An analysis of remote electric mini-grids in Laos using the Technological Innovation Systems approach

Nicola U. BLUM [a], Catharina R. BENING [a], Tobias S. SCHMIDT [b,c]*

[a] ETH Zurich, Department of Management, Technology, and Economics, Chair of Sustainability and Technology, Weinbergstrasse 56, CH-8092 Zurich, Switzerland

[b] ETH Zurich, Department of Humanities, Social and Political Sciences, Energy Politics Group, Haldeneggsteig 4, CH-8092 Zurich, Switzerland

[c] Precourt Energy Efficiency Center, Stanford University, 473 Via Ortega, Stanford, CA 94305, USA

* Corresponding author contact details: tobiasschmidt@ethz.ch

Published in *Technological Forecasting and Social Change*. (doi: 10.1016/j.techfore.2015.02.002)

Please cite this article as: Blum, N. U., Bening, C. R., & Schmidt, T. S. (2015). An analysis of remote electric mini-grids in Laos using the Technological Innovation Systems approach. *Technological Forecasting and Social Change.*

Abstract

The electrification of the world's rural poor is an important aim of the United Nations. Off-grid technologies, such as electric mini-grids are seen as appropriate solutions. However, their diffusion rate in developing countries is not sufficient to reach poverty reduction targets. In this paper we analyze the case of remote electric mini-grids in Laos, a least-developed country characterized by many barriers to the diffusion of modern technology. We apply the *Technological Innovation Systems (TIS)* approach in order to derive policy recommendations on how to increase the diffusion rate. As the *TIS* framework has hardly been applied to such challenging contexts, we also aim to produce insights for the theoretical advancement of the *TIS* literature. Our analysis, which draws from secondary and primary data collected through field work, points to two systemic root causes for the low diffusion rate: institutional mismatches within and across geographical levels as well as hampered flows of resources across these levels. Based on these findings we derive policy recommendations proposing to formulate a national technology-specific electrification strategy. In terms of insights for the *TIS* community, we suggest to strengthen the role of culture in empirical *TIS* analyses and to extend the definition of one specific *TIS* function.

Keywords: low-income country; rural electrification; local technology diffusion; technology transfer

1 Introduction

The electrification of the world's poor is one of the major aims of the United Nations' Sustainable Energy for All Initiative [1]. For least developed countries (LDCs), the development and diffusion of rural off-grid electrification technologies is understood to be an effective means to achieve this aim [2–4]. Specifically electric mini-grids carry a high poverty reduction potential as they can provide for productive use of electricity [5–7]. In case these grids are powered by renewable energy sources (such as hydro or solar energy), they are also in line with the global warming target of two degrees [8]. Despite these upsides and the fact that renewable off-grid technologies often bear lower costs than the baseline technologies [2,9], their current diffusion rates in developing countries are not sufficient to reach poverty reduction and global warming targets [10]. Therefore analyzing the dynamics behind the innovation and diffusion of renewable energy-based electric mini-grids, especially in LDCs, is highly relevant.

The literature has shown that innovation and diffusion processes of (modern) technology in LDCs is hampered by several factors (compare [11]), amongst others: a lack of human skills or technological capabilities [12]; under-developed infrastructure hampering the exchange of technical and other resources [13]; low income levels affecting the technology affordability [14,15]; regulations that hamper entrepreneurship [16], and low institutional stability (including corruption) increasing investment risks [17,18]. While each of these barriers can contribute to the low diffusion rate of mini-grids in LDCs, the innovation systems literature stresses the role of the interaction of such barriers and of systemic bottlenecks or system failures.

In this paper we therefore apply the framework of *Technological Innovation System (TIS) and its functional* approach. It has proven to deliver valuable insights into the development and diffusion of specific technologies as well the (sometimes systemic) bottlenecks hampering their innovation and diffusion, both being helpful for deriving policy recommendations [19–21]. Though the framework is universally applicable [20,22,23], it "has had a limited practical application in the global south so far" [21]. Hence, by applying the *TIS* framework in an LDC context, we do not only aim to generate practical insights on how to foster the diffusion of rural mini-grids, but also to further develop the theoretical *TIS* literature.

Our paper's geographic scope is the Lao People's Democratic Republic (Lao PDR, or Laos). It is characterized by the aforementioned LDC-typical innovation-hampering circumstances, as these numbers illustrate: The average literacy is 76% (men) and 53% (woman). In rural areas 32% of men and 53% of women never attended school [24]. Laos ranks 147 out of 162 countries in the ArCo technological capabilities ranking [13]; 131 of 160 in the 2014 World Bank Logistics Performance Index measuring transport infrastructure quality [25]; 160 of 174 in Transparency International's 2012 Corruption Perceptions Index [26]; and 163 out of 185 in the World Bank's 2013 Ease of Doing Business Report's ranking [16]. Additionally, Laos is characterized by a high ethnical and cultural diversity [27].In the remainder of this paper, Section 2 reviews the *functional approach to TIS* and specifically the existing literature applied in developing countries. Section 3 briefly introduces the case, i.e., the mini-grid technology and Laos, and describes our methodological approach. Based on the results described in Section 4, Section 5 derives policy recommendations and implications for the academic debate. We conclude with Section 6, summarizing the key policy recommendations.

2 A review of the TIS framework and its application in developing countries

The *innovation system (IS)* literature has its roots in evolutionary economics and theories of interactive learning. Depending on the investigated object, researchers have distinguished between national/regional, sectoral, and *technological innovation systems (TIS)* [28–30]. The *TIS* framework is frequently used to analyze systemic challenges regarding a specific technology's innovation and diffusion. Carlsson and Stankiewicz ([31], p.93) define a *TIS* as a "dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology." *Actors*, *networks*, *institutions*, and the *technology* are also referred to as the *structural elements* [23].[1]

Table 1 – Definitions of *functions* based on Hekkert et al. ([22], p. 586f) and Bergek et al. [23]

Function	**Definitions**
F1 Entrepre-neurial activities	Entrepreneurial activities encompass all actions that entrepreneurs take to "turn the potential of new knowledge development, networks and markets into concrete action to generate and take advantage of business opportunities." [22, p. 421]
F2 Knowledge development (learning)	The function knowledge development (learning) encompass all activities where learning takes place. It includes 'learning by searching' and 'learning by doing'.
F3 Knowledge diffusion	Knowledge diffusion encompasses the exchange of information within, and between networks. "The function captures the breadth and depth of the knowledge [...] and how that knowledge is diffused and combined in the system" [32]. It includes 'learning by interacting' and 'learning by using'. The latter can apply for example to networks between users and producers.
F4 Guidance of the search	Guidance of the search describes all activities "that can positively affect the visibility and clarity of specific wants among technology users." [22, p.423]It encompasses e.g. policy goals, but also expectations by the public or statements of opinion leaders.
F5 Market formation	The function market formation encompasses all activities that take place to form a market for the technology. Such activities can be taken by e.g. governments through the implementation of a favorable tax regime but also by other agents in the innovation system.
F6 Resource mobilization	The function resource mobilization describes activities which are undertaken to access and secure human, financial, and natural resources.
F7 Creation of legitimacy	Creation of legitimacy encompasses activities that are undertaken to increase the acceptance of a technology. This can, for example, be important in the case where an incumbent regime hast to be overcome.

The *TIS* literature has been further developed by introducing the concept of *functions*[2], which aims to identify bottlenecks in the diffusion of one technology in (typically) one country and to derive policy recommendations

[1] The central element, the *technology*, is defined by Bergek et al. ([23], p.408) as "material and immaterial objects [soft and hardware] […] used to solve real-world technical problems," and complemented by the concept of orgware [22]. *Actors* encompass all entities/agents that are (passively or actively) involved in the diffusion of a technology, while *networks* refer to the intermediate forms of organization that serve to exchange information and other resources [31]. *Institutions* refer to regulatory, normative and cognitive aspects that affect the *actors* and thereby the technological development [31,125,126].

[2] The concept of *functions* has originally been introduced by Carlsson and Jacobsson [127] to the *(T)IS*. Bergek et al. [128] defined a set of seven functions which was also published in the context of developing countries [37] . The in this research used definitions of the seven functions by Hekkert et al. [22] originate from this research stream. They are the outcome of a

[22,23,33,34]. The *functions* (compare Table 1) refer to core processes in a *TIS*, complementary to the *structural* components. Bergek et al. ([23], p.409) state that *functions* "focus on the dynamics of what is actually 'achieved' in the system rather than on the dynamics in terms of structural components only." Therefore, they are also referred to as *dynamic elements* of a *TIS*.

While the *TIS* approach was developed based on socio-economic theory [19,35], empirical research played a major role in the refinement of the concept. As the *functions* are an emerging concept there is no complete agreement on the set of *functions* and their definitions [19]. In our analysis, we rely largely on Hekkert et al. [22] and Bergek et al [23] as their definitions (see Table 1) are the outcome of a longstanding academic exchange between researchers from Sweden and Holland.

The general *IS* literature theoretically and empirically incorporates developing country contexts. E.g., Lundvall et al. [11] tackle the link between innovation and development, address *geographical* aspects, including *regional*, *national*, and *international* levels, and investigate *institutions* and policy making for development. Malerba and Mani [36] describe actors, structures, and dynamics of sectoral innovation systems on the examples of various developing countries. Jacobsson and Bergek [37] introduce the *IS* and *functions* to development studies and argue that an *IS* in a developing country focuses on catching up rather than on "new to the world" innovations. In the *TIS and functions* research, empirical analyses outside high income countries are however seldom. While Bergek [19] recently provided a comprehensive review of empirical studies using the *functional approach to TIS*, our literature review focusses on studies applying *TIS* analyses in developing countries. Out of the six identified studies (see Table 2), two focus on large industrializing economies, and the other three [21,38,39] on low-income countries, analyzing cook stoves and bio digestion.

Table 2 - Empirics on TIS and functions in a developing country context [a]

Authors, Year, Reference	Technology	Geographical Context
Agbemabiese et al., 2012 [38]	Improved cook stoves	Ghana
Binz et al., 2012 [40]	Onsite wastewater treatment	China
Liu and Kokko, 2012 [41]	Neighborhood electric vehicles	China
Schmidt and Dabur, 2014 [42]	Large biogas	India
Tigabu et al., 2013a [21]	Bio digestion	Rwanda
Tigabu et al., 2013b [39]	Bio digestion	Rwanda and Kenya

[a] Four additional papers using the *functions* framework in developing countries were identified [43–45], however, they apply the *functions* to several technologies or entire sectors and not to single technologies, as originally intended by the *TIS*, or focus on one specific *function* [35], only.

