# Applying the innovation systems framework to the study of the small wind turbine sector in Kenya: A review and research agenda

**Faith H. Wandera**
PhD Fellow
Moi University, School of Business and Economics, Eldoret, Kenya &
Aalborg University, Faculty of Social Sciences, Copenhagen, Denmark

IREK
Innovation and Renewable Electrification in Kenya

This research is supported by the Danish Ministry of Foreign Affairs, Grant: DFC 14-09AAU.
IREK is a development research project on Innovation and Renewable Electrification in Kenya with research partners at Aalborg University (Denmark), African Centre for Technology Studies (Kenya) and Moi University (Kenya). IREK seeks to provide a better foundation for selecting and deploying available technologies in a way that increases inclusiveness and contributes to poverty reduction.
Read more about the IREK project at
IREKPROJECT.NET

How to cite this publication: Wandera, Faith H. (2018). *Applying the innovation systems framework to the study of the small wind turbine sector in Kenya: A review and research agenda* (IREK Working Paper No. 3). Copenhagen/Nairobi/Eldoret: AAU, ACTS and MU.

# Applying the Innovation systems framework to the study of the Small Wind Turbine sector in Kenya: A review and research agenda

Faith H. Wandera, PhD Fellow, Moi University, School of Business and Economics, Kenya and Aalborg University, Faculty of Social Sciences, Department of Business and Management, Copenhagen, Denmark

**Abstract**

The need for empirical analysis of energy sectors in developing countries such as Kenya is occasioned by the energy access challenges faced and in particular electrification of communities who are geographically and economically disadvantaged despite inhabiting areas that are rich in wind energy resource. The role of decentralised approaches in achieving universal access cannot be over emphasised. Applying the National Innovation System approach to resolving the electrification problems using renewable energy has received limited attention. The Technological Innovation Systems approach has been used to study energy systems. Scholars however argue that the Technological Innovation Systems approach was primarily designed for developed economies and therefore applying it in the developed country context tends to mask important aspects in an emerging innovation system. The Innovation and Renewable Energy Kenya proposes a framework for better understanding the factors that affect innovation of small wind turbines technology in Kenya. The Innovation and Renewable Energy Kenya framework demonstrates that such modifications to the Technological Innovation Systems framework are necessary in understanding the rules and regulations, actors and capabilities, and flows and interactions within the innovation system under study. It identifies specific areas for attention relating to policy, knowledge flows and interactions. The paper concludes with a research agenda that could bring to the fore the blocking and inducing mechanisms to innovation of small wind turbines in Kenya.

**Key words**

Decentralised electrification, National Innovation Systems, Technological Innovation systems, Small wind turbines, Rules and Regulations, Actors and Capabilities, Knowledge flows and Interactions.

**Acknowledgements**

This research is supported by the Danish Ministry of Foreign Affairs grant DFC 14-09AAU. My supervisors at Moi University, Kenya and Aalborg University, Denmark, IREK team members, colleagues in Ministry of Energy and Petroleum, and all the respondents whose opinions have enabled the compilation of this working paper I extend my appreciation.

## 1. Introduction

The energy access sector is in dire need of empirical analysis that highlights how communities lacking access to grid electricity can benefit from innovation approaches (Practical Action, 2017). Of particular interest are the distributed renewable energy technologies which have become a major player in the global energy equation (Practical Action, 2017). The key energy challenges facing Kenya have been identified as energy access, climate change, energy security and energy decentralization (Batchelor, Smith, & Fleming, 2015). Practical Action, (2017) appreciates the fact that the costs of providing energy access are not prohibitive when real energy demands are identified and that urgent action is at the heart of the country's delivery on Sustainable Development Goal (SDG) 7. Addressing energy poverty, requires a critical review of how affordable, reliable and clean energy services can be delivered to the most marginalized people. Indeed national plans in energy-poor countries would take a different shape if energy sector actors were to place energy customers' needs first, and engage in ensuring the delivery of much more distributed energy than is used today (Practical Action, 2017). To date, the potential for stand-alone wind generation for electricity supply remains unexploited in Kenya, despite the long history of wind development. At the same time the country still faces major challenges to increasing grid connectivity particularly to a growing and dispersed population. At the same time, the 2010 Constitution of Kenya (Gok, 2010) confers the right to sustainable exploitation, utilisation, management and conservation of the environment and natural resources, and to ensure the equitable sharing of the accruing benefits while utilising the environment and natural resources for the benefit of the people. The Kenya Sustainable Energy for All action agenda sets the goal for achieving universal energy access to the year 2030 (MOEP (1), 2016).

The stark reality of meeting the energy demands of the geographically disadvantaged populations needs to be addressed through a double pronged approach that entails decentralised energy service provision, while at the same time meeting the demands of industrialisation through expansion of generation capacity if the objectives of Vision 2030 are to be achieved (Daniel, 1999). The country's persistent focus on large-scale generation lays more emphasis on increasing connectivity through the grid despite the knowledge that the economics of such an approach does not add up. The result has been a resounding social and developmental exclusion of minority inhabitants of wind rich areas that are remote from the national grid (Daniel, 1999). This trend of historical social exclusion from national development has serious consequences on social equity. The large gap between poverty levels and electrification rates in Kenya points at a significant supressed demand, with 93 per cent of the rural population lacking access to electricity, but 'only' 50 per cent is below the poverty line (Pueyo, 2015).

Distributed generation from renewable energy has been increasing as people become more aware of climate change and relate it to the choices of energy made by different economies worldwide. Small-scale, decentralized systems can play a significant role in meeting the combined challenges of development and environmental conservation (Daniel, 1999). A paradigm shift to decentralised electricity generation could provide a solution to increasing electricity access in wind-rich areas, otherwise it may take a painfully long period for populations in these areas to enjoy the benefits of electricity in their households and businesses for improved livelihoods. Such a shift must be evidence based so as to secure government buy-in to provide the necessary leadership in promoting small wind technology. Recent efforts to develop mini-grids using diesel and in some cases renewable energy have resulted in dramatic improvements in performance, market power, sales and leasing opportunities, and end-user satisfaction in both developed and developing nations (Daniel, 1999). Some of these technologies have already had a significant impact on local patterns of energy use, economic activity, and the environment. However, a general pattern of neglect and underinvestment in such systems is evident in many countries and Kenya is not an exception.

Malerba, (2002) noted the need to identify research gaps whose clarification could enhance the contribution of the study of innovation systems to improved access to clean energy sources and observed that studies that place the firm as the central focus in improving the empirical application of the innovation systems approach to the energy sector are still lacking. The study of NIS offers fresh rationales and approaches for government technology policies, while the concept of NIS draws the attention of government to possible systemic failures that may impede industries to innovate. Innovations result from elements within systems and the relations between them (Edquist, 1999). They encompass product technologies and organizational innovations, based on the understanding that developing a differentiated concept of innovation is necessary to comprehend the complex relations between growth, employment, and innovation. They also value the central role of institutions, which helps in understanding the social patterning of innovative behaviour which is considered to be "path-dependent" in character. Manzini, (2012) highlights the works of Friedrich List and other researchers such as Lundvall, Freeman and others that embrace the National Innovation Systems (NIS) perspective have drawn on the same body of literature. They argue for an integrated view of national actors in the economy, including the knowledge producing institutions, the productive sectors, technology and infrastructure thus building on a foundation laid over a century and a half ago which argues for the state as the most important actor in generating sustained economic well-being for a country (Manzini, 2012). By concentrating on developing its productive capacities, even at the expense of short-term gain within a generation, a nation can advance its industrial development through technological innovation, as a means to accomplish enduring economic well-being. Support for developing these capabilities is largely lacking in the Kenyan context but urgently needed (Manzini, 2012). This needs to be done at all levels from formal courses to shorter inputs for existing businesses. The small firms operating in clean energy technology markets are characterised by minor, incremental innovations with a weak science base despite the appropriateness of their innovations for low-income consumers or for particular distinctive operating environments (Suzuki, 2013). The potential for such firms to miss opportunities is high as they may develop the tendency to focus on consumers in their immediate locale.

Overall, the small wind turbine technology sector is reported to have experienced a long and cumbersome development trajectory, characterized by malfunctioning wind turbines and low quality products and services (Kamp & Vanheule, 2015). For example, there is no standardized training curriculum for training site assessors who instill confidence in consumers; the local resources and capabilities are poorly utilized; and the limited know-how in training of local employees in operation and maintenance suggests a need for institutional support to affect the desired technology-push (Suzuki, 2014). Strong local companies which ensure the use of advanced digital monitoring, first line maintenance by trained local engineers and second line support wind energy suppliers are still lacking. According to (Hansen, 2016) many of the companies that claim to deal with small wind are more oriented to solar photovoltaic (PV) services.

Hekkert et. al., (2011) notes that all innovation systems can be characterized by the same basic building blocks or components namely: actors, such as organizations responsible for education, R&D, industrial activities, and consumers; institutions, such as supportive legislation and technology standards; and networks, which are the linkages between organizations and technology in research projects and advocacy coalitions. Technology is part of the innovation system as it enables and constrains the activities of actors in the innovation system. Hekkert et. al., (2011) provides a step by step guide on how the functions of the Technology Innovation System (TIS) framework (Annex 1) can be used to analyse an innovation system. The TIS framework has got seven functions namely: (1) knowledge development; (2) knowledge diffusion through networks; (3) guidance of the search/articulation of demand; (4) creation of legitimacy/counteract resistance to change; (5) resources mobilization; (6) market formation, and; (7) entrepreneurial activities. The sectoral as well as the technological innovation system approaches adopt a certain technology (spanning multiple sectors) or the sector in which it is used (including various technologies) as their system boundary (Schrempf, Kaplan, & Schroeder, 2013). The boundaries of the system could be set to some specific or all applications (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). TIS literature refers to the focal TIS as "the realm where systematic interdependencies in a specific technological field play out" (Edsand, 2016). Setting the boundary of a TIS is complicated because it could be delimited by the sector of a technology or in terms of activities, e.g. wind or photovoltaic sector (Edsand, 2016). However for the purpose of this working paper the technology is adopted as the system boundary and therefore the TIS approach will form the basis for the review and research agenda.

The paper is structured as follows: Section 1 is the Introduction; Section 2 is the Context; Section 3 presents the experiences from other countries; Section 4 is the literature review and theories; Section 5 is the Empirical Section describing the SWT Innovation System in Kenya; Section 6 is the Discussion highlighting the proposed research agenda; Section 7 is the Conclusion; and Section 8 are the References.

