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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)?

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

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[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 technology (innovation). Carlsson (2006) recommended that "in order to understand how successful innovation systems are in generating economic growth, one would have to include the demand side as well, including entrepreneurial activity and business formation" (Carlsson, 2006, p. 65). Sharing the early concern of Carlsson, recent studies of TIS have given more emphasis to the system performance and in fact, one of our arguments in this study also originates from here. TIS build-up process in the context of less developed countries (technology receiving countries) needs to give more emphasis to the *diffusion* and *utilization* of the technology in focus and building capabilities (Van Alphen et al., 2008). Schmidt and Dabur (2014) proposed a division of TIS into two*: national* TIS and *international TIS* in which the former refers to the element of TIS in a focal country and the latter referring to the other remaining TIS in the rest of the world, and the two interact through international technology transfer and financial flows (Schmidt and Dabur 2014; Binz et al., 2014). However, besides showing the source and flow of technology, it is worth showing how the associated TIS are formed. To this end, we differentiated TIS into R&D-based and diffusion-driven TIS.

Carlsson and Stankiewicz (1991) defined technological systems (later referred in literature as TIS) as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology"[3] (Carlsson and Stankiewicz, 1991, p.111). Markard and Truffer (2008) have also recently defined TIS as a "set of networks of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion and utilization of variants of a new technology and/or a new product" (Markard and Truffer, 2008, p. 611). The common structural components of TIS include *actors*, *networks* and *institutions* (Bergek et al., 2008; Hellsmark and Jacobsson, 2009). *Actors* refer to individuals, private and public firms, universities and research institutes, financiers, etc. that contribute to the development and diffusion of the technology in focus (Hellsmark and Jacobsson, 2009; Musiolik et al., 2012); they could be technology developers, adopters of the technology, or they could also be regulators, financers, etc. (Suurs et al., 2010). *Networks* refer to relationships among different actors in the system, which include user-supplier networks, university-industry networks, political networks, etc. that work for influencing institutions (Hellsmark and Jacobsson, 2009). *Institutions* refer to the "rules of the game" which encompass sets of norms, beliefs, routines, laws, standards, etc. that regulate the relations and interactions between individuals and firms (North, 1990; Edquist, 2005; Hellsmark and Jacobsson, 2009; Musiolik, 2012).

System functions, referred here simply as 'functions', are sort of activities that contribute to the development, diffusion, and use of technological innovations (Bergek et al., 2008; Hekkert et al., 2007). Hekkert et al. (2007) suggested seven *system functions*: entrepreneurial activities (F1), knowledge development (F2), knowledge diffusion (F3), guidance of the search (F4), market formation (F5), mobilization of resources (F6), and creation of legitimacy (F7)[4,5]. Table 1 presents a brief description for each function and examples of indicators used to track the system functions in our study. We included relevant indicators to each system functions from the perspective of a nascent solar PV industry in a developing country context. For instance, *knowledge development* (F2) is measured by the number of patents and scientific publications in advanced economies (Bergek et al., 2008; Hekkert et al., 2007). However, in a developing country where mainly *learning by doing, using* and *interacting* (DUI) takes place (Lundvall, 1992), the indicators show how learning took place through feasibility studies, market assessment, testing new models of business and technology adopted from advanced economies, etc. Functional analysis helps to capture what has occurred within the system, rather than what constitutes the system (Tigabu et al., 2015a). Even though there have been efforts to assess the strength of *system functions*, there are yet "no standard combination of indicators for measuring the strength of (system) functions" (Jacobsson and Bergek, 2011, p.53). Diffusion of the innovation or technology in focus is a common indicator for the overall performance of TIS (Markard and Truffer, 2008; Jacobsson and Bergek, 2004). In our study, we also used diffusion volume and rate of the technology in focus/solar PV systems/as a performance measurement of the embryonic TIS.

Table 1
System functions and indicators (Functions category *adopted from* Bergek et al., 2008; Hekkert et al., 2007).

Functions	Descriptions	Indicators
F1: Entrepreneurial activities	Such activities form the core of any innovation system and involve trials of innovative commercial and/or demonstration experiments.	Entry of firms to PV market; Launching pilot PV projects; Experimenting new applications of PV
F2: Knowledge development	This function involves learning by doing and searching and addressing the socio-economic, technical and market related issues about the new technology.	Conducting feasibility studies; PV market research, appraisal and evaluation studies; Testing new models
F3: Knowledge diffusion	This function involves learning by using and interacting through networks and/or communication of knowledge among actors in networks.	Trainings of PV technicians, entrepreneurs, users; Organizing seminars, workshops & conferences; Conducting promotion campaigns
F4: Guidance of the search	This function encompasses activities positively affect the visibility and clarity of specific wants among technology users.	Formulating policies, rules & regulations; Planning targets; Publicizing expectations; Showing interest
F5: Market formation	It involves the creation of markets, where new technologies have a possibility to grow.	Providing subsidies, tax exemptions, and other incentives; government procurement programs; Standardizations
F6: Resource mobilization	This function involves mobilizing material and non-material resource inputs to the innovation system development.	Providing R&D budgets; Launching PV related educational programs; Providing financial grants and loans for companies; Funding scale up PV projects
F7: Creation of legitimacy	This function encompasses advocacy efforts for enhancing stakeholder support to the new technology.	Conducting lobbying and advocacy programs

3. Methodology

Because our study focuses mainly on how events occurred and influenced outcomes, we employed a case study as proposed by Yin (2009). For guiding the main part of the analysis, Event Historical Analysis (EHA) was employed. EHA has been used by other TIS researchers consistently (see Suurs et al., 2009, 2010; Agbemabiese et al., 2012; Negro et al., 2009). EHA helps to operationalize and measure system functions

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[3] Markard and Truffer criticized the definition of technological systems (TIS) forwarded by Carlson and Stankiewicz arguing that it fails to make distinction between new and established technologies (*radical* vs. *incremental* innovations). With further elaboration on that, the word 'generation' in the definition refers to new technologies and it serves well in this regard, while not in the incremental innovations case (Markard and Truffer, 2008, p. 599).

[4] Bergek and her colleagues also previously listed similar functions but their phrasing and order is slightly different (Bergek et al., 2008). For its comprehensiveness and clarity, we follow the seven functions in the order suggested by Hekkert et al. (2007).

[5] As an emerging field of research, there is no full agreement on the list of functions as well as their indicators (Blum et al., 2015).

by matching them to events. The major methodological steps followed in the study included:

Data gathering: Desk research was first conducted by referring reports, journal articles, websites and other publications such as online newsletters. Interviews, focus group discussions and observation in the field were also carried out. The process was iterative in that we were going back and forth to literature and field research as needed. Three research field trips were conducted to Ethiopia in 2012 and 2013. Overall, we conducted 35 interviews including experts, officers and users of solar home systems. As much as possible, triangulated data sources were employed.

