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Technological innovation system building for diffusion of renewable energy technology: A case of solar PV systems in Ethiopia

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ABSTRACT

Past studies on technological innovation system (TIS) were conducted to address the process and challenges of development and diffusion of renewable energy technologies, mainly in the context of developed countries. In this study, we classified TIS into R&D-based TIS and diffusion-based TIS and empirically investigated the formation of diffusion-based solar photovoltaic (PV) TIS in the context of a developing country. Based on historical event analysis, the study showed how the accumulation of *system functions* influenced the diffusion of PV technology and establishment of local solar PV industry in Ethiopia. Our case study sheds more light on the wider application of TIS framework in a context out of which it was born. The study recommends a policy intervention in building strong TIS for faster diffusion and further development of solar PV systems in Ethiopia and other developing economies.

1. Introduction

According to the International Energy Agency and UN organizations, 1.4 billion people in the globe still lack access to basic electricity services (IEA, 2010). Most of these people live in sub-Saharan Africa and South Asia countries (Pode, 2013; IEA, 2010). In the context of no access to the electricity grid, off-grid energy systems have been promoted by several stakeholders as a remedy to the energy poverty in these regions. Among the off-grid renewable energy technologies, particularly, solar photovoltaic technology (PV) has been promoted as a potential means of rural electrification in developing countries (Dornan, 2011). Despite several efforts to develop and promote such technologies, uptake remains very low and sluggish (Hirmer and Cruickshank, 2014; Mondal et al., 2010; Negro et al., 2012; Wong, 2012).

In Ethiopia, Ghana, Kenya, Tanzania, and Zamiba alone, a Lighting Africa report estimated that 40 million households are potential adopters of solar home systems (SHS)[1] (Lighting Africa, 2011). However, far less adoption has been achieved both through market and non-market mechanisms in this region, too. There are many diffusion barriers, and shifting from conventional energy sources towards renewables has been an arduous work, particularly in developing countries (Mondal et al., 2010; Negro et al., 2012; Wong, 2012). Also unless such technologies diffuse into the community, their economic and social impacts would be so minimal (Rogers, 2003; Hall, 2005). Adoption of SHS requires the active participation of users for they contribute to the adaptation and further diffusion of the technology (Antonelli, 2006; Kebede and Mitsufuji, 2014).

Recent studies have showed that the development, diffusion and use of new (energy) technology is influenced by the establishment of technological innovation systems (TIS) surrounding the technology in focus (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; Bergek et al., 2008). The presence of well-functioning TIS is believed to facilitate the diffusion of technologies through fulfillment of key activities and processes collectively known as *system functions* (Bergek et al., 2008; Hekkert et al., 2007). So far, TIS studies have been mainly associated with the development and diffusion of renewable energy technologies (Negro et al., 2012; Musiolik et al., 2012; Suurs et al., 2009; Jacobsson and Johnson, 2000). In addition, the TIS studies on renewable energy technologies were conducted mainly in the context of developed countries (such as the Dutch photovoltaic innovation system (Negro et al., 2009), hydrogen and fuel cell technologies in Netherlands (Suurs et al., 2009), biomass digestion in Germany (Negro et al., 2008), stationary fuel cells in Germany (Musiolik and Markard, 2011), and a generic study on RETs (Jacobsson and Johnson, 2000)).

So far, the low adoption rate of solar PV technology, as a solution for energy poverty particularly in least developed countries, was associated with random list of factors and barriers to diffusion; hence, the need to examine the problem from a *systemic* perspective in which TIS analysis

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[1] A typical SHS consists of a photovoltaic module, a battery, a charge controller, and light bulbs.

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plays a role. Despite some efforts in studying solar PV TIS in advanced economies (Negro et al., 2012), very little effort has been invested in empirically investigating PV TIS in a technology receiving country context. This study employs TIS as analytical framework to discuss the diffusion of solar PV systems and build up of associated PV TIS in Ethiopia.

In the study, we classified TIS into R&D-based TIS and diffusion-based TIS. The emphasis in the context of the latter lies on: (1) introducing technologies from industrialized countries (which may be new to the users, not to the world); and (2) aiming for adaptation, usage and generation of further innovations over time. Diffusion-based TIS describes the technological innovation system construction (building) in least developed economies (technology recipients[2]) focusing on diffusing an existing technology. And diffusion-driven TIS can be defined as a set of network of actors and institutions that interact and contribute to the diffusion of an existing technology along with building absorptive and innovative capacity for further improvement and diffusion of the technology in focus.