Our literature review illustrates the lack of empirical *TIS* studies in developing countries and specifically LDCs. By providing a new empirical *TIS* analysis in an LDC, we aim at deriving policy recommendations for the concrete case but also at contributing to the theoretical advancement of the *TIS* framework. Recently, Bergek [19] as well as Truffer and colleagues [20] identified some shortcomings of the framework. Bergek [19] focuses on the theoretical advancement of the *functions* concept and highlights the yet to be stabilized set and definitions of the *functions.* Truffer et al. [20] focus on the specific empirical field of energy-related *IS* to identify current

longstanding academic exchange between researchers from Sweden and Holland. Currently, there is no agreement in the *TIS* research community on whether *functions* are defined as processes or activities [19]. In our study, we will refer to *functions* as processes [23].

shortcomings. Among other things, they highlight the need to better incorporate *geographical* aspects in *IS* research (see e.g., [35,46–48]). While empirical research typically differentiates between *international* and *national* (or *regional*) levels [40,42,49] the *local* level has – apart from recent work by Dewald and Truffer [49] – mostly been neglected in the *TIS* research so far. Yet, this level seems to be very relevant for many TIS especially in developing countries: Research analyzing technology diffusion and innovation in developing countries based on the *Multi-Level Perspective* or the *Strategic Niche Management* frameworks has highlighted the role of the *local* geographical level and its interaction with other geographical levels (see e.g., [50–52]). The little empirical research on *TIS* in LDCs [21,39] also supports the role of the different levels. What makes mini-grids an interesting and new case (compared to previous *TIS* studies in LDCs) is their relatively high complexity in terms of use and maintenance at the local level. Innovation and diffusion of technologies are not independent from the socio-political context in which they take place [53,54] – especially for novel and relatively complex technologies [55–57].

3 Research case and methodology

3.1 Introduction to the case: Mini-grids in Laos

The mini-grid *technology* evolved in the 1980s in developing countries other than Laos when energy authorities realized that a centralized electrification approach, which until then was the dominant strategy (in both industrialized and developing countries), is often not the most economic option for electrifying remote areas [58]. As a consequence, less costly technologies evolved, among them mini-grids.

Our paper follows the World Bank's definition of a *mini-grid* as an isolated (i.e., off-grid), small (5 to 200kW) electricity grid which powers a rural village [59][3]. We focus on electric mini-grids based on renewable energy. A mini-grid's core components are the power source(s), synchronizers, transformer(s), potentially a back-up battery bank, switchgear, inverters and transformers, the software balancing load and supply, and wiring. While mini-grids typically serve a single purpose – to provide electricity to a village's households and other consumers (e.g., workshops) – no single standard design exists, as each mini-grid has to be adjusted to the context in which it is implemented [60]. While mini-grid technology has progressed over the last years (especially profiting from developments in electronic power switching, renewables and battery technologies), some technological challenges remain, such as increasing the reliability of the used components and balancing demand and supply in case of extreme events such as unusual weather events [58,61]. In order to resolve these issues, learning by doing and using are highly important. In addition, research into decreasing system costs is currently ongoing. An international community of researchers is addressing technical as well as economic, social, and political questions in theoretical studies (see, e.g., [62–64]). This community meets e.g., in specialized conferences [65–67], where researchers and practitioners share lessons from implemented projects (see, e.g., [47,61,62])..

[3] Frequently used power sources are diesel generators, micro hydropower plants, wind power plants, biomass gasifiers, solar PV power plants or a combination of these (the latter is referred to as a hybrid system). The choice of the power source depends on the availability (and cost) of natural resources.

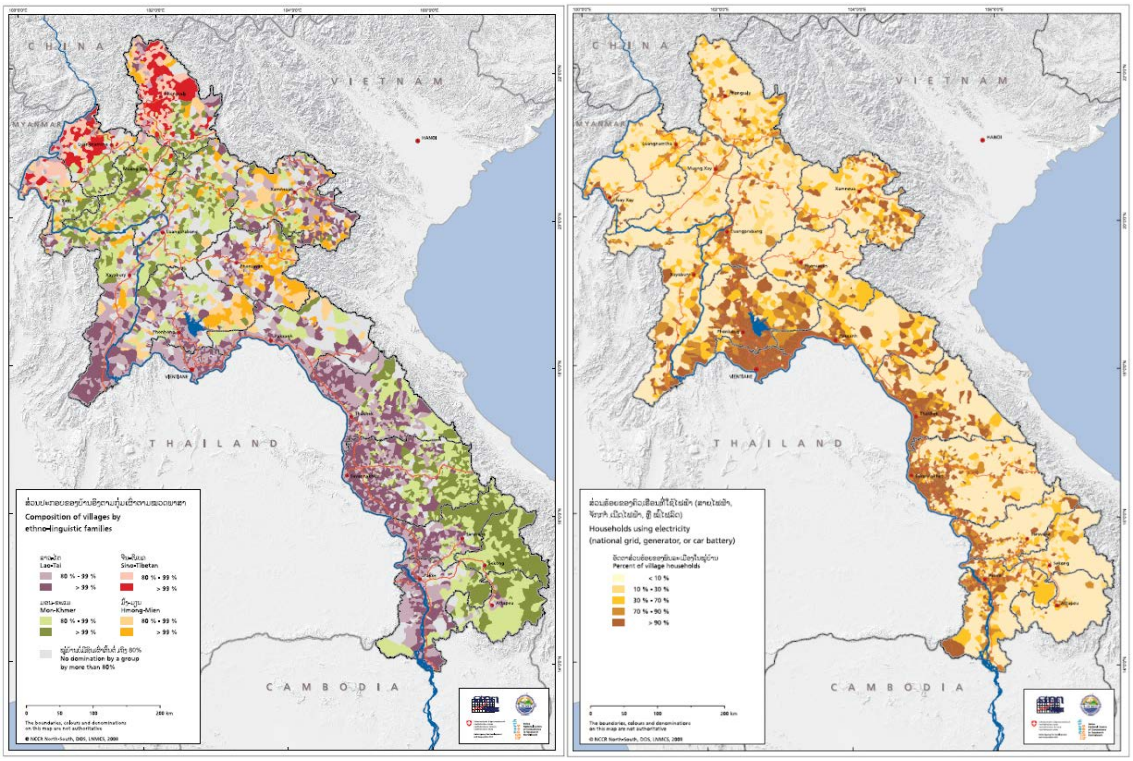

Figure 1a/b – Comparison of Laotian villages by ethno-linguistic groups (1a, left) and electrification rates (1b, right) in 2005 [70]

Laos is a relatively small (236,800 km^2), land-locked, mountainous South East Asian country with about 6.5Mio. inhabitants in 2012 [71]. Its population is characterized by multiple ethnicities, religions, and languages spoken (see Figure 1a). About 26% of its rural population live below the national poverty line (2010 estimates by [71]). Together with a GDP per capita of 1,338 USD/year in 2012 [72] this puts Laos in the category of LDCs [73]. Formerly a closed economy, Laos has become more market-oriented since adopting the "New Economic Mechanism" in 1986 and since allowing foreign investments in the 1990s [74,75]. Laos understands the provision of electricity as a major requirement to reach its envisioned development goals [76]. Today, the electricity sector is dominated by the state-owned electricity utility Electricité du Laos (EDL) operating under the Ministry of Energy and Mines (MEM) and controlling the grids as well as most power plants[4].

Laos managed to increase its electrification rate from 15% in 1995 to 73% in 2011 but the rate varies strongly across the country's regions (in counts of electrified households, compare also Figure 1b). The government aims to reach a 90% electrification rate by 2020 through grid extension, resettlement of villagers, and off-grid solutions [76,77]. Of these 90%, the government's current aim is to provide 81% of the population with grid electricity and 9% with off-grid solutions, namely in very remote and sparsely populated areas [78].[5] But while

[4] There are three major regional grids (the Northern, central, and Southern grid) which are not yet interconnected in a national grid but are projected to be so in the future [129]. In 2008, Laos' own electricity production (consisting of 97.3% hydropower and about 2.7% fossil fuels) was complemented by Thai and Vietnamese electricity supplies [91,129]. The import surplus might in future turn to an export surplus, as investors from Thailand are currently building a large hydro dam in Laos, which exclusively provides power to the Thai grid. For more information on this controversially debated project see, e.g., [130].

[5] Grid extension is a costly solution with estimated costs of 11,000 to 15,000 USD/km [77,91]. Therefore, in many geographical areas it is more expensive than off-grid solutions such as solar home systems or mini-grids [91].

for these 9% several (competing) electrification plans exist, no electrification plan has been developed for the remaining 10% of the population (comprising thousands of villages) [76,78,79]. Thus far, the investments in rural electrification have been managed by the Rural Electrification Division (RED) under the Ministry of Energy and Mines (MEM). Donations for rural electrification are to a large extent provided by international donors such as development agencies, international organizations (IOs), such as the World Bank and Asian Development Bank ADB), and non-governmental organizations (NGOs) [80]. There is no official strategy to develop mini-grids, nor are there any related statistics. Through our field research and review of the literature, we identified about 68 installed renewable mini-grids in Laos[6] indicating that mini-grids diffuse in Laos, although only to a limited extent compared to other LDCs, like Nepal.

3.2 Methodology

Following Yin [81] we apply a qualitative single case study design, using an iterative process in collecting and analyzing data. For our analysis we drew from primary data sources (such as semi-structured interviews and on-site observations of a mini-grid which we obtained during two stays in Laos in 2010 and 2011) as well as from existing literature such as reports, policy documentation, and other documentation (compare [82]). Specifically, we proceeded in seven steps described in Appendix A. Previous *TIS* research in LDC contexts [21,39] suggest that the diffusion rate of a technology is related to the accumulation of *functions*. We build on this notion and use the *functional approach to TIS* primarily to analyze the diffusion dynamics of mini-grids in Laos, while at the same time taking into account the innovation dynamics of the technology which mostly occur outside of Laos. For the definitions of the functions, we largely rely on Hekkert et al. [22] and Bergek et al. [23] see Table 1). In our analysis we do not take a historical perspective, as most of the technology's evolution thus far happened outside of Laos (compare 3.1). Instead we focus on the situation in the very recent years, since several installations of mini-grids in Laos are on the ground.