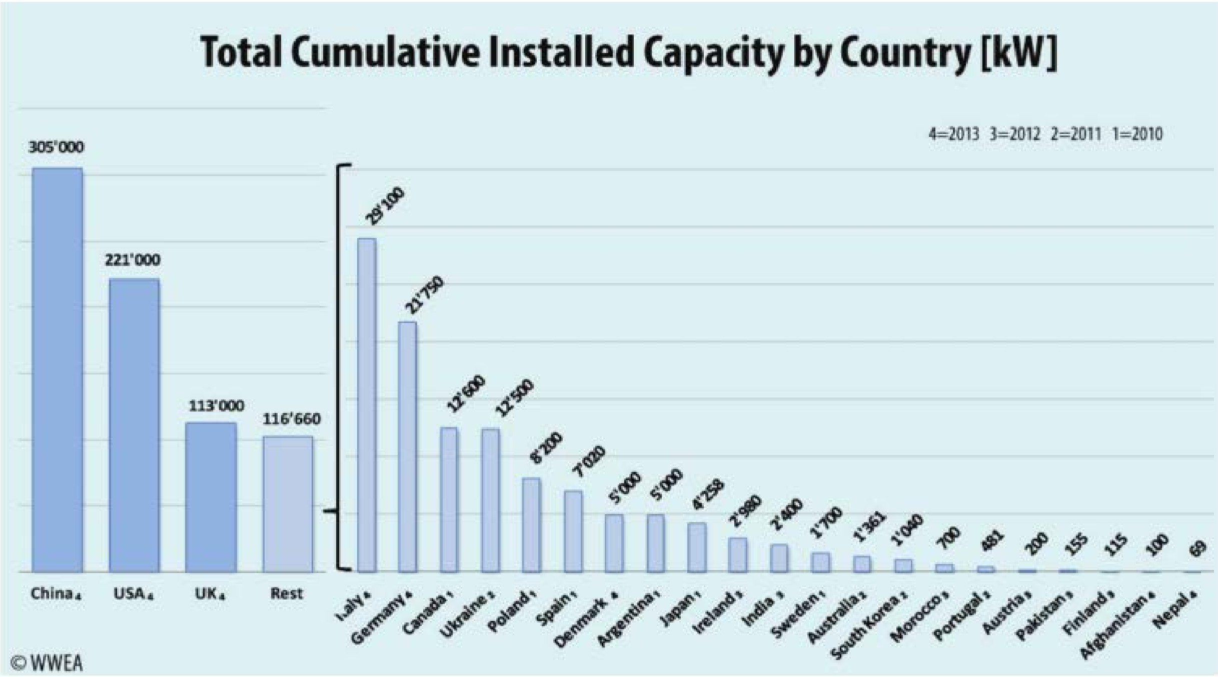
## 2. The Context

This review explores the concept of National Innovation Systems within the context of developing countries using Kenya as an example and draws on the TIS framework to examine how the functioning of the SWT innovation system could be improved with a view to enhancing the diffusion of small wind turbines. The key objective is to identify the underlying factors behind the low diffusion of SWT and suggest recommendations for research that could promote growth of SWT technology. The need for government intervention in the development of the SWT sector was established through a survey conducted in February, 2017. The respondents were drawn from Government (4), networks (2), Consultants (1), and private sector (4) portrayed a general opinion that small wind was a much easier technology to deal with compared to solar PV and yet it has received limited attention. An inclusive innovation approach is adopted to identify viable solutions to the low electrification of historically disadvantaged communities who live in areas where wind resources are abundant. Historically wind turbines are characterised by high maintenance costs which may vary with the site of installation. Levring, (2018) however observes that the price of wind energy is unidirectional leaning towards a steep downward trajectory. Levring further emphasises the importance of having electricity, but used in the right way to maximize the usage of renewable power. The justification for small wind turbines despite their high production cost per kWh compared to grid connected wind systems lies in the ability to provide a relatively economical power supply compared to fossil fuel generation. Further, SWT can be applied both on and off existing power grids as a result of their size and low energy output (LaMonica, 2011). Off grid application avoids the high cost of expanding transmission lines to rural regions of developing countries and their ability to operate on lower wind speeds presents more placement options. Correct placement in suitable locations assures more energy per dollar than other common alternative energy sources such as photovoltaics (LaMonica, 2011). The role of stand-alone electricity supply even where grid supply exists is underscored due to affordability and reliability issues, including the need for government and development partners to make this a high priority for ensuring electricity access and affordability for the poorest through decentralised supply options (Practical Action, 2017). It helps to minimize reliance of fossil fuels for electricity generation in this era when climate change is of global concern.

## 3. Experiences in diffusion of SWT from other countries

Across the rest of the world the experience in the growth of small wind turbines is varied as demonstrated in ***Figure 1***. China leads in terms of installed units in a market that started gaining ground in the early eighties. 43,000 units were added in 2015 (20,000 less than in 2014), reaching 732,000 units installed by the end of 2015. The Chinese market now represents almost 74 percent of the world market in terms of total installed units and 93 percent of the new installations in 2015. It is estimated that around half of the turbines continue to produce electricity in China (Pitteloud & Gsänger, 2017). The World Wind Energy Association observes that the wind market trend leans towards a grid-tied system with larger capacity. It is however noteworthy that off-grid applications such as rural residential electrification, telecommunication stations, off-shore generation, and hybrid systems with diesel and solar continue to play an important role in remote areas of developing countries. Globally, over 80 percent of the manufacturers produce stand alone applications. In China, off-grid units comprised 97 percent of the market in 2009, and 2.4 million households still lack electricity (Pitteloud & Gsänger, 2017). In USA, off-grid small wind turbines account for most of the units deployed in distributed wind applications.

**Figure 1:** Total cumulative Installed Capacity by Country




*Source:* (Gsänger & Pitteloud, 2015)

A review of technology developments on the international scene indicates that the growth of the small wind installations in Denmark benefitted from continuous government support. The role of subsidy in accelerating diffusion is demonstrated by the net metering support program for up to 6kW systems introduced in 2010 for household supply with solar, wind and biomass. Phasing out of the support scheme in 2012 in Denmark contributed to a shocking decrease of 41percent in sales in 2013 (AWEA, 2016). Subsequent introduction of a Feed-in Tariff program in February, 2015 resulted in installation of an additional 323 turbines just after eight months. The need for national market stability instead of intermittent support strategies has also been demonstrated in the Danish market. The Danish certification scheme (BEK 73) is seen as a model to emulate by other markets in the US, China and UK. It is also seen as a driving factor to boost reliable turbines (AWEA, 2016). Long-term government support strategies are cited as a key to maturity and independence from financial incentives. The establishment of the Danish Small Wind Turbine Association (DSWTA) in 2009 to promote the supply of wind power to individual homes, small and microenterprises, and small farms seems to have played a key role in the success of small wind systems. According to the Association, (Petersen M.V, n.d) the price of electricity is on a level where the payback time for having the own supply is under 5 years, and new ways of financing small wind turbines in rural areas are coming up.

Denmark has successfully utilized net-metering especially when the wholesale price of electricity has been sufficiently high. Standards and certification are useful in promoting sales of better performing technology and they also contribute to stability of markets. Of particular importance to technology users is the safety and noise. This has led to development of the internationally accepted standards such as the IEC 61400-2 (3rd edition, 2013) standard, from the International Electro-technical Commission which stipulates specific safety design requirements; the 2009, American, Canadian, and British Wind Energy Associations (now RenewableUK) coordinated Small Wind Turbine Performance & Safety Standard, a subset based on IEC61400-2 (SWTs design), IEC61400-12-1 (performance) and IEC61400-11 (acoustics). These standards were later adopted by the American Wind Energy Association (AWEA) and RenewableUK for their certification programs Small Wind Certification Council (SWCC) and Microgeneration Certification Scheme (MCS), respectively. As with California, Denmark has “automatic” approval procedures for systems up to 6 or 11 kW and fast-track application procedures up to 1.5 MW, with separate procedures for wind generators above 11 kW (GOK & EUEI-PDF, 2014). High standards of small wind turbines have also been achieved thus making small wind turbines a viable alternative to existing technologies such as diesel generators.

The Danish Wind Association recognizes the potential for cooperative ownership of small wind turbines which could provide a springboard for small agricultural societies without access to grid connected electricity or individual home supply where the latter makes economic sense (Petersen M. V, n.d). It emphasizes the importance of testing and certification in ensuring that small wind turbines which look very good on paper satisfy the expectations of customers and highlights that, what is written down often fails to be transparent in terms of what the buyer needs to know before making the purchase. The Association points out that a potential barrier could be strong influence from centralized power suppliers who can make it difficult to get the necessary allowance to erect turbines. For the case of Kenya this could be avoided by accessing the plans for grid extension within the target location of isolated systems.

A Danish committee (CanWEA, 2015) comprising manufacturers, blade producers and software consultancy that could be regarded as competitors formed a partnership, which in collaboration with Danish Technical University (DTU) Wind Energy achieved a historical milestone through identification of market potential in foreign markets. DTU Wind is a well-established national leading research center in Denmark with over 35 years’ track record of pioneering the development of the wind energy industry (AWEA, 2016). The success of the Danish small wind turbine sector could partly be attributed to collaboration of this research centre with Danish small wind turbines manufacturers and blade producers in several projects. Such collaboration has seen state-of-art online software developed exclusively for optimizing siting of small wind turbines in the vicinity of obstacles, including buildings and trees characterizing most of the small wind installation sites. While the evolution of the Danish wind sector was not a deliberately conscious effort of setting up a small wind turbine innovation system (Ebbe & Graversen, 2016), it presents certain elements that stand out as notable contributors to the success of the small wind sector and which could probably inform the transition for developing economies such as Kenya in the delivery of electricity to remote areas. These elements include research and development at the Danish Technical University, the formation of the association of business firms, development of standards, rules and regulations, and government support and policy. It is possible that the shaping of a functional innovation system in a developing economy such as Kenya would most probably take a different approach from that of the Danish wind industry which presents an opportunity for interactive learning.

America which is one of the countries cited as recording success in small wind turbines established a standard (AWEA9.1 2009), whose objective is to provide consumers with a measure of confidence in the quality of small wind turbine products meeting the standard, and an improved basis for comparing the performance of competing products. In September 2008, the American Wind Association introduced a law that allows homeowners and small business people to put up photovoltaic generators and small windmills and any other new sources of widely distributed generation that they can come up with. The Association has also developed Occupational Safety & Health Administration regulations enforceable by law and failure to adhere is subject to fines or jail. Similar developments are yet to be realised in Kenya. Individual motivation to buy in America is driven by the desire to have own renewable energy supply; residence in rural areas; interest in innovative technology and reasonable payback period of 6 to 10 years.

In Africa, including Kenya the diffusion of small wind turbines has been slow with only a few countries such as Morocco, South Africa, Ethiopia and Kenya venturing into wind development. The trend however, leans towards large wind systems (for example the latest installation of 310MW in Turkana County, Kenya) with limited attention paid to the contribution of small wind turbines towards electrifying off-grid areas (Kabendara, 2015). The 2015 Africa Progress report indicates that prices for renewable technologies, especially solar and wind-power, are falling at an extraordinary rate to the point at which they are competitive with fossil fuels. In spite of the existing barriers, the market in developed countries is promising for grid-connected and off-grid applications, due to promotion policies (such as capital cost buy-down, feed-in tariffs and net metering), and even more so for developing countries, because of the continuing decrease in specific costs and the increasing need for energy (Gardner et al., 2009). A research agenda that promotes small wind turbine technology could be complementary to other renewable energy technologies such as Solar PV and small hydro power which have received substantial attention in Kenya.

A common strategy for technology transfer from developed economies to developing economies that have developed advanced wind turbine technology is threefold: through a licensing agreement, or developed through collaborative research and development (R&D); joint-venture partnerships between foreign and domestic companies in which a technology license is usually transferred; and no license transfer and the know-how and intellectual property associated with the technology remains primarily in the hands of foreign firms (Lewis, 2007). While it is necessary to have a conducive a conducive national innovation context the role of firms in acquiring new technology and know-how has been emphasised. The role of national-level technology innovation systems and firm-level learning networks in the success of Suzlon's and Goldwind's wind technology innovation trajectories in India and China was documented by (Lewis, 2007). The Suzlon and Goldwind cases benefited from a supportive national policy environment for wind energy development and successfully used licensing as a mode of international technology transfer. The key difference between the two forms was the learning networks, and particularly the variation in how each firm accessed global networks. This provides empirical evidence of the value of learning networks for emerging wind turbine manufacturers (Lewis, 2007).

