arica	Chaca Hybrid Project	HIB (PV-diesel)	25			60.000	FNDR					GEF-PER
2	XV	Reg. Arica y Parinacota	PV Electrification: 10 Rural Schools and Health Clinic in Arica-Parinacota	PV	11	11	20	574.468	EXEC	2011	none		MIN. ENERGIA	DAEE-Min Energía
3	XV	Camarones	PV Camarones	PV	50			113.122	FNDR					GEF-PER
4	XV	Putre	PV Putre	PV	76			80.000	FNDR					GEF-PER
5	I	Camiña	Nama Hybrid Project	HIB (PV-diesel)	28			50.000	FNDR					GEF-PER
6	I	Iquique	San Marcos Hybrid Project	HIB (PV-diesel)	70			300.000	FNDR					GEF-PER
7	I	Huara	Sibaya Hybrid Project	HIB (PV-diesel)	40			60.000	STUDY					GEF-PER
8	I	Huara	Achacagua Hybrid Project	HIB (PV-diesel)	35			50.000	FNDR					GEF-PER
9	I	Pozo Almonte	Huatacondo Mini-grid hybrid proj.	HIB (PV-wind-diesel)	80	80	23	425.532	EXEC	2010	Partnership Academia-Private-Users	U. Chile - C. Energía	Collahuasi	U. Chile-Collahuasi
10	I	Reg. Tarapacá	PV Electrification: 8 Rural Schools and 5 Health Clinics in Tarapacá	PV	13	13	25	659.574	EXEC	2011	none		MIN. ENERGIA	DAEE-Min Energía
11	I	Pica	PV Pica	PV	6			10.000	FNDR					GEF-PER
12	I	Huara	PV Huara	PV	16			20.000	FNDR					GEF-PER
13	I	Colchane	PV Colchane	PV	21			25.000	FNDR					GEF-PER
14	I	Pozo Almonte	PV water pumping Pozo Almonte	PV	3	3	3	100.000	EXEC	2010	none	CT Nuevos Horizontes	MIN. ENERGIA	DAEE-Min Energía
15	I	Pica	PV Salar del Huasco	PV					EXEC	2003	none	Wireless Energy	Collahuasi	
16	II	Ollague	Ollague Hybrid Project	HIB (PV-diesel)	80			500.000	FNDR					GEF-PER

ID	Region	Council	Name	Tech. Type	Nº of connections	Nº SHS executed projects	Installed capacity (KW)	Total Investment (US$)	Implemented/ in pipeline (FNDR)/ Study only	Execution Date	Management Scheme	Executor/Contractor	Financed by	Developer
17	II	SPA	Camar Hybrid Project	HIB (PV-diesel)	22	22	10	218.577	EXEC	2008	Users (supported by Munic. San. Pedro Atacama)	Wireless Energy/J. Araya	FNDR-GEF	GEF-PER
18	II	Calama	PV Calama	PV	40			63.462	FNDR					GEF-PER
19	II	REG	PV Electrification: 6 Rural Schools and 5 Health Clinics in Antofagasta	PV	11	11	29	787.234	EXEC	2011	none		MIN. ENERGIA	DAEE-Min Energía
20	II	SPA	PV San Pedro	PV	26	26	18	96.662	EXEC	2006	Users (supported by Munic. San. Pedro Atacama)		FNDR-GEF	GEF-PER
21	II	Prov. Tocopilla	PV Province of Tocopilla	PV	11			11.000	FNDR					GEF-PER
22	II	Ollague	PV Ollague & Puquios	PV	26	26	8	30.000	EXEC	2006			FNDR-GEF	GEF-PER
23	II	SPA	PV Machuca	PV	23	23	10	20.000	EXEC	2006	Users (supported by Munic. San. Pedro Atacama)		PPS-PNUD	GEF-PPS-PNUD
24	II	SPA	PV Escuela E-26	PV		1	5,8		EXEC	2010	Users (supported by Univ. Antofagasta)	Juwi solar/ U. Antof.	German Cooperation/ Juwi solar	Juwi Solar-U. Antofagasta
25	III	Huasco	Carrizal Bajo Hybrid Project	HIB (PV-diesel)	100			750.000	FNDR					GEF-PER
26	III	Chañaral	PV Caleta Pan de Azucar	PV	20	20	2	100.000	EXEC	2010	none		FOSIS	GEF-PER
27	III	Reg. Atacama	PV Region of Atacama	PV	462	462	46	1.439.000	EXEC	2011	Private (SICE Chile)	SICE Chile	FNDR-GEF	GEF-PER
28	III	Reg. Atacama	PV existing systems Atacama	PV	200			250.000	FNDR					GEF-PER
29	IV	La Serena	Almirante Latorre Hybrid Project	HIB (PV-diesel)	70			250.000	FNDR					GEF-PER
30	IV	La Higuera	Los Morros Hybrid Project	HIB (PV-diesel)	42			194.000	FNDR					GEF-PER
31	IV	Canela	Electrification Totoral Rural School, Canela	HIB (PV-wind-diesel)	10	1	3	37.000	EXEC	2008	Users (supported by Mun. Canela)	F. Aceituno	ENDESA ECO	ENDESA ECO