Dataset building: A database was built encompassing list of events in a chronological order starting from the early solar PV days in the 1980s to current time. We cannot draw all the events that happened in the last 30 years. However, we believe that important events related to PV were included as it was also confirmed by feedback from expert interviews. We followed both the structural and functional components of TIS in collecting the data. Much emphasis was given to the last decade events and activities related to solar PV in Ethiopia.

Matching events to functions: After, listing the events chronologically, we matched the events to the seven system functions (F1 to F7). In doing so, we followed the assumption that every innovation event in the build-up of a TIS is attributable to at least one system function (Hekkert et al., 2007). Once matching events to functions was performed, analysis of the functional accumulation and the relationship between the functional build-ups and diffusion rate of PV and growth of local PV industry was carried out. The next sections present the results and discussion part of the paper.

4. Structural components of solar PV TIS in Ethiopia

Mapping out the main structural components including overview of the PV technology in Ethiopian context are included in this section.

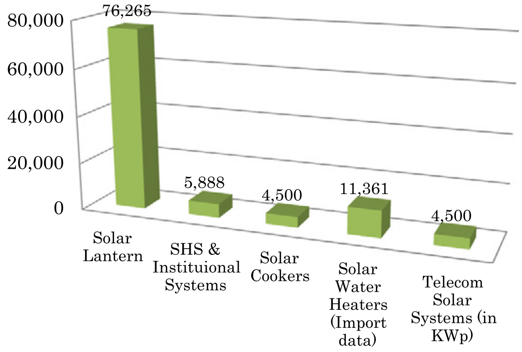

Fig. 2. Dissemination quantity of solar energy technology in Ethiopia until 2011. (Source: Kebede and Mitsufuji, 2014).

4.1. Solar PV technology

The solar PV study team at the International Energy Agency has roughly classified the solar PV systems into three: *Solar pico PV systems* (solar lanterns) which are equipped with solar panel with size ranging from 0.3 Wp to 10 Wp, a rechargeable battery and a charge controller. The Solar home systems category includes those solar systems with panel capacity ranging from 10 Wp to 100 Wp and *institutional PV systems* category includes systems equipped with panel capacity of >100 Wp (Lysen, 2013). All the PV system categories, being different in size, share the basic solar electricity generation principle and PV technology components (See Fig. 1).

So far, in the Ethiopian market introduced are all types and sizes of PV systems: Lanterns, SHS, institutional solar systems (relatively large systems used in telecoms, health clinics, and schools), solar water pumps, solar water heaters, solar cookers, and solar TV and radios. Most of the solar PV systems are used for rural lighting and telecom services (Kebede and Mitsufuji, 2014). As part of our previous effort in compiling the diffusion volume of each solar innovation in Ethiopia, dissemination volume of each types of systems were collected from importers and dealers (mainly in the last 7 to 10 years), governmental offices and local and international NGOs. The data in Fig. 2 represents the minimum

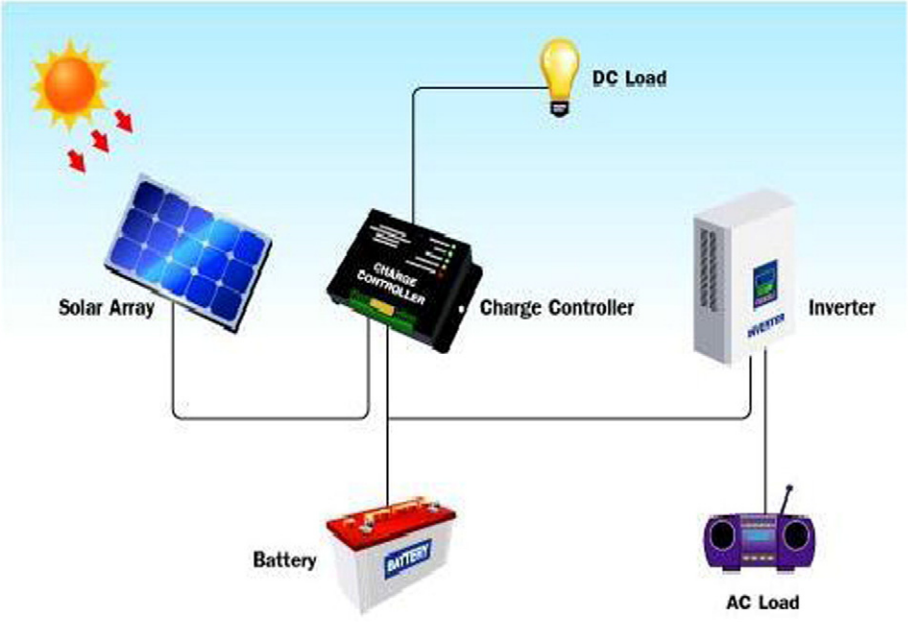

Fig. 1. Solar PV system and its components.
(Source: Leonics, 2014).

Table 2
Key actor-networks and renewable energy related education programmes in Ethiopia.
(Source: interviews and previous compilation).

	1980–1990	1990–2000	2001–2005	2006–2010	2011–
No. of private companies (Dealers/importers/installers)	None	3 to 4	10 to 12	12 to 15	>15
PV panel manufacturer	None				METEC PV module assembly factory
Financers/NGOs	World Bank/IFC; UNESCO; UNEP; UNIDO;EU;IGAD; GIZ;SNV; Plan International; Solar Energy Foundation				
Universities/education and research programmes	Research projects in Addis Ababa University	Research projects in Addis Ababa University	Short term trainings Few abroad trainees	3 training schools 2 M.Sc. programmes;	3 training schools 2 M.Sc. programmes; Several RE research centers
Networks (formal)	None			Solar Energy Development Society of Ethiopia	HoA-REC&N; TEA (Talk Energy Ahead, informal forum)

quantity of solar items in Ethiopia collected and compiled only from recorded and formal data sources. Further indication of the import trend of solar PV alone is presented in the next section (see Fig. 4).

4.2. Actors and networks

Ethiopia is naturally endowed with a large array of renewable energy resources. It is one of the highest solar radiation endowed countries in sub-Saharan Africa, with estimated annual total solar energy reserve of 2,199,000 TW·h/a and an average annual solar radiation energy density of unit area, 1, 992.2 kW·h/(m^2·a) (EMPWS, 2012). However, it has been one of the energy poorest nations in the globe, and the main sources of light in homes and small businesses particularly in the rural community are kerosene lamps and candles. Most of the rural energy electrification projects were donor-driven projects (Tessema et al., 2014). The key actors in the solar PV market in Ethiopia are few non-governmental organizations and a very limited number of companies (ERG, 2012). Since 2009, very few universities have launched renewable energy related post graduate programmes. The number of private companies involved and universities conducting training, research related to solar energy are presented in Table 2.