In our sampling of interview partners, all relevant stakeholder groups in the Laotian mini-grid *TIS* have been covered in order to get a complete picture of *actors*, *institutions*, *networks*, and the *technology* as well as the processes in the *TIS*. The created sample of interviewees is representative for the three levels involved, the *local*, *national*, and *international* levels. Table 3 provides an overview of the interviewees; the stakeholder group they belong to and the *geographical level* at which they operate, as well as a stakeholder code. This code is used in the results section to indicate the source of interview findings. Whenever insights stem from the literature analysis we reference the original source.

To analyze the collected data, we structured the information via coding. Throughout this process, we followed an explanation-building logic which is applicable to both explanatory and exploratory contexts. A defining characteristic of such logic is its iterative character, the consideration of rival explanations and the opportunity to examine the evidence from perspectives other than the one initially defined [81]. For our analysis we used the software Atlas.ti. We applied a code list including all *structural* and *dynamic* elements of the *TIS*, and the three *geographical levels*. The list of codes was extended along the coding process whenever a peculiarity was not covered by the codes [83]. Among these, we concluded that "culture" was the code most prominently lacking in

[6] Different sources estimate that between 31 and 68 renewable energy-based (and 46 diesel-based) mini-grids have been installed in Laos. However, it was not possible to determine how many are still operational ([78,79,129,131,132], PRV, PUB).

the existing set of codes derived from empirical *TIS* literature. Based on the coding of all interview transcripts from Laos, we identified bottlenecks in the *TIS*.

Table 3 – Overview of interviewees

Stakeholder group	*Code*	Person	Interviewees	*Geographical level*
Private sector (companies)	*PRV*	1	Director of a private Laotian company	*national, international*
		2	Communications manager at a Laotian private company	*national*
		3	Village technician, Laotian, male	*local*
		4	Renewable energy consultant	*international*
		5	Impact investor	*international*
		6	Project manager at a clean energy investor	*international*
		7	Regional manager at a clean energy investor	*international*
Public sector (Government)	*PUB*	1	Head of the RED at the MEM	*national, international*
Development cooperation sector (non-governmental organizations NGOs, international organizations IOs, development agencies)	*DEV*	1	European project manager in a development agency based in Laos	*national, international*
		2	European project manager in an NGO based in Laos	*national, international*
		3	Laotian project manager in an NGO based in Laos	*national, international*
		4	Regional renewable energy expert in an IO	*national, international*
		5	Regional mini-grid expert in a development agency based in South East Asia	*international*
Villagers	*VIL*	1	Hmong, female villager 1	*local*
		2	Hmong, female villager 2	*local*
		3	Laotian, male villager & technician	*local*
		4	Laotian, female villager	*local*

4 Results

This section presents our findings on the structural (Section 4.1) and dynamic (Section 4.2) elements of the mini-grid *TIS* in Laos. In both subsections, the findings touch upon the three *geographical levels* where relevant. Finally, we summarize the systemic root causes of the identified bottlenecks in Section 4.3.

4.1 Structural elements

The structural elements of the *TIS* comprise the *technology*, the *actors and networks* as well as the *institutional* settings [84]. The *technology* has been described in Section 3.1; the following paragraphs summarize the two remaining building blocks.

4.1.1 Actors and networks

We identified actors from the private sector, the non-profit sector, the public sector, and villagers. Table 4 provides an overview along the *geographical levels*. Different actors can be found at the *international* level, with the majority having a development-cooperation background. On the *national* level, the government and its sub-

units are the central actor; but there is also a small private company, a few research institutes, and NGOs. *Locally*, villagers – acting as both electricity consumers (customers) and partly as technicians – are the only actor group. In the subsequent paragraph we explain how the different actors are interrelated.

Networks on *international* levels are strong but mainly exist within or between developed countries. Networks between the *international* and *national* levels are based on work visits (e.g., consulting, technical implementation) and local representations of international NGOs in one direction and educational visits (e.g., national government representatives participating in international conferences or studying abroad) in the other direction. On the *national* level, there are formal networks such as the organizational structure within the MEM, which includes reporting, or project-based links between private companies and development-oriented organizations. At the same time, as most national actors live in the capital city Vientiane informal networks exist (which are more difficult to identify). Turning to the *local* level, we find that while international actors seem to be well connected to national actors and the national government formally interacts with villagers, e.g. through regulations, international actors are barely connected to local actors. The only exchange here occurs during the limited time of the implementation of a mini-grid. Within the *local* level, the villages have a strong sense of community and usually own a village council. Through relatives, single villages are connected to other villages and the towns, but those networks are typically limited to people of the same ethno. The lack of infrastructure together with the mountainous geography further limits this exchange.

Table 4 – Actors and networks in the Lao mini-grid *TIS*

	International level	***National level***	***Local level***
Actors	Private companies – Project-based working companies – Technology suppliers International organizations (IO) – World Bank & International Finance Corporation (IFC) – Asian Development Bank Development agencies – JICA, NEDO (Japan) – NORAD (Finland) Nongovernmental organizations (NGO) – Helvetas (Swiss) – Fondem (French) Research Institutes – Swiss Federal Institute of Technology – Finland Future Research Center – Université Paris-Sud	Private company – Renewable energy company Governmental units – Ministry of Energy and Mines (MEM) – Rural Electrification Division (RED) – Provincial Department of Energy and Mines (PDEM) Nongovernmental organizations (NGO) – National branch of Helvetas – PORDEA (Lao) Research institutes – Lao Institute for Renewable Energy (LIRE) – Local branch of the Finland Future Research Center	Villagers (Consumers, Technicians)
Networks	Within developed countries – National network for rural electrification in the development community, e.g. REPIC in Switzerland	Formal networks – The sub-organization of MEM which tackles rural electrification	Between neighboring villages – Through relatives and traveling merchants of the same ethnos

<table>
<tr><td rowspan="3"></td><td>Between developed (and to a limited amount developing) countries.

– International networks for rural electrification, e.g. Alliance for Rural Electrification</td><td colspan="2">Informal networks (difficult to identify)

– Most national actors live in the small capital city Vientiane and know each other</td><td>Within a single village

– Village community (village council)</td></tr>
<tr><td colspan="2">Between Laos and other countries. Exemplary:

– Through single international actors (see above) and their work visits in Laos
– Through educational travels by Laotian government representatives</td><td colspan="2">Between the Laotian government and villagers

– Network of regional governmental representatives</td></tr>
<tr><td colspan="4">Between international actors and villagers barely exist connections</td></tr>
</table>

4.1.2 Institutions

On the *international* level, there are no binding regulatory institutions which are relevant for mini-grids in Laos; however, international normative and cognitive (i.e., cultural) institutions are relevant in that it is regarded to be the developed countries' duty to support developing countries (e.g., as documented in the Millennium Development Goals) and as embodied in current thinking that market-based solutions can best address many of today's development challenges. At the *national* level, foreign support for development is welcomed in Laos (*PUB*), especially as Laos aims at lifting itself out of its LDC status. At the same time, Laos has a communist tradition and remains a single party-ruled socialist republic [74,85]. Values such as universal equality and the importance of community (collectivism) – values which are perceived to be in contrast to individuality and entrepreneurship – are promoted and prominent [74,85]. While Lao is the official national language, 80 different local languages are spoken in the countryside [74]. In terms of national regulation, only a few indirect policies exist which support mini-grids (*DEV*); on the contrary, mini-grids are negatively affected by the bureaucratic and often in-transparent process for obtaining permits (*DEV*) and high levels of corruption [26]. On the *local* level, national regulation applies. However, normative/cognitive aspects of institutions differ from national ones and often even from village to village, due to different ethnos [74,85]. While national educational levels are low, they are even lower in rural areas [70]. *Local* people largely lack language skills besides their native tongue, which is seldom Lao [74,85]. In addition, though purchasing power is generally low the villages differ in their poverty levels, income-generating activities, and entrepreneurial spirit (among other characteristics) ([74,85,86], *DEV*). Then again, they appear to be united in their conviction that grid electricity is more reliable than mini-grid-based electricity and that the government (as the general "caretaker" for infrastructure) will provide them with access to (grid) electricity (*DEV*). Table 5 provides an overview of the relevant institutions along the *geographical levels*.

Table 5 – Institutions in the Lao mini-grid *TIS*

	International level	***National level***	***Local level***
Institutions	Regulatory – No binding regulations Normative and Cognitive (i.e., cultural) – "Duty" of developed countries to support developing countries, e.g. Millennium Development Goals – Market-based approaches to support development in developing countries	Regulatory – Few indirect policies to support mini-grids, however lack of implementation – Bureaucratic and in-transparent processes to obtain permits – High corruption levels Normative and Cognitive (i.e., cultural) – Lao expects foreign development support – Communist tradition and single-party ruled socialist government foster national values such as universal equality and importance of community (collectivism)	Regulatory – National regulations Normative and Cognitive (i.e., cultural) – Most normative and cognitive institutions differ strongly from village to village due to different ethnos (e.g. entrepreneurial spirit, 80 different local languages). – Few normative and cognitive institutions are similar between villages (e.g. the villagers' belief that grid electricity is more reliable than mini-grid electricity)

4.2 Functions (dynamic elements)

After having described the building blocks of the *TIS* for mini-grids in Laos, we now turn to the *functions*.

4.2.1 Entrepreneurial activities (F1)

While in other developing countries, the relatively successful diffusion of mini-grids has mainly been driven by rural entrepreneurs [58], in Laos private sector engagement in constructing and operating mini-grids is limited. On a *local* (village) level, entrepreneurial experience with mini-grids and related technologies are lacking (*DEV*, *PRV*). This has mainly institutional reasons: In the prevailing communist thinking, entrepreneurial spirit is not solicited, and the state is expected to be the centralized supplier of infrastructure ([74,85], *DEV*). Hence, the extant mini-grid pilots have been (often completely) installed and/or heavily supported by international partners (e.g., by international development agencies) ([87], *DEV*, *PRV*). Due to an unfavorable national investment environment with high regulatory uncertainty [16] and high levels of corruption [26] international private investors often refrain from investing in (rural) Laos (*PRV*). Summarizing, the regulatory environment is a hurdle for international investors (see above) and hinders local business undertakings ([16], *PRV*).