ID	Region	Council	Name	Tech. Type	Nº of connections	Nº SHS executed projects	Installed capacity (KW)	Total Investment (US$)	Implemented/ in pipeline (FNDR)/ Study	Execution Date	Management Scheme	Executor/Contractor	Financed by	Developer
32	IV	Reg. Coquimbo	PV Region of Coquimbo, rural households	PV	3.064	3.064	383	7.400.000	EXEC	2006	Private (CONAFE SER)	CONAFE	FNDR-GEF	GEF-PER
33	IV	Reg. Coquimbo	PV Region of Coquimbo, Schools and Health Clinics	PV	34	34	78	2.300.000	EXEC	2011	none	Tecnored	MIN. ENERGIA	GEF-PER
34	IV	Reg. Coquimbo	PV existing systems Coquimbo	PV	1500	1500		1.500.000	FNDR	1994				GEF-PER
35	IV	Reg. Coquimbo	PV water pumping Coquimbo	PV	4	4	2	84.000	EXEC	2008	none		MIN. ENERGIA	DAEE-Min Energía
36	V	Petorca	PV Petorca	PV	38	38	5	171.000	EXEC	2006	Users (supported by Mun. Petorca)	CONAFE	FNDR-GEF	GEF-PER
37	VI	REG	PV O'Higgins coast sector	PV	30	30	8	245.650	EXEC	2009			FNDR-GEF	
38	VI	Reg. O'Higgins	PV Region of O'Higgins	PV	200			180.000	FNDR					GEF-PER
39	VII	REG	PV Region of El Maule	PV	365			600.000	FNDR					GEF-PER
40	VII	Empedrado	PV Empedrado I (Provoste)	PV	21	21	5	88.600	EXEC	2006	Users (supported by Mun. Empedrado)		FNDR-GEF	GEF-PER
41	VII	Empedrado	PV Empedrado II	PV	44	44	10	157.648	EXEC	2007	Users (supported by Munic. Empedrado)		FNDR-GEF	GEF-PER
42	VII	Empedrado	PV water pumping Empedrado	PV	1	1	0,5	21.000	EXEC	2007	Users (supported by Munic. Empedrado)		GEF	GEF-PER
43	VII	Colbún	PV El Melado	PV	21	21	5	45.000	EXEC	2006	Users (supported by Munic. Colbún)		FNDR-GEF	GEF-PER
44	VIII	Prov. Arauco	PV Arauco	PV	238			664.089	FNDR					GEF-PER
45	VIII	Prov. Bio Bio	PV Bio Bio	PV	164			170.000	FNDR					GEF-PER
46	VIII	Prov. Ñuble	PV Ñuble	PV	164			170.000	FNDR					GEF-PER

ID	Region	Council	Name	Tech. Type	Nº of connections	Nº SHS executed projects	Installed capacity (KW)	Total Investment (US$)	Implemented/ in pipeline (FNDR)/ Study	Execution Date	Management Scheme	Executor/Contractor	Financed by	Developer
47	XIV	Corral	PV Tres Chiflones	PV	41		13	370.153	FNDR				FNDR-GEF	
48	X	Futaleufú	PV Futalefú	PV	223			300.000	FNDR					
49	XI	PROV	PV Cochrane	PV	63			70.000	FNDR					
50	XI	Prov. Cap. Prat	PV Capitán Prat (Cochane, Tortel & Villa O'Higgins)	PV	90	90	46	1.834.499	EXEC	2010			FNDR	PER
51	XI	Prov. Cap. Prat	PV Capitan Prat II	PV	120		61,2	788.200	FNDR					
52	XI	Cisnes	PV Isla Toto	PV					EXEC	2006		Wireless Energy		GEF-PER
53	NAC	NAC	Solar PV Irrigation National Programme	PV			255	2.200.000	EXEC	2013			MIN. AGRICULTURA	INIA
54	NAC	NAC	Solar PV irrigation several rural Municipalities	PV	32	33	3,5	672.000	EXEC	2012			MIN. ENERGIA	INIA
55	I	Colchane	Colchane Hybrid Project	HIB (wind-diesel)	40			300.000	FNDR					GEF-PER
56	II	Calama	Cupo Hybrid Project	HIB (wind-diesel)	12	12	11	50.000	EXEC	2007			FNDR-GEF	GEF-PER
57	IV	Ovalle	Caleta Talcaruca Hybrid Project	HIB (wind-diesel)	10			100.000	FNDR					GEF-PER
58	IV	Ovalle	Caleta Totoral Hybrid Project	HIB (wind-diesel)	10			100.000	FNDR					GEF-PER
59	V	Juan Fernández	Juan Fernández Island Hybrid Project	HIB (wind-diesel)	300			2.000.000	FNDR					PER
60	X	Queilén	Acuy Island Hybrid Project	HIB (wind-diesel)	22			140.000	FNDR					GEF-PER
61	X	Calbuco	Chaullin Island Hybrid Project	HIB (wind-diesel)	26			140.000	FNDR					GEF-PER
62	X	Quemchi	Teuquelin Island Hybrid Project	HIB (wind-diesel)	11			50.000	FNDR					GEF-PER
63	X	Calbuco	Tabon Island Hybrid Project	HIB (wind-diesel)	131	131	54	1.000.000	EXEC	2012	Users (Supported by Munic. Calbuco)	Constructora Puerto Octay	FNDR-GEF	GEF-PER