4.3. Institutions

With its poor energy access at home, Ethiopia plans to be a "renewable energy hub in East Africa". Ethiopia, however, heavily relies on its hydropower potential and expands its investment in this sector, including the on-going construction of the largest hydroelectric power dam on Blue Nile River (maximum planned installed capacity of 6000 MW). As part of its ambitious plan, many institutional reforms have recently taken place including dividing the state monopolized Ethiopian Electric Power Corporation (EEPCo) into two entities- *Ethiopian Electric Power* and *Ethiopian Electric Services* (Jemal, 2013). EEPCo has been the sole actor in generating, transmitting, distributing and sale of electricity throughout the nation. Relying mainly on hydropower and a few on-going wind and geothermal energy projects, still less emphasis is given to other renewable energy sources including solar. Institutional framework lacking to support diversified energy sources and limited involvement of private sector are hindrances to address the energy poverty on Ethiopia (Mulugetta, 2008).

Besides the socio-cultural barriers to diffusion of solar PV technology, there are list of institutional barriers compiled in previous studies (Mondal et al., 2010; Negro et al., 2012; Tigabu et al., 2013; Kebede and Mitsufuji, 2014). In solar PV market in Ethiopia, lack of institutional support through working policy and incentive system remained a fundamental problem (ERG, 2012; Kebede and Mitsufuji, 2014).

5. Structural and functional build-up of solar PV TIS in Ethiopia

Here, we have deliberately classified the historical path of solar PV systems in Ethiopia into categories of periods (episodes) following chronological flow of events.[6] The full list of events and associated system functions are available in Appendix Tables A1 and A2.

5.1. Historical episodes

5.1.1. Pioneer PV pilot projects in the 1980s

The sudden rise of global oil price and the Ethiopian revolution around the mid of 1970s were mentioned as main triggers to engage in parallel efforts of testing every new energy technology in Ethiopia. The then government was welcoming proposals from professionals to test new energy resources and technologies; the push from global actors through awareness campaigns such as the UN conference in Kenya in 1981 that urged a shift from oil to modern energy sources was also notable[7] [*F4-direction of the search*]. As part of those early efforts, the first solar PV standalone system was installed in the mid of 1980s in the village of Mito, a village in Central Ethiopia and was fully operation since December 1986. This10.5 kWp (watt peaks) PV system was installed in the village as a mini-grid system to the villagers and it was by then claimed to be the "largest of its kind in sub-Saharan Africa" [*F1-entrepreneurial activities*] (Wolde-Ghiorgis, 1990). The PV system, imported from Italy, was installed in an area of 3000 m^2 serving 390 households. Each household was provided with a 20 W lamp to get a lighting service from the centralized power for about 4 h in the night. In addition, the village had a street light, a school and, a clinic utilizing the solar generated power for lighting and vaccine refrigeration (Wolde-Ghiorgis, 1990). Professor Wolde-Ghiorgis, now an emeritus professor of Addis Ababa University published the technical performance appraisal of this very PV system after two service years of the system [*F2-knowledge development*] (Wolde-Ghiorgis, 1990). According to a personal communication with Prof. Wolde-Ghirogis, this project was later upgraded to Mito II (to a size of 21 kWp) [*F1-enterpreneurial activities*] until it was later completely out of use during the civil war (Energypedia, 2014).

An indication for the then interest in identifying existing potential of renewable energy resources, a study on solar radiation distribution in Ethiopia was conducted by the Ethiopian National Energy Commission and CESEN, an Italian consulting company. The study result was released in 1986 [F2-*knowledge development*] (Hankins and Shanko, 2004). Another notable pilot project in the 1980s was aPV-powered community water supply for rural villages and refugee camps [*F1-enterpreneurial activities*] (Hankins, 2000). The use of solar PV for telecom applications was also reported to be a commonplace in the 1980s (Hankins, 2000). After those pioneer solar PV projects, there remained little progress for the next five to six years mainly due to the raging civil war in the country.

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[6] We followed the approach of Tigabu et al. (2015) who applied such sub-division of the historical events into episodes based on pattern observation.

[7] As written records were not available, part of this story was collected through personal communication with researchers including Prof. Wolde-Ghiorgis in 2013 and 2014.

5.1.2. 1990–2000 - the 'silent' period

After the throw of Derg regime in 1991, the new Government of Ethiopia (GoE) issued a new national energy policy in 1994 aimed at paving the way for privatization of energy services[8] [F4-*direction of search*] (ESD, 2002). However, due to the vast re-organization taking place in the country, very little progress was made regarding PV dissemination during the 1990s. A written record shows that there was a UNESCO funded 1.6 kWp PV water pumping system installed in Work-Amba in 1994so as to supply water for 3000 people in the vicinity [F1-*enterpreneurial activities*] (Mulugetta, 2008).

The GoE later established Ethiopian Electricity Agency (EEA) by Proclamation in 1997. EEA was responsible for attracting energy investors and granting licenses for public or private investors. As per the Electricity Proclamation (No. 86/97), any person or corporate entity could apply for a license for electricity production and distribution. However, there was a restriction in the investment proclamation which elaborated that the private investment in power plants should not exceed 25 MW [F4-*direction of search*] (Teferra, 2002; World Bank, 1997, 2003). By then only about 10% of Ethiopia's population had access to electricity (World Bank, 1997).

After a long silence in the PV market, two small scale PV systems were installed in 1998 inside the compound of Addis Ababa University as a pilot study by the Physics Department. The study was aimed at investigating the performance of each 55 Wp solar system under the Addis Ababa climatic conditions [F2-*knowledge development*] (Stutenbaumer et al., 1999).

5.1.3. 2000–2005 - functional emergence?

In 2001, the Intergovernmental Authority on Development (*IGAD*) conducted a study on the PV market potential in Ethiopia as a "complementary tool" for off-grid rural electrification [F2-*knowledge development*] (Hankins and Shanko, 2004). The IGAD project, besides the market survey, included provision of training courses for solar PV technicians and subsidizing pilot installations for awareness building, mainly in the Southern part of Ethiopia [F3-*knowledge diffusion*] (Hankins and Shanko, 2004; ESD, 2002). Estimated number of PV dissemination until 2001 was <1000 (Wolde-Ghiorgis, 2002). Import duty, which by then was up to 30%, was a major factor influencing the adoption rate as rural users couldn't afford to pay the very high upfront cost (Wolde-Ghiorgis, 2002).