4.2.2 Knowledge development (F2)

The mini-grid technology is mostly developed in OECD countries such as Germany, Switzerland or the US, but also in several non-OECD countries such as China or Nepal, i.e., at the *international* level (*DEV*, *PRV*, *PUB*). Also most knowledge on economic, managerial, and social aspects of mini-grids is developed *internationally* [60,62–64,88–90]. Despite the existence of a small Laotian Research Center (LIRE), technical knowledge development is lacking on the *national* and *local* levels; even if the technology is applied locally, once installed it is mostly not further developed or adapted (*DEV*). Only very limited local knowledge development takes place with regard to managerial and social aspects, e.g., consumer needs specific to each village (*DEV*, *PRV*). Such

local knowledge development is partly based on learning by doing as each mini-grid's technological system has to be strongly adapted to local circumstances. Learning by using the technology could massively improve the technology (*DEV, PRV*). At the same time, villagers often lack the basic knowledge necessary to allow for such learning. Hence, the learning feedbacks from using the technology *locally* to the re-engineering process on the *international* level are limited (*DEV, PRV*).

4.2.3 Knowledge diffusion (F3)

Knowledge is embedded in technology, written documents, and people; it travels with them within and between *geographical levels.* Additionally, networks are important for knowledge diffusion [22]. As discussed in Section 4.1, the networks are relatively strong between the *international* and *national* level, but the *local* level is not well connected to either of the other two. On the local level, while knowledge within villages is exchanged through word of mouth (*VIL*), the knowledge networks often do not go beyond single villages due to language barriers (see Figure 1a). *Internationally* developed knowledge of operations, management, and usage of mini-grids is diffused through training of local technicians and villagers (*DEV, PRV*). Much of this knowledge is forgotten though (*DEV, PRV, VIL*) mainly due to the institutional setting, e.g. the villagers' low educational levels paired with too few training units or manuals which technicians do not understand (e.g., because of language issues) (*DEV*). At the same time knowledge transfers from the *local* level – e.g., about consumption patterns – to the *international* level (*DEV*) are lacking. Such knowledge flows to suppliers would support the technical development of mini-grids and the replication of successful operations and management approaches, which are crucial for market formation [49]. The bottlenecks in the mutual exchange between the *international* and the *local* level stem in large part from (a) the villagers' low levels of education, lacking English skills, the weak infrastructure (e.g., no access to information and communication technologies) (*DEV, PRV*), and (b) the international actors' lack of understanding of and adaptation to the different languages, and heterogeneous customs across Laotian villages. Even if first attempts in acquiring international knowledge are promising (*DEV, PRV, PUB*), an organizational unit that can serve as an entity absorbing and storing knowledge, and making it accessible to actors on the *national* and *local* level, is missing.

4.2.4 Guidance of the search (F4)

As resources in Laos are scarce, resource transfer from the *international* level is a prerequisite for the functioning of the mini-grid *TIS*. Therefore, the *international* level has a strong guiding role through (a) financial resources (in the form of donation, grants, and soft loans), and (b) non-financial resources (e.g., in the form of capacity building or policy making support). Simultaneously there is strong competing international guidance for alternative technologies, i.e., grid extension or SHS [78–80]. This results in a lack of clear guidance (*DEV*). On the *national* level the government plays a central role and could potentially provide such clear guidance (*DEV, PRV, PUB*). But then it acts rather opportunistically by accepting financial support for all kinds of electrification concepts from international donors (e.g., the World Bank-funded Rural Electrification Master Plan strongly favors grid extension and SHS [77,91] or the resettlement of the rural population into towns with grid access ([92], *DEV*)). This lack of a clear technology strategy results in a discontinuity and inconsistency in the guidance of the search (especially as many international donors only provide support once for a single locale) [77]. On the *local* level, knowledge of electricity and its benefits diffuses to villagers by learning from acquaintances or

relatives living in town (*F3, F5*). However, villagers barely become informed about the different solutions (mini-grid, grid extension, SHS), and their advantages and disadvantages (*DEV, PRV)*. This often results in high expectations for any electrification approach (including mini-grids), e.g., in terms of reliability (*DEV, PRV)*.

4.2.5 Market formation (F5)

At present, the mini-grid market in Laos is in its "nurturing phase" (compare [93]), such as the entire mini-grid *TIS* in Laos. While international actors provide grants and donations for initial technology investments, and capacity building, they do not engage as financial build-own-operate (BOO) investors due to the unfavorable investment environment ([16], *DEV, PRV)*. This often results in pilot mini-grids with relatively low tariffs (*DEV, PRV)*, which in turn affects the other villages' – electrified or not – willingness to pay cost-covering electricity tariffs. In conclusion, international actors (unintentionally) do not support the formation of a self-sustaining market. National actors, most of all the government, would have the rationale to support the formation of a mini-grid market as economic calculations reveal it as the financially favorable electrification solution in remote areas [77,91]. The government, however, does not have a stringent strategy to foster mini-grids (compare *F4*). On the *local* level the demand for electricity depends on the size of the tariff and the villagers' knowledge of the benefits of electricity (willingness-to-pay, *F3*) (*DEV, PUB, VIL)*. A study by the World Bank revealed that the rural population is willing to pay about 0.13 USD/kWh [77], which is typically enough to cover the costs of mini-grid-based electricity generation [60,77] but more than triple EDL's current tariff of 0.04 USD/kWh [94]. On the contrary, the general willingness-to-pay for mini-grid electricity decreases if tariffs in pilots are low and/or technical problems cause supply bottlenecks (*DEV, PRV, VIL)*. Despite these potential revenues, local markets do not develop, which is related to the lack of entrepreneurial spirit (see *F1*) and the lack of resources (see below). Market formation based on "trust-based communication patterns" among users ([49], p.407) is geographically limited to one ethno, which often corresponds to single villages due to the high cultural diversity in rural Laos. Also the communication between villagers (i.e., the users) and the suppliers of technology is limited due to the lack of infrastructure, and language barriers, limiting the local market formation. Typically international NGOs and engineers planning and erecting the grids act as intermediaries. However, their stays in the villages are often short and their knowledge of local languages and customs limited.

4.2.6 Resource mobilization (F6)

On the *national* and *local* levels, human and financial resources are scarce (*DEV, PRV*). Laotian engineers and technicians are lacking in rural as well as urban areas [76]. On the positive side, the local manual labor force is theoretically abundant (*PRV)*. As for financial resources, a weak private financial sector exists on the *national* level; in addition, villagers typically do not have access to banks and have to rely on informal capital markets, which are also limited in financial power (*DEV)*. Furthermore, public financial resources are scarce and potential spending for electrification competes with other issues. Hence, Laos' electrification depends to a large degree on international resources (*PUB)*. International financial and human resources, however, are subject to high competition between different electrification approaches (mini-grid, grid extension, SHS, etc.), various

organizations in Laos[7], and developing countries and other topics in international development support (*PRV, PUB)*. This competition results in a lack of continuity of financial resource supply in the Lao mini-grid *TIS*.

4.2.7 Creation of legitimacy (F7)

Mini-grids' legitimacy is based on different factors depending on and varying between the levels. The general international community acknowledges mini-grids as promising solutions to rural electrification in developing countries [58]. However, despite their clear limitations in terms of poverty reduction [4,95,96], other technological solutions also enjoy a good reputation with many organizations [3,78,79]. *Nationally*, focusing especially on the government, mini-grids have low legitimacy ([77], *DEV, PUB*). This is a result of the government's tendency to follow their biggest donors' current strategy of trying to foster grid extension and SHS (compare *F4*). On the *local* level, mini-grids are legitimate as long as they offer reliable and affordable electricity ([77], *DEV, PRV, VIL*). But as the villagers' conviction is to trust the state as provider of the best solution, the *national* lack of legitimacy for mini-grids has spread to the *local* level, resulting in a local belief that grid electricity is more reliable and affordable than electricity supplied by mini-grids [77,87]. However, villagers have incomplete information on the reliability of the Laotian grid, which is in fact technically not more reliable than mini-grids (*DEV, PRV*). This misperception seems to be prevailing in several developing countries [97–100] .

4.3 Systemic root causes for bottlenecks

Other than a barrier analysis, the *TIS* approach encompasses the capability to identify systemic roots of these bottlenecks and to derive systemic policy recommendations [101,102]. While we described individual bottlenecks and how they affect each function in 4.2, systemic problems affect several *functions* of a *TIS* and thereby the innovation and diffusion process. In the following, we elaborate on the systemic problems we encountered in the mini-grid *TIS* in Laos.

One of the most important empirical observations that affects several functions is that the institutional settings (such as regulations, dominant convictions, expectations or beliefs) of the mini-grid *TIS* differ strongly across the three *geographical levels*. On the *national* level, the most decisive institutions – besides the communist heritage and Buddhist tradition – are arguably regulatory ones. While the government aims at economic growth and development, it is hesitant to implement and support policies that attract and support private investors and entrepreneurs. Furthermore, the regulatory actors display low technological capabilities and a reluctance to choose mini-grids as the appropriate technology for the electrification of the (at least) 10% non-electrified population outside of the grid range. Despite mini-grids' advantages over alternative technologies, national regulators indiscriminately support technologies of all kinds. Hence, the regulatory institutions on the *national* level remain weak (mostly affecting *F4* and *F7*). On the *international* level, the thinking that LDCs need external support to induce economic growth and development and that such support should foster private sector involvement is consistent across most actor groups. On the other hand, international actors' choice of appropriate technologies, the amount and means of resource transfer and the time horizons and scale of support differ widely. This results in technology plans and offers of support that are inconsistent and sometimes even

[7] Organizations compete for skilled employees; better salaries and the organizations' reputation matter and lead to a scarcity of skilled employees in small organizations in the non-profit and private sector.

contradictory (mostly affecting *F2*, *F3*, *F4*, and *F6*). At the *local* level as well, some institutional settings are homogeneous and others heterogeneous: across the country, villagers believe the central state should provide the infrastructure and are rather skeptical of entrepreneurship. Additionally, the general level of education and professional training is low, often leading to unrealistic expectations vis-à-vis electrification on the part of the villagers. The heterogeneity of the institutional settings is of a cultural nature: the many ethnicities, languages, and dialects even within very small areas (compare Figure 1a) make each village a case sui generis. This in turn strongly limits networks, one of the key elements of *TIS*, in their geographical range (compare [35]) (primarily affecting *F1*, *F3*, *F6* and *F7*). Consequently, spillover effects from village to village based on trust and communication, which are crucial in the market formation phase (compare [49]), are hardly observable.