Lewis, (2007) highlights Suzlon's growth model that is increasingly popular innovation practice for transnational firms that applies globally dispersed operations and utilizes regional variation in technical expertise and low input costs to its advantage. It enhances this with an expansive international innovation networks that enables it to stay abreast of wind technology innovations around the world and by incorporating new knowledge into local designs through its extensive research and development facilities. This has been achieved through a strong network of global innovation subsidiaries while maintaining control of enough intellectual property rights to remain at the forefront of wind turbine manufacturing and sales around the globe. Goldwind has relied on research and manufacturing operations that are primarily China-based, a strategy that limits its interaction with hubs of wind power innovation expertise outside of China (Lewis, 2007). Nevertheless China has become a hub in its own right, with diverse international players actively manufacturing wind turbines there, many in close regional proximity. These illustrations of energy leapfrogging are examples of how a creative blend of strategies can be used to enter new technology markets (Lewis, 2007). A combination of licensing intellectual property, creating strategic technology partnerships, accessing regional and global learning networks, and taking advantage of regional advantages like lower labor costs—were all important components of each company's successful business model. It is undeniable that technology development is becoming increasingly global and this offers developing-country firms an opportunity to take advantage of access to technological know-how that was previously developed primarily by and for the developed world for their own benefit.

## 4. Literature review and theories

The concept of the innovation system lays emphasis on the flow of technology and information among people, enterprises and institutions as being crucial to an innovative process. Flaws in an innovation system are often labelled as system failures or system problems (Hekkert, Gaston; & Harmsen, 2011). Technologies and regions differ and this makes it impossible to define an optimal configuration of the innovation system. As a result, it is difficult to benchmark innovation systems because what works in one country may not be applicable in another. Development of an innovation system often depends strongly on the competition in other parts of the world and very often has very technology specific dynamics. The use of specific diagnostic questions in the assessment of the functioning of innovation systems is therefore recommended (Hekkert, Gaston; & Harmsen, 2011). This entails mapping of technology, actors, networks and institutions. Technological innovation systems also differ greatly in terms of the knowledge base and learning processes related to innovation. The opportunities differ too and could arise from scientific breakthroughs, advancements in R&D or experimentation with equipment. The importance of an advanced market and a well- articulated critical demand as a driving force for innovation was recognised by innovation thinkers such as Schumpeter and Porter (Hekkert, Gaston; & Harmsen, 2011). The role of networks in solving problem, running of organisations and achievement of organisational goals is recognised. Measuring how innovation systems are functioning is considered as the big breakthrough in innovation systems research (Hekkert, Gaston; & Harmsen, 2011). The NIS framework is adopted in an attempt to define 'what is at play in the innovation system for small wind turbines in Kenya'. The focus on the NIS and how it relates to technology diffusion is informed by the role it plays in the national context in technology diffusion. An innovation system is conceptualized as comprising both blocking and inducing mechanisms (Charles Edquist et al., 2014). The blocking mechanisms impede the proper functioning of the innovation system while the inducing mechanisms promote the effective functioning. The combination of blocking and inducing mechanisms in any innovation system varies across sectors and countries and it may not possible to draw generalizations across sectors or countries.

### a. Supply side issues: encouraging innovation

Developing countries are characterised by weak financial systems, with local capital markets lacking long-term financial products in domestic currencies and well-developed financial intermediation (Practical Action, 2017). The use of public funds to close the financing gap is seen as crucial to the development of incentives and skills that are more people and development-centred. Practical Action, (2017) identifies financing in energy-poor countries as one of the blocking mechanisms owing to the scepticism that surrounds decentralised renewable energy (RE) investments which abounds among financiers, public and especially private actors. This attitude emanates from the limitations that businesses face with respect to their financial and operational track record which is compounded by lack of familiarity. Another limiting factor cited in accelerating distributed renewable energy is the dire need for technical and business skills which could be developed by tertiary institutions and vocational training centres (for example, Strathmore University in Nairobi). Kuratko, (2010) draws on Schumpeter's famous phrase "gales of creative destruction" noting that the scholarly community, has been more fascinated by the "creative" part and given relatively little emphasis to the "destruction" part which he considers a gross oversight. The need to understand how old combinations of factors of production are dis-assembled in order to understand the process of creating and implementing new combinations of factors of production. Kuratko refers to Baumol (2002) who proposes that innovation has become a life-or-death matter for established corporations in free-market economies. Literature also indicate that when a firm's assets consist not of physical things but of information and individual skills and knowledge, swift change in their constitution is more likely to happen as suggested by (Boisot, 1995). The destruction aspect is gaining prominence and this is corroborated by evidence from normative literature (Kuratko, 2010).

### b. Diffusion issues: encouraging demand

Not-for-profit actors (for example non-governmental organisations) have been the primary drivers of inclusive innovation and mostly depend on the availability of not for profit funds whose emergence has notably increased and mostly take the shape of public-private partnerships (Practical Action, 2017). The inducing mechanisms could include categorisation of SWT as public goods, in which case government intervention may be necessary to fill the gap left by market failure. Alternatively markets may depend on the emergence of new and innovative alliances of actors to meet the service needs of the excluded poor while delivering profits for business firms. Practical Action, (2017) recommends interaction between donors, financiers, businesses, and civil society to develop institutional support, human resources, and funding to facilitate development of leadership potential, update and alignment of institutional practices; upscaling successful experiences by strengthening the skills of business firms; and resourcing market activation campaigns and partnerships as potential means of creating the necessary demand, pressure, policy and regulatory foundation that is capable of sustaining distributed energy markets.

### c. Issues relating supply with demand

Kuratko, (2010) highlights that generally, the entrepreneurship literature implicitly focuses on supply side changes with most discussions of opportunity encouraging changes in inputs, ways of organizing, production processes, or products. Kuratko however observes that changes in demand alone have the potential to generate opportunities. He underscores the role of customer preferences in influencing the allocation of resources because producers need to respond to the preferences and purchasing habits of consumers. Thus, demand changes from exogenous shifts in culture, perception, tastes, or mood can open up opportunities. Kuratko quotes (Drucker, 1985) who identified opportunity whenever the increase in demand outpaces investments in production capacity, generating opportunities to add more capacity, perhaps on more economic terms. Kuratko (2010) further highlights views by Geroski (2001) that growing markets are likely to create new niches as well as the opportunity to specialize. Kuratko states that regardless of classification, policy options can prove difficult to evaluate as they pose measurement problems and that different policy measures could interact leading to ambiguous effects. Policies could either be complementary, but they may also counteract each other while policies geared toward other goals may also influence entrepreneurial activity. He explains that the effect of a policy tool depends on the whole policy mix in the economy, thus making it virtually impossible to fully identify the factors affecting entrepreneurial activity, let alone quantify their respective effect. The importance of the context in policy measures to affect supply or demand lies in the different political, economic, and cultural systems across countries. They display characteristics that cannot be replicated or imitated by public policies. The role of cross-national benchmarking and best practice comparisons is worthwhile when evaluating different policy tools and doing so largely ignore the importance of context. As noted by Kuratko (2010), an additional set of factors relevant in the developing country context to promote supply include entrepreneurship development for higher growth trajectory, an externalities-based framework based on the Knowledge Spillover Theory of Entrepreneurship (Acs & Armington, 2006; Acs et al., 2005; Braunerhjelm, 2010) which argues for a dense networks of entrepreneurial firms as being beneficial entrepreneurial activity (networks "foster fast learning" (Acs, 2002, 171) and perpetuate spillovers (Acs, 2002)); demonstration and failure externalities which are considered extremely important in developing countries with respect to "learning by watching" where "new investment projects in one sector of the economy have a demonstration effect on the efficiency of other sectors" (King & Robson, 1993, 449). Four core themes in the literature which affect demonstration and are identified as (1) culture, values, and norms; (2) views on outsiders and inclusiveness, (3) the level of economic freedom, and (4) an economy's fundamentals including its macroeconomic stability, infrastructure, and the level of development of its financial markets. Other aspects cited as influencing supply include knowledge and information externalities which affect entrepreneurship in developing countries in two important ways: discovery of what to produce and the impact of the technology and processes used in production. On knowledge and information externalities Kuratko, (2010) indicates that:

> "Knowledge and information externalities are in turn impacted by information asymmetries, transaction costs, education levels, research and development opportunities, and foreign direct investment. Network externalities have emerged as a major theme in the literature on entrepreneurship in developing countries. There are a number of dimensions. First, there are networks between entrepreneurs within the country (i.e., domestic associations) and then there are networks which extend internationally. Much of the literature also focuses on the lack of indigenous business networks in some countries and the importance of ethnic minority networks in others. These networks may also help to overcome some of the information failures associated with markets in developing countries."

Kuratko, (2010) concludes that:

> "An entrepreneurship-based development strategy which creates the institutions and incentives for productive, innovative entrepreneurship can positively impact growth and development in developing countries by (1) removing many of the distortions currently present in their markets, (2) encouraging human capital development (3) better allocating scarce resources through market processes, and (4) providing employment alternatives to the public sector. History has shown that governments, especially those in developing countries, are less efficient compared to the market in allocating resources. Indeed for developing countries which are rife with market distortions and uncertainty, the calculations and planning which would have to be completed by governments would likely fail. Entrepreneurs, therefore, acting through markets and supported by market-friendly institutions, are the best agents to achieve economic growth and development."

### d. Innovation systems literature

According to the innovation systems (IS) theory, the innovation process is interactive within the firms and among the different actors in the innovation system. The focus on innovation and learning processes in the study of IS emanates from the understanding that technological innovation results in generation of new knowledge or combines existing elements of knowledge in new ways, which essentially makes it a "learning process" (Edquist, 1999). According to Bozeman and Gaughan (2003), the complexity of innovation systems invariably precludes vast generalizations. As a result, there is general agreement among scholars and practitioners on the fact that technological development is primarily a nation-specific and industry-specific phenomenon. Within the concept of 'developing nations' significant variations exist and therefore the NIS needs to be applied within the specific context being examined (Bozeman and Gaughan, 2003). This is because individual economies vary with respect to on-going processes of learning, searching and exploring, leading to new products, new techniques, new forms of organization and new markets. In many developing countries, catching up technologically depends on the ability to position their national innovation systems and environments to best take advantage of knowledge flows originating at the global level. Local factors and global dynamics are intertwined in new ways requiring fresh approaches to domestic and international policy (Bozeman and Gaughan, 2003). Applying a sectoral perspective enhances the focus and narrow down to the problem area thereby allowing a deeper analysis.