ID	Region	Council	Name	Tech. Type	Nº of connections	Nº SHS executed projects	Installed capacity (KW)	Total Investment (US$)	Implemented/ in pipeline (FNDR)/ Study	Execution Date	Management Scheme	Executor/Contractor	Financed by	Developer
64	X	Calbuco	Quenu Island Hybrid Project	HIB (wind-diesel)	46	46	18	760.000	EXEC	2012	Users (Supported by Munic. Calbuco)	Constructora Puerto Octay	FNDR-GEF	GEF-PER
65	X	Quemchi	Tac Island Hybrid Project	HIB (wind-diesel)	82	82	30		EXEC	2000	Private (SAESA)	Wireless Energy	US DoE-NREL-Gov. Chile	PER
66	X	Chonchi	Chonchi Wind Project	HIB (wind-diesel)					EXEC	2003		Wireless Energy		
67	X	-	Rahue-La montaña Wind Project	HIB (wind-diesel)					EXEC	2003		Wireless Energy	Gov. of Japan	Gov. Japan
68	X	Chaitén	Auteni Island Hybrid Project (Desertores)	HIB (wind-diesel)	25	25	43	4.550.000	EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
69	X	Hualaihué	Llanchid Island Hybrid Project (Desertores)	HIB (wind-diesel)	19	19	11		EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
70	X	Chaitén	Chuit Island Hybrid Project (Desertores)	HIB (wind-diesel)	35	35	25		EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
71	X	Chaitén	Imerquiña Island Hybrid Project (Desertores)	HIB (wind-diesel)	6	6	6		EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
72	X	Chaitén	Nayahue Island Hybrid Project (Desertores)	HIB (wind-diesel)	31	31			EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
73	X	Chaitén	Talcan Island Hybrid Project (Desertores)	HIB (wind-diesel)	48	48	24		EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
74	X	Chaitén	Chulin Island Hybrid Project (Desertores)	HIB (wind-diesel)	50	50	43		EXEC	2012	Private (Wireless Energy)	Wireless Energy	FNDR-GEF	GEF-PER
75	XI	-	Puesto Viejo Police Station Hybrid Project	HIB (wind-diesel)	5	5	3	25.000	EXEC	2007			Carabineros de Chile	GEF-PER
76	XII	Pto. Natales	Villa Renovales Hybrid Project	HIB (wind-diesel)	12			64.000	FNDR					GEF-PER
77	XII	Laguna Blanca	Villa Tehuelche Hybrid Project	HIB (wind-diesel)	50	50		238.000	EXEC	1995				GEF-PER
				TOTAL	**9.045**	**6.119**	**1.346**	**36.823.470**						