These different institutional settings also reduce the flow of tangible and intangible resources – mainly knowledge – between the three *geographical levels* of the *TIS* in a situation where knowledge is relatively unbalanced between the levels (mostly related to *F3* and *F6*). The cultural heterogeneity of villages hampers knowledge flows on the *local* level, i.e., between villages, as well as from the *international* to the *local* levels and vice versa: As information related to mini-grids comes predominantly from the *international* level and is mostly coded in English or Laotian (not in the many languages that the different villages speak), it is not well received and is often not retained. For their part, villagers are unable to make their needs heard, which can result in a mismatch between local needs and international supply of resources. These lacking flows of knowledge consequently dampen systems building and market formation dynamics (affecting arguably all seven *functions*). Intensive communication between the various actors in the innovation system (e.g., suppliers and users) has been identified as crucial for the market formation [49,103] but is hampered due to the cultural and geographic distance of actors and the lack of infrastructure. Inconsistent notions of the appropriate electrification technology, villagers' noted attitudes towards the state's responsibility for infrastructure choice, along with the national government's lack of any technology preferences all contribute to great variability in technologies and concepts implemented from village to village. This further reduces the chances of realizing network effects, which undermines the diffusion of mini-grids beyond the demonstration stage.

5 Discussion

This section first discusses practical implications and then derives implications for the *TIS* literature.

5.1 Implications for policy makers and practitioners

In the same vein as Tigabu et al. [21,39], our results point to the fact that building a local *IS* around the technology is critical and should be striven for by policy makers and developing agencies. Instead of deriving recommendations based on the bottlenecks identified in each *TIS* function, in this section we start from the systemic root causes (Section 4.3) and offer suggestions for how mini-grids can be scaled up from demonstration projects through systemic political means (compare [102]). A first root cause was the observation that national regulators indiscriminately support technologies of all kinds. We suggest that a well-informed technology selection based on an electrification-specific technology needs assessment (TNA) (see e.g., [104]) by the Laotian government could help filter the international support offered and thereby increase the likelihood of systems building and economies of scale and consequently the effectiveness and efficiency of international support. While Laos' recently published climate change-related TNA [105] does not cover electricity provision activities,

the development plan [76] just mentions rural electrification without becoming specific in terms of preferred technologies. In other words, a technology preference is not given.

However, selecting one or a limited number of preferred technologies is not sufficient. To facilitate the limited knowledge and resource flows (the second root cause), actors at the *national* level need to take a "translating" role between the different villages as well as between the *international* and the *local* level. Our findings support earlier research in that "knowledge links […] tend to be informal, implicit, relational, and cultural among actors" ([30], p. 27). Consequently, installing a knowledge broker or system-building intermediary is especially important.

Policy measures which intent a systemic effect start with an alignment of the institutional settings as prerequisite for bringing the diffusion of mini-grids beyond the demonstration stage. To this end, Laos needs a consistent technology strategy for electrifying that portion of the population which cannot be electrified via grid-extension cost-effectively. First, an electrification-specific TNA which equitably balances the pros and cons of different electrification technologies and results in the selection of one or a few preferred technology/ies would be a cornerstone of such a strategy. The newly created institutions of the Technology Mechanism (TM) of the United Nations Framework Convention for Climate Change, which aim to address developing countries' technology-related needs, could support Laos in terms of formulating such strategy and in a second stage acquiring technologies as well as underlying capabilities. However, the TM requires the individual governments to request such support from the TM institutions [106], meaning the government of Laos should become active and request support by the TM. But in order to access TM support, electrification would need to become a climate change mitigation priority, which is currently not the case [105]. Also, the scope of these institutions will not allow them to act as knowledge-intermediary between villages. Here the national government has to actively step in. Second, once a technology strategy for rural electrification is derived from a TNA, it has to be made public, especially to the affected rural population. Road shows by representatives of the government to the villages as well as organizing trips where village mayors visit successfully electrified villages of the same ethnos would be appropriate means for such public campaign. Additionally, visits of rural decision makers (members of the village councils) to other villages (of the same ethnos) where the technology has been integrated successfully could leverage network effects and increase market acceptance and formation (compare [49]). The content of such a campaign run by the government should focus on the government's technology preference, emphasize reliability issues as well as the benefits of electricity in terms of productive use [96]. Third, to ensure the large-scale diffusion of the selected technologies, it also seems crucial to overcome the thinking shaped by the communist heritage and to allow policies that attract and support entrepreneurs and the necessary private investment [5]. Such political efforts should specifically foster productive use of electricity in rural villages, e.g. by reducing the bureaucratic hurdle of founding a small enterprise or supporting new financing mechanisms for rural SMEs (similarly to micro financing). In this regard, examples from other countries show, that new business models can help generating income and thereby assuring affordability in the long run: Instead of mere electricity provision, these business models offer services which are based on electricity (e.g., cooling) and result in efficiency gains or new economic activity [96,107,108]. Forth, to successfully implement the chosen rural electrification strategy, the provision of the required financial and human resources has to be ensured. Ideally, the Laotian government would channel foreign development support into the education of national electrification experts as well as rural technicians. In this vein, another important cornerstone would be the establishment of an

institutional body that collects mini-grid-related knowledge from the *international* and the *local* level, stores, translates, and passes it on to the *local* and *international* levels, and mediates between actors from different cultural backgrounds. Previous research has shown how important the feedback from the *local* level can be (e.g., [51]). Such institutionalized *system builder* [109,110] should be familiar with the different convictions, languages, and codifications for knowledge and customs, and it should have access to actors on all *geographical levels*. In summary, based on a consistent technology strategy for rural electrification, Laos could request long-term, appropriately scaled, technology-specific, foreign support and/or evaluate, filter and channel offered support to the villages based on the work of a newly institutionalized system builder that connects the three *geographical levels*.

While these practical implications are case-specific, we suppose that similar problems stemming from mismatches between institutional settings across the *geographical levels* can be found in many other LDCs where the diffusion of mini-grids (and other desired technologies) is slow. Lately, also development cooperation practitioners are increasingly becoming aware that in the past rural electrification projects and support programs have often been framed too narrow, ignoring "deeper barriers related to technologies; infrastructures (e.g., local manufacturing, installation, and maintenance capabilities); markets; government policies and regulation; user practices; social norm; and cultural meaning" ([111], p.1). Hence, a proper understanding of the situation in other countries and meaningful policy recommendations require case-specific analyses, which may utilize the *TIS* approach.

5.2 Implications for the ongoing TIS debate

The *TIS* framework generally functioned well in identifying the (systemic) bottlenecks for the diffusion and further improvement of technology diffusion in an LDC. Our analysis also supports recent findings that "the accumulation of TIS functions may determine rates of technology diffusion" in an LDC [21,39]. As summarized in Section 4.3, two main root causes for the non-diffusion of mini-grids in Laos may enrich the academic debate, which are likely to be present also in other LDCs: mismatches of institutional settings and the related impaired stock and unbalanced flow of knowledge. These two factors structure the discussion in the remainder of this section, describing how they relate to the definitions of *functions* and the role of *geographical levels.*

5.2.1 Institutional settings

Institutions are a *structural* element in the *functional approach to TIS. E.g.*, Bergek et al. [23] refer to the seminal definition by North [112] that focuses on culture, norms, laws, regulations and routines. Our case supports the view that formal (e.g., regulatory) as well as informal (e.g., culture-related) institutions should be fully considered in studies using the *TIS* approach. A review we performed of all studies that apply the *functional approach to TIS* empirically (compare [19,20]) revealed that while the regulatory aspect is typically well covered, the cultural aspect of institutions has been seriously neglected: Only one single empirical study makes cultural aspects explicit [113]. While obvious in our Laotian case, also in other contexts (including other developing but also developed countries) the factor culture might be relevant to explain the innovation and diffusion of a specific technology [114] but might be less obvious and therefore be overlooked in *TIS* analyses. Based on our case, we urge *TIS* scholars to include informal institutions in their analysis.

Shifting the discussion to the second debate, the one on the role of *geographical levels*, we note that in accordance with recent empirical research [40,42,49], our analysis differentiated three *geographical levels*[8]. In our case the *geographically* split analysis proved highly insightful where bottlenecks occur at *geographical* interfaces. As argued in Section 4.3, it is mainly institutional mismatches (including cultural aspects) on and between these levels that cause these bottlenecks. Hence, the selection of suitable *geographical levels* should consider institutional factors and not only be guided by the location of the technology source and usage, as often done in extant literature [40,42]. Our study supports the finding that *geographical*/territorial levels, such as countries or villages, do not necessarily have to be congruent with institutional, e.g., cultural, ones (compare heterogeneity concerning ethno-linguistic groups in rural Laos in Figure 1a). At this point, our case empirically supports earlier claims by Coenen et al. [47]; reviewing the work of economic geographers, they find that they "have drawn extensively on institutional analysis to successfully explain geographically uneven technology development, diffusion and innovation" ([47], p.973). Note that the relevant geographical levels (and their interfaces) are case specific, i.e., the *TIS* of technology A might be affected by different *geographical* levels than technology B's *TIS*; the same typically holds true for one technology in different geographical settings, i.e., technology A in country I and country II. Consequently, *TIS* researchers are confronted with the task of identifying the relevant scalar levels and their interactions [48]. A new methodology to identify *TIS* system boundaries based on network analysis [35] could be used to assess the impact of institutions including culture on geographic boundaries. However collecting the necessary quantitative data for such analysis is challenging in LDCs.

5.2.2 Knowledge stocks and flows

Our analysis shows that unbalanced stocks together with hampered flows of knowledge are another important bottleneck for a successful technology diffusion. We find that on the *national* and the *local* level, knowledge is often poorly absorbed or if absorbed at all, quickly lost.[9] In addition, knowledge that is transferred and retained *locally* is only seldom transformed and exploited. In a similar vein, earlier research on *IS* in developing countries noted that adaptation and acquisition of knowledge, skills and technologies is central [45,115] and that the diffusion of applied knowledge follows the building up of specialized human capital (resource mobilization) [37]. The *function knowledge diffusion* with its current definition therefore falls short and should be extended to include the retention and adaptation aspects, in order to be more universal. This finding is well in line with earlier research in development economics [116–118] which highlights the role of technological capabilities and knowledge absorption in the case of technology transfer. In this regard, organizational science literature provides

[8] While other authors considered *international* levels (often as technology sourcing) and *national* levels (as levels where relevant regulations are set in place) as well as *regional* ones (see e.g., [40,42,49]), we chose the *local* level instead of the *regional* level for case-specific reasons, as this is the level where the technology is implemented and used. Although this proved a valid choice in the case at hand, in general, the choice of levels of analysis that provide the most added value must be assessed on a case-by-case basis.

