ROYAL INSTITUTE
OF TECHNOLOGY

Power to the people:

Diffusion of renewable electricity in rural areas of developing countries

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To
Joe-Apijak Sriwannawit
My beloved late brother and my role model

Abstract

Nearly all the 1.3 billion people in the world with no electricity access live in developing countries. On the one hand, electricity is a basic need. On the other hand, the environment should not be further damaged. Thus, sustainable electricity in developing countries is clearly needed. The aim of this dissertation is to analyse the mechanism of the diffusion and adoption of renewable electricity with particular focus on rural electrification among low-income inhabitants in developing countries. The dissertation is comprised of a cover essay and six appended papers with a mix of qualitative and quantitative methods based on several means of data collection.

The first paper describes diffusion theory through a novel bibliometric tool. This novel method provides an overview, structure, and explanation of a large research area; complements a traditional literature review; and can be applied to any knowledge field. Here, the structure of the recent development of diffusion research, together with its application, are presented. With a specific focus on rural electrification among low-income inhabitants in developing countries, the diffusion framework is empirically applied with complementary concepts in the second, third, and fourth papers, based on three different cases. One case study investigates the adoption of electricity among rural inhabitants in Uganda and shows that a foreign company can be an important player in the rural electrification effort. Another case study addresses a large dissemination of photovoltaic systems provided by a local firm in Bangladesh and reveals that the diffusion of renewable energy can be effectively undertaken by a private local firm, rather than waiting for full government support or large multi-national corporations. The other case study discusses a small-scale diffusion of photovoltaic systems in a remote region in Thailand and presents an extreme case where full government support is necessary. In addition, through a systematic literature review, the barriers to adoption of photovoltaic systems are identified in the fifth paper, highlighting several remaining challenges. In the last paper, issues related to the transition to using photovoltaic systems in off-grid communities are discussed.

The diffusion mechanism of renewable electricity has been shown to be a highly complicated process, having several unforeseeable and context-specific factors. A technology with superior qualities does not diffuse by itself but requires tremendous effort and close collaboration on the part of stakeholders. There are complex relations, on the one hand, between technology and society and, on the other hand, between technology providers and adopters. No single, fast, or straightforward remedy can address the complex nature of diffusion of renewable electricity in rural communities. Therefore, understanding the local context is highly important, indicating the need for empirical investigation. This dissertation offers several contributions concerning methodological, theoretical, empirical, managerial and policy. It also provides implications that may be relevant for actors who attempt to introduce, disseminate, and manage new energy technologies in rural communities.

Keywords: adoption; bibliometric; developing country; diffusion; photovoltaic; renewable energy; rural electrification; solar energy; sustainable development

Sammanfattning

Nästan alla av de 1,3 miljarder människor som inte har tillgång till el bor i utvecklingsländer. Å ena sidan är el ett grundläggande behov. Å andra sidan bör miljön inte skadas ytterligare. Det finns således ett behov av förnybar el i utvecklingsländer. Avhandlingens syfte är att analysera mekanismerna bakom diffusion och införande av förnybar el med särskilt fokus på elektrifiering av landsbygden bland låginkomsttagare i utvecklingsländer. Avhandlingen består av en kappa och sex bifogade artiklar som är baserade på en blandning av kvalitativa och kvantitativa metoder och innehåller flera olika typer av datainsamling.

Den första artikeln beskriver diffusionsteori genom ett nytt bibliometriskt verktyg. Denna nya metod ger översikt, struktur, och förklaring till ett stort forskningsområde; den kompletterar en mer traditionell litteraturöversikt och kan tillämpas oavsett kunskapsområde. Här presenteras strukturen av den senaste utvecklingen inom diffusionsteori tillsammans med dess applikationsområden. Med ett särskilt fokus på landsbygdselektrifiering bland låginkomsttagare i utvecklingsländer tillämpas diffusionsramverket empiriskt med kompletterande koncept i den andra, tredje, och fjärde artikeln. Dessa artiklar är baserade på tre olika fallstudier. En fallstudie berör elektrifiering på landsbygden i Uganda och visar att utländska företag kan vara en viktig aktör i denna process. En annan fallstudie tar upp spridning av solcellssystem i stor skala som utförs av ett lokalt företag i Bangladesh och visar att spridning av förnybar energi effektivt kan genomföras av privata lokala företag, snarare än att vänta på statligt stöd eller stora multinationella företag. Den sista fallstudien diskuterar småskalig spridning av solcellssystem i en avlägsen region i Thailand och representerar ett extremfall som behöver full finansiering från staten. I den femte artikeln har hindren för införandet av solcellssystem identifierats genom en systematisk litteraturöversikt, artikeln belyser också många kvarstående utmaningar. Den sista artikeln diskuterar frågor som rör övergången till, samt användandet av solcellssystem i områden som inte är anslutna till elnätet.

Diffusionsprocessen för förnybar el har visat sig vara mycket komplicerad med flera oförutsedda och kontextspecifika faktorer. Teknik med överlägsna egenskaper kan inte spridas av sig självt utan kräver stora ansträngningar och nära samarbete mellan de inblandade aktörerna. Det är komplexa relationer, å ena sidan mellan teknik och samhälle och å andra sidan mellan teknikleverantörer och användare. Det finns inte en perfekt, snabb eller enkel åtgärd för att ta itu med den komplexa karaktären av diffusion av förnybar el på landsbygden. Därför är förståelsen för den lokala kontexten av stor betydelse och detta understryker behovet av empiriska studier. Denna avhandling bidrar med kunskap som täcker områden som metodologi, teori, empiri, ledarskap och politik. Studien visar även på relevanta implikationer för de aktörer som försöker införa, sprida och hantera ny energiteknik till landsbygden.

Nyckelord: bibliometri; diffusion; förnybar energi; hållbar utveckling; införande; landsbygdselektrifiering; solceller; solenergi; utvecklingsland

บทคัดย่อ

ปัจจุบันประชากรราว ๑.๓ พันล้านคนในประเทศกำลังพัฒนาดำเนินชีวิตโดยไม่มีไฟฟ้าใช้ ถึงแม้ไฟฟ้าจะเป็นความต้องการขั้นพื้นฐานแต่สภาพแวดล้อมก็ไม่ควรถูกทำลายเพิ่มขึ้น ดังนั้นการนำไฟฟ้าเข้าสู่ประเทศกำลังพัฒนาอย่างยั่งยืนจึงเป็นเรื่องจำเป็น จุดมุ่งหมายของวิทยานิพนธ์นี้คือการวิเคราะห์กลไกของการแพร่กระจายและการนำไฟฟ้าพลังงานหมุนเวียนไปใช้ โดยเฉพาะกับกลุ่มประชากรรายได้ต่ำในชนบทของประเทศกำลังพัฒนา วิทยานิพนธ์ฉบับนี้ประกอบด้วยบทความภาพรวมและบทความวิจัยหกชิ้น โดยมีกระบวนการวิจัยที่ผสมผสานวิธีการเชิงคุณภาพและเชิงปริมาณ ผ่านการเก็บรวบรวมข้อมูลหลากหลายวิธี

บทความวิจัยแรกอธิบายทฤษฎีการแพร่กระจายผ่านวิธีบิบลิโอเมทริกซ์แบบใหม่ ซึ่งเป็นวิธีการที่แสดงภาพรวม โครงสร้าง และคำอธิบายของงานวิจัยที่มีขนาดใหญ่ รวมทั้งเติมเต็มการทบทวนวรรณกรรมแบบดั้งเดิมและสามารถนำไปประยุกต์ใช้กับงานในสาขาอื่นได้ บทความวิจัยนี้ยังได้เสนอแบบแผนความก้าวหน้าล่าสุดของทฤษฎีการแพร่กระจายและการนำทฤษฎีไปใช้อีกด้วย เนื่องมาจากวิทยานิพนธ์นี้มุ่งเน้นการจัดหาไฟฟ้าพลังงานหมุนเวียนให้กับกลุ่มประชากรรายได้ต่ำในชนบทของประเทศกำลังพัฒนา ทฤษฎีการแพร่กระจายและแนวความคิดประกอบจึงถูกนำมาปรับใช้ในเชิงประจักษ์กับกรณีศึกษาที่แตกต่างกันสามกรณีซึ่งปรากฏในบทความวิจัยที่สอง สาม และสี่ ตามลำดับ โดยกรณีศึกษาแรกทำการสำรวจการรับไฟฟ้าพลังงานหมุนเวียนมาใช้ในหมู่ชาวชนบทของประเทศยูกันดา ซึ่งแสดงให้เห็นว่าบริษัทต่างชาติสามารถแสดงบทบาทสำคัญในการนำไฟฟ้าเข้าสู่ชนบทได้ กรณีศึกษาถัดมาศึกษาการแพร่กระจายของระบบเซลล์แสงอาทิตย์ในระดับใหญ่ซึ่งมีบริษัทท้องถิ่นในประเทศบังกลาเทศเป็นผู้ให้บริการ กรณีศึกษานี้แสดงให้เห็นว่าบริษัทเอกชนในท้องถิ่นสามารถดำเนินการแพร่กระจายพลังงานหมุนเวียนได้อย่างมีประสิทธิภาพโดยไม่ต้องรอการสนับสนุนอย่างเต็มรูปแบบจากรัฐบาลหรือบริษัทนานาชาติขนาดใหญ่ กรณีศึกษาสุดท้ายอภิปรายการแพร่กระจายของระบบเซลล์แสงอาทิตย์ในระดับเล็กในถิ่นทุรกันดารของประเทศไทย ซึ่งในขณะเดียวกันก็แสดงให้เห็นกรณีพิเศษที่การแพร่กระจายจำเป็นต้องได้รับการสนับสนุนแบบเต็มรูปแบบจากรัฐบาล นอกจากที่ได้กล่าวมาแล้ว บทความวิจัยฉบับที่ห้าในวิทยานิพนธ์นี้ซึ่งเป็นการทบทวนวรรณกรรมอย่างเป็นระบบชี้ให้เห็นอุปสรรคและความท้าทายต่างๆ ต่อการรับระบบเซลล์แสงอาทิตย์มาใช้ ในบทความวิจัยฉบับสุดท้ายได้มีการอภิปรายประเด็นที่เกี่ยวข้องกับการเปลี่ยนไปใช้ระบบเซลล์แสงอาทิตย์ในชุมชนที่ไม่เชื่อมโยงกับระบบสายส่งไฟฟ้า

กลไกการแพร่กระจายของไฟฟ้าพลังงานหมุนเวียนเป็นกระบวนการที่มีความซับซ้อนสูง เนื่องจากปัจจัยต่างๆ ที่เกี่ยวข้องเป็นปัจจัยที่จำเพาะต่อสภาพแวดล้อมและคาดการณ์ไม่ได้ เทคโนโลยีที่มีคุณสมบัติเหนือกว่าเพียงลำพังย่อมไม่แพร่กระจายตัวมันเอง หากแต่ต้องอาศัยความอุตสาหะและความร่วมมือของผู้ที่มีส่วนเกี่ยวข้อง ความสัมพันธ์ระหว่างเทคโนโลยีกับสังคมและระหว่างผู้ให้บริการเทคโนโลยีกับผู้รับเทคโนโลยีมาใช้เป็นความสัมพันธ์ที่สลับซับซ้อน ด้วยเหตุนี้จึงไม่มีวิธีใดวิธีหนึ่งเป็นสูตรสำเร็จในการแก้ปัญหาการแพร่กระจายไฟฟ้าพลังงานหมุนเวียนสู่ชุมชนชนบท ความเข้าใจในบริบทท้องถิ่นเป็นเรื่องสำคัญมาก ดังนั้นจึงจำเป็นต้องมีการศึกษาเชิงประจักษ์ วิทยานิพนธ์ฉบับนี้ก่อให้เกิดประโยชน์ในหลายด้าน ทั้งวิธีการวิจัย ทฤษฎี การประยุกต์ใช้ข้อมูลเชิงประจักษ์ การบริหารจัดการ และนโยบาย นอกจากนี้ยังให้แง่มุมที่อาจเป็นประโยชน์ต่อผู้ที่มีบทบาทในการนำเสนอ เผยแพร่ และบริหารจัดการเทคโนโลยีพลังงานรูปแบบใหม่ในชุมชนชนบท