In this period, the GoE established an autonomous institution called Ethiopian Rural Energy Development and Promotion Centre (EREDPC) in proclamation number No. 269/2002 with the goal of making a conducive environment for the development and promotion of rural energy technologies [F4-*guidance of the search*]. The amount of 15.61 million USD was also solicited from World Bank-GEF with a specific objective of supporting the GoE minimizing the barriers that impede the development of renewable energy. This was particularly for solar PV systems and micro hydro power plants [F6-*resource mobilization*] (World Bank, 2003, 2005). As part of this move, a study on the commercialization of solar PV in Ethiopia in 2004 identified the key players and challenges in the PV market. The challenges included (i) high tariffs on PV panels, (ii) high initial cost of renewable energy systems, (iii) lack of knowledge of the (dis)advantages of renewable energy systems, (iv) lack of collaboration by key stakeholders, and (v) lack of locally produced systems [F2-*knowledge development*] (World Bank, 2003; Hankins and Shanko, 2004). While the sales volume remained relatively low (<200 kWp/year), the number of local PV dealers almost tripled between 2001 and 2004 [F1-*enterpreneurial activities*] (Hankins and Shanko, 2004).

The SWERA project was also launched by the cooperation of UNEP and GEF to "provide solar and wind resource data and geographic information assessment tools to public and private sector executives who are involved in energy market development"[F2-*knowledge development*] (Schillings et al., 2004).

Another notable event in this period was the Barefoot College project where they trained farmers from Northern Ethiopia. The trained farmers then went back home and installed solar systems in about 30 households, a clinic and a primary school in their village with the support of Mekelle University [F3-*knowledge diffusion; F*1-*enterpreneurial activities*] (GlobalCom, 2005; Rajasekaran, 2006; Castonguay, 2009). Later, some 34 individuals from 5 provinces were trained for about six months as "Barefoot Solar Engineers" at the Barefoot College in Rajasthan, through the funding support of UNDP and other organizations [F3-*knowledge diffusion*] (Castonguay, 2009; Rajasekaran, 2006). Unfortunately, the approach of Barefoot College was not sustainable because it was too costly to train a farmer from Ethiopia by travelling to India with all the language and culture barriers (EciAfrica, 2007).

In this period, a number of other demonstration and pilot installations (mainly institutional PV systems) and trainings were provided throughout the country [F3-*knowlede diffusion*] (GlobalCom, 2005).

5.1.4. 2006–2010, the emergence of full set of system functions?

In this period, many NGOs and international donor organizations were working with both the public and the private sectors. The Rema project in 2005/2006 by Solar Energy Foundation (SEF) was a notable milestone in this period (Kebede et al., 2014). SEF installed around 1100 SHS in a village called Rema, later known to be a "solar village" [F1-*enterpreneurial activities*] (Schutzeichel, 2012). The project tested a new form of financing and PV system management through local staff administration set ups. SEF has outstandingly dominated the Ethiopian PV market in this period, aggressively expanding through the establishment of solar training school, micro credit system and, solar centers [F6-*resource mobilization*] (Schutzeichel, 2012; Kebede et al., 2014). SEF had also conducted several public lectures and awareness campaigns; trainings to energy bureau officers and college teachers were delivered between 2008 and 2010 [F3-*knowledge diffusion*]. Moreover, the visit of Rema village by donors and high level officers including the former US president Bill Clinton in 2008 popularized the solar PV market due to increased mass media coverage [F3-*knowledge diffusion*] (Schutzeichel, 2012). SEF had also met the Gold Standard quality criteria on climate change for its solar PV installations in Ethiopia, and it also won the Ashedn award in this period [F4-*guidance of the search*] (Schutzeichel, 2012).

Sahay Solar, another NGO from Germany, had initiated the first solar PV activities at Arba Minch University in 2009 by installing pilot PV systems, providing training and installing PV solar laboratory in the university [F1-*enterpreneurial activities; F*2-*knowledge diffusion*] (Sahaysolar, 2009). Furthermore, GIZ had conducted a study and released a report addressing the PV market challenges, potential and policy recommendations, thereby informing and attracting solar companies from Germany[F2-*knowledge development*] (GTZ, 2009). In this period, many government bilateral programmes raised fund for supporting PV market development, among which was the GIZ, EnDev[9] project [F6-*resource mobilization*]. Partly, as a result of such private sector development programmes, many new PV actors were emerging and joining the market which in turn resulted in a relatively higher number of both household level and institutional PV systems installations throughout the country [F1-*enterpreneurial activities*]. However, because a majority of those start- ups and existing companies were running PV as a 'side business', the majority of them do everything

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[8] IPPs up to 25 MW were, theoretically, allowed to operate, though there is no such known experience.

[9] EnDev - A Dutch-German Government partnership programme, Energising Development (EnDev) had budgeted 6 million euros for private sector development and bio energy and solar PV dissemination. An energy coordination office (GIZ-ECO) using this fund conducted awareness campaigns, trainings and installation of institutional PV systems throughout the country (Source: *personal communications*).

from import down to installation (WIPO, 2009;MEKETA, 2007; Kebede and Mitsufuji, 2014).

Around the end of this period, 2009 and 2010, Ethiopia was highly plagued by power outage as private sector was booming and the search for options became an agenda priority [F4-*direction of the search*]. This period was also noted for the launching of post graduate education in renewable energy and technology (including solar) for the first time in the country [F6-*resource mobilization*].

5.1.5. 2011 onwards

For the period 2010/11–2014/15, the GoE launched a national plan, Growth and Transformation Plan (GTP: 2010/11–2014/15) which embraced diverse energy sources including solar PV as sources of energy for the nation and in the strategy, specifically targeted goals included electrifying 153,000 households with SHS and supplying 3 million solar lanterns by 2015 [F4-*direction of the search*] (Energypedia, 2014).

In this period, a recent study by Lighting Africa revealed that there are still over 24 million households in Ethiopia as potential off-grid market in the country [F2-*knowledge development*] (Lighting Africa, 2011). Moreover, a new master plan report for wind and solar energy in Ethiopia by a Chinese consulting corporation was made available through the Ministry of Water and Energy [F2-*knowledge development*].

From 2011 onwards, as part of the GTP of the GoE, 25,000 SHS were installed in a subsidized form [F5-*market formation*]; many donor-based projects were also launched including the establishment of small enterprises and renewable energy technology centers by the coordination of HoA-REC&N[10] [F1-*enterpreneurial activities*].

Another notable land mark in this period is the establishment of the first solar panel assembly in 2012 which is taken as a remarkable shift in the PV value chain in Ethiopia [F1-*enterpreneurial activities*]. It was established under the government-owned Metal and Engineering Corporation (METEC) in a joint venture with an American company called Sky Energy (Osborne, 2012).

5.2. System functions dynamics

As presented in the previous sub-section, Ethiopia was among the prime movers in the sub-Saharan region in introducing PV systems for its rural community. In fact, early PV introductions to rural communities globally were also taking place in those periods, early 1980s (IEAPV, 2013). However, those early experiments could not be sustained for many reasons including lack of continuing government policies and scaling up efforts. Globally, the late 1980s and 1990s entertained neoliberal policies focusing on market-based approaches and privatizations but Ethiopia by then was under a communist government which could have deterred entrepreneurs to follow the PV market. Overall, in the early 1980s, the need for rural energy technology such as PV was briefly noted, and the early experiments could not trigger more entrepreneurial PV projects; hence, very limited system functions (F1 and F4) appeared in this period.