Technology diffusion is determined by the ability of national governments to enact policies that aid domestic firms in using and diffusing these technologies throughout the country. Establishment of networks that dissipate the tacit and codified knowledge underlying novel technological systems forms part of the country's social absorptive capacity (Feinson, 2003). Other agents of diffusion include non-firm organizations such as universities, financial institutions, government, and local authorities. They support in various ways innovation, diffusion of new technologies and production of firms within a sectoral system, but again their role greatly differs among sectors (Malerba et al., 2007). Institutional capacity to support such ventures, inadequate financing and limited political support to governmental and non-governmental organizations (NGOs), and the private sector limits the development and diffusion of the desired technologies (Daniel, 1999). Government incentives can be used to form formal and informal networks to improve information, training, and extension; subcontracting; and standards, testing, and quality control. Chataway, Hanlin, & Kaplinsky, (2014) argues for the role of small and medium sized firms in exploiting local markets, and use of locally available resources, while introducing new products more accessible to the poor and make use of new technologies which are more inclusive of poor producers. Small firms such as those that characterise the SWT innovation system in Kenya may face capacity problems that relate to adoption or production of new technologies. New entrants have the potential of bringing in new ideas, products and processes. The role of government in the creation of an enabling environment for such new entrants cannot be gainsaid. Survival of existing firms depends on their ability to continuously innovate (Chaminade & Edquist, 2005). Islam, (2014) identified trade as the most important channel of technology diffusion. New agents (both new firms and non-firm organizations) play an important role in sectoral systems by bringing into the innovation and production processes a variety of approaches, specialization and knowledge, and contribute to the major changes in the population of agents and in the transformation of technologies and products in a sector. Political barriers have long been believed to be an important deterrent to technology diffusion (Hanseman & Gustafson, 2014).

Successful innovation happens through building and improving effective routines. In the Lundvall framework, innovation is conceptualised as learning. This is because by definition, innovation is in the capabilities and knowledge which make up technology. Knowledge plays a central role in innovation and production. It encompasses both tacit and codified elements, and is closely related to the problem solving activities of firms (Malerba et al., 2007). Learning from foreign firms with expertise could be instrumental in developing the production capabilities as well as the market potential. Morgan (1997) noted that interactive learning helps organisations develop inimitable skills such as kaizen, which are important for continuous improvement, problem solving and innovation. It is less common to find multinational firms learning a great deal from their branch plants and in many cases they are more engaged in routine activities 'grubby and pedestrian forms of knowledge' (Morgan, 1997). Rosenberg argues that these forms of knowledge-engineering, production and the like often play a disconcertingly large role in learning and innovation, and yet they tend to be ignored by scholars. By focusing on the knowledge, learning and interaction among actors that gives rise to "systems of innovation" it is possible to examine the "national or local environments where organisational and institutional developments produce conducive conditions to the growth of interactive mechanisms on which innovation and the diffusion of technology are based" (Mytelka & Smith, 2002).

Causes of systemic failures could emanate from the enabling environment which may not offer a supportive National Innovation System (NIS) or a Sectoral Innovation System (SIS). Other contributory factors could originate from supply issues (the way a firm works) specifically (Governance, finance, training skills etc.); interaction with other agencies in the SIS such as Government, R&D Agencies, networks, technology adopters, and consultancy firms. The functioning of the market could also contribute to low diffusion. This relates to demand issues, specifically the attitude of consumers towards the technology and their ability to take it up for their own benefit, or limited awareness of how it functions. Generally, there has been low focus on the role of consumers in innovation in low- and middle-income economies. In many cases the innovation tendency displays strong characteristics of supply-push rather than demand pull (Chataway, Hanlin, & Kaplinsky, 2014). Among the constraints faced in introducing new technology is the small size of the early market which limits profit incentive to warrant market-led investments in the innovation cycle.

### e. Innovation systems and economic development

According to OECD (2008) the study of national innovation systems focuses on flows of knowledge. Analysis is increasingly directed to improving performance in "knowledge- based economies" which are directly based on the production, distribution and use of knowledge and information. Knowledge, which is embodied in human beings (as "human capital") and in technology, is central to economic development. Its importance has only gained recognition over the last few years and it is growing. Economic activities are becoming more and more knowledge-intensive for example in high-technology industries and the increasing demand for highly skilled people. Investments in knowledge, for example in research and development, education and training, and innovative work approaches are considered key to economic growth (OECD, 2008). The increasing attention given to the economic role of knowledge lays emphasis on mapping knowledge flows as a complement to measuring knowledge investments. Flows, particularly of knowledge "codified" in publications, patents and other sources, are both increasing and becoming easier to detect due largely to information technology (OECD, 2008). The key objective is to evaluate and compare the main channels for knowledge flows at the national level, identify bottlenecks and to suggest policies and approaches to improve their fluidity. This requires one to trace the links and relationships among industry, government and academia in the development of science and technology. By doing this it is possible to measure the "knowledge distribution power" of a national innovation system, which is considered one determinant of growth and competitiveness.

The NIS approach is an indicator of the rise of systemic approaches to the study of technology development as opposed to the "linear model of innovation", whereby knowledge flows are modeled quite simply (OECD, 2008). Science is believed to be at the root of innovation and an increase in scientific inputs into the pipeline is expected to directly increase the number of new innovations and technologies flowing out of the downstream end. Innovation can originate from many sources and any stage of research, development, marketing and diffusion (OECD, 2008). It can also take many forms, including adaptations of products and incremental improvements to processes. Innovation thus becomes the result of complex interaction between various actors and institutions. Technical change occurs in feedback loops within the innovation system rather than in a perfectly linear sequence.

Firms are recognised as a key element of innovation systems and consequently, for a nation to improve its competitiveness or experience improved productivity and economic growth, it needs to pay attention to the accumulation of technological capability by firms (Tidd, Bessant, & Pavitt, 2005) Innovation results from the ability of firms to recognize and understand effective routines (both developed in-house or observed elsewhere) and facilitating their emergence across the organization (Tidd et al., 2005). Factors that hinder entrepreneurial activities include lack of start-up finance, risk averse attitude from potential lenders, underdeveloped specific capabilities, and knowledge diffusion. The knowledge base underpinning firms' activities becomes highly distinctive at the firm level. Firms are involved in the innovation, production and distribution of sectoral products, and in the generation, adoption and use of new technologies (Malerba et al., 2007). The avenues through which such technological opportunities occur are varied depending on the sector and may include: conditions related to major scientific breakthroughs in universities; advancements in external R&D; equipment and instrumentation; and suppliers or users. At the level of the firm innovation can take place in any section (Chaminade & Edquist, 2005). The IS approach emphasises the fact that firms do not innovate in isolation but with continuous interactions with the other actors in the system (at regional, sectoral, national, and supranational level). They form a complex network of co-operating and competing firms and other institutions, building on a range of joint ventures and close linkages with suppliers and customers (OECD, 2008). Access to external sources of knowledge might be other firms, public and private research institutes, universities or transfer institutions. Such interactions may encounter systemic problems which may be technological in nature or related to capabilities.

Firms are likely to utilize their wider networks for developing capabilities, since advanced services generally require providers to take over a customer's business process activities, an activity that is both costly and difficult (Story, Raddats, Burton, Zolkiewski, & Baines, 2015). "Different sectors are characterized by different knowledge bases, and knowledge plays a central role in innovation and affects the types of learning and capabilities of firms" (UNIDO & UNU-Merit, 2014). Firms have increasingly appreciated the value in using networks to gain extra traction on the learning process (Tidd et al., 2005). Networking is useful in the innovation process because it provides support for shared learning and helps to spread the risk and in the process, extends the range of things which could be tried. This is particularly useful in the context of smaller firms where resources are scarce. Such networking could be firm to firm as well as rich linkages within the national system of innovation (Tidd et al., 2005). Such firms can enhance their enterpreneurship and intrapreneurship potential through diversification into new products, growth into new product areas and increased investment in new areas. This is especially possible where new products respond to the needs of consumers better than old products. Such growth has been known to accompany job creation and economic growth. New knowledge is acquired through learning processes, organisational capabilities and feedback from the market (Malerba et al., 2007). The early stages of technology development are characterised by rapid changes in knowledge, high levels of uncertainty and low barriers to entry, with new firms being the major innovators and key elements in industrial dynamiscs.

The emergence of knowledge intensive economic activities demands a large and growing number of institutions with specialised expertise of very different kinds in the production and diffusion of knowledge. Success of enterprises and of national economies as a whole depends on their effectiveness in gathering and utilizing knowledge from these institutions, whether they are in the private sector, public sector or academia. Knowledge flows could occur through 1) interactions among enterprises; 2) interactions among enterprises, universities and public research laboratories; 3) diffusion of knowledge and technology to firms; and 4) movement of personnel (OECD, 2010). A variety of approaches can be used to measure these flows. The ability of policy makers to understanding the national innovation system can is useful in the identification of leverage points for enhancing innovative performance and overall competitiveness. It can assist in singling out any mismatch within the system, both among institutions and in relation to government policies, which can thwart technology development and innovation. Differences exist between countries with regard to the structure of knowledge flows and in the relative importance of different types of institutions, actors and linkages for their respective production systems (OECD, 2010). In some countries institutional interactions occur more easily than in others. Framework policies within a specific country relating to regulations, taxes, financing, competition and intellectual property could ease or block the various types of interactions and knowledge flows. Technological innovation takes place within a specific industrial structure and national context and therefore a good understanding of this context or system is likely to lead to better government technology and innovation policies (OECD, 2010). Empirical studies have found persistent differences in the long-term performance of countries and markedly different patterns of national technological specialisation. This is evident among countries that show a broad convergence in macroeconomic performance as do the OECD countries, their technological profiles and innovation capabilities diverge considerably. Countries tend to develop along certain technological paths or "trajectories" determined by past and present patterns of knowledge accumulation. The path taken by a country is determined largely by institutional factors, often specific to a country, including the broad range of interactions which characterise the national innovation system (OECD, 2010).

Historically, developed nations occupy the role of technological leaders while developing countries act as technological followers; the key to development success lies in closing the “technological gap” by importing existing technology and creating the internal capabilities to utilize and improve on those technologies. This process entails heavy investments in technological and social infrastructures (Feinson, 2003). The absorptive capacity of the system is determined by the ways in which knowledge and resources flow between the narrow and broad levels, and amongst the institutions and organizations via both formal and informal routes. It is therefore important for policy-makers to shift to the different types of interactions among actors within and beyond the boundaries of a national system (Feinson, 2003). The absorptive capacity “depends heavily upon the level of education and training, where the key input is a technical human capital base able to assess and decide on technology matters. This requires a well-developed educational system that lays the necessary foundations at all levels. A strong scientific, engineering and socio-economic capabilities as a base for policy making is provided by university level, while the primary/secondary level acts “to speed the diffusion and adoption of new technologies, to make local adaptations and improvements on the shop floor, and more generally to increase the awareness and ability to take advantage of technological opportunities” (Feinson, 2003). Etzkowitz & Ranga, (2013) argue for a balanced configuration whereby the university and other knowledge institutions act in partnership with industry and government and even take the lead in joint initiatives. Localisation of wind power technologies can be achieved through the assembly of imported parts; manufacture of some components or entire turbines; local technology development through innovation and R&D carried out by a domestic firm often in combination with domestic research organisations; and technology transfer from an overseas firm via a licensing agreement which may or may not include the transfer of technological know-how (Baker & Sovacool, 2017).