คำสำคัญ: รับมาใช้; บิบลิโอเมทริกซ์; ประเทศกำลังพัฒนา; การแพร่กระจาย; เซลล์แสงอาทิตย์; พลังงานหมุนเวียน; การนำไฟฟ้าเข้าสู่ชนบท; พลังงานแสงอาทิตย์; การพัฒนาที่ยั่งยืน

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My underlying motivation for writing this dissertation is that the disparity in the world is undeniably too large and the threat from climate change is unequivocal. I know my dissertation is not going to solve these problems directly. However, I do believe doing something is important, no matter how negligible the outcome. As Mohandas Karamchand Gandhi said, "Whatever you do will be insignificant, but it is very important that you do it." Through academic research, I hope I can contribute a small piece in this tremendous puzzle. I would not have completed this PhD journey without support from many people.

First and foremost, my deepest gratitude goes to my supervisor, Staffan Laestadius. While giving me freedom and independence to pursue the topic of my choice, you made sure I was progressing on the right path. Your encouragement, trust, and confidence in me have been highly important to me, especially during difficult times when I was overwhelmed with self-doubts. Not only are you my supervisor, whom I will always have the highest regards on your intellect and knowledge, but you are also my mentor, with whom I can discuss other aspects of life. Additionally, I extend my gratitude to my co-supervisors: Cali Nuur from the Department of Industrial Economics and Management (INDEK) and Semida Silveira from the Department of Energy Technology (EGI).

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I am forever in debt for love, support, and kindness from my parents, Jit and Unchalee. In fact, the topic of this dissertation arose from a telephone conversation with my father one afternoon when I asked for his advice concerning how to choose a PhD topic. Apart from following my passion, he suggested I choose a topic that addresses a challenge not only today but also in the future and one that benefits the public at large. Your valuable advice has resulted in this dissertation. Moreover, I thank my mother who has always been there for me every time I needed her and for her unconditional love. In addition, my siblings—Job and Prae—have been my tremendous support from afar. Knowing that I will always have them no matter what happens in my life is a great comfort.

I dedicate this dissertation to my beloved late brother, Joe. Your kind heart, your engineering mindset, and your great interest in the environment and society at large are my valuable life lesson and the source of inspiration for this thesis. I love you eternally.

Pranpreya Sriwannawit
Stockholm, April 2015

List of appended papers

Paper I — Sriwannawit, P., and Sandström, U. (2015). Large-scale bibliometric review of diffusion research. *Scientometrics*, 102(2), 1615-1645.

Paper II — Eder, J., Mutsaerts, C., and Sriwannawit, P. (2015). Mini-grids and renewable energy in rural Africa: How diffusion theory explains adoption of electricity in Uganda. *Energy Research & Social Science*, 5 [Special issue on renewable energy in Sub-Saharan Africa: Contributions from the social sciences], 45-54.

Paper III — Sriwannawit, P., and Laestadius, S. Determinants of the diffusion of solar home systems: Case study among low-income inhabitants in Bangladesh. Tentatively accepted (revisions completed and awaiting final decision) for publication in *Energy and Environment*.

Paper IV — Sriwannawit, P., and Laestadius, S. (2013). Diffusion of photovoltaic systems for rural electrification in Thailand. *International Journal of Energy and Environment*, 4(1), 49-58.

Paper V — Karakaya, E., and Sriwannawit, P. (2015) Barriers to the adoption of photovoltaic systems: The state of the art. *Renewable and Sustainable Energy Reviews*, [Forthcoming].

Paper VI — Sriwannawit, P. (2014). Transition towards off-grid photovoltaic systems: Is price the final answer? *Energy Procedia*, 57 [Special issue from ISES Solar World Congress], 1546-1554.

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1 Introduction

This introduction begins with background information regarding the need for renewable electricity, the global urgency concerning sustainable development, and the importance and impact of technology diffusion. The second section addresses the scope and aim of this dissertation. The chapter ends with a section on the disposition of the dissertation.

1.1 Background

Energy is one fundamental need for social and economic development (WEC 2007; Smil 2006). Since the 18th century, the prime source of energy has been fossil fuels (Rosenberg 1982). It has commonly been thought that few alternatives exist. That idea was, however, incorrect. The spread of renewable energies—such as wind power, solar energy, and biomass—has been promising since the 1990s (Jacobsson and Johnson 2000). During the 1990s, Barnes and Floor (1996) identified two important problems for developing countries in the energy sector: inefficient production and use of traditional sources, along with uneven distribution and use of modern sources. Two decades later, these issues have not yet been resolved. This dissertation aims to address the second challenge to increase the dissemination of modern energy in the context of developing countries. In the recent global debate, energy is listed under seven critical issues that need priority consideration (United Nations 2012). Moreover, mitigating climate change through low-carbon economy is an urgent task. The extent of this issue has been emphasized in the international debates in all arenas: government, academia, and entrepreneurialism. Thus, in terms of the urgent need for a shift towards sustainable forms of energy, this dissertation is focused on electricity. Electricity is currently the preferred form of energy, and no other form of energy can match its convenient use (see e.g. Rosenberg 1982; Smil 2010).

The most recent statistics from the International Energy Agency (IEA) in 2014 show that 1.3 billion people are living without access to electricity. Almost all of them live in developing countries (IEA 2014). On the one hand, electricity is a basic need and a prerequisite for development. On the other hand, the environment should not be further damaged as a consequence of the development. Thus, sustainable electricity in developing countries is clearly needed. The push for sustainable development has received attention among a wide range of actors: policy makers, industry leaders, academics, business

developers, and so on.[1] Greater access to electricity has been shown to be directly related to increased income, a means to get out of poverty (Berthaud et al. 2004). Furthermore, on the global level, at least two issues need to be tackled: poverty alleviation and climate change mitigation. With the currently available technologies, renewable energy is one potential means to address both. Nevertheless, we need better understanding of the mechanisms behind the transition process towards more sustainable solutions. This thesis is focused on the diffusion aspect.

Diffusion research originated in and has been conducted largely by scholars in the advanced parts of the world. Various topics related to the diffusion of innovation have been studied since the 19th century (Boas 1896; Tarde 1903) and continue to be studied in academia. The framework is highly interdisciplinary in character. To date, this field has been addressed in a large amount of literature spanning such fields as folklore, cultural change, economics, technological change, and so on (Sriwannawit and Sandström 2015). Such depth and breadth of interest in diffusion research may be because of its wide application, the existence of many issues needing resolution, the specificities across cases, and the degree of generalization, among others. Despite its long existence and wide application, the framework is still debatable. An extensive and recent review revealed research contributions from all perspectives contribute to advancement, better understanding, a more unified view, and wider applicability of the theory (Sriwannawit and Sandström 2015). To complement the relatively few studies on this topic in the context of development, a particular focus in this dissertation is on developing countries. Innovation and its diffusion have been proved to have positive effects on development, but innovation alone without the diffusion process would have only a small effect (Hall 2005).

1.2 Scope and aim

In energy research, a large body of literature focuses on technical issues. Nevertheless, social aspects are of vital importance for the effective, inclusive, and sustainable implementation of renewable technologies. This line of research has recently received attention among academia.[2] The transition of the energy system to a more sustainable solution is a complex socio-technical process (cf. Rohracher 2008). In addition, diffusion should take place immediately, not later, because climate change mitigation can no longer wait. Unfortunately, previous

[1] An international debate on environmental concern and the notion of sustainable development have their roots here in Stockholm. In 1972, Stockholm hosted an international conference: the United Nations Conference on the Human Environment. It was an important starting point for formal political and public awareness of global environmental issues. This conference provided a basis for *Our Common Future* (WCED 1987), a report in which the definition of *sustainable development* was first coined (Vogler 2014).

[2] A new journal devoted to this issue, *Energy Research & Social Sciences*, was first published last year as a platform emphasising the importance and timely relevance of the topic to current global situation.

studies on technology diffusion have shown that the process often takes place more slowly than expected, despite its obvious advantages. This dissertation analyses the diffusion of renewable electricity; a large part of this study is empirically based on case studies from developing countries. Nevertheless, understanding diffusion experiences in developed nations can be valuable. Therefore, some parts of the dissertation address diffusion and energy technologies from a more general perspective.

The overall aim of this dissertation is to analyse the mechanism of the diffusion and adoption of renewable electricity with particular focus on rural electrification among low-income inhabitants in developing countries. The analysis is expected to reveal an understanding as to how the diffusion can be enhanced. To achieve this aim, three sets of research questions have been identified. The questions begin with the overall conceptual framework—diffusion. This topic is followed by an investigation of electricity adoption in rural areas and then with discussion of the diffusion of one specific power technology, photovoltaic (PV) system.

> *Research question I:* Describing the diffusion framework can be a complex task due to its large amount and wide penetration. Thus, the first set of questions is as follow: How can an interdisciplinary research field be described, despite its extensive amount of publications? What is the structure of the recent development of diffusion research and its application, particularly, to rural energy field?
>
> *Research question II:* The importance of electricity access in relation to local development makes rural electrification an urgent and timely issue. Because of strong local specifications, empirical investigation on a case-by-case basis is necessary to understand the local context for effective implementation. Thus, the second set of questions is as follow: How can the adoption of renewable electricity in rural areas of developing countries be better understood? What lessons can be compiled?
>
> *Research question III:* Despite PV technology being used for electricity generation for several decades and its rapid technological development and price declining over the last few years, its use in developing countries is still limited. In addition, comparatively little research has addressed the use of PV systems in developing areas. Thus, the third set of questions specifically addresses PV systems as follow: Can the diffusion of PV systems—especially in the context of developing countries—be enhanced, and how?

1.3 Disposition

This dissertation is comprised of two parts: a cover essay and six papers appended in full.

1.3.1 Cover essay

This cover essay includes reflection on the appended papers and presents how the different papers contributed to a single overall research aim, which is a common approach of an introductory essay of compilation doctoral theses. Common challenges for this type of dissertation lie in connecting different avenues of research with various methods and analysing the combined studies in a coherent manner. Attempts were made to avoid redundancy across the papers. Nevertheless, some degree of overlap occurs because necessary information must be provided to render clear understanding for readers of individual papers.

In this first chapter, necessary background is discussed to equip readers with basic understanding of the research topic and acquaint them with the overall research aim and scope. In Chapter 2, methodology used in this dissertation is discussed. Chapter 3 includes explanation of overarching conceptual frameworks. Chapter 4 addresses the findings of the dissertation in relation to the three sets of research questions. This cover essay ends with conclusions and implications in Chapter 5.