The 1990s to early 2000s was a ‘silent period’ in every dimension as Ethiopia entertained change of Government and went through reformation of organizations and policies. Even some of the early pilot PV projects suffered from lack of maintenance service and in some cases, they were looted during the civil war time (Energypedia, 2014). There was a relative drop in every market perhaps due to the Ethio-Eritrean conflict and the political volatility in the region. At the end of 1990s, the GoE re-initiated rural electrification as part of a rural development package (Hankins and Shanko, 2004).

In the early 2000s, projects supported by international funding institutions rehabilitated the PV market. It was further enhanced through the establishment of EREDPC and rural electrification fund (REF)[11] which were taken as manifestation of the relative commitment of the GoE towards adoption of solar PV and other rural energy technologies. Part of this commitment was the reflection of a push from donors (Tessema et al., 2014).

The 2005 to 2010 period entertained a relative boom in the PV market throughout the country. It is in those years that more or less full set of system functions were also fulfilled (F1 to F7). However, the fulfillment of the system functions does not guarantee that there was a well-functioning TIS (Tigabu et al., 2015a). The 2011 onwards is noted for the entry of METEC as a giant solar actor, establishing the first solar PV module assembly plant in the country.

Following the assumption that a TIS function emerges when an event/activity that matches the function is observed (Hekkert et al., 2007; Tigabu et al., 2013), we sketched the functional pattern observed throughout the years as depicted in Fig. 3. The full set of events and functional build-up pattern is included in Appendix Tables A1 and A2. The Ethiopian solar PV TIS began by functioning through guidance of the search and early entrepreneurial activities in the 1980s. *Guidance of the search* (F4), *entrepreneurial activities* (F1) and *knowledge development* (F2) functions are consistently observed since the introduction of PV to Ethiopia. A full set of system functional emergence (embryonic PV TIS) is observed between 2006 and 2010, fulfilling the seven systemic functions for the first time. But this still does not show the strength or weakness of the system functions (Bergek et al., 2008). It is also observed that *market formation* (F5) is the least served function by the TIS and it remained less served until 2012.

6. Formative phase assessment using process goals

Here we discuss on the diffusion trend of solar PV systems and local industry development as part of evaluating the formative phase of the solar PV TIS in Ethiopia.

6.1. Diffusion trend of solar PV systems in Ethiopia

As mentioned in the introduction, there are two phases of a TIS-*formative phase* and *growth phase* (Bergek et al., 2008). The formative phase is characterized by poorly articulated demand, high uncertainty in the future of the technology and its market, etc. (Jacobsson and Bergek, 2004; Bergek et al., 2008).

The diffusion rate of solar PV systems may not be a suitable measurement of the performance of the nascent TIS and infant solar PV market in Ethiopia (Bergek et al., 2008). However, as diffusion of PV systems is taken as a policy goal by the GoE, we argue that it is a potential and viable indicator whether the TIS is going in the right direction or not. Since the installation volume of solar PV systems could not be available from our informants and other published sources, we had to rely on the import data (which is the most reliable source as per a recommendation from an expert at the Ministry of Water and Energy in Ethiopia) as shown in Fig. 4.

The Ethiopian Revenues and Customs Authority in its database recorded the import of all solar PV items as ‘PV LED’ with minor descriptions available. Only since 2010, the database record separated the solar lanterns category with the PV modules and accessories category. Since Watt peak (Wp) based measurement is included in limited import periods in the database, we sorted and mapped the import data based

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[10] HoA-REC&N (Horn of Africa Regional Environmental Center and Network) is an autonomous institution established under Addis Ababa University which focuses on environmental and sustainable development issues within the Horn of Africa (http://www.hoarec.org/)

[11] REF was established by Ethiopian Government in 2003 so as to avail loan and technical service for rural electrification projects in the country.

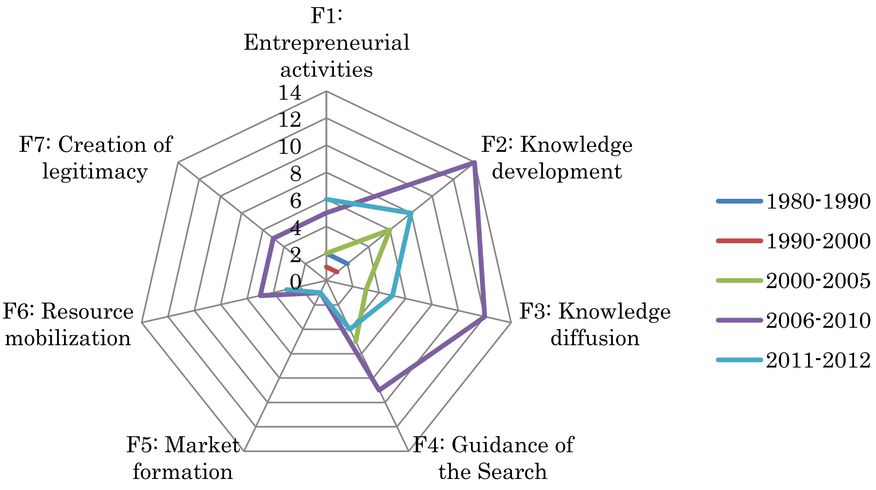

Fig. 3. System function dynamics of solar PV TIS in Ethiopia.

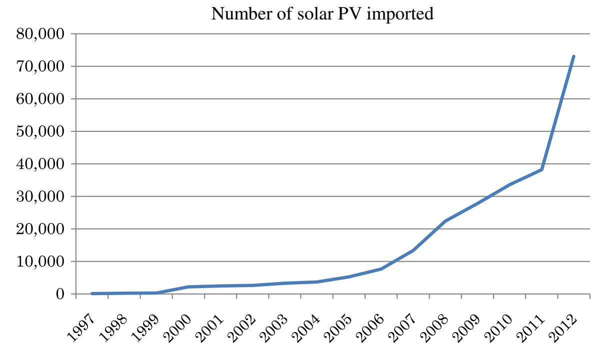

Fig. 4. The import volume of PV LED in Ethiopia.
The Ethiopian Revenues and Customs Authority database records the import of PV as PV LED with minor description. Since Wp measurement is included in limited import periods, we sorted and mapped the import data based on Units of PV items (modules) irrespective of their Wp size.
(Source: Raw data from Ethiopian Revenues and Customs Authority, sorted by author).

on Units (number of modules irrespective of Wp size) category. The figure only serve as a base to estimate the PV market/import/trend and it also does not guarantee whether all the imported PV systems were installed or not. As part of informing the market size in terms of financial transaction, we included the CIF[12] value of imported PV items (mainly modules) as shown in Fig. 5. As can be seen in the figure, solar PV was nearly a 3 million USD market in 2009 alone, which is a significant market in a least developing country context. Moreover, the trend has shown an increase since 2008.