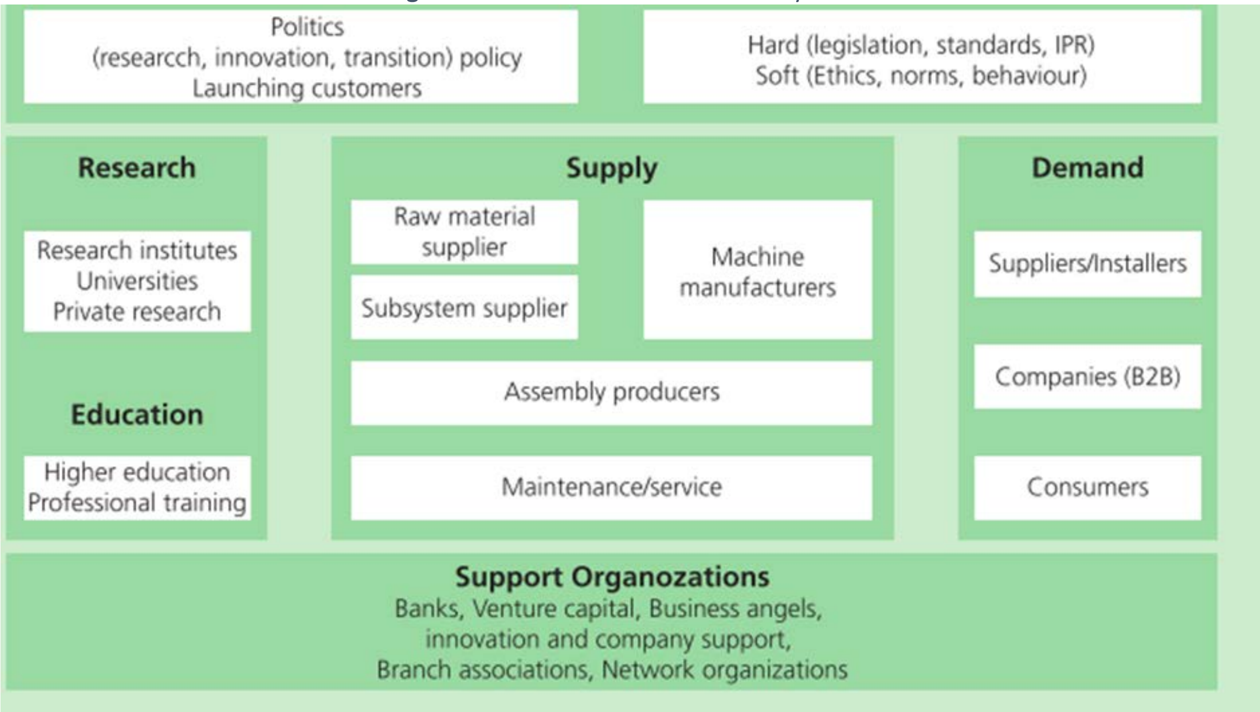
Technological innovation systems (TIS) could operate at the national level and may be delimited by the sector of a technology such as wind (Edsand, 2016). New technology must first undergo a formative stage which entails knowledge accumulation, necessary infrastructure and institutional configurations to reach the final phases of development, diffusion and utilization (Edsand, 2016). At the formative stage, the market conditions, actions taken by policy makers and industry actors are important (Edsand, 2016). Development of essential structural components sometimes takes ages before morphing into a growth stage whereby positive feedback is established between components, contributing to an accelerated development of the system. The momentum so sustained results into a stable and mature structure. The TIS framework can be used to analyse both the formation and growth stages of an innovation system and in developing economies it usually focuses on the formative stage, rather than on a later growth stage. As a consequence the exogenous factors could be of greater importance when mapping and analysing TIS systems in developing countries (Edsand, 2016). An understanding of the functioning of the TIS for small wind turbines in Kenya is necessary given that the formative stage has lasted for a couple of decades and signs of shifting to the growth stage are still elusive.

## 5. Empirical Section: the SWT innovation system in Kenya

Wind technology development in Kenya dates back to 1977 (MOEP/UNDP, 2015). Design and demonstration projects have been installed in Thika, followed by *Kijito pumps* in the late 1990s. The wind potential in Kenya is classified as low to moderate and integrated energy planning for wind as a substitute for fossil fuels is recommended in line with the national economic, social and environmental policies (MOEP, 2008). The largest off-grid wind sites in Kenya are served by the grid to a certain extent, but opportunities exist for wind based mini-grid development in the small-scale range of <100 kW(ECA, TTA, & Energy, 2014). It is estimated that 5.9 million households (56%) are without electricity or under-electrified (Practical Action, 2017). Much as the Kenyan policy framework reiterates the use of mini-grids to enhance electricity access in Arid and Semi-arid areas (MOEP 2013), mini-grids do not necessarily respond to the energy poverty that is rampant in communities that live away from the planned units. This could provide an opportunity for actors within the SWT innovation system to strengthen linkages towards the same goal of inclusive innovation in electrifying unserved populations. It is noteworthy that the attention given to solar PV and small hydro power through Government and private sector firms has not lived up to the expectation of fulfilling the inclusive innovation objectives of the geographically and economically disadvantaged communities.

The SWT innovation system in Kenya comprises various actors including firms, government agencies, networks and consultants, R&D agencies, technology adopters, development agencies, and representatives of multinational corporations Figure 2.

**Figure 2:** Structure of an Innovation System




*Source:* (Hekkert, Marko ; Heimeriks, Gaston; Harmsen, 2011)

**The Policy Environment**

Proposed Kenyan policies relating to small wind turbines include studies on capital expenditures and operating costs and development of analytical tools to inform the level of tariffs for different technologies and provision of capacity building programs and financial assistance to community projects, and the auction system is also being considered. The Energy Policy, 2004 and the draft energy policy 2015 indicate that grid-tied large electrical wind projects have gained prominence over the last 10 years and currently contribute 25MW to the national energy mix, anchored on the feed-in tariff policy and proven wind resource potential. Kenya's 5000+ MW Investment Prospectus, which is implemented under the auspices of the national development blueprint, Kenya Vision 2030 projects a wind generation capacity of 630 MW by 2016 (MOEP, 2013). A 310MW wind farm has been installed in Turkana County but is yet to be connected to the national grid. The policy framework recommends both isolated and grid connected wind technology innovation systems. Currently, off-grid systems contribute 1MW mainly for greening the diesel powered generation (MOEP 2016). Standalone small wind electrical systems (<100 kW), although appearing to have great potential, have achieved modest market penetration (UNDP, 2016), despite the existing regulatory provision for importing renewable energy generation equipment free of value added tax. The SREP mini-grid project document identifies opportunities for retrofitting (hybridising) existing mini-grids and mini-grids currently under construction as diesel sites, proposing investment in 1 MW of wind for 24 sites (ECA et al., 2014). In addition, green sites are proposed under the Rural Electrification Master Plan (REMP). The provision of a framework for connection of electricity generated from solar energy and wind energy to national and isolated grids, through direct sale or net metering is proposed in the draft energy policy (GOK & EUEI-PDF, 2014). Government targets to add at least 1,000 MW wind energy generation capacity in the short term, 2,000 MW in the medium term and 3,000 MW in the long term (GOK & EUEI-PDF(2), 2014). These policy provisions have so far not been operationalised to benefit the small wind sector and the draft energy bill does little towards this front.

The expertise for integrating wind with other forms of energy seems to be limited (CarbonAfrica, TecnoAmbiental, Africa, & Netherlands, 2015). There are many prospects on the table including at least one developer in Kenya and KPLC also has some experience but there are few operational sites to learn from. This is not to say that wind-hybrid systems have low potential or that the Levelised Cost of Energy (LCOE) is not competitive, in fact the opposite is the case (CarbonAfrica et al., 2015). The off-grid and decentralized electricity market in Kenya is estimated to comprise about 6.7 million households and is expected to comprise micro and Pico systems, mini-grids, and stand-alone systems – with solar, wind and hydro being the main resources in use (MOEP, 2016). However, translation of existing policy provisions to specific plans and targets for decentralised systems is not evident.

The Sustainable Energy for All Action Agenda (MOEP(1), 2016) identifies local manufacture of small wind turbines supporting electricity access as a high impact opportunity. However, it may be some time before the operationalization of this agenda is realised as the implementation structures are yet to be established. German Development Cooperation, through KfW (Financial Cooperation) and GIZ (Technical Cooperation), intends to assist the Government of Kenya in promoting the development of new medium-sized hybrid mini-grids (PV-/Wind-Diesel) focused on nascent small and medium-sized growth centres with an expected load of up to 1MW (ECA et al., 2014). This collaboration includes institutional support to the Kenya Rural Electrification Authority (REA) as the main official Kenyan institution responsible for rural electrification, MoEP as the policy maker and the Energy Regulatory Commission (ERC) as the regulator (ECA et al., 2014). As part of the package Project Technical Assistance to explore the viability of private sector engagement in rural electrification was included.

**Analysis of the TIS functions in the SWT innovation system in Kenya**

The following section presents an analysis of the innovation system for small wind turbines in Kenya and highlights the status of the seven functions of the TIS framework and whether this contributes to technology diffusion of small wind turbines. A summary table showing how selected indicators either block or facilitate SWT business is presented at the end of the section.

**Knowledge development**

Detailed and up to date information on the development and dynamics of the wind market in Kenya are lacking (Hansen, Gregersen, Lema, Samoita and Wandera, 2018). Limited specialisation and experience as well as related technical concepts and commercial applications has been accumulated owing to the lack of experimentation in wind power development. The characteristics of the knowledge and technological base for wind turbines technology in Kenya is reported to be relatively simple, highly informal and consisting of small-scale technologies manufactured locally which are tailored to different local contexts and manufactured from a range of locally available materials while still being relatively robust (Hansen et. al., 2018). Interviews with respondents from academia and independent consultants indicate that while data that is useful for developing small wind technology is accessible from the meteorological department and Ministry of Energy and Petroleum, more needs to be done to obtain sites specific measurements, because the data from the former was meant to inform weather rather than energy development. This is confirmed by the view of consulting firms who counteracted the business firms' assertion that the SWERA Atlas was not very useful for energy development. Consulting firms are of the opinion that the atlas was not meant to substitute site specific feasibility studies but are only indicative of the existing wind potential, and it is necessary for investors to go the extra mile and conduct the required measurements before committing to any investments as the Government does not bear this cost. Information from the Kenya Meteorological Department in indicates availability of wind data at 10 metres height. Extrapolation of available data requires specially designed software which could be obtained through collaboration with established research institutions such as the Danish Technical University, Denmark. The Ministry of Energy and Petroleum (MOEP) has also invested in training of technical staff who have been used to install 95 data loggers and operate software and hardware for downloading the collected data for 20 and 40 metre heights. The investment which was initiated in 2010 is yet to yield useful data for development of viable SWT projects. Furthermore, key actors in the innovation system such as the MOEP rely on technical expertise that leans towards the engineering discipline without taking into account the socioeconomic aspects of energy provision. Evaluation of results delivered in performance contracting in terms of the number of systems installed and their capacities without relating this to the populations served and the specific energy needs met precludes appreciation of the energy poverty in the country.