1.3.2 Appended papers

This dissertation is comprised of six independent yet interrelated research papers. All papers have undergone peer review process in six different journals. Four papers are published in refereed international journals; one paper is accepted for publication in a refereed international journal; one paper is pending review result. The order of these papers begins with more general topics and then moves further to specific discussion. Paper I provides broad understanding of diffusion research, which is the main theoretical framework for this dissertation. Thereafter, the adoption of electricity in rural Uganda is presented in Paper II. The diffusion process discussed in this paper is conducted by a foreign firm from a developed country operating in a developing country. Further understanding of the diffusion process is presented in two case studies of the diffusion of PV systems in Papers III and IV. While Paper III addresses a large diffusion process conducted by a local firm in Bangladesh, Paper IV discusses a small diffusion process by the government in Thailand. Paper V addresses the barriers to the adoption of PV systems and identifies them in four dimensions: socio-technical, management, economic, and policy. All four dimensions are evident in the case studies in Paper II, III, and IV. Finally, Paper VI discusses the transition to the use of PV systems in off-grid communities. Below is the list of these papers and their status.

Paper I
Sriwannawit, P., and Sandström, U. (2015). Large-scale bibliometric review of diffusion research. *Scientometrics*, 102(2), 1615-1645.

Paper II
Eder, J., Mutsaerts, C., and Sriwannawit, P. (2015). Mini-grids and renewable energy in rural Africa: How diffusion theory explains adoption of electricity in Uganda. *Energy Research & Social Science*, 5 [Special issue on renewable energy in Sub-Saharan Africa: Contributions from the social sciences], 45-54.

Paper III
Sriwannawit, P., and Laestadius, S. Determinants of the diffusion of solar home systems: Case study among low-income inhabitants in Bangladesh. Tentatively accepted (revisions completed and awaiting final decision) for publication in *Energy and Environment*.

Paper IV
Sriwannawit, P., and Laestadius, S. (2013). Diffusion of photovoltaic systems for rural electrification in Thailand. *International Journal of Energy and Environment*, 4(1), 49-58.

Paper V
Karakaya, E., and Sriwannawit, P. (2015) Barriers to the adoption of photovoltaic systems: The state of the art. *Renewable and Sustainable Energy Reviews*, [Forthcoming].

Paper VI
Sriwannawit, P. (2014). Transition towards off-grid photovoltaic systems: Is price the final answer? *Energy Procedia*, 57 [Special issue from ISES Solar World Congress], 1546-1554.

2 Methodology

According to Kuhn (1970), scientific investigation has three foci: determining significant fact, marching facts with theory, and articulating theory. They are not always or permanently distinct. In doing research, one seldom finds major novelties. Often, it is the articulation and contribution to knowledge formation, of which is the character of this dissertation.

This dissertation is of a pragmatic worldview.[3] The emphasis of a pragmatic worldview is on finding the solution to the research problem rather than on the method. Usually, this worldview involves studies using multiple methods to gain knowledge about a specific problem. Such combining of approaches is common practice among social scientists and are complementary to each other. As an investigation proceeds, complementary concepts can be integrated to explain phenomena that cannot be explained by existing theories (Collis and Hussey 2009). Considering myself a pragmatist, I strive to answer 'what' and 'how' research questions (Creswell 2009). In this dissertation, knowledge of various aspects of technology diffusion process has been developed. The theoretical point of departure was diffusion theory, largely inspired by an extensive and highly cited work by Everett Rogers (see e.g. 2003). As the research progressed over time, diffusion framework became insufficient to explain various aspects of my work, such as the interplay between adopters and source or technology and society. Therefore, other concepts have been incorporated into the papers to explain certain features of the investigated phenomena.[4] Regarding the way I treat the nature of reality or my ontological assumption, the social reality has been treated as objectively and externally as possible. However, researchers cannot be entirely separated from what they are researching. In fact, their mere presence affects, in varying degrees the objects they are investigating, even if they are 'just' observing. As a result, I realize that the interpretation of social reality cannot be treated without some degree of subjectivity.

This dissertation incorporates both qualitative and quantitative methods based on several means of data collection. The aim of using mixed methods is to try to understand various phenomena. In line with a pragmatic worldview, multiple methods provide complementary results, which can lead to a set of analyses that enable one to answer the overall research aim in a coherent way. Here I present the methods, data sources, and methodological limitations of this dissertation. This begins with discussion of the method that addresses general subjects and then narrows to more specific topics.

[3] The term *worldview* was coined by Guba (1990) as "a basic set of beliefs that guides action" (p. 17).
[4] For example, socio-technical system is integrated in Paper II, bottom of the pyramid in Paper III, and absorptive capacity in Paper IV.

First, bibliometrics was chosen to analyse publications quantitatively to investigate the recent development of diffusion research and explain its application. Bibliometrics is the application of mathematics and statistics to provide understanding of the development and formation of knowledge (Pritchard 1969). It has become an effective and popular option for working with large amounts of scientific literature (Rodrigues et al. 2014; van den Besselaar and Heimeriks 2006). Paper I provides extensive bibliometric and clustering analyses of the diffusion framework. In addition, that paper proposes a novel review method using the strategy of labelling and clustering. The bibliometric approach complements the traditional literature review and reduces subjectivity and bias in the description of diffusion research. Throughout the process of writing this paper, I was exposed to a large amount of literature on this broad topic. It helped me to select and understand the large theoretical framework. The data were retrieved from Thomson Reuters's Web of Science database. This database is commonly used for review studies with and without the bibliometric approach. In addition to this general review of diffusion research, Paper V reviews the diffusion topic with particular focus on PV systems found in the same database. In that study, the emphasis is on the most recent findings that explain barriers to adoption of PV systems in general.

Although, the methods used in Papers I and V are systematic and transparent, the body of literature, especially for Paper I, is vast, diverse, and complex. Several steps of the analysis involve subjective judgment. If another group of researchers were to conduct this study, they might end up with a slightly different set of publications. I kept this in mind at all times and strove to be as objective as possible. In fact, this assumption is not unusual in systematic review studies, and this limitation has also been noted in a widely cited review study by Greenhalgh et al. (2004). Both Papers I and V were conducted jointly by two researchers who were very familiar with the topic. In addition, the selection of keywords, publications, and categorization were in consultation with other academic fellows in order to minimize the degree of subjectivity. Thus, the analyses should provide meaningful results concerning the research fields.

Because of my particular interest in the development topic, Paper VI specifically investigates the use of PV systems among low-income inhabitants in rural areas where the transition is a shift from traditional energy sources directly to off-grid renewable power supplies. To understand the mechanism behind the diffusion of energy technologies in local contexts, Papers II, III, and IV are qualitative research based on three single case studies conducted in three different countries. A single case can be used to test, confirm, challenge, or extend theories (Yin 2009). The analysis may reveal the existence of a phenomenon (Popper 2006). To further emphasize the importance of context or settings, Bonoma (1985) stated that a case is context-sensitive and bound to temporal restraints while Eisenhardt (1989) explained that a case study attempts to understand "the dynamics present within single settings" (p. 534). Collis and Hussey (2009)

summarized the definition of a case study as "a methodology that is used to explore a single phenomenon (the case) in a natural setting using a variety of methods to obtain in-depth knowledge. The importance of the context is essential" (p. 82). Yin (2009) suggested a case study is suitable for explaining a situation in which researchers cannot control behavioural events with a focus on contemporary phenomenon in a real-life setting, such as how specific technological development occurs. In PhD dissertations (see e.g. Gomez 2014; Szogs 2010), the case study approach has been used to investigate phenomena in developing countries where data availability is limited and various means of data collection are required.

In terms of rural electrification, the projects must focus on and adapt to local needs and conditions to identify specific solutions for the contexts (Gomez and Silveira 2012). Thus, a case study approach is appropriate for this dissertation. Three case studies were conducted in Uganda, Bangladesh, and Thailand; they are presented in Papers II, III, and IV, respectively. These studies address a set of phenomena, of which some are particular for the specific cases while some are more general and can appear or be fundamental in other cases. Although the cases in Uganda, Bangladesh and Thailand have very different characteristics[5], the results from these three studies together lead to a conclusion that is proved to be true to a certain extent based on limited data with purposeful sampling. A case study can provide insights into probable and possibly contextual mechanisms. As with other qualitative research whose purpose is to understand a subject in depth instead of investigating what is generally true (Merriam 1995), these studies contribute to the advancement of knowledge within a diffusion framework, contributing empirical evidence. Thus, analytical generalizations are offered for the context of developing countries, but not statistical generalizations. Nevertheless, generalization is not a limitation for qualitative research; rather, it is the difference between the qualitative and quantitative approaches. The goal is not to investigate what is generally true but to comprehend a specific context in depth. Thus, analytical generalization can provide contributions to previous studies and existing theories (Hallin 2009; Merriam 1995; Yin 2009).

In this cover essay, cross-case analysis is used to provide insights that can be overlooked in within-case analysis. The subtle similarities and differences across cases can be found useful for the overall research aim (Eisenhardt 1989). A cross-case analysis of three empirical cases in Papers II, III, and IV, together with more general findings from Papers V and VI, is presented. Because of the limited length and focus of individual research papers, as required by journals, information not explicitly discussed in the papers was part of the empirical data gathered during the fieldwork. This information is provided in this cover essay. Information already mentioned in the appended papers will not be repeated more than necessary.

[5] More discussion on these differences is presented in Chapter 4.

Integrating several sources of data is suitable for case study research because it allows researchers to establish validity through triangulation. The main purpose of data collection in case-study research is to gain information about "actual human events and behavior" (Yin 2009: p. 98). Three of the papers contain both primary and secondary data. The primary data were collected via three means: interview, survey, and observation.[6] The secondary data are documented texts in various formats, such as government reports, company documents, presentations, and hand-outs. For interviews, local persons with good command in English was used as an interpreter. Prior to the interviews, the questions and objective of the interviews were discussed. In addition, because of a wide range of education levels among the respondents, some questions were rephrased in simpler terms, and several questions with similar meanings were asked to ensure the respondents and interviewers understood the questions in the same way. Transcription of the interviews is a necessary step towards interpretation; it should be done only as exactly and only as much as necessary for the particular research aim (Flick 2009). In this dissertation, the transcriptions were made by the researchers themselves by focusing on the content but not on linguistic exactness. Only the information used as quotations in the appended papers was transcribed exactly word-by-word. The surveys were translated into the native languages of the interviewees. The surveys were conducted to increase the reliability and verify interviewees' statements, as well as to obtain their subjective opinions in greater detail. The respondents were selected purposely to represent a large variety of people from different departments, positions, backgrounds, adoption choices, and so on. Information acquired from the respondents included facts or judgments that were not always correct (Flick 2009). It is the role of a researcher to validate information before including it in the analysis. Thus, observation can provide complementary insight into the nature of the social system in rural communities and the social and business activities of technology providers. The researchers participated in a limited way in the observation to ask some questions when necessary. The events and lives of people in the observed areas continued normally despite the presence of the researchers (Flick 2009).

