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Technological Innovation Systems and the wider context: A framework for developing countries

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Technological Innovation Systems and the Wider Context:
A framework for developing countries

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Abstract

The Technological Innovation System (TIS) framework is a systems approach for understanding the adoption and impact of technologies. This paper addresses limitations of the TIS functions approach by complementing its list of functions. As a result the breadth of application of the framework in developed countries is augmented, and made more applicable to the developing country context. In order to analyse the context in which the TIS operates, framework conditions are added to the TIS function approach, drawn from Multi-Level Perspective (MLP) literature.

JEL Classification Codes: O33; O38

Keywords: Technological transitions; Technological Innovation System; Multi-Level Perspective; Renewable energy technologies; developing countries

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1. Introduction

The evidence concerning the environmental, economic and human risks associated with a changing climate has brought renewable energy technologies (RETs) to the foreground in international debates as one of the most important aspects of climate change mitigation (IPCC, 2012).[1] The necessity to move from fossil fuels to renewable sources of energy in order to curb greenhouse gas (GHG) emissions has resulted in worldwide commitments accompanied by a significant increase in resources targeting new investments in RETs.[2] Moreover, according to the International Energy Agency (IEA), RETs have made significant gains in cost-competitiveness and many are today considered to have reached a level that is competitive with existing fossil fuel-based alternatives (IEA, 2011). RETs are also raising the importance of renewable energy policy and the need to monitor and measure renewable energy activities to support and evaluate policy implementation, especially in developing countries.[3]

To observe the success and failures in adopting and adapting RETs analytical tools and studies are required. Many such studies have been conducted in developed countries using the Technological Innovation System (TIS) function approach (Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004; Negro et al., 2007; Negro and Hekkert, 2008; Negro et al., 2008). However, the existing TIS function approach for analysing technological innovation systems has limitations. Firstly, the framework has been constructed from a developed country perspective and cannot be directly applied in developing countries, without first considering their characteristics. Secondly, the TIS function approach has been criticised for being *inward looking* and not sufficiently incorporating the contextual factors that may influence the success or failure of RETs diffusion.

This paper addresses these constraints by adding to the number of functions of the TIS. This process is informed by an examination of previous attempts to utilize the TIS function approach in developing countries, and by drawing on lessons from the Multi-Level Perspective (MLP) approach. The result is an extended TIS function approach, with functions that are applicable in developing countries, and with framework conditions that reflect the socio-economic context present in many of these countries.[4]

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[1] Renewable Energies, in the form of wind, solar, geothermal, small hydro, and biomass are all examples of energy derived from natural processes, which are replenished at a faster rate than they are consumed (IEA, 2011). Examples of other mitigation alternatives include carbon capture and storage and carbon sinks (e.g. through reforestation) (IPCC, 2007).

[2] In 2011, 118 countries had some form of renewable energy support policy or target for RETs at the national level, compared to 55 countries in early 2005 (REN21, 2011). During 2012 fiscal year, the World Bank approved US$3.6 billion towards financing of renewable energy projects, which represented 44% of the World Bank's total annual lending (The World Bank, 2012).

[3] Global projections estimate that global emissions in developing or emerging countries will exceed that of the developed world in the next decades (U.S. Energy Information Administration, 2013).

[4] No single definition of the term developing country is recognised internationally; however the term includes a multitude of countries, the developmental status of which varies widely. In this paper, the World Bank definition of developing countries, based on categories of income will be followed. Based on fiscal year 2015, countries with a Gross National Income (GNI) per capita of less than US$ 1,045 (Low-income), US$ 1,046-4,125 (Lower-middle-income) and US$ 4,126-12,735 (Upper-middle-income) are considered developing (The World Bank, 2015a). The suggested function changes and

In this paper, reflections and suggestions are made that can benefit future studies of technological transitions in a general sense, i.e., regardless of a specific technology. However, as indicated in the introduction, the aim of this paper is to understand how the TIS framework can be enhanced to understand the transition to RETs. Consequently, suggestions provided in this paper (section 5 and onwards) have been developed with renewable energy technologies in mind.

2. Technological Innovation System (TIS)

Since the emergence in the mid-1980s of Innovation Systems (IS) as an analytical framework and a policy tool, various IS approaches have been developed and are widely covered in the literature. The IS approaches include the National Innovation System (NIS) (Freeman, 1987, Lundvall, 1992; Nelson 1993), Sectoral Innovation Systems (SIS) (Breschi and Malerba, 1997), Regional Innovation Systems (RIS) (Cook et al., 1997; Saxenian, 1994) and Technological Innovation Systems (TIS) (Carlsson and Stankiewicz, 1991).

A technological system has been defined "as a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson and Stankiewicz, 1991: 94). The TIS focuses on a technology, rather than a geographical area, which is the case in the National Innovation System (NSI) and Regional Innovation Systems, or an industrial sector, as in the Sectoral Innovation System (SIS) (Hekkert, et al., 2007). However, despite their development as different approaches they are interrelated, i.e., a technology specific IS (TIS) could operate at the National, Regional and/or Sectoral level (Markard and Truffer, 2008).

2.1. Setting the Boundary of TIS

Setting the boundary of a TIS is a complicated undertaking. As suggested by Carlsson and Stankiewicz, the TIS could be delimited by the sector of a technology, e.g. wind or photovoltaic sector. Another suggestion is to delimit the TIS "in terms of activities" (Edquist, 2006: 15). TIS literature has referred to the focal TIS as "the realm where systematic interdependencies in a specific technological field play out" (Bergek et al., 2015: 52). But what would be considered a relevant innovation activity or what systematic interdependencies would be encapsulated in the focal TIS? If a narrow boundary is set, are there relevant dependencies outside the delimited TIS that are being missed? Edquist (2006:15) argues that understanding the various activities and their relative importance for any innovation system is "subject to change as our knowledge increases". This paper contributes to the TIS framework boundary debate from a developing country perspective.

2.2. Stages of Development

In order for a new technology to reach the final phases of development, diffusion and utilization, it first must first undergo a *formative stage*. At this stage, various

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framework conditions proposed in this paper have been developed with middle-income developing countries in mind.

components necessary for the formation of the TIS are taking shape, e.g. knowledge accumulation, necessary infrastructure and institutional configurations (Bergek et al., 2008b). Depending on the technology in question, market conditions as well as on actions taken by policy makers and industry actors this cumulative change of the different components of the TIS may last for decades (Van de Ven and Garud, 1989).

After the development of essential structural components, the TIS enters a *growth stage* where positive feedback is established between components, contributing to an accelerated development of the system. The momentum created by this positive feedback could make the system "increasingly self-sustained" and eventually it becomes a stable and mature structure, "resilient to external pushes and pulls" (Bergek et al., 2008b: 577-578). This can be contrasted to the earlier formative stage where exogenous factors may assert more influence on the system (Raven, 2005).

In short, the TIS framework can be used to analyse both the formation and growth of technological innovation systems (Jacobsson and Jacobsson, 2014). A TIS analysis in developing countries would, in most cases, be focused on the formative stage, rather than on a later growth stage. Consequently, the exogenous factors could be of greater importance when mapping and analysing TIS systems in developing countries.

2.3. TIS Function Approach

In 2001, Johnson and Jacobsson introduced system functions to the TIS approach in order to analyse the processes integral to the creation and development of a technical innovation system. Separately studying the underlying processes that make up the innovation system supports a systemic analysis that can help to identify characteristics of the system, such as weaknesses and strengths (Lundvall et al, 2002; Hekkert et al, 2007).

The dynamics of a technical system are considered a consequence of the interaction between different functions (Johnson and Jacobsson, 2001). Thus, a comprehensive analysis of the functions of the TIS may also allow for a better understanding of the dynamics within the system. Moreover, the function approach can generate important lessons concerning the drivers and barriers within a system, by identifying the performance of different functions. These lessons in turn can assist in devising policies for generating, diffusing and utilizing a new technology.

Over the last decade several authors have tested, adopted and further developed the TIS function approach, resulting in numerous lists of system functions.[5] The many sets of system functions available suggest that the TIS function approach is still in a developmental stage and continued improvements will be needed as the understanding of the system function advances (Edquist, 2006). This paper uses the list of system functions presented by Heekert et al. (2007) (see Table 1). This list has been chosen as the preferred baseline for this paper, as it has been tested in several empirical studies and the relevance of the functions has been demonstrated.[6]

[5] See for example: Johnson and Jacobsson, 2001; Edquist, 2006; Jacobsson and Bergek, 2006; Hekkert et al., 2007; Hillman et al., 2008; Suurs and Hekkert, 2009; Bergek et al., 2008a.
[6] See for example: Negro et al., 2007 and Negro et al., 2008.

Table 1. Innovation System Functions

System Functions		Description
F1	Entrepreneurial Activities	Activities concerning the new technology (projects started, planned etc.)
F2	Knowledge Development	Existing and new knowledge created regarding the technology (R&D, experimentation etc.)
F3	Knowledge Diffusion	How and to what extent knowledge regarding new tech. is shared among actors (number of workshops, conferences etc.)
F4	Guidance of the Search	Expectations set by government for new technology in terms of regulations and specific targets
F5	Market Formation	Market entry assistance for new tech. (protected space ("nursing") for niche market, new environmental standards, tax exemptions, feed-in tariffs etc.)
F6	Resource Mobilization	Funds allocated by government or industry towards R&D (Human Capacity) or Subsidies (Financial Capacity) for the tech.
F7	Creation of Legitimacy	Advocacy for new tech. (Lobbying to increase legitimacy and support for new tech.)