[9] Knowledge loss may be less frequent (and obvious) in industrialized country contexts but can be assumed to be an issue in many developing countries. Loss of knowledge can however be a serious issue in developed countries; e.g., if an actor or a person leaves an innovation system tacit knowledge might be lost (compare findings from the management literature, e.g., [133,134]).

a helpful concept: *absorptive capacity*, which is defined as a firm's " ability […] to recognize the value of new, external information, assimilate it, and apply it to commercial ends" ([119], p.128).[10]. We therefore regard using the concept of absorptive capacity as defined in organizational literature as valid and suggest extending the *function knowledge diffusion* to *knowledge absorption* and thereby enriching earlier definitions (e.g., those of [22,23]). To this end, borrowing from the corporate absorptive capacity literature [120] we propose defining *knowledge absorpti*on as all processes that influence information flows in networks, including the *acquisition*, *assimilation* (storage and distribution), *transformation* and *exploitation* of knowledge (also in terms of learning by doing, using and interacting). The concept of absorptive capacity is part of the dynamic capability field in the management literature. Dynamic capabilities are defined on the firm level as the abilities to "integrate, build, and reconfigure internal and external competencies to address rapidly changing environments" and thereby become a source of competitive advantage ([121], p. 516). The so-called Carnegie school, which was highly influential in the development of the concept of dynamic capabilities [122], defines firms as complex "systems of coordinated action" ([123], p.2).The similarity of this definition to the definition of *TIS* as "dynamic network of agents interacting" ([31], p.93) raises the question of whether the *functions'* role can be understood as *dynamic capabilities at the system level*. First attempts in a similar direction, for example by defining system resources [124], have been made and suggest that this may indeed be possible.

6 Conclusions and policy implications

This paper had two goals: to derive policy recommendations based on new empirical insights into the reasons for the low diffusion rate of the mini-grid technology in Laos; and to enhance the ongoing debate on how to advance the *TIS* approach. To these ends we applied a qualitative single case study design and conducted desk- as well as extensive field-research. In terms of implications for policy makers, in Section 5.1 we propose a national technology-specific electrification strategy which aligns the institutional settings and thereby removes the key barriers to the diffusion of mini-grids in Laos. Our findings specifically demonstrate the importance of two cornerstones of such strategy: a selection of preferred technologies based on a "technology needs assessment"; and the establishment of a national body (system builder) to collect, store, translate and pass on knowledge related to the selected technology as well as to mediate and translate between actors from different cultural backgrounds. International support should be requested, managed, and channeled based on such technology strategy. The analysis' theoretical findings point to a mismatch between the *institutional* settings on the *international, national,* and the *local* (i.e., village) levels, which seems to be reflected in the cultural differences identified. With regard to the ongoing theoretical debate on the role, set and definitions of *functions*, we suggest strengthening cultural aspects in empirical *TIS* analyses. For one specific *function – knowledge diffusion* – we propose an extension of the definition towards *knowledge absorption*. As for the theoretical debate on making *geographical levels* explicit in the *functional approach to TIS*, we suggest considering all relevant institutions in

[10] While the concept of absorptive capacity was originally developed to describe knowledge management processes within firms, it has also influenced the national innovation systems literature [135–139]. From its inception, the *functional approach to TIS* borrowed heavily from (evolutionary) economics and related innovation system literature as well as from organizational science [31]. Recently a *TIS* study used the concept of absorptive capacity, enriching innovation systems with management literature. However, it kept the level of absorptive capacity strictly to the firm [140]

the choice of appropriate *geographical levels*, instead of solely relying on the source and usage of technology. Our study is limited to one single case: mini-grids in Laos. Additional studies analyzing other technologies in the context of least-developed countries could improve and extend the findings and help increasing the generalizability of our findings.

Acknowledgements

We gratefully acknowledge the support of our interview partners, as well as the support provided by the Mercator Foundation Switzerland, the Swiss Study Foundation and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Appendix A: Seven steps for sampling of interviewees

(1) Through a web search, we obtained a first impression of the mini-grid *TIS* in Laos and its problems and identified a list of potential interview partners.

(2) To complete the list and to refine our semi-structured interview guidelines, we followed Yin (2003)'s suggestion to conduct a pilot, and we visited Laos in 2010 for the first time for an exploratory face-to-face interview. For this pilot interview we selected a central actor in the *TIS* based on our web search who would be helpful in testing our interview guidelines and identifying additional interview partners.

(3) After obtaining an extended list of potential interviewees, we requested interviews for mid-2011 and scheduled seven of a total of 17 interviews.

(4) As preparation for the interviews, we scanned related documents and tailored the interview guidelines to each interviewee.

(5) We then conducted the arranged interviews and arranged for ten additional ones, five of which were conducted with Laotian nationals (mostly end-consumers) in their native languages (Lao or Hmong), translated by a Laotian to English. The high number of interviews which were arranged during the stay in Laos highlights the importance of on-site research, especially if interviewees are not easy accessible by email or phone or, like the villagers, have no English language skills. Each interview lasted between 30 and 120 minutes. With the consent of the interviewee, interviews were recorded; otherwise the interviewer took detailed notes.

(6) To triangulate information provided by the different interviewees, we included observations of a visit in a mini-grid and additional written information obtained from interviewees. The visit to a mini-grid included a visit to the power plants, inspection of the civil construction, and a visit to the village and its grid network (see Figure 1). The observations were documented in videotapes and the researchers' notes. The additional written data provided by interviewees was of special value, as much of Laos-specific documents are not available online; interviewees therefore provide an important source of presentations, non-public policy documentation, and report drafts.

(7) Finally, interviews were transcribed and saved together with the other documents (videotapes from the mini-grid visit and written secondary data) in a central, standardized electronic case study database, which facilitates the replication of the analysis.

Bibliography

[1] UN, Sustainable Energy For All Initiative, (2013). http://www.sustainableenergyforall.org/.

[2] UN AGECC, Energy for a Sustainable Future: Summary Report and Recommendations, UN (United Nations)/The Secretary-General's Advisory Group on Energy and Climate Change. New York, USA, 2010.

[3] UNDP, Towards an "Energy Plus" Approach for the Poor, United Nations Development Programme (UNDP). Bangkok, Thailand, 2011.

[4] P. Cook, Infrastructure, rural electrification and development, Energy Sustain. Dev. 15 (2011) 304–313.

[5] REN21, Renewables 2013 Global Status Report, Renewable Energy Policy Network for the 21st Century (REN21). Paris, 2013.

[6] S. Rolland, G. Glania, Hybrid Mini-Grids for Rural Electrification: Lessons Learned, Alliance for Rural Electrification (ARE)/USAID. Brussels, Belgium, 2011.

[7] M. Takada, N. Charles, Energizing Poverty Reduction, A Rev. Energy Poverty Nexus Poverty Reduct. Strateg. Pap. (2007).

[8] J. Rogelj, D.L. McCollum, K. Riahi, The UN's "Sustainable Energy for All" initiative is compatible with a warming limit of 2 °C, Nat. Clim. Chang. 3 (2013) 545–551. http://dx.doi.org/10.1038/nclimate1806 (accessed June 04, 2014).

[9] T.S. Schmidt, N.U. Blum, R. Sryantoro Wakeling, Attracting private investments into rural electrification — A case study on renewable energy based village grids in Indonesia, Energy Sustain. Dev. 17 (2013) 581–595. doi:10.1016/j.esd.2013.10.001.

[10] GEA, Global Energy Assessment – Toward a Sustainable Future, Cambridge University Press, Cambridge UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, 2012.

[11] B.-Å. Lundvall, K.J. Joseph, C. Chaminade, J. Vang, Handbook of Innovation Systems and Developing Countries - Building Domestic Capabilities in a Global Setting, Edwards Elgar Publishing Limited, Cheltenham, UK; Northampton, USA, 2009.

[12] D. Ockwell, A. Sagar, H. de Coninck, Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: towards a needs driven approach, Clim. Change. (2014) 1–15. doi:10.1007/s10584-014-1123-2.

[13] D. Archibugi, A. Coco, A New Indicator of Technological Capabilities for Developed and Developing Countries (ArCo), World Dev. 32 (2004) 629–654.

[14] S. Dutta, B. Lanvin, F. Paua, The Global Information Technology Report 2003-2004: Towards an Equitable Information Society, Oxford University Press, New York, 2004.

[15] D.F. Barnes, W.M. Floor, Rural Energy in Developing Countries: A Challenge for Economic Development, Annu. Rev. Energy Environ. 21 (1996) 497–530.

[16] The World Bank, Doing Business 2013 - Smarter Regulations for Small and Medium-Size Enterprises, 10th ed., World Bank Group, Washington, D.c., USA, 2013.

[17] T.S. Schmidt, Low-carbon investment risks and de-risking, Nat. Clim. Chang. 4 (2014) 237–239. http://dx.doi.org/10.1038/nclimate2112 (accessed June 04, 2014).

[18] O. Waissbein, Y. Glemarec, H. Bayraktar, T.S. Schmidt, Derisking Renewable Energy Investments, United Nations Development Programme (UNDP). New York, 2013, 2013.

[19] A. Bergek, Ambiguities and challenges in the functions approach to TIS analysis: a critical literature review, in: 3rd Int. Conf. Sustain. Transit. 2012, 2012: pp. 45–71.

[20] B. Truffer, J. Markard, C. Binz, S. Jacobsson, Energy Innovation Systems - Structure of an emerging scholarly field and its future research directions, Strategic research alliance for Energy Innovation Systems and their dynamics - Denmark in global competition (EIS). Lyngby, Denmark, 2012.

[21] A.D. Tigabu, F. Berkhout, P. van Beukering, Technology innovation systems and technology diffusion: Adoption of bio-digestion in an emerging innovation system in Rwanda, Technol. Forecast. Soc. Change. (2013).

[22] M.P. Hekkert, R. a. a. Suurs, S. Negro, S. Kuhlmann, R.E. Smits, Functions of innovation systems: A new approach for analysing technological change, Technol. Forecast. Soc. Change. 74 (2007) 413–432.

[23] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Res. Policy. 37 (2008) 407–429.

[24] H.A. Peters, Girls' and Women's Education in Laos, UNESCO, Bangkok, 1995.

[25] J.-F. Arvis, D. Saslavsky, L. Ojala, B. Shepherd, C. Busch, A. Raj, Connecting to Compete - Trade Logistics in the Global Economy, The International Bank for Reconstruction and Development/The World Bank. Washington, DC, 2014.

[26] Transparency International, Corruption Perceptions Index Ranking, (2013). http://www.transparency.org/cpi2012/results.

[27] J.D. Fearon, Ethnic and Cultural Diversity by Country*, J. Econ. Growth. 8 (2003) 195–222.