Conducting case studies in developing nations while residing in Europe was a challenging task but very fulfilling and fruitful. Relatively little diffusion research has addressed the context of developing countries compared to that of developed nations.[7] This lack of research may be because of limited budgets for funding such research, less gain for industry because of less demand and a smaller profit gap, less accessibility due to remoteness, the large cognitive gap between local inhabitants and researchers due to difference in education and other social backgrounds, language barriers, and inability to articulate findings within local contexts. To comprehend specific local contexts, which can be very

[6] The discussion about primary data presented here applies to the three case studies in general. The specific methodology of each case is discussed in the specific paper.

[7] During the research process for Paper I, I found significantly fewer studies in diffusion literature addressing developing countries.

different from what one initially expected or was accustomed to, research in developing countries requires certain skills and some degree of sensitivity in handling the information (Sidaway 1992; Szogs 2010). For me, these issues made such research more challenging and appealing. Fortunately, I was privileged to conduct this research because of two apparent advantages. First, I originally came from a developing nation and witnessed poverty and underdevelopment since childhood. This background has provided me with intrinsic and inherent understanding of such contexts. At the same time, working and residing in a developed part of the world, where financial resources are accessible, made it possible to conduct such research.

Nevertheless, conducting fieldwork in rural areas also poses some limitations. Foreign researchers are 'outsiders' and often considered 'privileged' or 'superior' visitors. This status can create a barrier with local inhabitants (Sidaway 1992). This issue can be partially overcome by following local conduct and collaborating with local people. In addition, information on rural electrification projects is not well documented in comparison to developed parts of the world, and a large amount of the documented information is available only in the local language. Some relevant documents were obtained and translated into English. This limitation emphasizes the need to complement the research by collecting primary data. Concerning language barriers, they were minimized by using native interpreters. However, some information was missed during the observation because many of the informal conversations were in local languages. Despite these limitations in the research, it should not be assumed this line of research should only be left to 'locals' or 'insiders' and can be abandoned by researchers from the developed parts of the world. Thus, one must be continually aware of the issue of the 'insiders versus outsiders' and the 'researchers versus researched' (Sidaway 1992).

Last, three constraints that every research faces are time, manpower, and financial resources. This dissertation has also faced these challenges. Several data collection aspects (such as sample size, case selection, and fieldwork duration) could have been improved if all these constraints were eliminated. Nevertheless, researchers must improvise appropriate tools to analyse the limited data. In this dissertation, a large part contains values, insights, and findings that cannot be measured or quantified. I opt for qualitative analysis to capture the varying nature of the information in such a way that analytical implications can be drawn from the studied phenomena.

3 Conceptual frameworks

Instead of presenting a detailed and extensive literature review, this chapter discusses the concepts in an encompassing fashion to avoid redundancy with the appended papers. Related concepts are incorporated into individual papers to provide complementary grounds deemed relevant to answer specific research questions. Greater details can be found in the appended papers. The next section addresses the diffusion framework, which is the main theoretical concept, used to explain the dissemination of energy. Because of a significant difference between developed and developing countries, a particular focus is put on the development context, of which the perspectives and roles of users are emphasised. Nevertheless, diffusion theory does not explicitly aim at sustainability. Therefore, the following section presents a complementary perspective addressing sustainability transition with a particular focus on niche management. This chapter ends with an overall reflection where the relations of research questions and concepts are presented.

3.1 Technology diffusion in developing countries

This section discusses the diffusion of innovation, particularly in the context of developing countries.

Diffusion of innovation

The diffusion framework has been applied to various products that enter a new market (see e.g. Ryan and Gross 1943 for agriculture; Walker 1969 for policy; Jacobsson and Lauber 2006 for renewable energy). Although a technology provider often perceives a product with superior advantages should spread by itself with little effort, this is in fact not necessarily the case, especially for renewable energy (see e.g. Weiss and Dale 1998; Karakaya et al. 2015). Diffusion is complex, and the introduction of innovations on a global scale cannot be regarded as a uniform process. Various local processes must be considered. By adapting the existing patterns of regulation and innovation to the specific conditions, this process can be facilitated (Bauner 2007). Therefore, it is worthwhile to look at the diffusion process in different cases because it could illuminate other processes. Diffusion and adoption also depend on change drivers, which can be economic, legal, social, or technical. The issue of why an innovation often takes a long time to take off and develop into a dominant design is widely discussed (Utterback 1974). An innovation may become dominant and more defined after it is used in the pioneer market (Utterback 1994).

The seminal book *Diffusion of Innovations*, by Everett M. Rogers (1962), has been the core of a large body of literature in diffusion research (Sriwannawit and Sandström 2015). It is now in its fifth edition (Rogers 2003). The definition of *diffusion*, according to Rogers (2003), is "the process in which an innovation is communicated through certain channels over time among the members of a social system. It is a special type of communication, in that the messages are concerned with new ideas." (p. 5).

As with most works, Rogers' work does contain some shortcomings (see e.g. Mallett 2007; Sriwannawit and Sandström 2015). Rogers' definition of *diffusion* implies an emphasis on a one-way process rather than a two- or multi-way process. The diffusion process is not just a passive diffusion of innovation; rather, it is a complex set of innovations with incremental adjustments needed to make all the parts of a system fit together (Rosenberg 1994). In fact, the process involves several related activities even before the actual diffusion takes place (Rosenberg 1976). These activities result in a better product that can be more easily accessed by later groups of adopters. The cost of adoption at a later stage of the diffusion process is significantly lower because technical and commercial risks have already been reduced and production costs have also declined. Moreover, there is also competitive pricing in the market. It is not enough to assume that the factors affecting technological change are only economic incentive and regulation. Other factors, such as the feeling of insecurity and paying high up-front costs for adopting new technology, must also be considered (Bauner 2007).

Despite its being studied and used in scholarly research, Weiss and Dale (1998) stated Rogers' attributes of diffusion theory[8] have been perceived as abstract and containing little relevance for practitioners. Nevertheless, they indicated these attributes are, in fact, simple to understand and can be operationalized in practical cases but it is crucial that the attributes be analysed as 'perceived' not as 'intrinsic'. In addition, Griliches (1960) showed that diffusion occurs when adopters perceive an innovation as useful or more economical. Thus, a strong emphasis in diffusion research should be placed on users.

Users' perspectives and roles

The users' dimension is crucial in shaping and diffusing technologies. Collaboration of users in energy technology can lead to greater diffusion, technological development, and possibly new product innovation (Ornetzeder and Rohracher 2006). Nevertheless, since the 1980s, when there was an attempt to implement renewable energy technology, social acceptance has been neglected. Initial surveys of public acceptance of renewable energy, in fact, showed very high support of renewable energy. However, in reality, a large difference exists between general public support and support for specific projects or

[8] See Papers II and III for further discussion and application of the attributes.

implementations. Policy makers have been misled by this discrepancy between general positive support and low support for specific contexts directly affecting individuals. Moving from general to specific and from the global or national to the local level, direct investigation of public support of local sites should be investigated. Acceptance of general projects and resistance to specific implementation may occur because people tend to support renewable energy as long as it is not in their backyards.[9] Therefore, specific cases must be investigated to provide understanding of local contexts (Wustenhagen et al. 2007). The inclusion of users in technology diffusion research can provide better understanding of environmentally friendly technologies and enhance dissemination. Recently, there has been an interest in academia in investigating social acceptance and users' perspectives through the case-study approach (see e.g. Rohracher 2003 in Austria; Mallett 2007 in Mexico; Muggenburg et al. 2012 in Ethiopia; Shyu 2013 in China). For small-scale renewable energy technologies, like household PV systems, Wustenhagen et al. (2007) suggested diffusion of innovation literature (Rogers 1995) can help in understanding social acceptance because it can be regarded as market acceptance or a market adoption process. Nevertheless, because of the nature of energy technologies, which are constrained to other infrastructures, their diffusion can be more complicated than that of other products.

When discussed in relation to Rogers' four elements of diffusion (2003), the roles of potential users are of high importance and exist in all elements: innovation, communication channel, time, and social system.[10] First, in terms of the innovation itself, understanding users' needs is a vital determinant of its success. Users' involvement in the innovation process leads to development of a more valuable innovation, enhancing its adoption. Therefore, integrating users from an early stage and actively engaging them throughout the process are necessary. Second, an appropriate communication channel must be selected for effective facilitation of the diffusion process. Along with the communication channel, the cognitive distance between the source and the recipient and users' absorptive capacity should be taken into account. Third, the time element and its three sub-aspects are strongly connected and highly dependent on users. The first sub-aspect, the decision-making process, involves users' deciding whether to adopt or reject the innovation. The second aspect is the relative earliness or lateness of its adoption by other members in a social system. The last aspect is the rate of adoption, measured directly by counting the number of users who choose to adopt the innovation within a certain time frame. Finally, users are obviously the main part of the last element: the social system. Without users, the

[9] The notion of "not in my backyard" (NIMBY) refers to people who object to a new development being implemented in their own neighbourhoods. While they often understand that such developments are good for society at large, they believe they should be geographically further away. For example, residents may realize that wind turbines or homeless shelters are necessary and beneficial for the community, but they should not be located next to their own residences.

[10] See Paper IV for detailed discussion regarding the elements of diffusion.

system would not be complete because the function of the system would not be fulfilled.

Developing countries and the energy issue

Developing nations should be included in technological change and development so that the already large disparity between developed and developing nations will not become even greater. Even though this idea may sound logical and should have been attended to by international organizations, it has not been well received in the past. In 1970, *The Sussex Manifesto: Science and Technology for Developing Countries during the Second Development Decade* was written at the request of the UN (Singer et al. 1970). It has been an influential document that calls for harnessing science and technology for development. However, it was rejected by the UN's sponsors. They did not approve the target of the manifesto to redirect science and technology for developing nations (Kaplinsky 2011). Almost two decades later, another UN report, *Our Common Future* or *The Brundtland Report* was published (WCED 1987). The report is focused on the push towards more sustainable development and collapses development and environment into one single concern. In this report, the concept of sustainable development was first defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987: p. 43). Two key notions lie behind this definition: the priority of the world's poor and the limitation of the environment. They emphasize that environment and development should go hand-in-hand. In the past decades, energy has been an essential component of the international debate on sustainable development (Toth and Videla 2012). Although the energy issue was not explicitly incorporated into the Millennium Development Goals (MDGs) established by the United Nations (UN) in 2000 (United Nations 2013), experts agree that eradicating energy poverty can significantly contribute to achieving the MDGs (Brew-Hammond 2012). In addition, it is widely believed that energy is one primary divide that must be bridged between the developed world and poorer countries (see e.g. Kumar et al. 2010).

This dissertation is focused on developing countries through the studies of three cases in Uganda, Bangladesh, and Thailand. Despite the originality of innovation studies of the industrialized world, it aims at understanding how innovation affects economics in terms of growth, development, and catching up, even in the context of a developing country (Szogs 2010). Because of the many differences in various conditions between developed and developing nations, the definition of *innovation* in this dissertation is not limited only to something new to the world; but it is extended to the newness for the country or market in which it is introduced (OECD 1997) and the newness to individual adopters (Rogers 2003). It also includes the absorption of innovation that exists somewhere else in the world and is adapted to the local context (Lundvall et al. 2009). As a result, technologies already existing in the western world but new to the social system in which they are used may still be considered innovations. Focusing on innovation

while there are other acute problems, such as famine, education, and child mortality, may be considered a luxury. However, innovations can help solve and reduce some of the acute problems that developing countries face. In fact, the root cause of these problems stems from poverty. Innovation is essential for growth and industrial competitiveness and, hence, for catching up with the developed world (Chaminade et al. 2009).