Annex 2: List of Interviewees

	Name	Interview Date	Interview	Field visit	Role	Institution/Agency	Sector affiliation
1	Rosa María Argomedo	09-mar-11	x		Energy Access Division Officer in Charge	Ministry of Energy	Government/National Level
2	Oliver Page	22-mar-11	x		Latin American Technical Advisor (UNDP-GEF)	UNDP-GEF (LAC)	Int. Organisation
3	Daniel Vargas	06-abr-11	x		GEF Project Consultant and Project Director (2007-2008)	UNDP-GEF Project	Int. Organisation/Government
4	Royal Smith	08-abr-11	x		Former Executive Director	SAESA	Private Sector
5	Franco Aceituno	09-abr-11	x		former PER Officer in Charge and CEO CRELL (Distribution Utility)	National Energy Commmission and CRELL	Government/National Level
6	Guillermo Jiménez	12-abr-11	x		Deputy Director Energy Centre	Energy Centre at Univ. of Chile	Academia
7	Natalia Garrido	12-abr-11	x		Researcher	Energy Centre at Univ. of Chile	Academia
8	Anselmo Muñoz	14-abr-11	x		Officer, Rural Electrification Technical Unit (UTER)	Atacama Regional Gov.	Government/Regional Level
9	Jaime Marín	14-abr-11	x		Rural Electrification Technical Unit Chief (UTER)	Atacama Regional Gov.	Government/Regional Level
10	Luz Cabello Tabilo	14-abr-11	x		Budget Officer	Atacama Regional Gov.	Government/Regional Level
11	Alejandro Leiva	15-abr-11	x		Contracts Admininstrator	SICE-Chile	Private Sector
12	Fabián Collao	15-abr-11	x		Operations Manager	SICE-Chile	Private Sector
13	Raúl Muñoz	15-abr-11	x		PV Technician	SICE-Chile	Private Sector
14	Álvaro Böhme	19-abr-11	x		Project Manager	NGO Casa de la Paz	NGO
15	Jaime Espinoza	20-abr-11	x		Energy Innovation Centre Director	Federico Santa María University (USM)	Academia
16	Eva Tirado	05-may-11	x	x	School Principal	Totoral Rural School	RET User
17	Segundo López	06-may-11	x	x	Technical Director (PV Systems)	CONAFE	Private Sector
18	Jaime Soto	06-may-11	x		Commercial Director	CONAFE	Private Sector
19	Luis Henríquez	06-may-11	x		Management Control and Administrator Officer in Charge	Coquimbo Regional Gov.	Government/Regional Level

	Name	Interview Date	Interview	Field visit	Role	Institution/Agency	Sector affiliation
20	Alfredo Pavez	06-may-11	x		Rural Electrification Technical Unit Chief (UTER)	Coquimbo Regional Gov.	Government/Regional Level
21	Norma Ormeño	06-may-11	x	x	Rural inhabitant (Andacollo, Coquimbo region)	PV User + PV pumping station	RET User
22	Mrs. Hilda	06-may-11	x	x	Rural inhabitant (Andacollo, Coquimbo region)	PV User	RET User
23	Manuel Carvajal y Sra. Visitación	07-may-11	x	x	Rural inhabitants (Illapel, Coquimbo region)	PV User	RET User
24	Cristian Sjögren	09-may-11	x		CEO	Solar Chile Ltd.	Private Sector
25	Luis Costa	18-may-11	x		Former UNDP Officer-Strategic Advisor to GEF	UNDP (Chile)	Int. Organisation
26	Solange Duhart	20-may-11	x		Former PER Officer in Charge	National Energy Commission	Government/National Level
27	Miguel Márquez	03-jun-11	x		Academic and RET Consultant	Austral University (UACh)	Academia/Private Sector
28	Guillermo Céspedes	06-jun-11	x		PER Co-ordinator	SUBDERE-Central Gov.	Government/National Level
29	Gerardo Canales	06-jun-11	x		Project Management Director	Renewable Energy Centre (CER – Chile)	Government/National Level
30	Rodrigo García	06-jun-11	x		Technical Director	Renewable Energy Centre (CER – Chile)	Government/National Level
31	Cristóbal García	09-jun-11	x		Programme Coordinator Regional Level	Los Lagos Regional Gov.	Government/Regional Level
32	Hernán Díaz	09-jun-11	x		Officer, Rural Electrification Technical Unit (UTER)	Los Lagos Regional Gov.	Government/Regional Level
33	Paula Zattera	09-jun-11	x		Social Worker, Rural Electrification Technical Unit (UTER)	Los Lagos Regional Gov.	Government/Regional Level
34	Nelson Stevens	09-jun-11	x		CEO Wireless Energy	Wireless Energy Ltd.	Private Sector
35	Mónica Eugenín	10-jun-11	x		Rural Electrification Project Manager	Los Lagos Regional Gov.	Government/Regional Level
36	Carlos Douglas	10-jun-11	x		Energy Sector Evaluation Unit (SERPLAC), Los Lagos Region	Los Lagos Regional Gov.	Government/Regional Level