[28] B. Carlsson, S. Jacobsson, M. Holmén, A. Rickne, Innovation systems : analytical and methodological issues, Res. Policy. 31 (2002) 233–245.

[29] F. Malerba, Sectoral systems of innovation and production, Res. Policy. 31 (2002) 247–264.

[30] Y.-C. Chang, M.-H. Chen, Comparing approaches to systems of innovation: the knowledge perspective, Technol. Soc. 26 (2004) 17–37.

[31] B. Carlsson, R. Stankiewicz, On the nature, function and composition of technological systems, Evol. Econ. (1991) 93–118.

[32] S. Jacobsson, The emergence and troubled growth of a "biopower" innovation system in Sweden, Energy Policy. 36 (2008) 1491–1508. doi:10.1016/j.enpol.2007.12.013.

[33] S. Jacobsson, A. Johnson, The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy. 28 (2000) 625–640.

[34] A. Johnson, Functions in Innovation System Approaches, in: Druid Conf., 2001: pp. 1–19.

[35] C. Binz, B. Truffer, L. Coenen, Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology, Res. Policy. 43 (2014) 138–155.

[36] F. Malerba, S. Mani, Sectoral Systems of Innovation and Production in Developing Countries, Edwar Elgar Publishing, Glos, UK; Massachusetts, USA, 2009.

[37] S. Jacobsson, A. Bergek, A framework for guiding policy makers intervening in emerging innovation systems in ' catching up ' countries, Eur. J. Dev. Res. 4 (2007) 687–707.

[38] L. Agbemabiese, J. Nkomo, Y. Sokona, Enabling innovations in energy access: An African perspective, Energy Policy. 47 (2012) 38–47.

[39] A.D. Tigabu, F. Berkhout, P. van Beukering, The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda, Technol. Forecast. Soc. Change. (2013).

[40] C. Binz, B. Truffer, L. Li, Y. Shi, Y. Lu, Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China, Technol. Forecast. Soc. Change. 79 (2012) 155–171.

[41] Y. Liu, A. Kokko, NEV technology in China, Chinese Manag. Stud. 6 (2012) 78–91. doi:10.1108/17506141211213762.

[42] T.S. Schmidt, S. Dabur, Explaining the diffusion of biogas in India – a new functional approach considering national borders and technology transfer, Environ. Econ. Policy Stud. 16 (2014) 171–199.

[43] E. Dantas, The evolution of the knowledge accumulation function in the formation of the Brazilian biofuels innovation system, Int. J. Technol. Glob. 5 (2011) 327. doi:10.1504/IJTG.2011.039770.

[44] M. Gebreeyesus, T. Sonobe, Global Value Chains and Market Formation Process in Emerging Export Activity : Evidence from Ethiopian Flower Industry, J. Dev. Stud. 48 (2012) 37–41.

[45] K. van Alphen, M.P. Hekkert, W.G.J.H.M. van Sark, Renewable energy technologies in the Maldives—Realizing the potential, Renew. Sustain. Energy Rev. 12 (2008) 162–180.

[46] L. Coenen, B. Truffer, Places and Spaces of Sustainability Transitions : Geographical Contributions to an Emerging Research and Policy Field, Eur. Plan. Stud. 30 (2012) 37–41.

[47] L. Coenen, P. Benneworth, B. Truffer, Toward a spatial perspective on sustainability transitions, Res. Policy. 41 (2012) 968–979.

[48] B. Truffer, L. Coenen, Environmental Innovation and Sustainability Transitions in Regional Studies, Reg. Stud. 46 (2012) 1–21.

[49] U. Dewald, B. Truffer, The Local Sources of Market Formation : Explaining Regional Growth Differentials in German Photovoltaic Markets, Eur. Plan. Stud. 20 (2012) 397–420.

[50] F. Berkhout, G. Verbong, A.J. Wieczorek, R. Raven, L. Lebel, X. Bai, Sustainability experiments in Asia: innovations shaping alternative development pathways?, Environ. Sci. Policy. 13 (2010) 261–271.

[51] H. Romijn, R. Raven, I. de Visser, Biomass energy experiments in rural India: Insights from learning-based development approaches and lessons for Strategic Niche Management, Environ. Sci. Policy. 13 (2010) 326–338.

[52] G. Verbong, W. Christiaens, R. Raven, A. Balkema, Strategic Niche Management in an unstable regime: Biomass gasification in India, Environ. Sci. Policy. 13 (2010) 272–281.

[53] G. Dosi, Technological paradigms and technological trajectories, Res. Policy. 11 (1982) 147–162. doi:10.1016/0048-7333(82)90016-6.

[54] N. Rosenberg, Inside the Black Box: Technology and Economics, Cambridge University Press, 1982. http://books.google.com/books?hl=en&lr=&id=GSyGBicq1NIC&pgis=1 (accessed August 14, 2014).

[55] T. Hughes, The Evolution of Large Technological Systems, in: W.E. Bijker, T.P. Hughes, T.J. Pinch (Eds.), Soc. Constr. Technol. Syst. New Dir. Sociol. Hist. Technol., MIT Press, 1987: pp. 51–82.

[56] M. Tushman, L. Rosenkopf, Organizational determinants of technological change: Toward a sociology of technological evolution, Res. Organ. Behav. 14 (1992) 311–347.

[57] R.R. Nelson, K. Nelson, Technology, institutions, and innovation systems, Res. Policy. 31 (2002) 265–272. doi:10.1016/S0048-7333(01)00140-8.

[58] L. Peskett, The history of mini-grid development in developing countries, Policy Brief. by GVEP. 3 Suppl 1 (2011) 143–6.

[59] ESMAP, Technical and Economic Assessment of Off-grid , Mini-grid and Grid Electrification Technologies, Energy Sector Management Assistance Program (ESMAP). Washington D.C., USA, 2007.

[60] N.U. Blum, R. Sryantoro Wakeling, T.S. Schmidt, Rural electrification through village grids - Assessing the cost competitiveness of isolated renewable energy technologies in Indonesia, Renew. Sustain. Energy Rev. 22 (2013) 482–496.

[61] L.A.C. Lopes, F. Katiraei, K. Mauch, M. Vandenbergh, L. Arribas, PV Hybrid Mini-Grids: Applicable Control Methods for Various Situations, International Energy Agency (IEA)-Photovoltaic Power Systems Programme. Paris, France, 2012.

[62] S. Phrakonkham, J.-Y. Le Chenadec, D. Diallo, G. Remy, C. Marchand, Reviews on Micro-Grid Configuration and Dedicated Hybrid System Optimization Software Tools: Application to Laos, Eng. J. 14 (2010) 15–34.

[63] A.C. Brent, D.E. Rogers, Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context, Renew. Energy. 35 (2010) 257–265.

[64] C. Alvial-Palavicino, N. Garrido-Echeverría, G. Jiménez-Estévez, L. Reyes, R. Palma-Behnke, A methodology for community engagement in the introduction of renewable based smart microgrid, Energy Sustain. Dev. 15 (2011) 314–323.

[65] OTTI, 3rd European Conference on PV-hybrid and mini-grid, Ostbayrisches Technologie-Transfer-Institut OTTI, Regensburg, Germany, 2006.

[66] OTTI, 2nd European PV-hybrid and mini-grid conference, Ostbayrisches Technologie-Transfer-Institut OTTI, Regensburg, Germany, 2003.

[67] IOREC, International off-grid renewable energy conference & exhibition, (2012).

[68] S. Khennas, A. Barnett, Best practices for sustainable development of micro hydro power in developing countries, Washington D.C., USA, 2000.

[69] H. Feibel, How micro hydro power systems implemented during ENDEV 1 are performing, entec AG and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). St.Gallen, Switzerland, 2010.

[70] P. Messerli, A. Heinimann, M. Epprecht, S. Phonesaly, C. Thiraka, N. Minot, Socio-Economic Atlas of the Lao PDR an analysis based on the 2005 Population and Housing Census, 1st ed., Geographica Bemensia, Swiss national Center of Competence in Research (NCCR) North-South, University of Bern, Bern and Vientiane, 2008.

[71] The CIA World Factbook, Lao PDR - Numbers, (2013). https://www.cia.gov/library/publication/the-world-factbook/geos/la.html.

[72] International Monetary Fund, International Monetary Fund, (2013). http://www.imf.org/external/index.htm.

[73] UN-OHRLLS, Least Developed Countries, (2013). http://www.unohrlls.org/en/ldc/25/.

[74] A. Kislenko, Culture and Customs of Laos, 1st ed., Greenwood Publishing Group, Westport, US, 2009.

[75] IMF, Lao People's Democratic Republic : Poverty Reduction Strategy Paper, Washington D.C., USA, 2004.

[76] Lao PDR's National Assembly, The Seventh Five-year National Socio- Economic Development Plan (2011 - 2015), Vientiane, Lao PDR, 2011.

[77] NIPPON KOEI, LCG, Rural Electrification Master Plan and Hydro Assessment Studies in Lao PDR, The World Bank/GEF GRANTS, Ministry of Energy and Mines of Lao PDR, Vientiane, 2010.

[78] M.J. Bambawale, A.L. D'Agostino, B.K. Sovacool, Lighting Laos: The governance implications of the Laos rural electrification program, Energy Governance Case Study, Lee Kuan Yew School of Public Policy, Singapore, 2010.

[79] ADB, Sector Assistance Program Evaluation for the Energy Sector in the Lao People' s Democratic Republic, Asian Development Bank (ADB), 2010.

[80] M.J. Bambawale, A.L. D'Agostino, B.K. Sovacool, Realizing rural electrification in Southeast Asia: Lessons from Laos, Energy Sustain. Dev. 15 (2011) 41–48.

[81] R.K. Yin, Case Study Research - Design and Methods, 3rd ed., Sage Publications, Thousand Oaks, USA; London, UK; New Dehli, India, 2003.

[82] K.M. Eisenhardt, M.E. Graebner, Theory Building From Cases: Opportunities and Challenges., Acad. Manag. J. 50 (2007) 25–32.

[83] C. Marshall, G.B. Rossman, Designing Qualitative Research, 4th ed., Trade paperback, Sage Publications (CA), 1989.

[84] S. Jacobsson, A. Bergek, Innovation system analyses and sustainability transitions: Contributions and suggestions for research, Environ. Innov. Soc. Transitions. 1 (2011) 41–57.

[85] V. Pholsena, Post-War Laos: The Politics of Culture, History, and Identity, 1st ed., Cornell University Press, New York, USA, 2006.