A development perspective in technology diffusion integrates a variety of conditions that differentiate this market from other higher income markets. Poverty is one obvious challenge. According to Sen (2000)[11], poverty is not only the lack of money but the lack of capabilities to fully realize one's own potential as human beings. This wider definition of poverty does not deny that low income is one root cause for underdevelopment. It also includes other constraints related to the diffusion of new technology, such as lack of infrastructure, lack of policy support, and lack of education among potential adopters. Miller (2009) gave special attention to this market segment by focusing not only on adopters' access to financial resources but also on integration of entrepreneurs and other related organisations that can help potential adopters overcome the hurdle of low income. Various approaches to investigating how to increase the dissemination of technologies suited for low-income markets have been called for.

Schumacher (1973) argued that technologies from developed countries are not appropriate for developing countries because such technologies are often operated on a large scale and are capital intensive. Thus, a need exists for intermediate technology operated at a smaller scale. Small-scale operations tend to be less harmful to the environment than larger ones because of their relatively small individual force in comparison to the resilient power of nature. Schumacher further stated that economic development should be done "as if people matter" (as highlighted in the title of his book). In developing countries, a few people have higher incomes, living standards, and affordability at a par with those in developed nations. Nevertheless, the larger part of the population lives with very limited resources and has unsatisfactory living conditions. This segment, Schumacher asserted, has a need for intermediate or appropriate technology to help the people who need it most. He further explained that intermediate technology should be simple, making it easy to understand, maintain, and repair on site. This quality would make it suitable for use in an unsophisticated environment. This market is related to what Prahalad (2010) referred to as "bottom of the pyramid" (BOP) or the poorest people of the world, who make up more than half of the global population. Prahalad argued the low-income market is a high-potential segment for firms seeking profit while doing business with these firms can boost development and alleviate poverty in the area. His joint paper with Hammond *Serving the World's Poor, Profitably*

[11] Amartya Sen received the 1998 Nobel Laureate in Economic Sciences for his vital contribution in welfare economics (Nobelprize.org 2014).

(Prahalad and Hammond 2002) and his book *The Fortune at the Bottom of the Pyramid: Eradicating Poverty Through Profits* (Prahalad 2010) have been widely cited. The low-income market is viewed as a prospering and high potential market with opportunities for firms. The emphasis is put on multi-national corporations rather than local and small-scale enterprises. Nevertheless, even if large corporations can sell the same products or services to the low-income market as they do in developed countries, different business models or strategies are required, and developing such strategies is not easily accomplished. In fact, more than half of executives believe that a business model is more crucial to a company' success than the product or service innovation (Johnson et al. 2008).

The concepts of intermediate technology and the BOP market have been shown to be useful in development studies, gaining popularity and international praise. However, these concepts may be considered too ideological and unrealistic. Kaplinsky (2011) argued the diffusion of intermediate technology is an act of charity rather than a pursuit for profit. He further contended the ability of multi-national corporations to grasp the BOP market is untested for two reasons. First, large firms are usually very good at responding to the demand of their existing customers but very bad at satisfying new customers because of their core strength of investing resources in understanding their existing customers. They are capable of developing and commercializing as long as a new technology answers the needs of those customers. On the other hand, they have difficulty commercializing new technology that is appealing to emerging market but not to their mainstream clients (Bower and Christensen 1995; Christensen 2000). Second, standards applied in developed countries are likely to be of very little importance for developing country markets. Such lower standards may be difficult for multi-national corporations to grasp. Nevertheless, it can be an opportunity for local or regional operating firms because they no longer need to comply to the high standard barrier (Kaplinsky et al. 2011).

In addition, Karnani (2007, 2009) wrote critical responses to the BOP concept, indicating that Prahalad's book did not provide empirical support for assuming the poor are "value-conscious consumers" (Prahalad 2010: p. 25). Karnani indicated this is a "romanticized view of the poor" and, in fact, "harms the poor" (Karnani 2009: p. 76).[12] Banerjee and Duflo (2007; 2011) revealed the poor have difficulty saving and spend a large amount of money on things that do not benefit their well-being, such as cigarettes and alcohol. In addition, as with higher income consumers, the poor have difficulty resisting the temptation to buy non-necessary items. A conception that the poor will put all their income into food to stop their hunger, which is a basic need, is not entirely correct. As with all people, the poor make choices, and those choices are not always the best

[12] There is an interesting remark in the strong disagreement between Prahalad and Karnani. In fact, both of them are professors at Ross School of Business at the University of Michigan. They also have very similar backgrounds, holding masters' degrees from the Indian Institute of Management and doctoral degrees from Harvard Business School. Despite these similarities, their views on the strategies for low-income economies are very different.

or most rational. An article in *The Economist* referred to the idea held by development economists that the poor make rational choices as an "item of faith" (The Economist 2007). Making the private sector a main player and emphasizing free market to reduce poverty undermine the crucial role and responsibility of the public sector. The poor are vulnerable consumers, and they should be protected (Karnani 2009). Thus, the role of the governmental body to intervene in this market is deemed crucial.

Despite the criticisms, for this dissertation, intermediate technology and the BOP are useful concepts and can help in understanding and explaining the diffusion of energy technology. A complementary approach from the entrepreneurial perspective can help overcome these criticisms to a certain extent and make them operational. Therefore, this dissertation incorporates the concept of social entrepreneurship, which is an alternative form of entrepreneurship. Based on existing research on entrepreneurship, the concept of social entrepreneurship is developed. The core characteristic distinguishing social entrepreneurship from others is its objective. Business entrepreneurship often aims at economic wealth, with social wealth being a by-product (Venkataraman 1997). In comparison, a primary objective of social entrepreneurship is social wealth, with income functioning as a necessary element for sustainability of the business and for financial self-sufficiency. That is, both social and economic value creation are integrated into this form of entrepreneurship. This practice has long existed on the global level; examples include Ashoka and Grameen Bank. Scholarly research on this topic, however, has received relatively less attention among academia in comparison with business entrepreneurship. Although there are more studies recently, conceptual studies outnumber empirical investigation (Mair and Marti 2006; Short et al. 2009; Zahra et al. 2009). From the private sector perspective, presenting the poor with whatever product firms can reap benefits from may make the companies prosper in this market. Nevertheless, doing so will not lead to local development. Short et al. (2009) suggested the integration of social entrepreneurship research with established theories such as diffusion of innovation. In this dissertation, the diffusion of energy technology in developing countries can be explained and facilitated with a social entrepreneurship approach.

3.2 Sustainability transition and niche management

Sustainability is sometimes considered a buzzword in many arenas, be it for attracting research grants among academia or projecting a better image of corporations. Here, sustainability is not treated as such but is, indeed, an essential in this dissertation. In fact, the world today is undeniably facing several sustainability challenges, such as energy security, poverty, disparity among nations, gender inequality, climate change impact, and so on.

Transition is a fundamental change process that deals with a shift from one trajectory to another (Geels and Kemp 2007). This thesis is focused on the transition to more sustainable energy sources. This transition can be considered a socio-technical transition, rather than a technological transition. Practices, users, institutions, cultures, and other "soft" aspects are embedded, in addition to the technological element. Moreover, the socio-technical transition incorporates complementary technical as well as non-technical innovations, such as infrastructures, management, and policy (cf. Markard et al. 2012; Rohracher 2008). In other words, the social and technical sides of socio-technical transition are inseparable and emphasized in social studies of science and technology (see e.g. Rohracher 2001; Yearley 2005).

The introduction and diffusion of sustainable technology has high societal relevance. Research on the transition to more sustainable options has recently developed substantially. It has a high level of complexity because of the great number and variety of players and interests. Nevertheless, sustainability transition is an emerging field, and current research is only in the beginning stages and can be empirically improved by extending the geographic focus beyond European countries. One of the prominent theoretical frameworks in transition studies is strategic niche management (Markard et al. 2012).

Strategic niche management (SNM) is "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 (2) enhancing the further development and the rate of application of the new technology" (Kemp et al. 1998: p. 186). In addition, SNM focuses on the early adoption of technology that can contribute to sustainable development. While the concept of niche has long existed in innovation studies, it is not particularly focused on the goal of sustainable development (Schot and Geels 2008). The SNM approach assumes that sustainability transition "can be facilitated by modulating of technological niches, i.e. protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures" (Schot and Geels 2008: p. 538). In line with the pragmatic approach of this dissertation as discussed in the methodology chapter, SNM is also a practical framework for analysing ex-post cases regarding management of an innovation that is socially desirable with a long-term aim, such as sustainability, and innovations that initially experience mismatch, such as practices and infrastructures. In SNM literature, three processes for developing a technological niche have been emphasized: expectation alignment, network formation, and learning process[13] (Kemp et al. 1998; Schot and Geels 2008).

[13] Further elaboration on these three processes is discussed, together with their implications, in Chapter 5.

Diffusion of small-scale off-grid energy technologies in rural markets may be considered a niche (cf. Weiss and Dale 1998). For several decades, the power sector has largely been a state-owned and centralized monopoly. The dissemination of decentralized small-scale power generation technology, which is now on the rise, imposes systemic challenges because of socio-technical factors. While technical aspects have been identified as less crucial, the understanding of social processes is still a challenge. Institutional frameworks have been identified as inhibitions to such implementation. The institutions built around existing technical systems tend to undergo only incremental changes. Radical change may be necessary to handle effectively this technology shift towards a more decentralized power generation based on renewable sources (cf. Rohracher 2008; Sauter 2008).

In the past, achieving environmental targets and increasing industrial competitiveness were considered the trade-offs between private costs and social benefits. However, the notion of competitiveness is changing towards a more dynamic approach in which improvements and innovations that can shift incumbent constraints are valued. Environmentally friendly features of products can compensate for additional costs and may even become competitive advantages, with cost no longer being the first criterion. This change can be facilitated with policy support to promote both industrial competitiveness and environmental goals (Porter and van der Linde 1995), thus providing opportunities for both existing energy companies and new entrants. If existing firms are going to compete in this emerging market, finding new ways of doing business is unavoidable. Transforming business opportunities are never entirely about finding and commercializing a superior technology, but the new technology must be supported by a suitable business model (Johnson et al. 2008). In this dissertation, experiences from previous effort in the diffusion of renewable electricity are presented in the appended papers. In addition, managerial and policy implications have been drawn and presented in Chapter 5 of this cover essay. These may be relevant for actors engaging in the dissemination of environmentally friendly innovations.

3.3 Reflection of the concepts

Diffusion framework has been used to explain the spread of something new. The "newness" in the process poses uncertainty and underscores the importance of diffusion study. This dissertation aims to analyse the mechanism of the diffusion and adoption of renewable electricity, which is new to the adopters and their communities. Hence, diffusion theory is taken as an appropriate tool for explaining the mechanism and it is the framework leading to answer the overall research aim. However, diffusion is a large and complex framework. Therefore, it is a prior necessity to describe the structure of the development of diffusion

research and its application, corresponding to the first set of research questions. This is further elaborated in Section 4.1.

Because of a specific focus on rural electrification among low-income inhabitants in developing countries, the concepts presented in this chapter focus on development perspective in energy research. There are relatively little studies conducted in rural areas of developing countries compared to that of developed nations. Thus, empirical investigation on the diffusion and adoption of renewable electricity, particularly PV systems, can increase understanding of local contexts, of which the roles and perspectives of users are emphasized. This corresponds to the second and third sets of research questions and is further elaborated in Sections 4.2 and 4.3.