	Name	Interview Date	Interview	Field visit	Role	Institution/Agency	Sector affiliation
37	Jaime Bravo	12-jun-11	x	x	Rural Inhabitant and RET Entrepreneur (Chiloé)	Wind power user	RET User
38	Francisco Yunge	13-jun-11	x		Commercial Director Chiloé	SAESA	Private Sector
39	Drago Bartulín	13-jun-11	x		Former UTER Staff Los Lagos and RET Consultant	Independent	Private Sector
40	Fabián Matamala	14-jun-11	x	x	Planning Officer (SECPLAN)	Quemchi Council, Chiloé	Government/Council Level
41	René Contreras	15-jun-11	x		Former RET Engineer and Project Consultant	Wireless Energy Ltd.	Private Sector
42	Several people	15-jun-11	x	x	Rural inhabitants (Costal area, Atacama region)	PV User	RET User
43	Verónica Miranda	16-jun-11	x		Planning Officer (SECPLAN)	Petorca Council	Government/Council Level
44	Reinhold Schmidt	17-jun-11	x		RET Consultant	NGO 'Nuevos Horizontes' Technology Centre	NGO
45	Marta Vega	22-jun-11	x		Rural Electrification Technical Unit Chief (UTER)	Bio-Bio Regional Gov.	Government/Regional Level
46	Irene Righetti	23-jun-11	x		Rural Electrification Officer	MIDEPLAN (Ministry of Planning)	Government/National Level
47	Nancy Whittle	23-jun-11	x		Methodology and Assessment Unit, Officer in Charge	MIDEPLAN (Ministry of Planning)	Government/National Level
48	Edgardo Muñoz	23-jun-11	x		Energy Sector Officer BioBio	SERPLAC (MIDEPLAN) Bio Bio Region	Government/Regional Level
49	Rodrigo Torres	23-jun-11	x		Regional Officer in Charge, Ministry of Energy (SEREMI)	Ministry of Energy, SEREMI Bio Bio	Government/Regional Level
50	Hilarion Cruz (Technician) & Silvia Cruz (JJVV President)	27-jun-11	x	x	Rural inhabitants (Camar, Antofagasta region)	PV User	RET User
51	Jaime Coria	28-jun-11	x	x	Public Works Department Officer	San Pedro de Atacama Council	Government/Council Level

	Name	Interview Date	Interview	Field visit	Role	Institution/Agency	Sector affiliation
52	Patricia Lanas Veliz	28-jun-11	x		Municipal Administrator	San Pedro de Atacama Council	Government/Council Level
53	Juana Anza and Technician/MCH Operator	28-jun-11	x	x	Rural inhabitants (Río Grande, Antofagasta region)	RET User	RET User
54	San Pedro de Atacama School (visit guided by Jaime Coria)	28-jun-11	x	x	Field visit-PV project under implementation	PV Project	RET User
55	José Araya	29-jun-11	x		Electricity Technician	San Pedro de Atacama Council	Private Sector
56	Darío Morales	01-jul-11	x		Energy Unit Coordinator	CORFO	Government/National Level
57	Carlos Arenas	01-jul-11	x		Regional Officer in Charge, Ministry of Energy (SEREMI)	Ministry of Energy, SEREMI Antofagasta	Government/Regional Level
58	Rodrigo Escobar	13-jul-11	x		Director MSc Energy Engineering	Catholic University (PUC)	Academia
59	Jorge Silva	15-jul-11	x		Officer in Charge, Irrigation Department	INDAP	Government/National Level
60	Sergio Carvallo	15-jul-11	x		Irrigation Department officer	INDAP	Government/National Level
61	Francisco Yáñez	05-oct-11	x		Rural Development Department Director	Empedrado Council	Government/Council Level
62	Orlando Bello	31-may-13	x		Planning Officer (SECPLAN)	Calbuco Council, Chiloé	Government/Council Level
63	Juan Gutiérrez	Notes from previous Interview (2010)	x	x	Planning Officer (SECPLAN)	Empedrado Council	Government/Council Level
64	Gonzalo Tejos	Notes from previous Interview (2010)	x		Council Mayor	Empedrado Council	Government/Council Level

	Name	Interview Date	Interview	Field visit	Role	Institution/Agency	Sector affiliation
65	Rubén Cárdenas	Notes from previous Interview (2010)	x	x	Council Mayor	Calbuco Council, Chiloé	Government/Council Level
66	Carlos Estay	Several times April/June-11	x		GEF Project Consultant	National Energy Commission (CNE)	Government/National Level
67	Ramón Granada	Several times May/July-11	x		Energy Access Division Deputy Officer in Charge	Ministry of Energy	Government/National Level
68	Carlos Canales	Several times May/July-11	x		Project Director (2002-2007 and 2009-2011)	UNDP-GEF Project	Int. Organisation/Government