[86] M. Epprecht, N. Minot, R. Dewina, P. Messerli, A. Heinimann, The Geography of Poverty and Inequality in the Lao PDR, 1st ed., Geographica Bernensia, Swiss National Centre of Competence in Research (NCCR) North-South, Berne, Switzerland, and International Food Policy Research Institute (IFPRI) Washington D.C., USA, 2008.

[87] C. Milattanapheng, H. Sysoulath, J. Green, M. Kurukulasuriya, A Renewable Energy Strategy for Lao PDR, in: Proc. Int. Conf. Energy Sustain. Dev. Issues Strateg., 2010: pp. 1–6.

[88] A. Yadoo, H. Cruickshank, The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya, Energy Policy. 42 (2012) 591–602. http://www.sciencedirect.com/science/article/pii/S0301421511010354 (accessed June 02, 2014).

[89] K. Ulsrud, T. Winther, D. Palit, H. Rohracher, J. Sandgren, The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems, Energy Sustain. Dev. 15 (2011) 293–303.

[90] ESMAP, Maximizing the Productive Uses of Electricity to Increase the Impact of Rural Electrification Programs, Energy Sector Management Assistance Program (ESMAP). Washington D.C., USA., 2008.

[91] LIRE, Helvetas Laos, Decentralised Production of Electricity in Lao PDR (on and off-grid) Scoping Phase Final Report, Lao Institute of Renewable Energy (LIRE). Vientiane, Lao PDR, 2011.

[92] P. Cunnington, Village resettlement in Laos, Presentation, European Commission, 2011.

[93] E.M. Rogers, Diffusion of Innovations, 5th ed., Free Press, New York, London, Toronto and Sydney, 2003.

[94] M. Ibrahim, M. Anisuzzaman, S. Kumar, S.C. Bhattacharya, Demonstration of PV micro-utility system for rural electrification, Sol. Energy. 72 (2010) 521–530.

[95] G. Legros, I. Havet, N. Bruce, S. Bonjour, The Energy Access Situation in Developing Countries - A Review Focusing on the Least Developed Countries and Sub-Saharan Africa, United Nations Development Programme (UNDP) and World Health Organization (WHO). New York, USA, 2009.

[96] A. Yadoo, H. Cruickshank, The role for low carbon electrification technologies in poverty reduction and climate change strategies: A focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya, Energy Policy. 42 (2012) 591–602.

[97] C.P. Andrews-Speed, Energy Policy and Regulation in the People's Republic of China, Kluwer Law International, The Hague, 2004.

[98] C.M. Haanyika, Rural electrification in Zambia: A policy and institutional analysis, Energy Policy. 36 (2008) 1044–1058.

[99] E. Ilskog, B. Kjellström, M. Gullberg, M. Katyega, W. Chambala, Electrification co-operatives bring new light to rural Tanzania, Energy Policy. 33 (2005) 1299–1307.

[100] K.Q. Nguyen, Alternatives to grid extension for rural electrification: Decentralized renewable energy technologies in Vietnam, Energy Policy. 35 (2007) 2579–2589.

[101] R.E. Smits, S. Kuhlmann, The rise of systemic instruments in innovation policy, Int. J. Foresight Innov. Policy. 1 (2004) 4.

[102] A. Wieczorek, M.P. Hekkert, Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars, Sci. Public Policy. 39 (2012) 74–87.

[103] M. Patankar, A. Patwardhan, G. Verbong, A promising niche: waste to energy project in the Indian dairy sector, Environ. Sci. Policy. 13 (2010) 282–290.

[104] UNDP, Technology Needs Assessment for Climate Change, United Nations Development Programme (UNDP). New York, USA, 2010.

[105] Lao DDMCC, Technology Needs Assessments Report - Climate Change Mitigation, Lao Department of Disaster Management and Climate Change (DDMCC). Vientiane, 2013. http://unfccc.int/ttclear/sunsetcms/storage/contents/stored-file-20130820162442730/TechnologyNeedsAssessment-Mitigation_Laos.pdf.

[106] UNEP, Climate Technology Centre and Network, (2013). http://www.unep.org/climatechange/ctcn/AboutCTCN/tabid/106203/language/en-US/Default.aspx.

[107] B.P. Bastakoti, Rural electrification and efforts to create enterprises for the effective use of power, Appl. Energy. 76 (2003) 145–155.

[108] J. Aron, O. Kayser, L. Liautaud, A. Nowlan, Access to energy for the base of the pyramid, HYSTRA, Paris. (2009). http://scholar.google.ch/scholar?hl=en&q=Access+to+Energy+for+the+Base+of+Base+of+the+Pyramid&btnG=&as_sdt=1,5&as_sdtp=#0 (accessed June 04, 2014).

[109] H. Hellsmark, S. Jacobsson, Opportunities for and limits to Academics as System builders—The case of realizing the potential of gasified biomass in Austria, Energy Policy. 37 (2009) 5597–5611.

[110] J. Musiolik, J. Markard, M. Hekkert, Networks and network resources in technological innovation systems: Towards a conceptual framework for system building, Technol. Forecast. Soc. Change. 79 (2012) 1032–1048.

[111] O. Johnson, Universal Energy Access : Moving from Technological Fix to Poverty Reduction, Bonn, Germany, 2013.

[112] D.C. North, Economic Performance Through Time, Am. Econ. Rev. 84 (1994) 359–368.

[113] G. Vidican, L. McElvaney, D. Samulewicz, Y. Al-Saleh, An empirical examination of the development of a solar innovation system in the United Arab Emirates, Energy Sustain. Dev. 16 (2012) 179–188.

[114] S. Wirth, J. Markard, B. Truffer, H. Rohracher, Informal institutions matter : the relevance of professional culture for the development of biogas technology in, Environ. Innov. Soc. Transitions. (n.d.) 1–33.

[115] M. Bell, K. Pavitt, The development of technological capabilities, in: Trade, Technol. Int. Compet., 1995: pp. 69–101. http://books.google.ch/books?hl=en&lr=&id=-43AHZspBWgC&oi=fnd&pg=PA69&dq=The+development+of+technological+capabilities&ots=1h25rzmj3s&sig=UM53hO5s7v9_cmjgH06qqDYeFI0 (accessed June 04, 2014).

[116] J.M. Katz, Domestic technological innovations and dynamic comparative advantage - Further reflections on a comparative case-study program, J. Dev. Econ. 16 (1984) 13–37.

[117] M. Bell, M. Albu, Knowledge Systems and Technological Dynamism in Industrial Clusters in Developing Countries, World Dev. 27 (1999) 1715–1734.

[118] M. Bell, B. Ross-Larson, L.E. Westphal, Assessing the performance of infant industries, J. Dev. Econ. 16 (1984) 101–128.

[119] W.M. Cohen, D.A. Levinthal, Absorptive Capacity : A New Perspective on Learning and Innovation, Adm. Sci. Q. 35 (1990) 128–152.

[120] G. Todorova, B. Durisin, Absorptive capacity: Valuing a reconceptualization, Acad. Manag. Rev. 32 (2007) 774–786.

[121] D.J. Teece, G. Pisano, A. Shuen, Dynamic capabilities and strategic management, Strateg. Manag. JournalJournal. 18 (1999) 509–533.

[122] G. Gavetti, D. Levinthal, W. Ocasio, Perspective--Neo-Carnegie: The Carnegie School's Past, Present, and Reconstructing for the Future, Organ. Sci. 18 (2007) 523–536.

[123] J. March, H. Simon, Organizations, 2nd ed., Blackwell Publishers, Oxford, 1993.

[124] J. Markard, H. Worch, Technological innovation systems and the resource based view - Resources at the firm , network and system level, in: DIME Work. Environ. Innov. Ind. Dyn. Entrep., Utrecht, Netherlands, 2009: pp. 1–24.

[125] J. Markard, R. Raven, B. Truffer, Sustainability transitions: An emerging field of research and its prospects, Res. Policy. 41 (2012) 955–967.

[126] J. Markard, B. Truffer, Technological innovation systems and the multi-level perspective : Towards an integrated framework, Res. Policy. 37 (2008) 596–615.

[127] B. Carlsson, S. Jacobsson, Dynamics of Innovation Systems - Policy-Making in a Complex and Non-deterministic World, in: 'International Work. Funct. Innov. Syst. Univ. Utr., 2004.

[128] A. Bergek, S. Jacobsson, B. Carlsson, S. Lindmarki, A. Rickne, Analyzing the dynamics and functionality of sectoral innovation systems - a manual, in: DRUID Tenth Anniv. Summer Conf. 2005, 2005: pp. 1–34.

[129] D. Phonekeo, Overview of Energy Subsector Activities in the Lao PDR, Presentation by the Laotian Ministry of Energy and Mines at subregional Energy Forum 2, Ho Chi Minh City, Vietnam, 2008.

[130] The Economist, River elegy, (2012). http://www/economist.com/news/asia/21565676-laos-admits-work-going-ahead-controversial-dam-river-elegy.

[131] Helvetas Laos, Rural Energy & Climate Workshop, Phnom Penh, Cambodia, 2011.

[132] FONDEM, De l'électricité verte pour trente-cinq mille ruraux au Laos, Fondation Énergies pour le Monde (FONDEM), Paris, France, 2009.

[133] S.M. Jasimuddin, J.H. Klein, C. Connell, The paradox of using tacit and explicit knowledge: Strategies to face dilemmas, Manag. Decis. 43 (2005) 102–112.

[134] R. Hall, P. Andriani, Managing knowledge associated with innovation, J. Bus. Res. 56 (2003) 145–152.

[135] M. Goodwin, R. Johnston, Absorptive capacity innovation systems : the case of Australia, Sci. Public Policy. 26 (1999) 83–90.

[136] R. Narula, Understanding Absorptive Capacities in an "Innovation Systems" Context: Consequences for Economic and Employment Growth, in: DRUID Work. Pap. No 04-02, 2003.

[137] C. Dahlman, R. Nelson, Social absorption capability, national innovation systems and economic development, in: D.H. Perkins, B.H. Koo (Eds.), Soc. Capab. Long-Term Growth, Macmillan Press, Basingstoke, UK, 1995.

[138] C. Edquist, Systems of innovation - Technologies, institutions and organizations, Psychology Press, 1997.

[139] F. Castellacci, J.M. Natera, The dynamics of national innovation systems: A panel cointegration analysis of the coevolution between innovative capability and absorptive capacity, Res. Policy. 42 (2012) 579–594.

[140] H. Pohl, M. Yarime, Integrating innovation system and management concepts: The development of electric and hybrid electric vehicles in Japan, Technol. Forecast. Soc. Change. 79 (2012) 1431–1446.