Previous studies estimated installation capacity was < 1.7 kWp until early 2000s (about 550 systems in total) and the majority of the installations were also for telecom applications (Hankins and Shanko, 2004). In the years 2005–2010, there was high number of installations, which can be traced and matched to the accumulation of system functions as shown in Fig. 3. A nascent PV market, mainly the household SHS has sprung up in Ethiopia during this period. It is worth noting here that it was in this period that the full *system* functions (F1 to F7) build-up took place in Ethiopia. Following the system functional build-up in the aforementioned category of periods, the matching of system functions with diffusion rate can lead us to a tentative conclusion that the system functional build-ups by then enhanced the diffusion of solar PV systems in Ethiopia.

Through the examination of the early entrepreneurial experimentation projects and market formation practices in Ethiopia, which are mainly-donor driven, we find that sustaining the PV market is still daunting. The involvement and attraction of the private sector to this infant market is worth recommending (Kebede and Mitsufuji, 2014). There have been many trials and 'good' practices in terms of market delivery systems (pay up front; lease; pay for service, etc.) in the solar market (ERG, 2012; Kebede and Mitsufuji, 2014; Kebede et al., 2014). However, considering the potential off-grid market alone, amounting up to 24 million rural households, still <4% of the potential market for off-grid PV systems is addressed (Schutzeichel, 2012).

As gleaned from our informants, the diffusion of PV systems is still hampered by many market related factors including:

- lack of incentive for the private sector,
- poor standardization,
- poor taxation system,
- lack of proper promotion and awareness campaigns, and
- poor linkage among solar actors.

Hence, market formation (presented as a process goal but less addressed among system functions) needs further 'systemic instruments' in addressing the blockages and expanding the PV market. The government still believes that PV technology, especially in the off-grid market, would be a commodity type of market in the near future. Officers from the Ministry of Water and Energy claim that the recent government bulk purchase of >25,000 PV systems is taken as a "model for the PV market". However, that remains to be seen in the

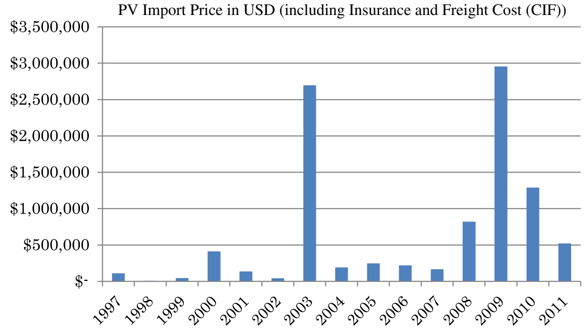

Fig. 5. Solar PV import market trend in Ethiopia (Raw data from Ethiopian Revenues and Customs Authority, sorted by author).

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[12] CIF value is *the amount which shows the price paid for the goods including insurance and freight.*

coming few years. A recently launched project involving installation of a 300 MW (solar park project) may also guide the market to large scale PV systems installation. This is yet in contrast to the previous goal of electrifying the rural community through decentralized small scale PV systems.

6.2. Growth of local solar PV industry

Among the other system functions, knowledge development (F2) is "situated at the heart of any innovation system…" (Bergek et al., 2008, p.414). Bergek et al. (2008) proposed indicators of knowledge developmentincluding: number and types of R&D projects; bibliometrics; number of professors; number of patents; and learning curves (p.415). Hekkert et al. (2007) also elaborated this function as a "prerequisite within an innovation system" and proposed indicators for its measurement including R&D projects and investments in R&D and patents (p.422). The indicators proposed by these scholars are more fit to the *R&D-based TIS* than to the *diffusion-based* TIS.

There are different levels and types of knowledge and learning (Lundvall, 1992). In the context of developed countries, the type of knowledge generated through basic research (R&D) could generate "new form of knowledge and technology". However, in the context of developing countries, mainly the DUI form of learning is prevalent and generates primarily more of 'incremental' innovations (Blum et al., 2015). Blum et al. (2015) evaluated how *learning by doing* and *learning by using* contributed to the local TIS building process around electric mini-grids in Laos. Using this background, we evaluated the status of the system function knowledge development (F2) and thereby the establishment of local PV industry.

The GoE showed interest in establishing a PV industry as presented by a study in a national workshop in 2012, planning to create >50,000 green jobs for its citizens (ERG, 2012). It launched the first PV assembly plant at the end of 2012. Even though the knowledge development function (F2) seems well served by the TIS as depicted in Fig. 3, the events associated with the measurement of this function only entail a 'low' level of learning and knowledge development. In the TIS studies in advanced economies, there is an implicit assumption that there are potential actors somewhere out there (Musiolik, 2012). Hence, an emerging industry may not be in acute shortage of potential entrants into the incoming industry. Despite the interest of the GoE in establishing PV industry, due to lack of proper skilled force, the installation and first sample production of the solar panels was carried out by a partner company in US (SKYei, 2013). It was also previously claimed that there were hardly any solar technicians in the early 2000s in Ethiopia (GIZ, 2009). A single training institute of one foundation later managed to graduate about 60 technicians by 2010 and as a result, contributed to the relatively higher installation volume of SHS between 2006 and 2010 (Kebede et al., 2014). As presented in Table 2, there are now few postgraduate programmes that provide solar and other renewable energy related courses. Very limited number of graduate students and professors have been conducting research in the field and the link between the universities and the industry, in general, remained weak (Mulugetta, 2008). The knowledge of the market is not yet fully captured by the present actors including the newly established PV factory. The factory plans to produce large size PV modules while the common off-grid market needs smaller size (commonly <80 Wp) of panels. Due to the unavailability of smaller size modules locally, companies still import mainly from China and India. Hence, the local PV industry could not even serve the local market and the immediate policy goal of rural electrification. Besides the PV module, part of the balance of systems for PV systems could be produced locally which would reduce the solar PV system cost. As we learnt from a focus group discussion, the awareness level about the PV market is limited among actors in other sectors. For instance, local car battery assemblers are potential actors to join the PV industry as they have the capability to produce (at least to assemble) PV batteries locally. Since the PV market is not yet attractive to the private sector, such companies are reluctant to join the PV industry. PV market has been taken as a "side business" and only very few private companies dedicated resources in joining the PV market (industry) (Kebede and Mitsufuji, 2014).

7. Concluding remarks

In this study, we have mapped out the system functions of an embryonic solar PV TIS in Ethiopia. The historical events were chronologically listed and matched to a set of system functions as proposed by innovation system scholars. The system functions were initially developed in the context of advanced economies where the TIS do not start from 'scratch'. In our study, we employed the system functions with a modified set of indicators to explain the technology-specific innovation systems dynamics in a least developed country setting. The emphasis in the context of developing (technology receiving) countries lies on: (1) introducing technologies from industrialized countries and (2) aiming for adaptation, usage and generation of further innovations over time. Hence, we differentiated the *R&D-based TIS* from the *diffusion-based TIS*, because the latter describes the innovation system construction (building) in least developed economies (technology recipients) focusing on diffusion of an existing technology, thereby building absorptive and innovative capacity for further improvement and diffusion of the technology.