Source: Hekkert et al., 2007.
Note: The description of the functions is provided in a concise format. For a more elaborate discussion of the functions see Hekkert et al., 2007.

Most lists of functions, including Hekkert et al. (2007), have been primarily developed for, and applied in, a developed country context, where a technology has achieved a later growth stage. However, with an appropriate adjustment to the list of functions along with the inclusion of relevant exogenous factors in the analysis, the function analysis in a developing country context is relevant. Mapping the functioning of the innovation system at an early formative stage will provide important information regarding the status and trends of processes considered essential for achieving the later growth stage of generating, diffusing and utilizing the technology in question. The next section will discuss some limitations raised in previous literature concerning the TIS and specifically the function approach. In section 5, suggestions for general improvements to the function approach, along with specific aspects relevant for its application in a developing country context will be provided.

3. Limitations of the TIS Approach

3.1. Limitation 1: Inward looking

While the TIS function approach has been credited with being a useful tool for analysing dynamic processes, the approach has been criticised for not sufficiently taking into account the influence of external factors on the technological innovation system (Geels et al., 2008; Coenen and Lopez 2010; Markard and Truffer, 2008).[7]

Markard and Truffer (2008) refer to the TIS approach as "myopic with regards to the

[7] In this context external factors refer to aspects that are not considered to be integral internal factors to the formation of a specific technical innovation process (e.g. organizations and individuals directly contributing with specific knowledge, technical skills and resources), but that may equally assert influence on the TIS.

explanation of technological transitions" (p. 610). They elaborate by describing the system perspective as being "inward oriented and does not pay much attention to the system's environment" (p. 610). The recognition of the potential influence of the external landscape is not a new notion but was already emphasised my Gunnar Myrdal in 1957, when he argued that a principal scientific task is "to analyse the causal inter-relations within the system itself as it moves under the influence of outside pushes and pulls and the momentum of its own internal processes" (18). In other words, what the authors emphasise is that beyond the boundary of the focal technological innovation system, there is an external context that may influence the system in a positive or negative manner. Over the years, the "structures and processes inside a focal TIS are generally well conceptualised in the literature" (Bergek et al., 2015: 53). However, given that a technological sector would need to be geographically delimited, i.e., nationally or perhaps even internationally, accurately defining a boundary for a TIS is not an easy task (Edquist, 2006). A focus on the focal TIS has meant that what happens outside and across the system boundary has not been systematically studied (Bergek et al., 2015: 53).

To clarify, the criticism of the myopic nature of the TIS approach is partly justified but not entirely. Some of the early TIS literature does mention the relevance of a wider context, referring to the potential influence of other external systems and national system-level factors.[8] However in a recent paper by Jacobsson and Jacobsson (2014), they acknowledge a lack of explicit reference to this wider context in subsequent analyses, which can partly be explained by "taking for granted certain features in the disciplines from which TIS emerged" (p. 820).

More importantly, the wider context has not sufficiently been systematically integrated to complement the existing focal TIS function analysis.[9] Given that one of the purposes for adding functions to the TIS analysis was to be able to produce concrete policy suggestions for enabling development and diffusion of new technologies, the lack of systematically incorporating the wider context into the analysis constitutes a limitation to the approach.

Consequently, by neglecting the wider context in the analysis, the comprehensiveness of the TIS function approach may be reduced, which could result in incomplete policy recommendations that leave out essential aspects concerning existing drivers and barriers for the system. Given that exogenous factors may potentially have a stronger influence at the formative stage (Raven, 2005), the lack of explicit recognition and analysis of the wider context can be of greater concern when applying the TIS function approach in a developing country.

3.2. Limitation 2: TIS Function Approach is Based Primarily on Developed Countries

The TIS function approach has been developed for, and primarily applied in, developed industrialised nations such as the Netherlands, Sweden and Germany (e.g.

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[8] See for example: Ehrnberg and Jacobsson, 1997, Jacobsson and Johnson, 2000 and Johnson and Jacobsson, 2001.

[9] An exception being the inclusion of the function "development of positive externalities", referring to positive external economies (see Bergek et al., 2008a).

Jacobsson and Bergek, 2004; Negro et al., 2007; Negro et al., 2008; Negro and Hekkert, 2008; Suurs and Hekkert, 2009).

The previous focus on developed countries would suggest a lack of comprehensiveness in the framework when applied to developing countries. Revisions and certain adjustment would be required before applying the TIS framework in a developing country context. In fact, several authors have questioned the applicability of the innovation system approach to developing countries (Arocena and Sutz, 2000; Van Alphen et al., 2008 and Schott and Jensen, 2008). Schott and Jensen (2008), for instance, argue that without considering the specific context the innovation system approach cannot be applied to developing countries. The context may involve institutions, the socio-economic environment of the country, and existing dynamics within the country (Arocena and Sutz, 2000).

In 2012, Radhika Perrot applied the TIS function approach to analyse the transition of renewable energies in South Africa and India. The paper provides some interesting insights into the case of the South African and Indian technical innovation systems, but does not address the apparent need to improve the existing list of TIS functions to better incorporate the developing country context. At the same time, the article clearly states that existing frameworks do not sufficiently take into account the context of developing countries and that "there is a pressing need to develop new analytical frameworks when analysing renewable energy industries in developing countries" (Perrot, 2012: 8).

4. Energy Transitions in Developing Countries

According to the World Bank, 135 countries are considered developing countries, 63% of all world countries (The World Bank, 2015a). The vast variety of characteristics encapsulated in this category of countries emphasises the complexity in designing a generic framework for developing countries. Not withstanding, the suggestions proposed in section 5 have been made while considering commonalities found in developing countries.

Global projections have estimated that GHG emissions in developing or emerging countries will exceed those of developed countries over the next decades (U.S. Energy Information Administration, 2013). These projections emphasise the need for developing countries to divert from the carbon intensive development path that characterised today's developed countries. By "leapfrogging" over the carbon intensive stage, developing countries can therefore avoid the 'carbon lock-in' experienced in many developed countries (Watson and Sauter, 2011). Leapfrogging in terms of technology refers to "the implementation of a new and up-to-date technology in an application area in which at least the previous version of that technology has not been deployed" (Davison et al., 2000; p 2).

Given that most technologies have been created in developed countries, a transfer of technology from developed to developing countries must occur to enable leapfrogging (Gallagher, 2006). Beyond the transfer of the technology, a successful technology leapfrogging is dependent on appropriate organizational structure changes and policy reforms (Steinmueller, 2001; Perkins, 2003). The broad list of functions provided by Hekkert et al. (2007) provides a good starting point for analysis. The following section will provide suggestions for how this list of functions can be adjusted to incorporate the developing country context.

5. Suggestions for the Function Framework

5.1. Suggestion 1: Function 2 - Knowledge Development and Creating Adaptive Capacity

Since most technologies were created in developed countries, several authors have stressed the need for placing attention on technology transfer and technological absorptive capacity (Cohen and Levinthal, 1990, Arocena and Sutz, 2001; and IPCC, 2001). Most of the absorptive capacity research has focused on the firm level (Criscuolo and Narula, 2008). Absorptive capacity at the firm level has been described as the capability of firms to digest and utilize external knowledge (Cohen and Levinthal, 1989). Several studies have used various forms of research and development (R&D) as a proxy to measure absorptive capacity of firms (Flatten et al., 2011).[10] In the TIS function list chosen for this paper (Hekkert et al., 2007), however, R&D is referred to as a proxy for knowledge development for a particular technology (see table 1: function 2).[11] In this paper, R&D will be associated with the development of new technological knowledge domestically, rather than the absorptive capacity of external knowledge.[12]

This does not imply that absorptive capacity should be ignored in the TIS function approach. On the contrary, the ability of countries to assimilate and utilize external knowledge is highly relevant, especially in a developing country context, where transfer of technology is common practice. The focus however, when discussing the transfer of technology, should be on the capability of countries to successfully receive the technology in question. Therefore, a better proxy than R&D for assessing the absorptive capacity of countries at the receiving end of a technological transfer is their level of technical and higher education (Mowery and Oxley, 1995).

In addition, in the developing country context, attention should also be directed towards the institutional and organizational capacity to receive a new technology. This necessitates a wider focus on the national absorptive capacity, rather than the sole attention of the absorptive capacity of firms. A country's national absorptive capacity can be defined as "the ability to learn and implement the technologies and associated practices of already developed countries" Dahlman and Nelson (1995 cited in Criscuolo and Narula, 2008: 57).

An example where this has been tested is in the study by van Alphen et al. (2008), which analysed the diffusion of RETs in the Maldives. They refer to "the development and strengthening of human, organizational, and institutional capacity" as *creating adaptive capacity* (Van Alphen, 2008: 166). They chose to replace the *knowledge development* function with *creating adaptive capacity*, which was

[10] See Oltra and Flor (2003) for an example of R&D input (intensity) and Ahuja and Katila (2001) for an example of R&D output (patents). See Flatten et al. (2011) for a more extensive list of studies using R&D as a proxy.

[11] Hekkert et al. (2007) refer to this function as including learning by searching and learning by doing.

[12] The use of R&D (input and output) to measure the knowledge creation/development function of the TIS is widely used. See Bergek et al. (2008) for an extensive comparative list of TIS functions.

motivated by arguing that the Maldives is not "capable of developing the appropriate technology domestically" (Van Alphen, 2008: 166).[13]

While replacing the knowledge creation function with an adaptive capacity function may have been motivated in the case of the Maldives, there are reasons for caution when discussing a general framework for developing countries. When considering a framework to be used in developing countries, replacing *knowledge development* with *creating adaptive capacity* may lead to missing important information concerning knowledge development trends or learning curves. In other words, even though the country under study may not be capable of domestically developing the technology, there may still be ongoing knowledge development in the form of research projects or experimentation for a specific technology.