The dissemination of renewable electricity can be considered as a socio-technical transition towards more sustainable energy sources. The findings of this dissertation may provide valuable implications for academics and practitioners. In order to draw the implications across the studies, SNM concept is a suitable approach because it specifically addresses the sustainability aspect and has been used by policy makers. Therefore, it is used for drawing managerial and policy implications, which are presented in Chapter 5 of this cover essay.

4 Results and discussion

The overall aim of this dissertation is to analyse the mechanism of the diffusion and adoption of renewable electricity with particular focus on rural electrification among low-income inhabitants in developing countries. Based on this overall aim, three sets of research questions have been developed. This chapter[14] is structured according to the research questions. Because of the interrelation of these questions, discussions of their topics can overlap. An overview of the papers corresponding to the research questions is shown in Table 1.

Table 1. Overview of appended papers corresponding to research questions

Research question	Paper					
	I	II	II	IV	V	VI
I. Description of diffusion framework	■	▒	▒	▒		
II. Adoption of renewable electricity in rural areas		■	■	■	▒	▒
III. Diffusion of PV systems in development context			■	■	■	■

Note: Solid and dashed cells indicate papers that provide significant and moderate contributions, respectively, to the corresponding research questions.[15]

4.1 Description of diffusion framework

The first set of questions is as follow: How can an interdisciplinary research field be described, despite its extensive amount of publications? What is the structure of the recent development of diffusion research and its application, particularly, to rural energy field? This is largely addressed in Paper I. The description of a large interdisciplinary research field can be done through bibliometric approach, of which a novel method was proposed.[16] Because of the non-conformity of the diffusion process characterized by local contexts, Papers II, III, and IV also present the application of diffusion theory in development contexts as shown in three empirical cases in the rural energy field.

Historically, diffusion has been an important element of ethnological research addressing how cultural innovations have spread among cultures and whether specific innovations are the results of autonomous processes or dependent on

[14] Some parts of this chapter contain texts directly excerpted from the appended papers. Quotation marks are omitted to facilitate the flow.
[15] In fact, all papers contribute to some extent to meeting these research questions, but this matrix shows their main contributions only.
[16] This is briefly discussed in the methodology section of this cover essay and more details are presented in Paper I.

diffusion. Academically, diffusion has been used in various branches of social sciences and has been given various definitions. Studies in diffusion research have been focused on explaining the variables that influence the adoption process. Diffusion and adoption processes are highly complicated, having several unforeseeable and context-specific factors. In addition, diffusion processes are almost always associated with something new, magnifying the degree of uncertainty and, hence, resulting in unpredictable outcomes. Therefore, studying a diffusion, its pattern, its model, its factors, and its effects can help scholars and practitioners to understand better the process and to formulate increasingly more efficient, fruitful, and productive innovation diffusion schemes.

Paper I discusses historical development of diffusion research and reviews this research arena in the widest perspective, using a bibliometric approach as a complement to the traditional literature review. Such a study is lacking and has never been conducted before. Thirteen research lines or clusters that are relevant within the general area of diffusion have been identified. The following lists the clusters in decreasing order by the number of publications: geography of innovation, diffusion, knowledge management, technology acceptance, spillover, marketing model, policy diffusion, e-business, financing innovation, network effect, intellectual property rights, technological capability, and cognitive behaviour.

The dominant disciplines in diffusion research are business economics, innovation studies, and business management. Everett M. Rogers was identified as the most influential scholar in all the clusters combined. The analysis revealed diffusion research is highly interdisciplinary in character, involving several disciplines from ethnology to economics, with many overlapping research trails. Regarding the most influential reference across all clusters combined, Rogers's extensive books (in various editions) on the diffusion of innovation (see e.g. Rogers 2003) ranked first. His books also appear among the top-cited references in several clusters. They penetrate various arenas, presumably owing to the extensive collection of a large variety of empirical work supporting a proposed general theory of diffusion. Other frequently cited references are based, to varying extents, on empirical findings.

Rogers is the most influential author and his works the most influential knowledge base in diffusion research. Papers II, III, and IV also have his work as their core theoretical frameworks, but complemented with other concepts and extended to explain the specific cases. For example, disruptive innovation and the socio-technical system are integrated in Paper II in discussion of the adoption process in a local social system; the bottom of the pyramid and social entrepreneurship are discussed in Paper III to explain unique strategies in low-income markets; absorptive capacity and cognitive distance are used in Paper IV to explain the technological understanding of adopters.

Rogers' books do, however, have shortcomings. A number of other studies can be considered complementary, filling in gaps in the diffusion framework. For example, Cohen and Levinthal's work on absorptive capacity (1990) addressed the importance of users' capability in the exploitation of new knowledge based on related prior background. This work implies that adoption requires appropriate knowledge and some form of training. Their concept has been widely applied at the firm and organizational level. In addition, also emphasizing knowledge, Nonaka and Takeuchi (1995), together with Jaffe, Trajtenberg, and Henderson (1993), help to fill in this complex understanding of the creation, utilization, and diffusion of knowledge, which is an intangible matter. This intangible aspect of diffusion may be lacking in Rogers' work.

The diffusion framework, despite its long existence, is still debatable. Research of every sort—conceptual, methodological, and empirical—can contribute to the advancement, better understanding, more unified view, and wider applicability of diffusion research. The result from the bibliometric analysis indicates the spread of diffusion theory as an encompassing theory. It is a very useful concept for the study of how technologies, practices, or programs are adopted and spread in different environments. Diffusion research relies heavily on empirical studies. High-impact publications rely on empirical data that support and change theories in modest ways. Even though those empirical data are derived from specific areas, it seems that diffusion theories can be applied to multiple contexts.

Papers II, III, and IV empirically apply diffusion theory to adoption of electricity. These papers contribute to the understanding of the diffusion process in developing countries. In fact, in the 1960s, the growth in diffusion research in third-world countries rose because of the assumption that technology is the key factor in the development (Rogers 2003). However, shortcomings still exist in this research arena, and past diffusion research conducted in developed countries is not always applicable in developing areas. Many factors differentiate developing nations from the developed ones.

The category of adopters based on their innovativeness is widely recognized. From a marketing point of view, this categorization may be useful for developing strategies to attract certain groups of customers based on common characteristics among the adopter groups (Kotler 1997). However, this classification is not always applicable in low-income communities. As Griliches (1960) pointed out, the time lag in the diffusion process is not always caused by insufficient information or conservative behaviour. In addition, Rogers (2003) was quite careful in using the term *laggard* to refer to the last group of adopters, aware that the term has a negative connotation. Nevertheless, diffusion scholars sometimes put individual blame on late adopters and consider them irrational or traditionally against change, perhaps because of a lack of understanding among highly educated researchers themselves. The non-adoption decision can be very rational and should be investigated based on potential adopters' points of view

(as discussed in Section 3.1). Possible explanations are that the innovation may not correspond to potential users' needs, the innovation is not cost efficient, or the target adopters simply cannot afford it. Thus, being laggards or late adopters is not necessarily connected to the innovativeness but can be a matter of choice. By calling the very first and very last adopters *innovators* and *laggards*, respectively, could be misleading. In development work, it may be more useful to distinguish potential adopters based on the amount of capital they have or on their access to credit (Miller 2009). Thereby, the diffusion chasm (cf. Moore 2006) could be crossed through appropriate policy and business strategies uniquely designed to suit the potential adopters. For example, those in extreme conditions may need government intervention in terms of financial and other infrastructure support (see Paper IV) while those with more capital could be potential customers of companies that offer appropriate payment schemes (see Papers II and III).

In addition, the past diffusion studies—regardless of their subjects—were focused on the change that could be accounted for by economic variables. In development work, the adoption of new technology is not always linked to higher profitability but rather to improvement in the quality of living and well-being. While economic situations may also be improved, such improvement is not always the ultimate goal. Profit maximization or cost saving is among the main factors that influence adopters to purchase products, but it is not the only factor. As shown in Paper VI, the transition towards off-grid PV systems provides non-economic advantages that can be even more important than economic ones. These non-economic aspects are best investigated directly from the adopters' perspectives. Such empirical studies are undertaken in Papers II, III, and IV. This approach is also in line with the objective of social entrepreneurship, in which economic wealth is not the primary target but social wealth is of vital importance.

To conclude, the description of a large interdisciplinary research field can be done via a bibliometric and clustering analysis. Here, it is applied on diffusion research to explain the structure of the recent development and its application. Thus, it provides not only theoretical understanding of diffusion theory but also methodological contribution that can be applied to other research fields. Through this method, it shows that diffusion framework is a very interdisciplinary area. It relies heavily on empirical studies as can be seen from high-impact publications. Its applications are also highly diverse. In development context, the application of diffusion theory on rural energy can still be further explored empirically, leading to the discussion in the next section. Adjustments and extension of existing theory may be necessary such as adopter categories, entrepreneurial approach, and non-economic and non-tangible aspects.

4.2 Adoption of renewable electricity in rural areas

According to the latest *World Energy Outlook* (IEA 2014), 68% of global power generation comes from fossil fuels, 11% from nuclear energy, and the other 21% from renewable sources. The use of renewable energy resources has very high potential to meet the rising demand for electricity and raise its share in the power sector. However, the quest for renewable electricity still faces several challenges. The second set of questions is as follow: How can the adoption of renewable electricity in rural areas of developing countries be better understood? What lessons can be complied? Unlike most areas of the world that were initially electrified by a centralized system powered by fossil fuels, the rural electrification process studied here shifts from traditional energy sources, such as lighting from kerosene, to electricity based on renewable sources. This technology shift requires empirical investigation, which is presented in Papers II, III, and IV.

Nearly half of the 1.3 billion people who have no access to electricity reside in sub-Saharan Africa (IEA 2014). Paper II is an empirical investigation into the adoption of electricity in rural Uganda, where only 7% of the population in rural areas has access to electricity (IEA 2014). With a poor infrastructure and support system in Uganda, foreign actors play a crucial role in the electrification effort. In this case, a small Swedish energy service company, Pamoja, was investigated. Pamoja distributes electricity to rural households via a mini-grid powered by a small-scale biomass gasification power plant.[17] Adopters' perceptions significantly influence their decisions. Three critical dimensions were identified and analysed: (a) the technological dimension, particularly the emphasis on the relative advantages; (b) the economic dimension, especially a viable financial system for adopters in a low-income market; and (c) the social dimension, particularly the collaboration of foreign firms with local actors. The study sheds light on a technology-transfer process from developed to developing countries, where a lack of understanding among the local communities can lead to failure of diffusion attempts.

Papers III and IV investigate the adoption of power technology: PV systems. While Paper III explores the diffusion of a local company in Bangladesh, Paper IV investigates the diffusion of a government project in Thailand. These topics are closely related to the third research question; therefore, further discussion of these two cases is provided in the following section.

Rural electrification by independent PV systems or a mini-grid can be considered intermediate technology because of its relatively small size in comparison to a

[17] Biomass gasification is an electricity generation method using a thermochemical process that converts biomass into a gaseous mix through oxidization. The conversion process begins with the gasification of biomass with heat and steam and results in a mixture of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), light, other heavy hydrocarbons, and char. Biomass feedstock is usually obtained from agricultural waste. Thus, biomass gasification not only provides electricity but also addresses the waste-management issue (Ni et al. 2006).

centralized power plant. Although it may not cause major impact on people's lives at large, it greatly affects the individual household. Collectively, this small-scale level of technology can have a positive impact on the community, and the lessons learned could be very beneficial for the diffusion of renewable energy (cf. Miller 2009).