In our case study, it was tried to evaluate the performance of the solar PV TIS in Ethiopia based on the two policy goals promoted by the Ethiopian Government. The study provided an evidence of how the accumulation of *system functions* influenced the diffusion of PV technology in Ethiopia. The system functions build up enhanced the adoption volume of PV systems in Ethiopia but did not guarantee that *market formation* (F5) was a well-served system function. There needs to be more effort from every actor in sustaining the solar PV market and addressing the energy poverty of the nation at large through building a well-functioning TIS. Also while the system function *knowledge development* (F2) seems well served by the PV TIS in Ethiopia, the strength of this function in terms of policy goal is weak. Further policy intervention in clearly articulating the local demand and the local PV industry development is essential. Building the right skill (and absorptive capacity) through academic and research institutions is also proposed as a way to go from *diffusion-based* to *R&D based* TIS.

As our study is a case study, it may suffer from the common case study limitations. Moreover, the solar PV TIS building in Ethiopia may not fully represent a typical strategy for other emerging economies or least developing countries. As previous studies indicated, there are emerging economies which succeeded in first importing the technology, and through further adaptation, they moved to the upper ladder of innovation; for instance, the wind power and solar PV in China. To make a more plausible generalization and learning about the TIS formation for successful diffusion of RETs in developing countries, the solar PV TIS in Ethiopia has to be compared to other TISs, for instance, to a nearby country, Kenyan PV TIS.

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Appendix A

Table A1
Events and associated system functions.
(Source: Events were gathered from various sources; functions are adapted from (Hekkert et al., 2007)).

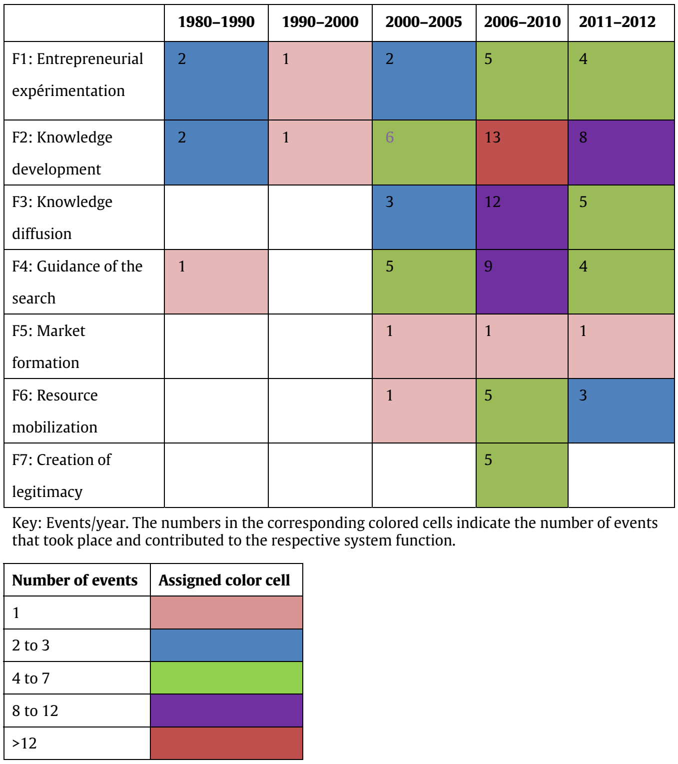
Year	Events	Function
Early 1980s	The government urged and welcomed energy technology proposals to address the energy problem as a follow up to oil crisis	F4
Early 1980s	University professors, expert and consultants were urged and invited to submit proposals	F6
1986	The first Solar PV stand-alone system (10.5 kW) introduced to Mito village in Central Ethiopia	F1
1986	A study on solar radiation distribution in Ethiopia was conducted and released by the Ethiopian National Energy Commission and CESEN, Italian consulting company	F2
1989	Technical appraisal of the Mito village pilot project was carried out by an Ethiopian professor	F2
1989	Mito II project was expanded to 21 kWp system	F1
1994	UNESCO funded PV-powered solar pumping for a village	F1
1998	Two small system of 55 Wp module installed in AAU for climate research/feasibility study	F2
2000/1	IGAD conducted market study and supported demonstration projects training of solar technicians	F2
2002	Establishment of Ethiopian Rural Energy Development and Promotion Center to support RE	F4
2003	Establishment of Rural Electrification Fund through the support of World bank, IFC and UNDP	F4
2003	World Bank(WB)-GEF provided loan to energy project of GoE	F6
2003	The WB Program set a minim 6000 solar system installation	F4
2003	Study on the commercialization of solar PV conducted	F2
2003	More private companies joined PV market	F1
2004	UNEP-GEF funded a SWERA (Solar and Wind Energy Resources Assessment) project in Ethiopia released	F2, F4
2004	Barefoot College started training farmers from Ethiopia	F3
2004–2005	Tukul, solar village, was visited by Donors, NGOs, UNDP staff and it was talked about	F4
2004–2006	Additional 34 trainees of Barefoot College by the fund support from UNDP	F2
2005	Trainees promoted and installed systems in their villages	F2
2005	A solar home systems pilot project kicked off, by Solar Energy Foundation(SEF), about 30 SHS were in installed in Kechemober	F1
2005	Inspection of Kechemober installations for techncial problems and community acceptance study conudcted	F2
2005	Visit of Kechemober by other rural communities including Rema villagers	F3
2006	Establishment of the Solar Training and Competence Centers in Addis Ababa	F6
2006	EEPCO power system expansion b/n 2006–2015 focused on Hydro power; no mention of solar	F1
2006	Universal Electricity Access Program released	F6
2007	1100 SHS installed in Rema-1100 huts (around 6000 people inside) including Police and Adminstration Offices; Church and Mosques	F1
2007	National mass media reported widely about Rema SHS installations	F3
2007	SEF launched further plan (1675 signatories received from Dire and other villages) to solarify a vilalge in 2007/2008 and established a training center	F5
2007	International Solar Energy School (ISES) established at Rema	F6
2007	Seminar on “Photovoltaics: Technology and Practical Applications” was given to Electrical Engineering Staff of Ethiopian Universities	F3
2007	Public Panel Discussion on “Solar energy in Ethiopia”, with participation of Senior Officers from Ministry of Mines and Energy	F3
2007	Training course on “Rural Solar energy manager” aimed at Electrical Engineers, focused on Solar technology, management and practical, 3 month training started	F3
2008	Local assembly in Rema was started	F2
2008	Japan Embassy released a study both in Japanese and English on Energy Sector and Investment Potential in Ethiopia	F2
2008	SEF made agreement with Rema, Rema ena Dire for installation of 1000SHS	F7
2008	24 first graduates from ISES followed by practice b/n April and August in installing in Rema &Dire	F3
2008	Rema became a member of Worldwide One Laptop Per Child Project and teachers given training on how to use the small pc (soar using laptop)	F6
2008	Bill Clinton visited Rema, the solar village	F7
2008	Training of 25 members from Regional Energy Bureaus at ISES	F3
2009	GTZ conducted PV market assessment in Ethiopia	F2
2009	Market study indicated potential up to 52 MW PV market in Ethiopia	F4
2009	A number of PV systems were installed on rural health centers and primary schools by GTZ	F3
2009	PV system design and installation (ES 3482:2009) code of conduct published by Ethiopian Quality and Standards Authority	F4
2009	Private companies were joining the market	F1
2009	A study on “Diversity and Security in Ethiopian Power Reform” funded by Heinrich Boll foundation and Forum for Environment, Ethiopia released	F2
2009	Sahay Solar initiated the first activities at AMU in 2009 by installing the AMU solar laboratory	F1
2009	Ethiopian Solar Development Society (ESDS) established for lobbying and advocacy	F7
2009	The first manual (handbook) on “Rural electrification with PV” for developing countries launched by SEF	F2
2009	Solar energy and the refrigeration of medicine training held in cooperation with WHO in Addis Ababa by trainers from ISES	F3
2009	Ashden Award granted to SEF	F4
2009	ISES with ECBP gave a one week training for Ethiopian Lecturer (Department heads of Electrical Engineering) in Further training Adama	F3
2009	ISES's course, Rural Solar Energy Technician Course recognized by Amhara Regional State Education Bureau	F7
2009	Feasibility study for 120 MW grid connected PV system in Afar region by EEPCO	F2
2009	Power outage plagued the country	F4
2009	The Ethiopian Minister of Energy visited Rema, impressed and promised to ease import bars	F4
2009	Ministry of Finance and Economic Development (MoFED) lifted the import duty fees on PV modules and balance of system (BOS)	F5
2009	EnDev budgeted 6Mio Euro for Bio-energy, solar PV and private sector development	F6
2009	GTZ-ECO through EnDev programme installed 55 solar PV systems (1.43 kWp) on health centers	F1
2010	Training for Ethiopian Microfinance providers, Banks and public authorities representatives	F3
2010	UNDP with its partners conducted a study on and showed capacity on Local Manufacturing of Renewable Energy Technology Components in East Africa (in Ethiopia and Uganda)	F2, F4
2010	A number of institutional PV systems were installed by GTZ and other NGOs	F3
2010	Inauguration of the Solar Valley Ethiopia and ceremonial initiation of the solar system under the dena Solar Roofs Program. International guests, the Ethiopian Minister of Energy and a representative of the German Embassy attended	F3,F7
2010	SEF met the Gold Standard quality criteria on climate change for its Ethiopian PV projects	F4