In that respect, it is important to recognize the wide discrepancies between developing countries in terms of their ability to develop new knowledge. For example, expenditure in R&D differs widely among developing countries (low, lower-middle, upper-middle income). In 2012, El Salvador spent 0.03% of GDP in R&D, compared to 1.92 % of GDP spent by China (The World Bank, 2015b).[14] The varying levels of R&D expenditure would suggest different capabilities for domestic knowledge development amongst developing countries. Moreover, the capability for knowledge development of a developing country is not static but changes over time, along with its ability to shift from purchasing technologies to developing technologies domestically.

India and China represent two examples that demonstrate developing countries' ambition to rapidly move from buying technology from industrialised countries to manufacturing and developing it. Within a span of about 10 years, China and India went from importing all wind turbines from foreign companies to having a large domestic manufacturing industry and prominent RET companies (Lewis, 2007). Put differently, India and China transitioned from an early formative stage to a growth stage with widespread diffusion within a decade. Incrementally improving their knowledge creation played an essential part in moving China and India from the formative to the growth stage. Earlier literature has also emphasised the importance of recognizing the potential of developing countries of improving technologies or adapting them to the local context (Fransman, 1982; Voss, 1988).

The examples of the China and India represent an extraordinary rapid transition from an early formative stage to growth stage. This transition may take much longer, or perhaps never fully occur, in other developing countries. However, given the dynamic quality of knowledge development in developing countries, the inclusion of the knowledge development function in future TIS studies should be considered. Moreover, recognizing the influence of knowledge development in cases that have successfully moved from purchasing technology to domestic innovation further motivates this approach.

[13] Van Alphen (2008) began with Heekert et al., 2007 as a baseline (function) list.

[14] The data include both private and public R&D expenditure for basic research, applied research, and experimental development.

To conclude, the first suggestion of this paper is that new *knowledge development* in a TIS function analysis could be mapped by reviewing R&D (input and output), but should be analysed separately from *creating adaptive capacity*. The former will strictly assess new knowledge being created, which can be analysed by mapping the number of research projects, R&D expenditure, and patents relating to the technology in question. Considering including *knowledge development* in a developing country study may alleviate the risk of missing valuable information concerning knowledge trends. The latter (i.e., *adaptive capacity*) will evaluate the readiness of a particular country to receive a new technology, which can be done by mapping the existing level of human, institutional and organizational capacity. A proxy for human capacity can be the level of technical and higher education in a country.

5.2. Suggestion 2: Function 6 – Resource Mobilisation

The second suggestion to better adapt the function approach to a developing country context is to split the resource mobilisation function (F6) (see table 1) into two categories of resources. Most developing countries receive grants and loans for technical assistance (e.g. for human capacity building) and financing of projects for renewable energies and other mitigation efforts from bilateral and multilateral organizations. International financing also involves Foreign Direct Investment (FDI) and other sources such as carbon offsets or specific climate change funds. International investments in clean energy in South America, Middle East and Africa, and Asia and Oceania, grew by more than 400% between 2005-2009 (Limaye and Zhu, 2012). Therefore international resource mobilisation towards renewable energies and other mitigation efforts play an important role for developing countries and regions. For example, in May 2014, the Global Environment Facility (GEF) had 25 projects (out of 53 executed by the Inter-American Development Bank) dedicated to energy efficiency, renewable energy and carbon markets, totalling US$301 million (IDB, 2015). Including an analysis of international resource mobilisation towards RET in developing countries would most likely provide a more accurate assessment of function 6.

The suggestion is therefore to split function 6 into two categories, (F6a: *resource mobilisation (government))* and (F6b: *resource mobilisation (international loans and grants*)), in order to analyse domestic resources and international resources separately. The international resource function could be analysed by examining the availability, size and type (human and/or financial) of international resource mobilisation for the technology in question.

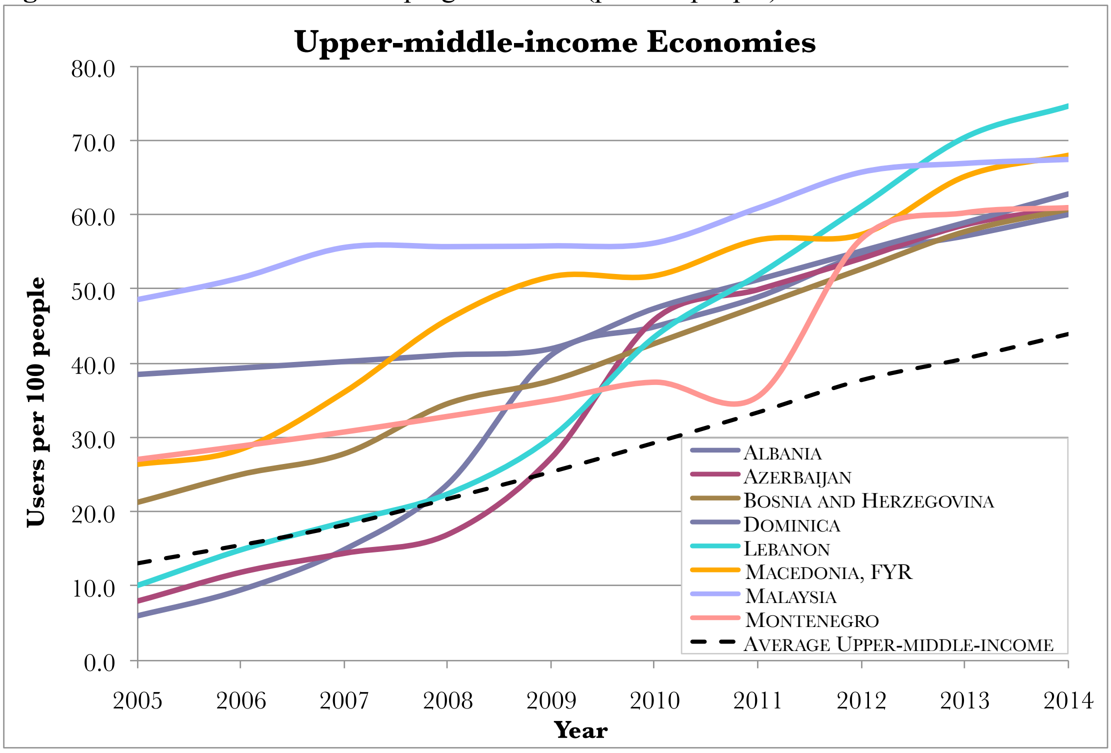
5.3. Suggestion 3: Function 7 - Creation of Legitimacy/Advocacy Coalition

Enhanced legitimacy for a new technology can potentially influence several other functions, such as increased resource mobilisation (F6) or improved tax regimes (F5) (Hekkert et al., 2007). Heekert et al. have mapped the advocacy coalition/creation of legitimacy function through changes in interest groups and their lobbying activities, as well as public support and acceptance. The lobbying groups in these studies are generally organised, well financed and often with political and economic interests and influence, such as firms, government, knowledge institutions, NGOs or environmental groups. Industries can for example utilize their existing financial strength to form specialised divisions responsible for lobbying upon their behalf (Unruh, 2000).

However, lobbying can also occur from groups of people that lack initial organization, financial strength or economic and political influence. This form of lobbying may involve engaged individuals and smaller environmental or university research groups, advocating for clean technologies. Negative lobbying, i.e., resistance to new technologies may also be present in the form lack of social acceptance, e.g. resistance to the visual impact of wind energy (Wüstenhagen et al., 2007).

The emergence of the Internet, and subsequently the information age, has revolutionised the way information is shared and accessed. Social media in the form of blogs, twitter, Facebook and YouTube allow for public opinion to be shaped at a speed that was not possible a few decades ago. In recent years, the forming of public opinion on social media has been accredited as an important force for political change, such as the Presidential election of Barack Obama, the 2011 demonstrations in Spain and the 'Arab Spring' (Qualman, 2010). Internet access in developing countries has steadily in the last decade, and in several upper-middle income countries 60 (or more) out of 100 people use the Internet (see fig 1). Clearly a wide discrepancy exists in Internet users across developing countries, e.g. 1/100 people in Burundi to 68/100 people in Malaysia, and the usefulness of this suggestion will need to be decided based on the country under study (The World Bank, 2015c). However, for the purpose of a general framework, the rise in Internet users in developing countries justifies attention to public opinion expressed in online forums.

Figure 1. Internet Users in Developing Countries (per 100 people)



Source: The World Bank, 2015c

Note: Developing countries with the highest Internet usage has deliberately been chosen to emphasise the suggested split is not only relevant in high-income developed countries.

With the emergence of public opinion being expressed through social media, a new form of potential lobbying can occur, which may influence other TIS functions (e.g.

guidance of the search or resource mobilisation). The argument is therefore made that it would be beneficial to separately analyse this relatively new form of lobbying when mapping activities for function 7 (legitimacy and advocacy coalition). The suggestion is therefore to split function 7 into two categories, namely *formal* (F7a) and *informal lobbying* (F7b). Formal lobbying refers to legitimacy and advocacy coalition exercised by well-established lobbying groups with economic and political weight, while informal lobbying includes advocacy by smaller groups, associations or individuals. Informal lobbying can be examined through changes in public opinion, support and acceptance in social media for the technology in question. This split also holds relevance for future TIS analyses in high-income countries. A limitation of suggestion 3 is in developing countries where access to Internet is very low, where the suggested split of function 7 may loose its relevance.