Furthermore, through empirical insight across cases, it was found that the technological development of two devices may significantly enhance the adoption of small-scale power generations in rural areas. First, the emergence of LED lamps makes lighting—one of the most common and basic usages of electricity—more accessible because of its low electricity consumption, thereby imposing less demand on the battery storage unit. Second, the widespread use of mobile phones in rural areas motivates adoption of electricity. The dissemination of these two recently developed devices helps create new demand for electricity among rural inhabitants.

Although this dissertation does not focus on the long-term consequences of electricity access, some interesting aspects were found. The Bangladeshi case reveals a positive impact on a gender aspect. In close connection with Grameen Shakti, the Grameen Technology Center was established in 2005 to assemble devices for manufacturing PV systems. The centers only recruit women. In addition, access to electricity enables women to generate income through productive usage. These can be a means to empowering women, making them become more independent. On the other hand, electrification may have unintended negative effects. Empirical investigation indicated electrification poses social challenges to rural communities. For example, young people in remote mountainous areas in Thailand want to leave their villages after seeing on television alternative modern life choices in the cities. Such movement may lead to aging communities where elderly persons are left behind. In addition, having electricity access in the communities where some of the inhabitants cannot afford the technology may create disparity that leads to social conflict, as in the case of Uganda.

To conclude, the diffusion of renewable electricity can be better understood through empirical studies where lessons can be compiled. These may be relevant for academics and practitioners who work with renewable energy in rural settings. In this dissertation, the adoption of renewable electricity in rural areas was empirically investigated through three case studies in three developing countries. The development of other related technologies facilitates and leads to more electricity demand. The adoption poses some challenges; as electricity access is very new to the community. Although electricity access has advantages and may be looked upon as a self-motivated innovation among potential adopters, there can be resistance and barriers to the adoption. The increase in electricity access does not always constitute positive consequences and this should not be overlooked by technology providers.

4.3 Diffusion of photovoltaic systems in development context

A new technology's being superior to the preceding technology does not guarantee its successful dissemination, as is the case for PV systems (Miller 2009). The third set of questions is as follow: Can the diffusion of PV systems—especially in the context of developing countries—be enhanced, and how? This is largely addressed in Papers III, IV, V, and VI.

Photovoltaics (PV) is an electricity generation method using solar radiation. From photon energy captured from sunlight through semiconductors, direct current electricity can be produced. The semiconductors are doped with additives to create positive and negative layers. The photons that strike a semiconductor facilitate the movement of electrons from positive to negative layers, creating electric current (Bradford 2006). Based on grid connectivity, PV systems can be separated into two categories: on-grid and off-grid. An on-grid PV system is integrated into the utility grid. During the day, electricity is generated via the PV system. The excess amount is transferred to the national grid for general use at any grid-connected location. When the PV system cannot generate sufficient electricity, the electricity can be taken from the utility grid; thus, a battery is not a necessary component. On the other hand, an off-grid PV system is used in remote areas where the grid is unavailable; hence, a battery is an important part of the off-grid system. During the day, solar energy is collected and transformed into electricity. The excess amount of electricity is stored in batteries for later use.

Despite the use of PV technology for rural electrification since the 1960s (Lorenzo 1997) together with its rapid technological development and price decline during the last few years, its use is still low compared to conventional energy sources (REN21 2014). The rapid price drop has made PV systems an attractive energy technology, even among low-income inhabitants. However, the significant price decline has not been fully appreciated by relevant actors, such as policy makers and users who still perceive a PV system as an expensive option (Bazilian et al. 2013). Papers V and VI show that price is not the only concern in the implementation of PV systems. Focusing on its adoption by households, Paper V investigates the barriers to adoption in a variety of contexts, and Paper VI investigates the transition to off-grid application.

The state-of-the-art barrier analysis in Paper V represents all ranges of income economies according to the World Bank definition: low, lower middle, upper middle, and high (The World Bank 2014). The results reveal the adoption of PV systems—either as a substitute for other power generation in urban areas or for rural electrification—is still a challenging process. The barriers are evident for low- and high-income economies and classified into four interrelated dimensions: (a) socio-technical, (b) management, (c) economic, and (d) policy, as

elaborated in Paper V.[18] These barriers are socially and locally embedded, underscoring the need for empirical investigation as can be found across all three case studies. Paper II[19] addresses all dimensions except the policy aspect; Paper III touches upon all dimensions; Paper IV addresses all dimensions except the economic barrier. Several socio-technical barriers are evident, such as lack of adequate knowledge and low education level among adopters. With regards to management, post-adoption aspects, such as maintenance and stakeholders' collaboration, were found to be some of the main barriers. Moreover, the adoption of renewable energy faces several economic barriers. These are often related to the high initial cost of adoption. In conjunction with the economic barrier, policy support becomes crucial in developing countries and is presented as another dimension of barriers. In addition, Paper VI indicates policy can have both positive and negative effects on the competitiveness of renewable energy.[20]

In terms of rural electrification, Paper VI shows the transition among rural inhabitants to using off-grid PV systems is not entirely based on system cost that the adopters need to pay because other factors affect the adoption decision. Two interrelated aspects were investigated: PV system price and relative advantages for rural adopters.

Concerning price, two distinct features with profound effect on the PV system price are cost in conjunction with performance and government incentives (IRENA 2012). When cost and affordability do not correspond, government incentives function as a complementary element for adopters. Three main mechanisms behind the decline of PV cost are identified as follow: (a) technological advancement in both PV modules and balance of systems, (b) a change in the production system that benefits from economies of scale and the shift of production sites to lower cost locations, and (c) the experience curve of solar industry since 1960s. In terms of government policy, it can have both negative and positive effects on PV system price. Negative impact on a PV system means the government incentives favour other competing alternatives, such as fossil fuels, which lower the financial benefit for potential adopters purchasing PV systems. On the other hand, a positive impact is evidenced when the incentives favour PV systems and result in lower price of those systems.

Concerning relative advantages for rural adopters, they are both economic and non-economic. Economic advantages can be considered (a) cost reduction compared with other existing competing technologies, such as kerosene lamps and diesel generators, and (b) income generation as a result of productive use of

[18] Although the barriers have been derived from the body of literature concerning the adoption of PV systems, these dimensions are applicable—to some extent—to other energy technologies.
[19] Although Paper II discusses the adoption of renewable electricity provided by a biomass gasification system, there are some learning points that are not directly dependent on the power technology. These can be relevant for the third set of research questions presented in this section.
[20] See Sriwannawit et al. (2014a; 2014b) for studies that quantitatively analyse the impact of government policy on the competitiveness of renewable energy in developing countries.

PV systems, such as increasing productivity and efficiency compared to working manually. Using PV systems for rural electrification also has non-economic advantages. For example, replacing kerosene lamps with PV systems yields health benefit because kerosene is a hazardous substance. Non-economic advantages can also be referred to as social wealth, which is, in fact, the main advantage targeted by social entrepreneurs working with rural electrification. Paper III provides a case study of the diffusion of PV systems by a social entrepreneur in Bangladesh, where more than half of the rural population does not have access to electricity (IEA 2014).

Paper III is a case study of Grameen Shakti, a local energy company operating in the BOP market in rural Bangladesh. Miller (2009) identified two types of capital that are barriers to entrepreneurs dealing with solar energy. First, market infrastructure capital—such as local branches, sales people, and technicians—is necessary. Second, customer finance is important in order to make the products affordable for the target group. Grameen Shakti has overcome these two barriers, and its diffusion is at a large nationwide scale. The variables determining the adoption rate in the BOP market were analysed and re-conceptualized into three basic components: source, innovation, and adopter. The extension from previous typology as identified by Rogers (2003) encompasses the characteristics of the source that are specific to the BOP market, here identified as a social entrepreneur. These source characteristics that equip Grameen Shakti with competitive advantage comprise four items: (a) unique company background in development work related to the source's history, leader, and values; (b) good qualifications and strong effort of change agents highly involved with local communities, both before and after the adoption; (c) affordable and manageable economic schemes specifically designed for the low-income adopters; and (d) a distribution system quick to respond to adopters' financial situations. The source characteristics are assumed to be the most important factor affecting the high adoption rate of PV systems in Bangladesh because they are unique and they specifically address the BOP market. Understanding the source characteristics can equip various types of actors with the capabilities to begin a diffusion process in the low-income segment. The Grameen Shakti case reveals that a local social entrepreneur can drive the diffusion process by building a previously unattractive market to become a market with large potential adopters. The social characteristics of Grameen Shakti may be largely because of its founder, Muhammad Yunus, and his 'innovation' of the microfinance concept. As opposed to Prahalad's BOP concept, which may be considered a top-down approach, Grameen business may be considered a complementary perspective, focusing on capability building in local firms rather than waiting for investment from multi-national companies.

Paper IV presents the diffusion in Thailand led by the government. The overall electrification rate in Thailand is 99%, far higher than that of Bangladesh[21] (IEA 2013). The remaining 1% is of a very special character in terms of remoteness, income, living standard, and so on, putting them outside the scope of an ordinary market segment. Thereby, government intervention becomes necessary. Paper IV discusses the diffusion of PV systems to remote areas in Thailand. This is an extreme case in which PV systems and services were provided free of charge. Thus, it may be initially assumed that the project could be executed without difficulty because one main challenge—capital cost—had already been eliminated. However, this assumption was shown to be incorrect. The project was conducted with collaboration among eight governmental agencies. The diffusion process is analysed in terms of four classic elements: innovation, communication channel, time, and social system. Users' perspectives are highly integrated into the analysis. Including users in the early stage and keeping them active are necessary for technology diffusion. The innovation part in this project is not only the PV system itself but also the management that involves various governmental agencies, with each organization assumed to contribute in terms of its special competence. This management style may be considered novel in the Thai context because it is uncommon to incorporate a large number of agencies in a single project. It was mutually agreed upon by the respondents that the complication in electrification is not the technology itself but how to manage it. The challenge was to provide a technical solution with suitable management tools to lead to sustainable electrification. Education was shown to be of immense importance. Effective training was carried out by education experts rather than technical experts to reduce cognitive distance with the adopters and take users' absorptive capacity into account. The existence of royal family support eased the diffusion process. In Thailand, royal family is deemed a highly significant institution. Thus, their existence in this project helps overcoming some difficulties. Despite the basically favourable conditions of having capital cost eliminated and strong institutional support, the project faces several constraints. Even with public funding, the project as a whole is underfinanced. More importantly, each agency uses its own funding for its share of the joint project. Thus, significant financial imbalances exist among agencies, creating severe challenges, resulting in less maintenance than previously planned. A possible solution could be achieved if the central government allocates a total budget for the project and distributes it to all agencies. Governmental regulation or a formal institution controlling proper use of funds is also necessary so funds will be used in the most appropriate way. Because of the large number of organizations involved, the issue of coordination and collaboration among various agencies is a crucial one. The respondents believed the collaboration on

[21] The large difference in electricity access in Thailand and Bangladesh results largely from government initiatives during the 1970s. Both countries launched state-funded rural electrification programs in 1977. Even though the approaches were similar, their outcomes were very different. In Thailand, electricity access increased from 7% in the 1970s to 97% in 2000, whereas in Bangladesh, access increased from a negligible level to only 19% during the same period (Shrestha et al. 2004).

this project was satisfactory but not outstanding. Naturally, there is a large difference between setting up policy and executing it. This project also faces this challenge. This study revealed the collaboration did not occur as initially planned. In addition, the project relies solely on government funding. The financial aspect was not studied, and the project is small scale. The issues of how to make it self-sustaining and how to expand the dissemination are still open questions. These aspects are complemented by Papers II and III, as discussed above.