(continued on next page)

Table A1 (*continued*)

Year	Events	Function
2010	The Growth and Transformation Plan (GTP: 2010/11–2014/15) mentioned RE including solar as source of energy for the nation	F4
2010	GTP set goals on SHS and Lanterns dissemination to electrify 153,000 households with SHS and to supply 3 million solar lanterns by 2015	F4
2010	Indian Government sponsored and trained Ethiopian University staff on Designing and Implementing Solar Energy Projects for Rural Communities	F2
2010	Renewable Energy related Master Programs launched at least in two universities	F2
2011	Ethiopia Solar – The initiation of a solar trade in Ethiopia, 2005–2011 report published	F2
2011	Adama Institute for Sustainable Energy established in Adama University	F6
2011	ACP-EU Energy Facility Grant of the 10th European Development Fund a project of HoA-REC&N entitled “An Integrated Approach to Meet the Rural Household Energy Needs of Ethiopia” – kicked off	F6
2011	A number of institutional PV systems were installed by different organizations	F3
2011	Lighting Africa conducted a study and released a policy report on solar PV and modern lighting in Ethiopia	F2
2011	Lighting Africa also released a study report on Off-grid market in sub-Saharan African countries including Ethiopia	F2
2011	The study of Lighting Africa showed over 24 million households in Ethiopia are potential off-grid market	F4
2011	HoA-REC&N started to organize 20 SMEs for establishing renewable energy centers	F1
2011	ETV news coverage on Solar and Wind Energy investment of Ethio-German Konnect Event	F3
2011	Training of Trainers for Solar PV conducted in Adama University by the support of GIZ-ECO	F2
2011	Training of Trainers on Solar Business Management in Adama University by the support of GIZ-ECO	F2
2011	Staff and students trainings on solar PV systems in different Universities including AMU	F3
2011	A Master Plan Report of Wind and Solar Energy in Ethiopia conducted by a Chinese Corporation	F2
2011	GoE developed Climate Resilient Green Economy (CRGE) strategy	F4
2012	Installation of solar system at a Hotel Lodge in the Arbaminch area-commercial project	F1
2012	Inclusion of PV-teaching modules into existing curricula in Arbaminch University	F2
2012	World Bank provided soft loan for REF 25,000 SHS installation throughout the country	F4
2012	Market Development for Renewable Energy and Energy Efficient Product Fund made available	F6
2012	Solar PV system promotion through REF projects	F3
2012	REF disseminated PV systems to regional bureaus for training and demonstration purpose	F5
2012	SEF and ESDS conducted a national workshop on solar PV industry in Ethiopia and released a study report	F2
2012	GIZ and Selam Vocational school provided 8 days training to cooperatives on solar PV installation and maintenance	F3
2012	A national feasibility study indicated that 50,000 jobs can be created in solar sector	F4
2012	Federal Democratic Republic of Ethiopia (FDRE), Scaling Up Renewable Energy Program Ethiopia Investment Plan, 2012	F4
2012	The first Solar Kiosk launched in Langano area	F1
2012	1st Solar PV modules Assembly plant launched by METEC	F1

Table A2
Dynamics of functions in the Ethiopian solar PV TIS (1980–2012).
(Source: Own depiction).



	1980–1990	1990–2000	2000–2005	2006–2010	2011–2012
F1: Entrepreneurial expérimentation	2	1	2	5	4
F2: Knowledge development	2	1	6	13	8
F3: Knowledge diffusion			3	12	5
F4: Guidance of the search	1		5	9	4
F5: Market formation			1	1	1
F6: Resource mobilization			1	5	3
F7: Creation of legitimacy				5	

Key: Events/year. The numbers in the corresponding colored cells indicate the number of events that took place and contributed to the respective system function.

Number of events	Assigned color cell
1	▨
2 to 3	🟦
4 to 7	🟩
8 to 12	🟪
>12	🟥

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