5.4. Suggestion 4: Incorporating the External Landscape

The fourth and last suggestion relates to the concern that the TIS approach does not sufficiently account for factors beyond the activities of the actors in the focal technological innovation system, i.e., concern of being too *inward looking*. While it is possible to find a theoretical discussion in the TIS literature concerning the relevance of the wider context, the TIS function approach has not sufficiently included explicit contextual factors as part of the framework that would enable a systematic empirical analysis of the wider context. Therefore, the following section will discuss how the TIS function approach could incorporate lessons from the Multiple Level Perspective (MLP) about the wider context, as a systematic manner to complement the existing TIS function approach. This section will begin with a general discussion about the TIS and Multi-Level Perspective (MLP) by reviewing the existing literature. This will be followed by a set of explicit contextual factors based on MLP literature along with conditions found in many developing countries that may have an influence on the Focal TIS.

5.4.1. *Learning from MLP*

While the Multiple-Level Perspective (MLP) and the TIS are both rooted in evolutionary economics and share the same conceptual basis such as path dependency, lock-in and nonlinearity, the two analytical frameworks have formed separately from one another over the last two decades. While the TIS is concerned with *institutions, actors* and *networks* to help explain the performance, growth and decline of a technology, the MLP refers to niche, regime and landscape *levels* when analysing technological transitions (see Table 2). More specifically, the principal postulate of the MLP is that transitions occur from an interaction between the three levels, where landscape levels creates pressure on the regime, which in turn can destabilize existing regimes and provide opportunities for new niche-innovations (Schot and Geels, 2008).

Complementary Characteristics

Despite their disconnected development path, several authors have recognised the various overlapping and complementary characteristics between the TIS and MLP. For example, Coenen and Lopez (2010) highlighted that the concepts from one framework include aspects that are considered a weakness in the other framework. For example, while one of the strengths of the TIS is its capacity to analyse dynamic processes (Hekkert et al. 2007), the analysis of the interaction between actors, institutions and agencies of various actors is considered a weakness of the MLP (Farla et al. 2012; Smith et al., 2005). In contrast, the lack of analysis of the socio-technical regime and socio-technical landscape in the TIS framework is considered one of the strengths of the MLP (Markard and Truffer, 2008). Geels, Hekkert and Jacobsson make a similar point by stating that, even though both TIS and MLP utilize levels in their analysis, "it seems fair to say that the MLP has progressed further in conceptualizing interactions between internal and external processes" (Geels et al., 2008: 530).

Table 2. Integral TIS and MLP Elements

Technological Innovation System (TIS)		Multi-Level Perspective (MLP)
Actors Organizations and individuals that contribute to the development of the technology (Hellsmark and Jacobsson, 2009). E.g. Associations, research institutes, firms, financial institutions, governmental agencies or policy makers each with specific competences, resources and strategies (Carlsson and Stankiewicz, 1991).		***Niche Level (Micro)*** "Niches are 'protected spaces' such as R&D laboratories, subsidised demonstration projects, or small market niches where users have special demands and are willing to support emerging innovations" (Geels, 2011: 27).
Networks Interlined network of different actors; Interactive learning (e.g. university-industry networks or user-supplier) and formation of political networks (Jacobsson and Lauber, 2006; Bergek et al., 2008b).		***Socio-Technical Regime (Meso)*** "Account for the stability of existing socio-technical systems", and "include scientists, users, policy makers and societal groups besides engineers and firms" (Geels and Kemp, 2007: 443).
Institutions "Sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups" (Edquist and Johnson 1997: 46)		***Socio-Technical Landscape (Macro)*** An external environment consisting of factors that influence both the regime and the niche level. "Set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems" (Geels, 2002: 1260). Growing environmental awareness (Smith et al., 2010).

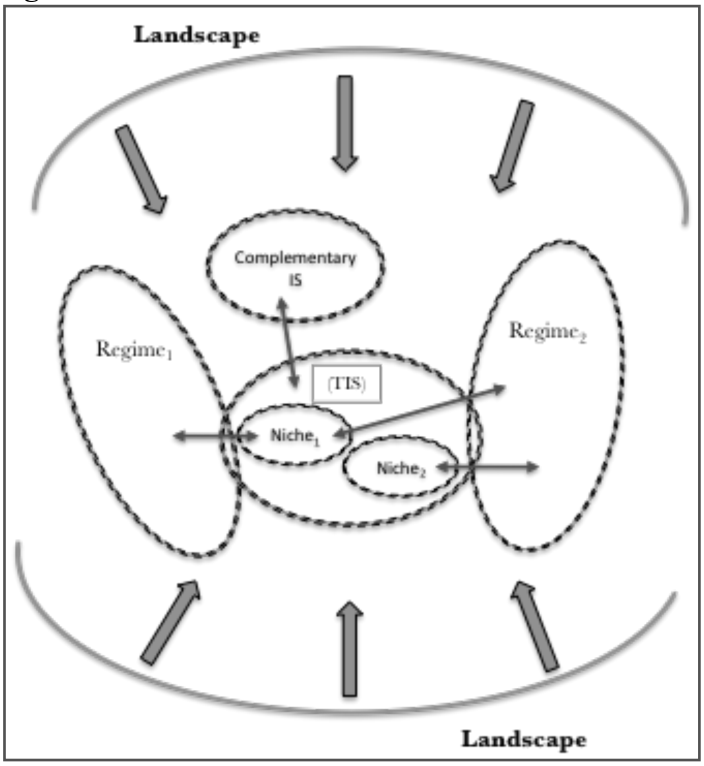
Source: Author tabulation.

The complementing aspects of the two frameworks have resulted in two recent attempts to combine the MLP and TIS (Markard and Truffer, 2008 and Meelen and Farla, 2013). The paper by Markard and Truffer (2008) explains the interaction between the elements of the multi-level framework and the TIS, where it is apparent that the TIS primarily concerns the niche level, while partly analysing existing regimes but leaving out the potential effects generated by the landscape level (see Figure 2).

While the purpose of this paper is not to integrate the two frameworks, but rather to find practical improvements that could benefit the existing TIS framework, the model by Markard and Truffer emphasises an important point. In their paper they accentuate the strength of the MLP approach to account for potential landscape influence on technological systems.

As stated before, while the landscape factors have been emphasised to be influencing both existing regimes and the TIS, these factors have been mostly left out of empirical analyses. Two studies that have attempted to incorporate the wider context as described in Figure 2, are Markard et al., (2009) and Wirth and Mackard (2011). The former, which empirically analyses biogas development in Switzerland, do emphasise the role of landscape factors, such as changes in environmental laws and climate change; but they do not engage in a deeper analysis concerning the influence of other landscape factors. The second empirical study leaves out landscape factors all together and instead focuses on the impact of other competitive or supporting TIS, along with a deeper analysis of existing socio-technical regimes.

Figure 2. Interaction between TIS and MLP



Source: Adapted from Markard and Truffer, 2008: 612.

Recent TIS literature has called for engaging more with the geographical context, i.e., the context outside the defined focal TIS (Coenen, 2015). For example, Bergek et al. (2015) highlight the need for conceptualising the interaction between the focal TIS and its context, while also suggesting four contexts structures.[15] Moreover, they emphasise the existing research gap, and one of the main contributions of this paper, namely the need for understanding contextual structures in developing or emerging countries.

This study has chosen to use the terminology landscape factors, rather than context structures, given that the suggested landscape factors in this paper will be to a large extent based on a review of the MLP literature.[16] Using the MLP literature to assist in

[15] The four context structures suggested in Bergek et al. (2015) are: industrial sectors, geographical territories, other TISs and political structures.

[16] It should be noted that the socio-technical landscape factors is the complete denotation used in the MLP approach. For simplicity, the term landscape factors will be used throughout this paper.

selecting relevant landscape factors is justified by the more extensive conceptualization made by MLP approach of the wider context (Markard and Truffer, 2008).

The following section will discuss landscape factors relevant for developing countries, and which could be systematically integrated as a part of the existing TIS function approach. This will contribute to addressing an existing gap in the literature, while also improving the comprehensiveness of future empirical TIS studies. As previously mentioned, in this paper, a specific focus is placed on the transition of technologies that could advance sustainable development. Consequently, RETs are central in the selection and discussion of landscape factors in the follow section.

5.4.2. *Landscape Factors Influence on TIS in Developing Countries*

Changes in external landscape factors can contribute to positive change (towards sustainable transition) by providing pressure on existing regimes and create possibilities for niche development (Schot and Geels, 2008). Smith et al. (2010) argue that while landscape factors can generate opportunity for niche developments they can also negatively influence transition to more sustainable technologies by reinforcing the existing trajectory of a regime (Smith et al., 2010). The notion that factors exogenous to the focal TIS influence the "strengths of the functions" is widely accepted and emphasised in the TIS and MLP literature (Bergek, 2008b: 579). As depicted in Table 2, the landscape or socio-technical landscape has been defined by Geels as a "set of heterogeneous factors, such as oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems" (Geels, 2002: 1260). Growing awareness concerning environmental sustainability and the role of renewable energy has also been identified as a landscape process, which by questioning existing regimes can create opportunities for niche development (Smith et al., 2010).