In this case study, we empirically investigated a *system in construction* and identified system functional build-ups which in turn correspond to the diffusion rate of solar PV systems in Ethiopia. In this regard, we pursue the argument that system functions with a modified set of indicators can explain the technology-specific innovation systems dynamics in least developed countries (Blum et al., 2015; Tigabu et al., 2015a). Our study offers at least four important contributions. Firstly, the study is in a geographical context where few TIS studies have been conducted (Tigabu et al., 2015a). Secondly, TIS studies have mainly been conducted in the context of advanced countries where the emphasis lies on *generating*, *diffusing* and *using* a new technology (which we call it *R&D-based TIS)*. Whereas in this study context, the emphasis is on first *introducing, diffusing* and *using* a technology developed in technologically advanced countries and then aiming for building local innovative capacity in the process (which we call it *diffusion-driven TIS*). Hence, the TIS building process and its aim initiates at a different stage which would shed more light on the applicability of TIS framework in a domain out of which it was born. A third contribution is linked to the relationship between *system functions* build-up and diffusion rate of PV technology and local "knowledge development and diffusion" in the country. We restricted our analysis in these core functions at this formative phase of the TIS and analyzed the system functions in addressing the two policy goals promoted by the government of Ethiopia: an immediate goal of finding a solution to an acute rural electrification problem (through diffusion of solar PV systems) and a broader goal of establishing a local PV industry. The paper addresses how the policy goals were addressed and how those goals have been influenced by the presence (absence) of system functions. Fourthly, the context of Ethiopia is a suitable case for showing the building process of diffusion-based PV TIS as there was has hardly any R&D ground to develop the solar PV industry in the last two decades, and the focus was on diffusing the existing PV technology. Hence, Ethiopia represents the situation of many developing nations, particularly in the context of Africa.

The following research questions guided the study:

What were the system functions in the solar PV technological innovation system building in Ethiopia between 1980s and 2012? And
How have the system functions influenced the diffusion of solar PV systems and the local industry development tin Ethiopia (i.e. formation of diffusion-driven PV TIS in Ethiopia)?

[2] It does not necessarily mean that diffusion-driven TIS is applicable only in the context of developing (least developed) countries; rather, any country receiving a foreign technology may follow this approach; i.e. the contexts for developing countries and diffusion driven TIS may not coincide fully. There may be cases of diffusion driven TIS development in technologically advanced countries and on the other hand, there may be also R&D driven cases in industrializing countries like India and China. (Thanks to an anonymous referee for pointing out this).

The rest of this paper is structured as follows. Section 2 provides overview of the theoretical background of IS application in developing countries and the TIS framework as analytical tool. Section 3 explains the methodology employed in the study. The structural components of the formative PV TIS are discussed in Section 4, followed by analysis of historical episodes and system functional build up in Section 5. The penultimate section discusses the relationship between system functions and diffusion rate of solar PV and local industry development in Ethiopia. Concluding remarks including policy intervention areas are included in the last section.

2. Theoretical background

Innovation systems (IS) study has been attracting the attention of researchers and policy makers since its introduction in the 1980s (Freeman, 1987; Lundvall, 1992; Metcalfe and Ramlogan, 2008). IS can be analyzed on *technological*, *sectoral*, and *national* levels in which the emphasis and unit of analysis is technology, industry and geography respectively (Carlsson and Stankiewicz, 1991; Lundvall, 1992; Malerba, 2002; Bergek et al., 2008). However, the goal of any systems of innovation remains identical, i.e. to *develop*, *diffuse* and *utilize* new technology and technological knowledge (Jacobsson and Johnson, 2000; Edquist, 2005; Markard and Truffer, 2008).

There has been a debate on the use of IS framework in the context of developing countries. Some argue that since developing countries often rely on importing existing technology from the industrialized world, the prevailing definition of IS may not be directly applied (Muchie, 2003; Siyanbola et al., 2012; Szogs and Wilson, 2008). On the other hand, others claim that despite low potential of radical innovations, the IS approach is applicable for developing countries in which case both the innovation and the system can be realized simultaneously (Muchie, 2003; Siyanbola et al., 2012). International organizations such as United Nations Convention in Climate Change (UNFCC) have been promoting systems of innovations in developing countries (Carlsson, 2006). However, as recommended by IS scholar such as Johnson and Lundvall (2003), there is a need to shift the focus from the "reproduction of the system to its "construction" in developing countries (Johnson and Lundvall, 2003, p. 24). While sharing their views, above all, IS has been a "focusing device", and it may still serve as an "analytical construct" and a "lens" which gives freedom to use the framework while the system is being built or emerging (Bergek et al., 2008, p. 412).

One of the problems claimed in conceptualizing systems of innovation is the system boundary (Radosevic, 1998). Further specific criticisms on national innovation systems framework included: its emphasis on 'structural components' of the system, giving less emphasis for the dynamics of innovation systems, suffering from 'institutional determinism' and less applicability for 'micro-level' analysis (Hekkert et al., 2007, pp. 414–415). As part of addressing such limitations in other innovation systems approach, a group of scholars argued that TIS approach that takes a technology as a starting point and is not delineated by geographical boundaries has been promoted as a resourceful approach for analyzing innovation processes and early industry emergence (Hekkert et al., 2007; Markard and Truffer, 2008; Binz et al., 2014). Carlsson and Stankiewicz were among the pioneers who introduced the notion of technological systems with indeterminate boundaries, elaborating that such systems could be local, global, or national (Radosevic, 1998).

The TIS framework has been predominantly applied in the context of advanced economies where the technology development may originate from. However, recent studies showed that TIS framework can also be applied to the contexts of latecomer economies (Van Alphen et al., 2008; Gosens and Lu, 2013; Tigabu et al., 2015a,b; Blum et al., 2015). And often, TIS scholars have been focusing on the first goal of the innovation system, i.e. the *generation* of the technology in focus, while the remaining goals are less emphasized, i.e. the *diffusion* and *utilization* of