**Knowledge diffusion through networks**

There is an apparent lack of actors and networks driving small wind turbine technology. Typical actors in the small wind turbine industry include local wind turbine manufacturers, NGOs and local community entrepreneurs involved in various small-scale projects typically implemented by donors in rural villages who do not possess advanced engineering knowledge or skills (Hansen et. al., 2018). The local manufacturers rely on local supply chains and distribution networks and utilize connections in the local environment to source materials and related know-how. Information on the involvement of local suppliers of wind components in projects is generally lacking (Hansen et. al., 2018). Other actors include local universities and individual engineers involved in testing a specific technical design for rural applications. They sometimes provide highly applied research input to specific projects for instance the collaboration between Jomo Kenyatta University of Agriculture and Technology and the Japanese Government on small wind technology. Formal research and development on small wind turbine technology is generally lacking (Hansen et. al., 2018). Preliminary interview with an independent consultant suggest that "It is absolutely unclear why the Ministry of Energy and Petroleum has continuously operated independent of research institutions such as Kenya Industrial Research and Development Institute (KIRDI)". This points to the limited application of research findings to Energy Policy planning which could be a reflection of the limited interactive learning between actors within the innovation system. Government agencies such as the Ministry of Energy and Petroleum is involved in the installation of wind speed data loggers at 20m and 40m , while the Rural Electrification Authority promotes rural electrification in off-grid areas through specific projects either directly or indirectly via technical support (Hansen et. al., 2018. It is notable that none of these organisations are explicitly focused on wind-powered mini-grids, and lean more towards supporting solar-powered mini-grids (Hansen et. al., 2018). An exception to this is the UNIDO-funded project in the Ngong Hills implemented in 2009, which involves a solar–wind–diesel hybrid mini-grid with a total installed capacity of 10 kW (including a 3 kW wind turbine) (Hansen et. al., 2018). The presence of foreign industry actors in the small wind turbine innovation system is limited (Hansen et. al., 2018). The possibility of international collaboration for example, with the United States (NASA satellite or EMD Windpro) in extrapolating/interpolating available data also seems to be unexplored. This software is capable of utilising previously collected data but is not useful for making future predictions. Generally speaking the software requires measurements of at least 5m/s done over a period of one year so as to take into consideration seasonal variations. The role of interactive learning in strengthening such initiatives is important as indicated by the finding that the SWERA Atlas was a result of collaboration with DTU. Furthermore, turbulence of turbines can translate wind speeds of 2 metres per second to 7 metres per second using 2009 patented technology which is applicable in Africa (according to Triple Helix discussion). Research at Folkecentre indicates that it is possible to come up with different designs of turbines for different wind speeds and applications. This study has not established the existence of such research efforts in Kenya. Such practice offers an opportunity for applying interactive learning to technological breakthrough in the uptake of SWT in Kenya. This could provide a great opportunity for expanding decentralized generation based in wind technology.

**Guidance of the search/articulation of demand**

The domestic market for wind turbines is limited compared to the emerging market for solar PV (Hansen et. al., 2018). This is attributed to the decrease in the price and the relative ease of installation and maintenance of solar panels compared to small wind turbines. Small wind turbines are produced and diffused at relatively low cost, but the final performance and standards tend to vary greatly (Hansen et. al., 2018). The main supportive institutional conditions promoting wind-powered mini-grids are the initiatives emanating from the implementation of the rural electrification master plan to hybridize the existing diesel-fired mini-grids with wind and solar (Hansen et. al., 2018). Most of these are supported and complemented by various donor programs. Small wind turbine development has mostly been influenced by state and donor support for hybridization of the existing diesel-fired mini-grids owing to increasing operational costs. A key challenge however remains of the lack of a regulatory framework for the development of commercial mini-grids (Hansen et. al., 2018). The unclear policy signals and ongoing discussions concerning the possible introduction of new incentive structures and regulatory models are cited as contributing to the difficulties in attracting funding. Another factor established from the interviews is weak leadership. One respondent indicated that:

> "The lack of leadership in developing appropriate pathways for decentralised energy systems is evident in the energy sector. Not much has been done to define a conceptual framework for the best route of developing and growing decentralised energy systems powered by small wind turbines". The structure of the Ministry of Energy does not seem to favour development of these pathways and many people, both external and internal to the Ministry need to be convinced that small energy supply systems have a place in the country. Such a route would include a definition of what works best, for what purpose and at what cost".

**Creation of legitimacy/counteract resistance to change**

There is a dominance of large wind projects which has arisen after the introduction of the feed-in tariff (FiT) of US$ 0.11/kWh for capacities 50-100 MW. The market for large-scale wind projects is poised to move forward, for example, the flag-ship Lake Turkana project (Hansen et. al., 2018) and Kipeto wind energy projects which continue to draw attention from policy makers and private sector players. Increasing government support for large-scale wind has been used as a strategy to attract foreign investment and has enabled the inclusion of private, independent power producers (IPPs) in the energy sector (Hansen et. al., 2018) but less so for small wind turbines. The role of the local communities and actor groups has been through exerting a strong indirect influence on project development as in the Kinangop wind project where disagreements over land rights issues have occurred. There is little evidence of community involvement in wind mini-grid projects (Hansen et. al., 2018). The support for developing hybrid mini-grids is notable among donor programs and national plans. Small wind power projects seem to have suffered both from the comparative success of the solar mini-grid market and the apparent under-prioritisation of the sector by actors otherwise engaged in the mini-grid sector (Hansen et. al., 2018).

**Resources mobilization**

The FiT was first introduced in 2008 and revised in 2012 and has attracted interest from a number of private developers, donors and development banks (Hansen et. al., 2018). Support for the development of small wind turbines in Kenya happens through various donor organisations, such as the World Bank's Scaling-up Renewable Energy Program (SREP), which aims to install 3 MW of wind and solar hybridized with the existing diesel generators in twelve isolated grids with a total installed capacity of 11 MW (Hansen et. al., 2018). Other organisations include the Department for International Development (DfID) and the German Corporation for International Cooperation (GIZ) whose support targets the hybridization of existing diesel-fired mini-grids with wind or solar PV and the development of private mini-grids. These actors have mainly provided financial support and advisory services to move ongoing projects toward reaching financial closure (Hansen et. al., 2018) but have not contributed to the development of small wind turbines. The Spanish embassy has provided financing for the development of five new solar–wind–diesel hybrid mini-grids, while UNIDO funded, community-based Olosho Oibor mini-grid (a solar–wind–diesel hybrid of 10 kWp). The absence of budgets for SWT promotion was found to be an issue of concern, as indicated by a respondent to the effect that “budgets have been set aside for developing small scale renewables such as small hydropower, biogas, solar PV the same can be done for small wind systems”.

**Market formation**

Wind energy in Kenya occurs in form of pockets with high wind speeds but site specific assessments are still lacking. The logistics of planning for transportation of equipment presents significant difficulties, because wind resources in Kenya are found in difficult to access areas, served by poor infrastructure and therefore it takes significant resources to successfully plan implementation. The capability of local companies to profit from such an undertaking is yet to be established (Pueyo and Linares, 2012). Imported turbines are available in the range of 1-5 kW, however, their average efficiency, reliability and price are generally higher than those of locally produced wind turbines (Hansen et. al., 2018). The number of local manufacturers offering imported local turbine has been increasing, mainly sourced from China but detailed information on these turbine is still limited (Kamp and Vanheule, 2015). The market for small wind turbines and in particular, small-scale wind-based mini-grids appears to have stalled, with very few hybrids existing or planned, coupled with a shift of focus by private suppliers of wind-powered mini-grids (Hansen et. al., 2018). Majority of the population find the grid electricity expensive and unreliable. The solar PV sector has grown significantly compared with the small wind sector (Hansen et. al, 2018). The capability to integrate small wind with other renewables is still limited.

**Entrepreneurial activities**

Only one local Kenyan manufacturer has been active in the production of electricity generating small wind turbines since the late 1990s and three foreign manufacturers started activities in 2010-2011 by installing a small number of wind turbines. From around 2011, there has been a shift of focus and activities by domestic small wind turbine suppliers toward the emerging market for solar-powered mini-grids, as in the case of the companies RIWIK and SteamaCo (Hansen et. al., 2018). According to Kamp and Vanheule (2015) there are about twenty companies offering imported wind turbines, however they are predominantly installers of solar PV systems that complement their energy product portfolio with wind turbines. The capacity of locally produced wind turbines ranges from 150 W to 3 kW, and between

120 and 150 wind turbines within this range have been installed in Kenya to date (Hansen et. al., 2018). These systems have been mostly installed by telecoms players, NGOs and both commercial and household clients but their capacity rated as low and therefore unsuitable for serving the needs of the Kenyan market (Hansen et. al., 2018). Imported turbines generally display higher performance and price levels compared to locally manufactured turbines.

Table 1 presents a summary of the inducing and blocking mechanisms for the SWT innovation system in Kenya based on the Hekkert et. al. framework for analysing innovation systems. The above analysis of the SWT innovation system highlights several inducing and blocking mechanisms. The policy framework recognizes the contribution of SWT to the energy supply mix in Kenya. A survey of the SWT innovation system (2017-18) points at weaknesses in implementation of policy provisions are reflected in the form of lengthy planning periods to realize set targets, limited technical expertise in integrating wind with other forms of energy, focus on minigrids rather than stand-alone SWT, inadequate efforts and capability to conduct of site-specific measurements, limited interactive learning among actors of the innovation system and with international actors, inadequate capability of actors to collate available datasets, inadequate knowledge base on developments in successful economies and how these can be applied to the local situation, inadequate utilization of local research institutions, weak leadership and institutional structure, limited acknowledgement among actors on the contribution of SWT to rural electrification, inadequate application of lessons learnt to policy review, reliance on consultants for conducting studies without strategic development of local capabilities.

**Table 1:** Summary of inducing and blocking mechanisms for SWT Innovation System in Kenya

| | Function | Indicators | Status of the SWT in Kenya | Drivers (Inducing) | Barriers (Blocking) |
|---|---|---|---|---|---|
| 1 | Knowledge development | • Utilisation of existing knowledge | • Weak | | ✓ |
| | | • Evidence Base (Learning by doing/using) | • Limited | | ✓ |
| | | • R & D | • Weak | | ✓ |
| | | • Local worker skills development | • Weak | | ✓ |
| | | • Deployment of new knowledge | • Limited | | ✓ |
| | | • Utilisation of lessons from previous policies | • Weak | | ✓ |
| | | • Availability of technology software | • Limited | | ✓ |
| 2 | Knowledge diffusion through networks | • Networking capabilities with local actors | • Low | | ✓ |
| | | • Networking capabilities with foreign actors | • Low | | ✓ |
| | | • Capability to tap into new knowledge developments | • Limited | | ✓ |
| 3 | Guidance of the search/articulation of demand | • Leadership/Institutional structure | • Weak | | ✓ |
| | | • Adequacy of existing policy | • Fairly adequate | ✓ | |
| | | • Adequacy of regulations & standards | • Weak | | ✓ |
| 4 | Creation of legitimacy/counteract resistance to change | • Development focus | • Leaning towards large scale projects | | ✓ |
| | | • Policy framework | • Favourable | ✓ | |
| | | • Grid extension | • Limited | ✓ | |
| | | • Policy planning, implementation | • Weak | | ✓ |
| 5 | Resources mobilization | • Government Investments/priorities | • Limited | | ✓ |
| | | • Foreign investments/Technical assistance | • Limited | | ✓ |
| | | • Effectiveness of resource utilisation | • Weak | | ✓ |
| 6 | Market formation | • Wind Potential | • Low to moderate | ✓ | |

| | | | | | |
|---|---|---|---|---|---|
| | | • Awareness of Technology/benefits | • Low | | ✓ |
| | | • Affordability of grid electricity | • Limited | ✓ | |
| | | • Reliability of grid electricity | • Limited | ✓ | |
| | | • Access to grid | • Limited | ✓ | |
| | | • Competition with solar PV | • Strong | | ✓ |
| | | • Market feedback | • Inadequate | | ✓ |
| | | • Sales person capabilities | • Limited | | ✓ |
| | | • Integration with other RE | • Low | ✓ | |
| | | • Market size | • Moderate | ✓ | |
| 7 | Entrepreneurial activities | • Activity level of local actors | • Low | | ✓ |
| | | • Capability to conduct site specific assessments | • Limited | | ✓ |
| | | • Demonstration projects | • Few | | ✓ |
| | | • Capability to adopt new technology/innovate | • Low to moderate | ✓ | ✓ |
| | | • Capability for local manufacture | • Limited | | ✓ |
| | | • New entrants | • Few | | ✓ |
| | | • Resource endowment | • Low | | ✓ |
| | | • Marketing capabilities | • Limited | | ✓ |
| | | • Knowledge of customers/changing needs | • Limited | | ✓ |
| | | • Aftersales service provision | • Limited | | ✓ |

*Source:* Author's modification based on Hekkert et.al

Analysis of the Kenyan SWT innovation system based on the TIS functions in Table 1 to identify the inducing and blocking mechanisms portrays an emerging innovation system, whereby most of the functions have not been operationalized. This in a way obscures the activities that may be ongoing but are not easy to notice perhaps because of the choice of indicators adopted. Using the TIS framework and the indicators highlighted in Table 1 to understand the status of knowledge development in the diffusion of small wind turbine brings out weaknesses in the SWT innovation system in Kenya for most of the indicators identified. The analysis in Table 1 based on the Hekkert framework shows that the blocking mechanisms out-weigh the inducing mechanisms.