Given the vast complexity and multitude of factors existing in the landscape level it will not be possible to incorporate all aspects. Based on the factors of the socio-technical landscape raised by Geels (2002), Smith et al. (2010), and others, along with the justifications provided below, the paper proposes six Landscape Factors (LF) to complement the existing TIS function approach in a developing country context. The proposed landscape factors are: *Economic Growth, Environmental Awareness, Climate Change, Armed Conflicts, Corruption and Inequality (Unequal Access to Higher Education).* The proposed list of landscape factors consists of nationally bound factors along with those transcending the national level.

Certain landscape factors will also be relevant in developed countries. However, as previously mentioned, including a more comprehensive landscape factor analysis is particularly relevant when performing a TIS analysis in developing countries. This position is based primarily on two specific aspects found in many developing countries. The first aspect relates to the reasoning made by Raven (2005; 2010), that system components (functions) are not fully developed in the early formative stage of a system, which results in a larger influence from exogenous factors. Since TIS in many developing countries can be described to be in an early formative stage, an emphasis on exogenous factors (landscape factors) is justified. The second aspect is that some of the landscape factors that are being proposed are generally stronger and more dominant in many developing counties, e.g. corruption, unequal access to education and armed conflicts. This higher landscape factor prevalence and how it may influence the TIS functions in developing countries will be discussed in greater length below.

Landscape Factor (LF) 1: Economic Growth

A tight coupling between increased economic activities and energy demand has been demonstrated (Stern, 2004). With four countries (Saudi Arabia, Iran, Iraq and Kuwait) responsible for about half for the World's oil reserves, price volatility for oil has contributed to increased long-term energy insecurity (Sadorsky, 2009). In the interest of tackling energy insecurity and sustaining economic growth, energy production from renewable energy sources offers an alternative to these concerns (Dincer, 2000; Sadorsky, 2009). Given that the majority of the increase in energy demand in the future will come from developing or emerging countries, it is relevant to better understand the influence of economic growth on a developing country focal TIS system.[17]

Economic growth is also correlated with an increased availability of government resources as a result of higher tax revenues. Increased availability of government resources does not necessarily result in more subsidies, tax reductions, or R&D investments beneficial for RETs, as this also depends on aspects such as political will, government policies, strength of advocacy groups, etc. However, it is fair to assume that the likelihood for more resources being mobilised towards RETs will be improved with additional public and private resources available.

While increased economic growth contributes to government revenues, a decline in economic growth due to domestic and/or international events may also prove conducive to technological change. Economic growth may in fact generate inaction from dominant actors with the preference of preserving the existing regime, while an economic decline or recession may create pressure on government and existing regimes for change (Geels, 2013). The 2008 financial crisis, for example, arguably provided a 'window of opportunity' for transitioning towards more sustainable energy sources during the early years of the crisis (Geels, 2013: 93). In other words, a financial crisis may enhance the demand for change from the incumbent system, which could contribute to legitimising (function 7) new technologies such as RETs. The opposite may also occur, where a financial crisis may redirect attention away from sustainability issues towards shorter-term concerns such as employment opportunities and securing personal income.

Whatever the impact of economic growth, i.e., positive or negative, its potential influence as a landscape factor on technological transition justifies its inclusion in the landscape analysis. The changes in economic growth can be mapped by tracking changes in the Gross Domestic Product (GDP) and domestic and international economic events, along with its influence on TIS functions such as resource mobilisation (F6) and legitimacy creation (F7).

[17] China and India alone are expected to drive 45% of the World's increased energy demand between 2005-2030 (IEA, 2007).

Landscape Factor 2: Environmental Awareness

"Growing environmental awareness is a socio-cultural development that can be considered a landscape process, and which is questioning the performance of multiple regimes, whilst generating opportunities for niches" (Smith et al., 2010: 441). The United Nations Environmental Programme (UNEP) describes environmental awareness (EA) as:

> the ability to emotionally understand the surrounding world, including the laws of the natural environment, sensitivity to all the changes occurring in the environment, understanding of cause-and-effect relationships between the quality of the environment and human behaviour, an understanding of how the environment works as a system, and a sense of responsibility for the common heritage of the Earth, such as natural resources - with the aim of preserving them for future generations (UNEP, 2016: 4.2).

In this paper, the inclusion of environmental awareness as a landscape factor for transition of RETs considers this definition of environmental awareness to be a state of mind, which facilitates an understanding of the mitigating role that RETs play, e.g. on climate change and air pollution. The inclusion of the EA as a landscape factor is motivated through the assumption that changes in EA amongst actors such as civil society and government may lead to increased pressure on existing energy producing regimes to diversify towards cleaner technologies.

An increase in environmental awareness in civil society may assert influence on both government and actors in the energy sector to invest more in clean technologies.[18] This pressure can be consumer-driven, i.e., demand for energy produced from RETs or through the support or acceptance of environmental policies (informal lobbying) exercised by organised environmental groups or individual citizens.[19]

Evidence from environmental psychology research has shown a link between environmental awareness and a higher preference for utilizing energy produced from renewable energy technologies (see for example, De Groot et al., 2012: Steg et al., 2005 and Van der Werff et al., 2013). While, the mentioned empirical studies were performed with data from Hungary and the Netherlands, there are several reasons for including the EA influences in developing country contexts as well. Firstly, large cross-national studies have shown that concern for the environment is equally important for developed and developing countries, including minor differences in the willingness to pay to protect the environment (Dunlap and Mertig, 1995).[20] Secondly, the theory of post-materialist values[21], which has as a central argument that people of affluence and education are who primarily exercise environmental concern, does no

[18] The potential impact that public EA can have on environmental policies and regulation has been documented by Ramachandra Guha (1999) in his book 'Environmentalism: A Global History'.

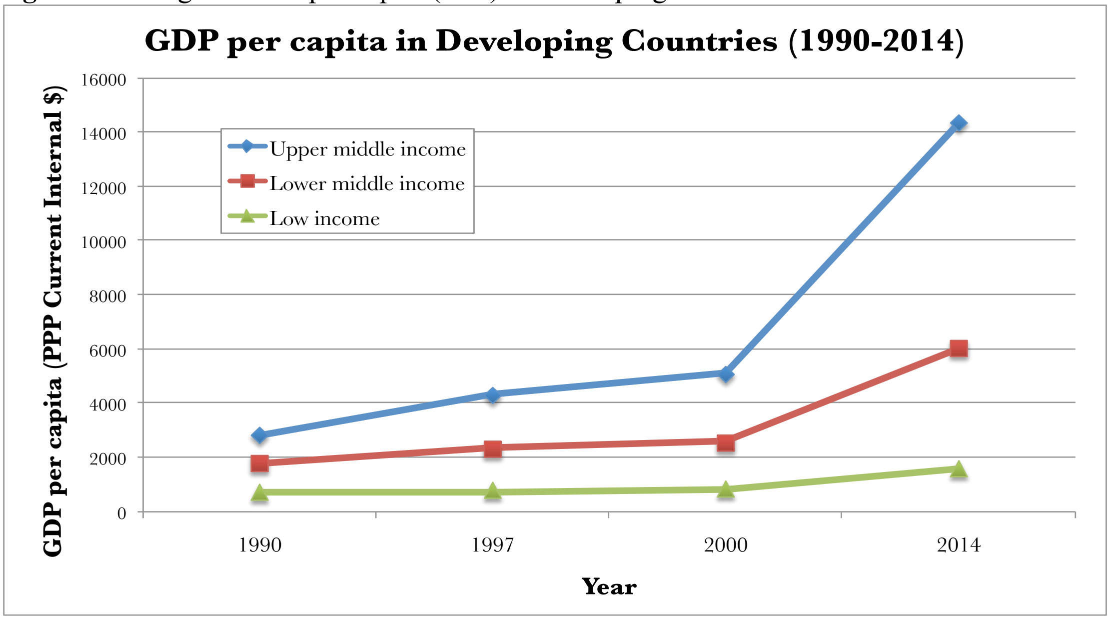
[19] See for example Stern et al. (1999) or Stern (2000), for a detailed discussion about the Value-Belief-Norm (VBN) theory and possible avenues of influence derived from environmental awareness: i.e., Environmental Activism, Non-Activism, Private-Sphere environmentalism and Organizational actions.

[20] The data used in Dunlap and Mertig (1995) are based on the Health of the Planet Survey (1992), which included 22 developing and developed countries.

[21] For a more detailed discussion about the theory of post-materialist values, see e.g. Inglehart (1977; 1990; 1997).

longer exclusively apply to high-income industrialised countries. As shown in figure 3, the GDP per capita income level has significantly risen in many developing countries. As a comparison, GDP per capita in upper-middle income countries, based on purchasing power parity (PPP), is almost at the same level as it was for high-income countries in the early 1990s (The World Bank, 2016a).