To conclude, this dissertation tests, broadens, and deepens knowledge about the diffusion of PV systems in rural context. It presents advantages and motivations to adopt PV systems that can span beyond economic terms. Moreover, it unfolds barriers, factors affecting the adoption decision, and lessons learned in the implementation of PV systems. The diffusion can be enhanced with proper management and this requires thorough understanding of the local contexts. For example, Grameen Shakti's strategy and their characteristics of a social entrepreneur are of immense importance in making them become the largest rural energy company in Bangladesh; the outcome of this study presents the extension of source characteristics that are specific for low-income market. Although the deployment must take local contexts into accounts, the diffusion of PV systems can still be learnt from other cases and there are still several remaining challenges. The importance of collaboration among stakeholders is emphasized across cases in different forms. In Uganda, it shows the collaboration between a foreign actor and various types of local actors. This underlines challenges for a foreign firm from a developed country operating in a developing country. In Bangladesh, the collaboration was within the firm and also between the firm and rural adopters. Within the firm, there is collaboration among various units, e.g. between management in the headquarters and sales and technicians in rural villages. In Thailand, the collaboration among the government agencies and interaction with local people are crucial. In general, the interaction between technology providers and adopters together with the understanding of adopters' perspectives are of importance.

5 Conclusion and implications

The diffusion mechanism of renewable electricity is a highly complicated process, starting with the invention of the technology itself, its introduction to the new market, development of the market from an early to a mature state, and sustainable maintenance. This process is by no means linear but it is rather an interactive loop process with feedback and adaptation. In addition, the transition takes time and requires considerable efforts from and collaboration of various stakeholders. Thus, supporting structures, particularly post-adoption-maintenance, must be available throughout the entire product lifetime.

Rural electrification investigated in this dissertation has a special character because it is a transition to sustainable solutions that bypasses fossil fuels. Thus, path dependency on existing institutions and infrastructures may be circumvented. Through a diffusion framework, the diffusion mechanism of renewable electricity can be better understood. In addition, integration of other complementary concepts has been shown to be valuable in the context of developing countries. To understand the local context, empirical case study is a useful approach.

The empirical cases presented in this dissertation underscore the particular dimensions of rural electrification. The Ugandan case presents a small start-up company from Europe operating in Africa with limited prior experience in development work and shows that a foreign company can be an important player in the rural electrification effort. The Bangladeshi case presents a very large market dominated by one company and reveals that the diffusion of renewable energy, if properly managed, can be effectively undertaken by a private local firm, rather than waiting for full government support or large multi-national corporations. The Thai case discusses a small-scale diffusion in a remote region in Thailand and presents an extreme case that needs full government funding. Together, the findings and implications contribute to the understanding of diffusion of renewable energy in these specific contexts in developing countries. The mechanisms presented across cases can be considered complementary to one another; they are conducted by different kinds of actors in different countries.

Strategies that are successful in one rural setting may not be copied and applied successfully in another context, in line with case-study methodology. Nevertheless, the experience is still valuable, even in terms of cases with very different characteristics. The lessons learned from three case studies provide analytical generalization of the diffusion of renewable energy in rural areas of developing countries. It underscores the varying nature of implementation of new environmental technology in rural context and highlights specific characteristics of each case, which warrants the need for case research. In doing

case study, collecting retrospective information is one usual mean. That is, the information retrieved from the respondents was based on the time the research was conducted and it could change over time. In addition, PV systems are an emerging technology in many countries. Their price and performance can significantly change over a short time. The analysis in this dissertation is timely but may become less relevant in the next few years because of rapid technological change. However, understanding the current situation, especially social aspects, is important and can still be beneficial for future projects because they are embedded in the society and rural contexts. For diffusion research, this retrospective form of study has been widely used. One way to improve this type of research is to conduct the study in the same context at different points of time. However, doing so can be very difficult in reality because of limited time and resources (Flick 2009; Rogers 2003). To complement the qualitative case-study approach, future research could focus on quantitative aspects of the factors affecting adoption or rejection of new technologies. In addition, the long-term consequences of electrification have not been investigated in this dissertation. Future research could investigate the effects of electricity access on local communities from users' perspectives because the outcomes may not always be positive, as discussed in Section 4.2. Such research is important for an inclusive and sustainable approach to electrification.

No single, fast, or straightforward remedy can address the complex nature of diffusion of renewable electricity in rural communities. This dissertation contributes a part to this tremendous puzzle. The following managerial and policy implications may help in overcoming some barriers. They may be relevant for actors who attempt to introduce, disseminate, and manage new energy technologies in rural communities. The proposed implications are drawn from the findings in this dissertation through the lens of SNM literature. The diffusion of sustainable innovations requires shielding and promoting mechanisms (niche protection), aligning expectations, forming networks, and learning (Kemp et al. 1998; Schot and Geels 2008).

Niche protection through public policy

Papers IV, V, and VI reveal the government is an important actor and policy is one of the main barriers or facilitators to the adoption process. Furthermore, Papers V and VI reveal the economic and policy dimensions are important and their interplay can significantly affect the potential of energy technology. This opens up a potential for further research on a quantitative approach to analyse the impact of policy on economic viability of renewable energy.[22] In several developing countries, fossil fuels not only account for most of the energy, but are also subsidized. Originally, the subsidy was intended to favour low-income inhabitants. In reality, only 8% of the fossil fuel subsidies in 2010 benefited the

[22] I have already started working with this topic in two conference papers (Sriwannawit et al. 2014a; Sriwannawit et al. 2014b), which were presented and published in the proceedings of UNESCO sponsored conference on Sustainable Development of Energy, Water, and Environment Systems (SDEWES).

poorest 20% of the population (IEA 2011; Chakrabarty and Islam 2011). Fossil fuel subsidy distorts the market and reduces incentives for adopting renewable energy. It undermines government and industry efforts to transition towards sustainable energy sources (IEA 2013). Governments could undertake a subsidy reform to reallocate fossil fuel subsidies to renewables. The case study in Thailand in Paper IV can be seen as a shielding mechanism by allocating full public subsidy to fund the project. This mechanism may be necessary for forming the niche of sustainable energy in an extreme market. Nevertheless, policy makers should not assume that only financial support is enough. Other complementarities are equally, if not more, important. This aspect is further discussed under network formation.

Expectation alignment

As discussed previously, it may not be assumed that an innovation more economically competitive than its preceding option will be readily adopted. Therefore, actors engaging in the diffusion of renewable energy should not only focus on price but also promote other advantages, which extend beyond measurable economic terms. (Some of these advantages are explicitly addressed in Papers II, III, and VI.) Doing so will help align expectations of adopters concerning the benefits they may gain from adopting renewable electricity. In fact, even if relative advantages may seem obvious, switching costs, such as the feeling of insecurity, habit change, and so on, may cause resistance during sustainable energy transition. In addition, aligning expectations between companies and potential adopters is necessary. Paper II emphasizes that users' expectations must be properly managed and aligned with what a company can deliver and false promises should be avoided.

Network formation

The role of the public sector in niche protection is crucial, as noted previously. Nevertheless, leaving the responsibility entirely on the government, as in the case in Paper IV, is unrealistic if rural electrification targets larger populations. Even though rural markets may not seem attractive for private investors at first glance, this dissertation shows that a private company can earn profit from such markets. To achieve this, a network that can provide supporting functions, such as training and service, should exist. The case study of Grameen Shakti in Paper III reveals the company's relation with other Grameen companies is beneficial in disseminating PV systems. For foreign companies, networking with local actors, for example, university and opinion leaders, is crucial, as presented in Paper II. A foreign company can provide 'out-of-the-box' insights and generate new ideas to make it competitive.

Learning process

Because of the importance of adopters' perspectives, actors engaging in rural electrification should try to understand local contexts; and their strategies should be adapted to local communities. As revealed in the Bangladeshi case study, such

adaptations may be in terms of product design, payment schemes, and business approach, all of which are the outcome of a learning process. Once critical mass of adoption is reached, the diffusion tends to be less difficult and can continue with less effort. Nevertheless, a constant learning process and insights into local markets are still important to maintain the diffusion and have sustainable use of the product. Moreover, it should be emphasized that education or training is of immense importance for proper usage and sustainable diffusion of renewable energy. This issue can be more complex for rural electrification efforts than it is in urban markets because rural inhabitants often have lower access to capital and have much lower education levels. Even if the technology may seem simple for most people, it is not likely to be perceived as such among rural inhabitants who have very limited prior experience with electricity. Without education, diffusion of energy technology will not be sustainable.

This dissertation is an aggregate of findings derived from six papers delivered during my PhD work on the diffusion of renewable electricity in rural areas of developing countries. It contributes to the advancement and better understanding of diffusion theory in the contexts of developing countries. Apart from the contributions on managerial and policy implications presented above, it also offers methodological, theoretical, and empirical contributions as discussed in Chapter 4.

In summary, the methodological contribution is a novel bibliometric tool that provides an overview, structure, and explanation of a large research area. This cannot be conducted by manually selecting and analysing the extensive amount of publications. It also reduces subjectivity from selective literature that usually exists in traditional literature review. This method complements traditional literature review and can be applied to any knowledge field.

In this dissertation, the bibliometric method was applied to diffusion research. It provides theoretical contribution on understanding and organizing the structure of the recent development and application of the framework, thereby, making diffusion theory more accessible and easily grasped by other academics. In addition, theoretical contribution of this dissertation is also the application and extension of diffusion theory, which originally initiated from the developed parts of the world, on development context. For example, the category of adopters and source characteristics that are specific for low-income markets were explored. In line with diffusion theory, adopters' decisions are significantly affected by people around them such as peers, opinion leaders, and change agents. Therefore, strategies could be targeted towards the few influential people, which may eventually lead to larger population. Moreover, complementary concepts to diffusion theory in development context are also integrated in case studies in order to explain specific phenomena. It must be emphasized that a technology with superior qualities does not diffuse by itself but requires tremendous effort and collaboration on the part of stakeholders. There are

complex relations, on the one hand, between technology and society and, on the other hand, between technology providers and adopters. Such complexity warrants further investigation.

Three case studies provide empirical contributions in rural energy sector within the low-income segment in developing countries and supplement the relatively less body of literature in the development context. The studies underline the importance of choosing and implementing appropriate strategies for the targeted community, emphasizing tailored solutions that can be achieved through case study research. The involvement of all stakeholders—adopters, local communities, firms, international organizations, financial institutions, and government—is crucial and was presented across cases. In addition, as noted previously, the BOP is a large yet vulnerable market, and the collaboration between public and private sectors can be important. Future research could focus on the collaboration among actors, the institutional aspects, and their interplay.

This dissertation has focused on bringing electrical power to rural areas. Hopefully, this also can be a means to empowering the people in rural communities in many places of the world; but analysing that would take us far beyond the aim of this thesis.

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