Alphen et.al (2008) used the TIS framework to analyse the potential of Renewable energy in the Maldives but omitted knowledge development and included "creating adaptive capacity" in the analysis. It is however noted that the Education and Training programmes which were factored as inducing mechanisms in creating adaptive capacity could typically be included under "knowledge development". Alphen proposed combining knowledge development with creating adaptive capacity. Alphen found the TIS approach to be too inward looking in that it does not sufficiently account for factors beyond the activities of the actors in the focal technological innovation system, and thus suggested the incorporation of the external landscape. He goes further to recommend revisions and certain adjustment before applying the TIS framework in a developing country context. Perrot (2012) applied the TIS function approach to analyse the transition of renewable energies in South Africa and India. While providing some interesting insights into these specific technical innovation systems, he did not address the need to improve the existing list of TIS functions to better incorporate the developing country context. He however recognised "the pressing need for existing frameworks to develop new analytical frameworks" when analysing renewable energy industries in developing countries. Perrot further noted that the TIS function approach does not sufficiently include explicit contextual factors as part of the framework that would enable a systematic empirical analysis of the wider context and therefore suggested inclusion of landscape factors. The interaction of land scape factors with system functions is summarised in Table 2.

**Table 2**: Possible landscape factors influence on specific system functions

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

Note: Black check marks indicate possible interaction
*Source:* Edsand, 2016

Hekkert (2011) notes that while different innovation systems may have similar components, they may function in a completely different way. Edsand (2016) recommends an approach that separately studies the underlying processes that make up the innovation system noting that this supports a systemic analysis that can help to identify characteristics of the system, such as weaknesses and strengths.

## 6. Discussion

The government is keen to support the burgeoning distributed solar sector, but has largely adopted a central strategy to increase grid connectivity through the subsidised Last Mile Connectivity Project (LMCP) which has led to increased connectivity from 23 per cent in 2012 (1.8 million domestic customers) to 70 per cent in 2017 (Practical Action, 2017). Government focus on mini-grids to enhance electricity access in Arid and Semi-arid areas (MOEP 2013), does not adequately respond to the energy poverty highlighted in the preceding review of the Kenyan SWT sector. Interactive learning between the actors in the small wind turbine innovation system is still weak and so are the relationships with foreign companies to promote business-matching and capacity building (Pueyo and Linares, 2012). There is limited technology-push (in the renewable energy sector) through implementing demonstration projects and demand-pull policies which could improve internal capabilities through learning by doing (Pueyo and Linares, 2012). Innovation in policy based on best practices is still limited and this subsequently curtails the ability to develop strong networks, promote interactive learning, research and development, and capacity enhancement of local institutions that could potentially play a role in promoting the diffusion of small wind turbines.

Kamp and Vanheule (2015) noted that the diffusion of small wind turbines in Kenya is characterized by one-time experiments, limited research and development, fragmented learning experiences, lack of focus and low quality products and services, a weakly aligned network, many underperforming actors and the inability to attract buy-in from utilities to embrace innovation in the provision of energy services. The study by (Kamp & Vanheule, 2015) indicates that small wind in Kenya has not been adequately studied. Technological designs and breakthroughs in developed economies have had little impact in Kenya.  Existing firms in the small wind turbine innovation system mostly rely on imported technology which may not necessarily be suited to the Kenyan conditions and the local capacity for manufacturing small wind turbines is not well developed. The capability of existing firms to undertake such feasibility studies with a view to initiating new projects has not been established. The programme has experienced weak monitoring and collation of the data generated and the framework for utilising such data appears to be weakly defined and suffers inherent neglect. Turbines that operate under low speeds have been manufactured in developed countries such as Germany and the United States (www.fusystems.com/index.html?). While speeds of lower than 2m/s are not ideal for commercial applications they could prove useful in residential settings.

The need to strengthen interaction between actors is deemed pertinent to the Energy Sector in Kenya with respect to exploiting the potential for SWT. The growth of small wind turbines in Denmark has benefitted greatly from the existence of research institutions such as the Danish Technical University and the Nordic Folkecentre which has played a role in research on small wind turbines in Denmark and indicates that development of small wind turbine technology can be achieved at wind speeds measured at heights of 10-30 metres over periods of at least one year. It has also resulted in development of site specific technologies suited to the local conditions. The fact that similar developments are still lacking in Kenya points toward the limited interactive learning that takes place between the SWT actors in developed and developing economies. The SWT industry in Kenya could benefit from such interactions which could enhance the capability to develop appropriate technology that is suited to the Kenyan conditions rather than directly transferring technology from Europe, the US or China to Kenya.

Developments in the UK indicate that the cost of wind power is now lower than that of nuclear (The Guardian). This demystifies previous conceptualisation in the energy sector that investment costs for wind are a deterrent to widespread use of available technology and opens a whole new chapter for actors in the small wind turbine sector to be innovative through the interactive learning process while accelerating technology diffusion. By doing this it is possible to address the disparity in clean energy access between the underserved regions which in turn addresses the constitutional right of access to clean energy services irrespective of their locations in Kenya. The adage that “Small is beautiful” seems to be evasive among actors in the small wind turbine innovation system. This could be a pointer to limitations in capabilities and knowledge among various actors in the SWT sector, as well as limited interactive learning from trends in the local innovation systems and international technological and policy developments. Policy planning has drawn very few lessons from implementation of the 2004 Energy policy. This is particularly evident in the draft energy policy review of 2015/16 which also displays a tendency to carry over statements from previous documentation without critical review. The 2016/17 development plans that have laid emphasis on the Last Mile Connectivity Programme (LMCP) and improvement of the distribution networks also attest this finding. The plans tend to favour communities that are proximal to the grid but do little to address the off-grid community needs who are mainly disadvantaged by the geographical distribution and low population density. The inadequate synchronisation of supply and demand patterns is well known but little has been done towards the resultant wastage. The extent to which studies on wind conducted by consultants contribute to development of the capabilities of various actors within the innovation system forms a subject for research. It is notable that current performance contracts in the MOEP focus on installing data loggers rather than technology provision despite the fact that the energy policy recognises the role of decentralised systems in the provision of energy services to communities that reside far from the grid.

### a. A proposal for a research agenda

The proposal for a research agenda on small wind turbines in Kenya complements the study by Kamp and Vanheule (2015) which uses the strategic niche management and multilevel perspective to study the same sector and brought out a number of issues affecting the diffusion of SWT in Kenya. The findings by Kamp and Vanheule, (2015) reflect an incomplete and unstable network, actors who lack focus and/or underperform, limited interaction amongst actors and end-users, inadequate facilitation and fragmented lessons that have failed to yield effective solutions. Other barriers noted include low government participation, high poverty levels and skepticism towards new technologies an underdeveloped infrastructure, lack of raw materials, “dependency syndrome”, negative image of self-employment, low quality manufacturing culture, corruption and years of resistance to knowledge sharing. The need to develop a complete network, in which the actors are strongly linked and have shared and realistic expectations is underscored in addition to increasing awareness, provision of high quality products with reliable after sales service to potential customers. The importance of having well performing actors and transferring lessons learned into appropriate solutions is also highlighted.

The key objective of the research agenda is to bridge the knowledge gap in the relationship between small wind turbine innovation system and technology diffusion with a view to enhancing widespread use of small wind turbines in the provision of clean energy. Of particular interest is how the IREK framework which draws from the innovation systems framework could be applied to the study of the small wind turbine innovation system in Kenya. As earlier mentioned, the IREK framework applies three dimensions namely: Actors and capabilities; Rules and Regulations; and Flows and interactions. This is captured in a separate study leading to a Phd thesis, which investigates the relationship between interactive learning, firm capabilities and technology diffusion of SWT. It is hypothesised that there is no relationship between interactive learning within firms, between firms and with other actors and firm capabilities on technology diffusion within the context of the SWT innovation system in Kenya. The study is designed to identify the relationship between interactive learning, firm capabilities and technology diffusion.

### b. Justification of a research agenda

The trends in developed economies point towards gaps which if addressed could unlock the unutilized potential for small wind turbine systems in Kenya and the Sub-sahara region. A research agenda centering around the innovation system with the firm as a central focus is deemed necessary in bringing out the existing weaknesses in the SWT innovation system as a way of enhancing socioeconomic equity particularly for communities not served by the national grid, a phenomenon prevalent in the African continent. This working paper brings out specific areas of exploration within the proposed research agenda, namely: an examination of the trends of small wind turbines in China and India which was reported by the WWEA 2017 as leading globally and the contributory factors and exploration of the international leading countries in small wind turbines to establish the existence of similarities and differences in their approaches. Goldwind in China has benefitted extensively through learning from the other wind hubs of the world, as they all tested their designs in China and hiring many employees trained by foreign-owned firms (often when they were based in China), taking advantage of the small but specialized work force that the presence of these foreign wind power technology firms brought to China. Goldwind has relied greatly on China's policies that mandate local content, as well as an unstated but ubiquitous preference for Chinese-owned technology. In addition, its status as a partially state-owned company has provided it with direct government support for technology development. A combination of licensing arrangements with foreign firms and internationally based R&D and other facilities, complimented by the hiring of skilled personnel from around the world, has created a global learning network for Suzlon in India, customized to fill in the gaps in its technical knowledge base (Lewis, 2007). Suzlon has been able to draw upon a self-designed learning network to take advantage of regional expertise located around the world, such as in the early wind turbine technology development centers of Denmark and The Netherlands. Wind technology developments in India and China were done within the constraints of national and international intellectual property law, and primarily through the acquisition of technology licenses or via the purchasing of smaller wind technology companies.

The fact that the countries in Africa rich in wind have laid more emphasis on large scale wind and lesser emphasis on small wind turbine and reasons behind this trend despite apparent policy emphasis on decentralized energy systems which is not complemented by implementation where solar PV is dominant. The untested hypothesis that this trend in African countries is driven more by the convenience and possibly individual gains of actors who may not necessarily fit into the category of business sector, and the fact that investigation of this hypothesis poses significant methodological challenges which cannot be resolved using the interview or case study method. It also demonstrates how the innovation systems approach could be applied to emerging innovation systems and in particular specific energy technology industries in developing economies such as Kenya by perceiving them as systems. There has been a paradigm shift to decentralized electricity generation that has favoured small scale solar more than wind. Chataway et. al., (2014) notes that evidence on the role of government as a driver for inclusive innovation is gathering pace and a stronger evidence base is called for effective promotion of inclusive innovation by both private and public actors. The deficiency in relevant private sector knowledge bases on low-income markets stands out and the gap for public sector actors is even larger. The argument is for the research community to throw more light on the evidence of the extent, the nature, the inducements to and the obstacles to the development and deployment of inclusive innovation. The research agenda is based on Kenya as a case study for an emerging economy that prioritizes wind energy development for enhancing national electrification efforts. This approach draws from (Lewis 2007) who indicates that many proponents of the case study research method advocate for in-depth studies of specific renewable energy technologies, as lessons learned can often apply to other regions in that country, or to other countries. The proposed research agenda is summarised in Table 3.