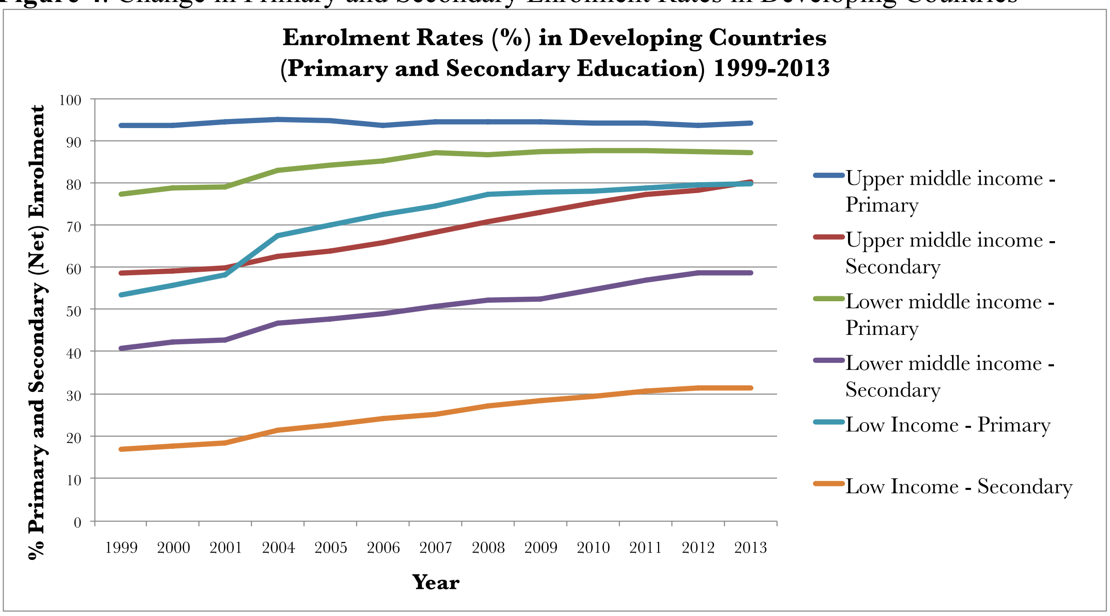
Figure 3. Change in GDP per capita (PPP) in developing countries



Source: The World Bank, 2016a

In a similar fashion, primary and secondary enrolment rates in developing countries have increased across developing countries, with primary enrolment above 80% in all income categories (fig. 4). This is not to say that the arguments made by Inglehart about post-materialist values are irrelevant, but rather to stress that affluence and education levels in many developing countries have improved significantly over the last decades.

Figure 4. Change in Primary and Secondary Enrolment Rates in Developing Countries



Source: The World Bank, 2016b

Following the logic of post-materialist value theory (e.g. Inglehart, 1997), the rise in GDP per capita and education levels in developing countries suggests that the relevance for including environmental awareness in a developing country study is steadily rising. Moreover, the falling prices of RETs, such as wind and solar power, further enhance their competitiveness against conventional energy alternatives (IRENA, 2015). In the context of assessing the potential influence of environmental awareness on the focal TIS, it helps to reduce a barrier, namely costs, from the equation.

Finally, while an increasing EA could have a positive influence on the focal TIS, the absence of awareness in a population can slow down the diffusion of RETs. Specifically, the lack of awareness for new energy technologies, e.g. awareness about the benefits and costs of RETs, has been stressed as a significant barrier in developing countries (Reddy and Painuly, 2004; Kennedy and Basu, 2013; Luthra, 2015). For example, in an Indian study of barriers to RET adoption, “lack of consumer awareness to technology” together with “lack of sufficient market base” were found to be the most important market barriers, in front of aspects such as “lack of paying capacity” (Luthra, 2015: 770).

Awareness of the benefits and actual costs of RETs is an essential first step for both informal lobbying (F7b) carried out by individual citizens or organised environmental groups, and for consumer-driven demand to occur. Therefore, tracking changes in environmental awareness can unveil barriers or drivers at the landscape level and can contribute to making the TIS function approach more comprehensive. Environmental awareness can be analysed by mapping changes in societal trends, which can include frequency in online discussion forums regarding sustainability and the role of RETs, changes in participation in environmental programs (higher education), changes in overall environmental awareness among actors from existing national surveys, as well as the perceived influence of environmental awareness on system functions.

Landscape Factor 3: Climate Change

Climate change is impacting nations in different ways, from the intensification of precipitation events leading to flooding in some parts of the world, to increased heat waves and droughts in other parts, for example (IPCC, 2012). The impacts of climate variability and change may influence technological transitions in several ways, affecting other landscape factors as well as TIS functions.

First, the economic costs of environmental disasters caused by an intensification of extreme weather events are placing a strain on businesses (LF1: Economic growth) and government resources (F6a: Resource Mobilisation), in both developing and developed countries. According to the Stern review of 2006, extreme weather could, by the middle of this century, amount to losses of 0.5-1.0% of global GDP per year. The 2003 heat wave in Europe alone contributed to approximately 35,000 deaths and a loss of approximately US$ 15 billion from reduced agricultural yields (Stern, 2006). Conversely, bilateral and multilateral aid grants and loans to response to climate change-related impacts will positively influence available government resources (Resource Mobilisation: F6b).

Second, the human and economic costs of climate change can induce awareness (LF2) about the risks of inaction, which can contribute to mobilizing support and creating legitimacy (F7) for alternative sources of energy such as RETs. Thirdly, the increased attention towards the severity of a changing climate has resulted in several international agreements and commitments to curb GHG emissions, partly by increasing the share of RETs in the energy mix.[22] These international agreements may influence the targets set by governments (F4: Guidance of the Search) and if covered in mainstream media raise public awareness (LF2) concerning the importance of climate change mitigation and adaptation.

In short, climate change as a landscape factor has the potential to support RETs diffusion in various ways. This landscape factor can be analysed by mapping climate change related events and corresponding costs along with international and domestic commitments to alter the energy mix towards sustainable sources of energy.

Landscape Factor 4: Armed Conflicts

Any form of violent conflict, whether state-based or non-state based is defined as conflict when at least 25 battle-related deaths have occurred in one conflict. Under that condition, a state-based armed conflict can be further defined as a "contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state" (Uppsala University, 2014).[23] A more detailed discussion regarding the different forms of conflicts and the varying impacts they pose on populations is beyond the scope of this paper.[24] In this paper, armed or violent conflicts will be used when discussing their possible influence on the success or failure of technological transitions.

In 2013, about 1.5 billion people across the world were impacted by violent conflicts (World Bank, 2013). A total of 38 armed conflicts, with the majority taking place in Africa (13), followed by Asia (12), Middle East (7), Europe (5) and Latin America (1) were reported during 2012 (Armengol et al., 2013). Larger macro-economic effects from armed conflicts have been widely studied and generally demonstrate a reduced income per capita, increased military expenditure, technological degeneration, damaged infrastructure as well as reduced human capital, innovation and economic growth (Abadie and Gardeazabal 2003; Collier and Duponchel (2013); Brück et al., 2013). For example, one study (Collier, 1999) estimated an annual reduction of 2.2% GDP in countries affected by conflict.

The direct impact that armed conflicts have on entrepreneurial activities has been less studied, and has so far yielded contradictory results. Ongoing conflicts have been found to provide a worsened business environment in the form of higher uncertainty and transaction, reduced markets and lucrative investment prospects, which can

[22] Doha Amendment to the Kyoto Protocol extends the previous commitments made in the 1997 Kyoto protocol until 2020 (UNFCCC, 2014). Nationally Appropriate Mitigation Actions (NAMAs), agreement for developing countries, with financial assistance from Annex 1 countries (developed countries).

[23] Non-state based conflict is defined as "the use of armed force between two organised armed groups, neither of which is the government of a state" (Uppsala University, 2014).

[24] For more details on types, cases and trends of armed conflicts, see for example: Scherrer, 2003.

contribute to reduced entrepreneurial activities (Naudé, 2007). However, a study by the International Labour Organization (ILO) and the Global Entrepreneurship Monitor (GEM) found an increase in new firms start-ups during the crises (Brück et al., 2013). Moreover, there are examples throughout history for how technological innovations have occurred during armed conflicts, e.g. the development of the Internet or the invention of firearms (Humphreys, 2003). Whether an armed conflict will obstruct or provide opportunities for entrepreneurial activities within renewable energy sectors, e.g. in the form of directed military R&D spending towards RETs would have to be scrutinised on a case by case basis. The possible influence (positive or negative) of armed conflicts on entrepreneurial activities, human capital, economic growth and technological innovation, however, justifies its inclusion as a landscape factor to complement the TIS function analysis.

By including armed conflicts in conjunction with the TIS function analysis, the aim is to better understand their influence on technological transitions by shedding light on the following type of questions: Does the cost of the conflict influence the government expenditure to the extent of hampering resource mobilisation towards RETs (F6a: Resource mobilisation)? Does the conflict contribute to levels of insecurity that have obstructed potential new developments of renewable energy infrastructure (F1: Entrepreneurial activity)? Does the conflict contribute to an increase in technological innovation and development? This landscape factor can be analysed by mapping the cost of the armed conflict (as percentage of government expenditure), mentioned number of entrepreneurial activities cancelled or never initiated, or new technological innovations initiated, as a consequence of the conflict.

Landscape Factor 5: National Corruption

Transparency International (2015) defines corruption “as the abuse of entrusted power for private gain”, and can involve various forms such as embezzlement, state capture, bribery, rent seeking, and nepotism. Corruption exists to some extent in all nations around the world, however, it is often more prevalent in developing countries. The presence of corruption has been argued to negatively affect democratic systems and rule of law, social trust among citizens, public resources, economic growth, and inequality (Transparency International, 2014).

For the purpose of analysing corruption as a landscape factor for the TIS, the paper suggests to concentrate on its influence on entrepreneurial activities (F1), resource mobilisation (F6), economic growth (LF1), and unequal access to quality education (LF6). Globally, it has been estimated that 5% of the world’s GDP is lost to corruption each year, with bribes comprising approximately US$ 1 trillion. According to the African Union, in 2002 about US$ 148 billion constituting approximately 25% of GDP of African States was lost to corruption (OECD, 2013). The loss of public revenues due to corruption in turn influence the amount of funds that can be dedicated towards R&D, subsidies, investment and infrastructure that are essential for an emerging technology. Moreover, by distorting market mechanisms such as free competition, corrupt countries receive about 5% less investments, and the cost of doing business is on average 10% higher (OECD, 2013).

This landscape factor can be analysed by reviewing the estimated loss in public resources (percentage of GDP), mentioned cancelled/never initiated entrepreneurial activity, and estimated impact on economic growth, as a result of corruption.

Landscape Factor 6: National Education System: Unequal Access to Education

The inclusion of *unequal access to education* as a landscape factor, is motivated by the central role of knowledge creation in relation to TIS system development. As put by Lundvall, "it is assumed that the most fundamental resource in the modern economy is knowledge and, accordingly, that the most important process is learning" (Lundvall, 1992:1). Lundvall further emphasises the "historical establishment" as well as the "institutional and cultural context", in order to understand learning as a "socially embedded process" (1992:1). In many developing countries, institutions have developed in a more elitist and extractive direction, which has contributed towards less inclusive economic and political institutions (Acemoglu and Robinson, 2012). In wider system analyses (e.g. national innovation systems), unequal access to education in developing countries has been accredited as one of the central aspects for explaining their "lack of technological congruence" (Soete et al., 2010: 1172).[25] In the systems of innovation literature, the national education system is commonly discussed in the wider NIS, which can be considered exogenous to the focal TIS and its functions. With the inequality component embedded in the national education systems in developing countries, it would be reasonable to treat it as landscape factor, rather than as an actor within the focal TIS. By including this landscape factor the aim is to bring clarity to the relationship between the national education system and technical innovation system in a developing country context.

As shown in the environmental awareness discussion (LF2), in the last decades, access to primary and secondary education has significantly improved in most of the developing world (see fig. 4). Access to higher education, however, remains limited and restricted to a privileged elite in many developing countries, leaving a large portion of the population without access to higher education. The latest available data (2013) show that in low, lower middle and upper middle-income countries the total gross enrolment rates at the tertiary level are 8%, 22% and 35%, respectively (The World Bank, 2016c). These tertiary enrolment rates can be compared to 74% in high-income countries (The World Bank, 2016c).

The dual role of the education system, namely generating human capital (individual learning) while contributing to new knowledge, gives it a central role in the knowledge and learning environment (Edquist, 2001). If a large part of the population is excluded from higher education, it may contribute to shortages in human capital and reduced learning to an extent that obstructs the focal TIS in question.[26] A reduced possibility for generating awareness for the environment (LF2) and sustainable development is another potential consequence of low access to higher education (Lambrechts et al., 2013). Accordingly, the aim of including this landscape factor is to reveal its influence on knowledge development (F2a), adaptive capacity (F2b),

[25] Abramovitz introduced technological congruence in 1986 when discussing catching-up countries and absorptive capacity (Soete et al., 2010).

[26] Note that in addition to universities, new knowledge is also created in research institutes and research oriented firms (Edquist, 2001). R&D can be carried out within firms or academia, this has been classified as search and exploration, respectively (Soete et al., 2010).

entrepreneurial activities (F1) and other landscape factors. This landscape factor addresses questions such as how does unequal access to vocational and higher education influence human capacity and learning? and how does it influence the focal TIS? More specifically, in what way does unequal access to education influence the availability of researchers, engineers, project managers, and technical personnel? This landscape factor can be evaluated by mapping changes in access to higher education (post-secondary, vocational and tertiary education (including research), along with expressed mismatch (lack of trained personnel) by the industry of the technology in question, as a result of lack of access to quality education.

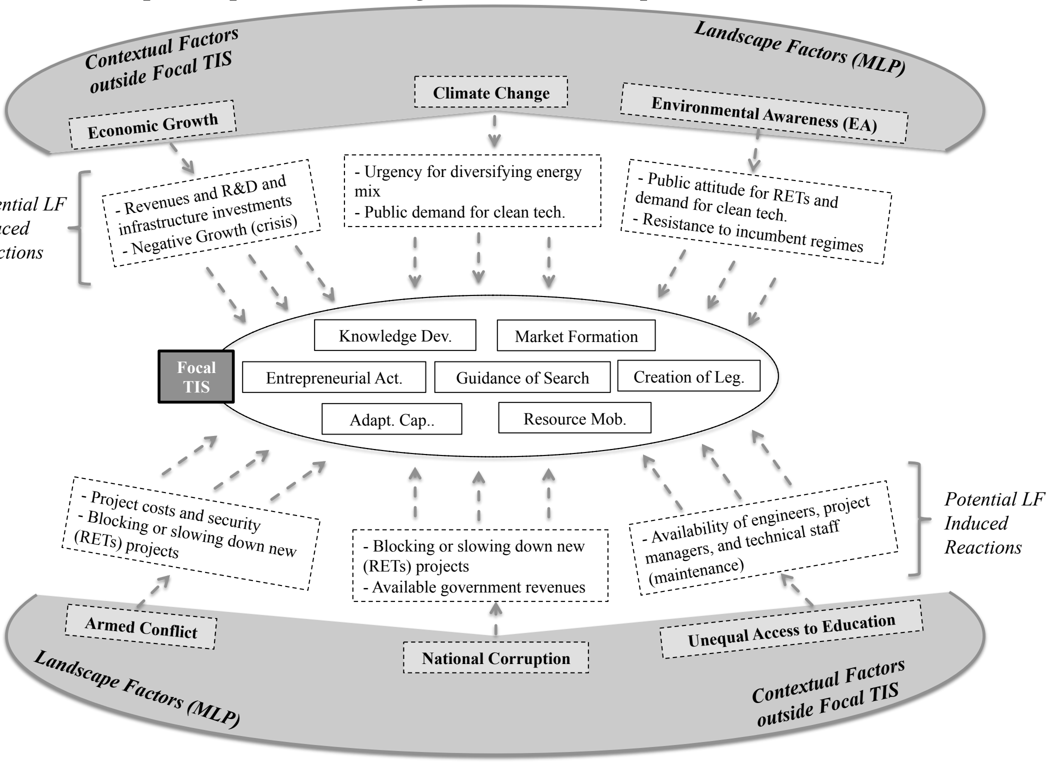
6. Interactions between Landscape Factors and Functions

A rationale for including the abovementioned landscape factors into the analysis is to understand the different pressure that they assert on the focal TIS in question. The suggested landscape factors can be nationally bound or transcend the national level. Economic growth and climate change are clearly landscape factors that operate across the national boundary. The performance of the national education system and the level of national corruption are nationally bound landscape factors. Armed conflicts or environmental awareness are relevant to analyse from a nationally bound perspective, i.e., how they influence the country under study, but may be transnational in nature. For example, the long lasting armed conflict in Colombia is predominately a domestic conflict, but it has involved neighbouring countries, such as Venezuela and Ecuador, when armed groups have crossed the borders or displaced population has moved to these neighbouring countries, for example. With the emergence of Internet and access to information across the national boundary, it can be debated whether domestic environmental awareness is linked with a changing global awareness, resulting from international environmental campaigns and movements.

Widening the analytical lens by systematically incorporating landscape factors to complement the TIS functional approach could assist in explaining the slow diffusion of RETs in many developing countries. In addition, the objective is to determine if the landscape level influence is having a reinforcing or disrupting effect on the incumbent system. In the MLP literature, disruptive landscape factors can create opportunities for change, while reinforcing factors do not contribute to innovation (Geels and Schot, 2007).

The different landscape factors can induce reactions (disruptive or reinforcing) amongst different actors, e.g. incumbent regimes and/or policy makers. These reactions can influence the conditions for the focal TIS, or concrete changes in the TIS functions. Figure 5 provides examples of potential reactions induced by the selected landscape factors. It is important to note that the landscape factors are macro-level factors operating outside the focal TIS, and do not exclusively influence specific technology sectors. Instead, the landscape level influence should be seen as an overarching umbrella, which can produce potential spillover effects that can prove conducive or impeding for a specific technology.

Figure 5. Examples of pressure arriving from the Landscape Level



Source: Author
Note: Fig. 5 draws inspiration from a compilation of interdisciplinary literature (see section 5)

The previous section (5.4.2), discussed the potential influence that the proposed landscape factors can have on TIS functions from a theoretical perspective. Based on these arguments, table 3 provides a summary of the potential influence that different landscape factors may pose on specific TIS functions. Table 3 is not suggested to be an exhaustive list of potential influence, but rather an initial guide for future empirical studies that opt to include the landscape factor influence into the analysis.

Table 3. Possible Landscape Factors influence on Specific System Functions

		Functions							
		Entrepreneurial Activities	Knowledge Development	Adaptive Capacity	Knowledge Diffusion	Guidance of the Search	Market Formation	Resource Mobilization	Creation of Legitimacy
Landscape Factors	Economic Growth							✔	✔
	Environmental Awareness				✔				✔
	Climate Change					✔		✔	✔
	Armed Conflicts	✔					✔	✔	
	National Corruption	✔						✔	
	Unequal Access to Education	✔	✔	✔	✔				

Source: Author (based on findings discussed in section 5)
Note: Black check marks indicate possible interaction

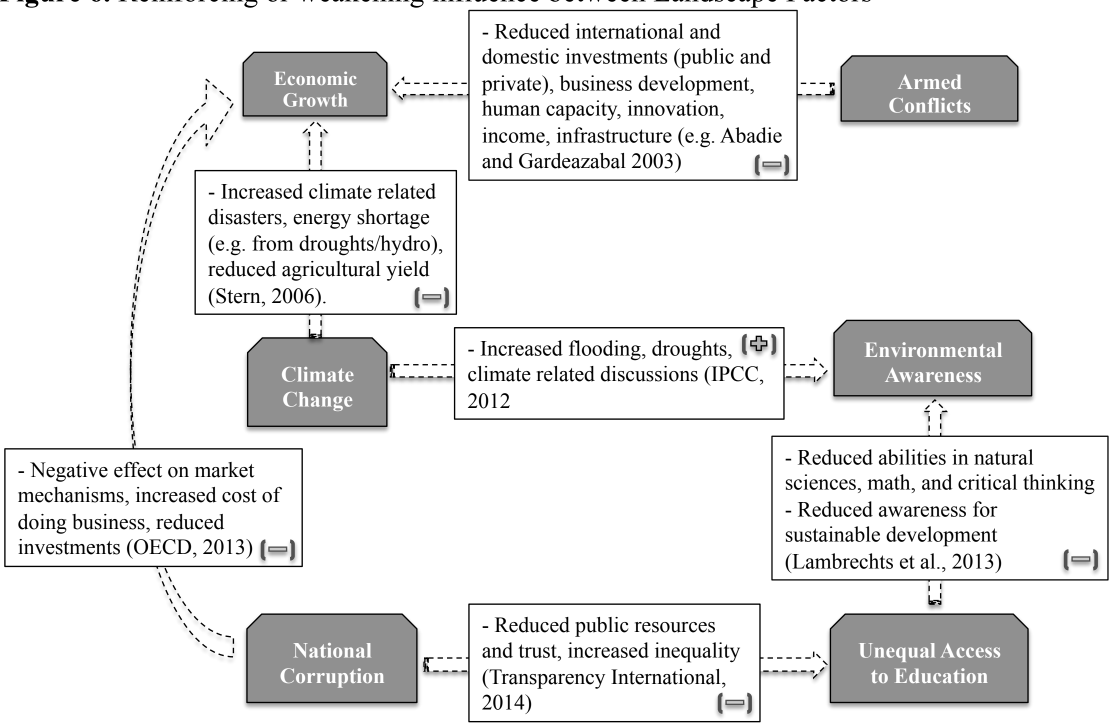
The landscape factor-induced influence on TIS functions, could then initiate reinforcing actions between different functions, known as positive feedback loops.

These feedback loops between the functions can lead to a positive momentum that ultimately improves the performance of the system as a whole. The feedback loops between functions have been covered in previous literature and will not be discussed further in this paper (e.g. Jacobsson and Bergek, 2004; 2006; Hekkert et al., 2007). Instead, examples of possible reinforced influence between landscape factors will be discussed below (see fig. 6).

Landscape Factors Reinforcing Effects

While the main focus of this paper is on the influence that landscape factors may have on a focal TIS and its functions, landscape factors also influence each. Evidence from existing literature (covered in section 5.4.2) suggests that reinforcing and weakening influence is occurring at the landscape level. The reactions or activities generated by one landscape factor may have reinforcing or weakening influence on another landscape factor. A non-exhaustive summary of possible influence between landscape factors is displayed in figure 6.

Figure 6. Reinforcing or weakening influence between Landscape Factors



Source: Author
Note: Generated reactions are displayed in the white box. Reinforcing influence is denoted by (+) and the weakening influence by (-).

In this paper, the potential influence of the individual landscape factors on TIS functions has been emphasised. As it follows, the landscape factor to landscape factor (LF- LF) influence can contribute to shaping a more or less beneficial external landscape for technological innovation. Again, the selected landscape factors should be seen as a first step to systematically mapping out the wider context, and its weakening or reinforcing influence for a given focal TIS at an early formative stage. The focus of this paper on environmental sustainability is reflected in the suggested framework. While landscape factors such as climate change or environmental awareness have been included with RETs in mind, other mitigating technologies, such as carbon capture and storage (CCS) or energy efficient technologies could also benefit from the suggestions made in this paper. It is also the aspiration that the reflections made concerning the processes and landscape factors of the Technological Innovation System in developing countries will also benefit future empirical studies focused on technologies beyond the sustainability niche.

7. Proposed Framework

The following section offers a summary of the suggestions provided in this paper in the form of a proposed framework. Based on previous literature on the TIS approach, empirical studies in developing countries and lessons from the MLP, four suggestions have been proposed. These suggestions show how the existing TIS framework can be elaborated upon to enhance its comprehensiveness and broaden the applicability of the framework to developing countries.

Table 4 displays the added suggestions to complement the original list of functions by Hekkert et al. 2007, namely including creating adaptive capacity, a split of the resource mobilisation function and a split in the creation of legitimacy/advocacy of coalition function. The landscape factors are added at the end of the list of functions and suggested indicators to measure these factors are provided. The fulfilment of system functions and the influence of landscape factors on system functions can be analysed by a combination of a history event analysis, literature review and expert evaluations, i.e., structured and/or semi-structured interviews with experts in the field from the country under evaluation. In order to enhance the analytical comprehensiveness of the TIS framework, the findings of the external landscape assessment would be analysed together with the findings from the Innovation System Function analysis.

Table 4. Suggested Framework and Potential Indicators

System Function		**Indicators**
F1.	Entrepreneurial Activities	Started and planned projects, experimentations and activities from incumbent actors for new technology
F2.a	Knowledge Development	Planned and ongoing research projects and patents filed; trends in publications relevant to the technology
F2.b	Creating Adaptive Capacity	Human (level of technical and higher education), organizational, and institutional capacity to receive new technology
F3.	Knowledge Diffusion	Number of workshops, conferences, or other forums (social media) organized about the new technology
F4.	Guidance of the Search	Expectations set by government or industry for new technology in terms of regulations and specific targets
F5.	Market Formation	Market entry assistance for new technologies (protected space ('nursing'), new environmental standards, tax exemptions, feed-in tariffs, etc.)
F6.a	Resource Mobilisation (Government)	Resources allocated by government or industry towards R&D (Human Capacity) or subsidies for the new technology (financial).
F6.b	Resource Mobilisation (International loans and grants)	Availability, size and type (human and/or financial) of international resource mobilisation for new tech.
F7.a	Creation of Legitimacy/Advocacy	Change in lobbying activities by formal and established lobbying groups with economic and

	coalition (formal lobbying)	political weight
F7.b	Creation of Legitimacy (informal lobbying)	Changes in public opinion, support and acceptance for new technology in social media
Landscape Factors (LF)		**Indicators**[1]
LF1.	Economic Growth	Changes in Gross Domestic Product (GDP), Global Economic Events
LF 2.	Environmental Awareness	Changes in frequency of online discussion forums, enrolment in environmental programs (higher education), changes in public awareness for RETs (e.g. national polls).
LF 3.	Climate Change	Changes in international and domestic commitment to RETs adoption; economic costs as a result of climate change
LF 4.	Armed Conflict	Cost of Conflict (% of Gov. Expenditure), number of cancelled (or not initiated) entrepreneurial activities
LF 5.	National Corruption	Loss in public resources (% of GDP), cancelled/not initiated entrepreneurial activity
LF 6.	National Education System: Unequal Access to Education	Access to upper secondary, vocational or higher education (including research), expressed mismatch from industry on available human capacity for new technology

Source: Expanded by author

Note: Baseline system function list before changes is based on Hekkert et al., 2007. Indicators for unchanged functions also reflect suggestions provided in Hekkert et al., 2007. F2.b is based on study by van Alphen et al., 2008.

1 All indicators include the perceived influence on functions and other landscape factors

8. Conclusions and Suggestions for Future Research

This paper has discussed limitations of the TIS function approach and proposed a framework that both takes into consideration the wider context in which the focal TIS operates, while making adjustments to better account for the context found in many developing countries. While the changes to the previous function list were made with the consideration of developing countries, there are suggestions that also hold relevance for future studies in developed countries. For example, the split of the *creation of legitimacy* function that was made to better reflect changes in public support for renewable energy is also relevant in developed countries.

The landscape factors proposed in this paper have been selected to hold special relevance in a developing country context, given the higher prevalence of corruption, inequality and unequal access to quality education often found in developing countries. This is not to say that certain landscape factors would not benefit future studies in developed countries. Landscape factors such as climate change, economic growth and the role of the national education system to reduce mismatch are aspects that could have an influence on incumbent regimes and focal TIS in developed countries as well. More generally, given the increased connectedness in the form of globalization and information technologies, countries may experience more rapid changes in landscape factors such as economic growth or environmental awareness today than a few decades ago. Thus, as a consequence, the inclusion of the potential effect of landscape factors on the TIS may be of even greater relevance.

The inclusion of the socio-technical landscape in the analysis of TIS proposed in this paper should be seen as a first step to improve the analytical comprehensiveness of the TIS framework. The list of landscape factors proposed in this paper must be empirically tested in developing countries to determine its relevance for the formation of the focal TIS. Thus, a pragmatic approach to potential reductions and additions of the landscape analysis is to be preferred.

Moreover, while a systematic landscape analysis arguably improves the comprehensiveness in explaining barriers and drivers of technological transitions, there are other aspects that are considered external to the focal TIS. For example, during the attempt to combine the TIS and MLP framework by Markard and Truffer (2008), they stress the influence of one niche-level technological innovation on another niche innovation. The potential effect of a complementary innovation system is also held up as an additional consideration for future research. Overall, more work is needed to map the role that the wider context has on the development, diffusion and utilization of a new technology.

Finally, given the multitude of factors that can serve as a driver or barrier to RETs adoption, additional empirical studies determining the relative pertinence amongst factors is needed, in order for the TIS function approach not to become excessively complex and lose its practical applicability. It is important to find a balance between a comprehensive framework that takes into account the intricacy of the system and the factors that influence it, and a practical framework that can contribute to the decision making process.

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