**Table 3:** Summary of the research agenda

| | Aspect | Specifics for value addition through research |
|---|---|---|
| 1 | Growth of the SWT sector in China | The driving factors for China and how this could inform the strengthening of the SWT sector in Kenya |
| 2 | Growth in other parts of the world (Denmark, UK, USA) | Lessons that could be drawn from developed economies for application to African economies whose innovation systems are just emerging. Of particular interest is how the declining LCOE for wind in developed economies could be applied to the African wind resource development |
| 3 | The emphasis on large scale generation in Africa | The driving factors and reasons why decentralised electrification using SWT has not root as an option despite extensive documentation of low levels of energy consumption and support of this approach to exploit the vast wind on African continent. Methodological issues are presented by the untested hypothesis that large scale development in Africa is driven by convenience and individual gains. Appropriate methods of researching such a hypothesis are currently lacking. |
| 4 | Potential for integrating solar PV with SWT | How the development can piggy-back on the vibrant solar PV sector to tap into the wind energy potential in Africa the extent to which this can meet the needs of geographically and economically disadvantaged communities |
| 5 | Adapting the TIS framework to developing economies | The SWT innovation systems falls in the category of emerging innovation systems and therefore could benefit greatly from empirical research such as the integration of TIS with the IREK framework to better understand how the Kenyan IS for SWT could be strengthened to contribute to electrification of needy communities using wind energy. |

### c. A conceptual framework or typology for use in research

This working paper uses insights from the Innovation and Renewable Energy Kenya (IREK) framework to suggest refinements of the TIS framework based on the argument that the TIS framework was developed for, and primarily applied in, developed industrialised nations such as the Netherlands, Sweden and Germany and suggests that it could lack comprehensiveness when applied to developing countries (Edsand, 2016). From the IREK framework perspective it is argued that the type of knowledge developed at the global, national and project level dimensions is different for the diffusion of small wind turbines and therefore research is warranted to understand the extent to which the knowledge generated from the specific dimensions contributes to the growth of the SWT sector. Similarly, there is need to understand how the evidence base available within the three dimensions could best be put to use. The type of research and development that takes place within the three dimensions could shed more light on areas that needs to be strengthened in the developing country context. Understanding the level of skills possessed by the workers at the various levels provides opportunity for strengthening weak areas.

The Innovation and Renewable Energy Kenya (IREK) conceptual framework (Lema, 2017) which draws on different bodies of literature within the innovation and development landscape but endeavours to adopt a common language and to work along similar dimensions for ease of comparison. The IREK framework situates renewable energy projects within the national and global context and adopts three levels of analysis, namely: global (solar/wind industry and governance mechanisms); national (national-sectoral system of innovation production; and project (renewable energy project). Based on these three levels it uses separate studies to examine each level and to trace the interactions between them. Three dimensions are suggested for investigation namely: Rules and regulations; Actors and capabilities; and Flows and interactions while remaining highly cognitive of the danger of remaining very schematic, and equates this approach to forcing round objects into square holes. Under this framework, Rules and regulations are defined as both formal and informal rules of the game that structure behaviour by enabling and constraining. These are perceived to function at three levels: global; national; and project. At the global level they constitute domains such as trade regulation (from WTO), global standards (by ISO) and institutional infrastructures such as those concerned with the Technology Mechanisms (and CDM before it, within the UNFCC). At the national level they refer to numerous policy domains, including feed-in tariffs, electricity generation licences and permits etc. as well as cross-ministry development plans which (in principle) synchronise regulation across ministries. At the project level they are contracts that specify and agree on rules and roadmaps and project design documents that stipulate who does what and how.

Actors and capabilities refer to the firms and organisations directly and indirectly involved in renewable electrification and their various focal areas which are associated with their resources and capabilities. At the global level these include large equipment producers (such as Vestas and Yingli Solar), project developers, and investment funds, consultancy firms, NGOs and providers of overseas development assistance. The national level comprises state policy and regulatory bodies, utilities, transmission systems operators and education systems. It also includes private sector players such as local equipment manufacturers and assemblers, wholesale importers and distributors, logistics firms, sectoral trade organisations and others. The project level refers to the various actors involved in installing and operating wind or solar PV technology, including principally firms and other actors involved in installation and operation of renewable energy projects. These may include owners, project development firms, equipment producers, operators, maintenance firms etc. Production and consumption of electricity is physically co-located in the case of mini-grids, but it is separated in the case of grid-connected facilities. In other words, end-users are not necessarily an ‘actor’ in these projects (Lema, 2017).

Flows and interactions refer to inter-organisational flows of physical artefacts and services (input-output relations), financial flows and flows of embodied/disembodied knowledge. At the global level these are, not least, inter-national linkages formed ‘vertically’ between producers, project developers, financers and consultancies in China and Europe and renewable electrification firms/organisation in Kenya. Nationally there are vertical value chain links as well horizontal links within the systems that provide various types of inputs to the electrification processes. Whereas innovation systems linkages may be ‘durably’ and slowly evolving, interactions in projects are more ‘temporal’. There are particularly intense interaction between project participants during the phase of project design, engineering and installation. The framework is cognitive of the futility of attempting to pre-define all of the elements since it depends on much more in-depth research. Such research can help to fill in identified gaps within the specific innovation system being analysed. This requires clear definition of typologies for actors and flows (in particular) which could be informed by literature.

**Features of the IREK framework**

Introduction of the IREK framework is an attempt to address the production and delivery of innovative solutions to the problems of the poorest and most marginalised communities and income groups (inclusive innovation) in a bid to contribute to environmental and social sustainability (Kaplinsky, 2013). This has its origins in the works of (Schumacher, 1973) “Small is beautiful”. The objective is to meet the needs of poor consumers, who collectively have considerable buying power because they are seeking products that are affordable, that are robust, that are compact and suit their needs. This approach has been used in China and, to a lesser extent, India, whereby products designed and developed in developing countries initially for domestic consumers are increasingly being exported to other developing countries where producers have similar needs. This has resulted in capital goods imports by developing countries from other developing countries rather than from developed countries. Innovation is led by firms based in developing countries who are often in a better position to gauge the needs of consumers and are more familiar with the challenges posed and they can act more swiftly to meet demand (Schrempf et al., 2013). The M- Pesa mobile money has been cited as an excellent example of innovation developed in Kenya launched in 2007 as a money transfer and micro-financing service and has worked well as inclusive innovation. Key ingredients of the Mpesa success were very small-scale distribution networks of agents, with deep penetration into poor urban and rural communities. Embedded intermediaries adapted their business models, retailing patterns, and support and service offerings so as to meet the precise needs of the market and provide feed-back information on customer needs to the lead firms who made a number of adjustments to further enhance demand. Achieving this entails cross-country collaboration between governments, research institutions, firms, philanthropists and NGOs who can be perceived as key actors in the TIS. The knowledge and learning perspective in the TIS is biased towards technological learning, whereas social learning is usually not sufficiently considered. At the level of concept validation the TIS approach depends upon purposefully designed data sets (Schrempf et al., 2013).

The policy challenge to inclusive innovation at government level has been the lack of clarity on how to assess and measure inclusive innovation and the level of resources that should be devoted to it. Identification of the constraints to inclusive innovation and the design of innovation policies that address these constraints is still very much a work-in-progress (Schrempf et al., 2013). Incentives for private businesses to allocate resources to meet the needs of the poor are still lacking and the needs of these poor consumers and communities cannot be expressed via market signals. Their needs are implicit and have to be made explicit, and this requires expenditure of public resources. These consumers need 'voice.' Policy opportunities, mostly targeted at the institutions within the system include, but are not limited to, legal rules and norms at the national level; fostering collaboration between industry and universities at the regional level; the introduction of new rules or standards for certain technologies at the sectoral level, and support for public-private partnerships in inclusive innovation. The IREK framework could be regarded as a tools for use in making policy decisions in regard to innovation in highly complex, non-linear and interactive systems such as the SWT innovation system in Kenya.

Public perceptions of new technologies are formed through interactions among proponents and opponents and modified by experience (Torvanger & Meadowcroft, 2011). The learning processes which ensue from the interactions among producers as well as between producers and users of technology facilitate especially the incremental development and diffusion of innovations (Bauer, Lang, & Schneider, 2012). Technology and institutions change in interactive processes which are mediated and influenced by individual and collective actors. A firm's R&D efforts not only contribute to generation of new knowledge, but also improve the relationship between several entities such as research institutions, universities and industries. Diverse literature on technology development and innovation underlines the importance of cooperation and networks across these entities (Cavdar & Aydin, 2015). The interaction of societal and state actors is responsible for defining problems, building the necessary consensus on problems and solutions, consolidating conflicts of interests, and (pre-) determines political decisions (Etzkowitz & Ranga, 2013). This interaction is rooted in trust and is regulated by rules of the game negotiated and agreed by the participants. Rules and regulations (or lack thereof) that can create obstacles for the collaboration (for example, a weak culture of collaboration and organizational silos). Networks have been seen as 'the middle way' between the loose coupling of markets and the tight relationships of hierarchies. Providing a clearer view of innovation actors, knowledge and resources flows within and among the spaces and of existing blockages and gaps between them helps to accelerate the transition from the low-risk, low-gain development model that is currently in place in many regions and countries. It is conducive to slow, incremental innovation patterns with low economic returns, to a higher-risk, higher-gain development model that could favour more radical innovations and the accelerated creation of new markets, new growth opportunities, new jobs and new skills (Etzkowitz & Ranga, 2013). The basic framework for empirical analysis focuses on the diffusion of small wind turbines as depicted in Table 4:

**Table 4:** Framework of analysis for SWT innovation system in Kenya

| | | TIS FUNCTIONS | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IREK Framework dimensions | | Knowledge Development | Adaptive Capacity | Guidance of the search/Articulation of demand | Creation of legitimacy/counteract resistance to change | Resources mobilization | Market formation | Entrepreneurial activities |
| | Rules and regulations | | | ✓ | ✓ | ✓ | | |
| | Actors and capabilities | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Flows and interactions | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ |

✓: *Indicates possible areas of overlap between the IREK dimensions and TIS functions but segregated into Global, National and Project levels*

*Source:* Author's Modification of the TIS Framework

### d. Interaction of the IREK Dimensions with the TIS Functions (Elaborating on Table 4)

#### *i. Rules and Regulations*

The rules and regulations that apply at the global, national and project level differ. At the global level they may include international agreements, trade relations which may facilitate of hinder transfer of technology from industrialized to emerging economies. The interaction between the national level and global actors is dependent on bilateral cooperation agreements towards the implementation of specific projects that offer developmental opportunity for the countries involved. Experience has shown that the balance of bilateral trade relations tend to favour industrialized countries as providers of technology but little emphasis is laid on developing local capacity in emerging economies with the result that local institutional and technological capability depends does not incorporate a package and largely remains dependent on foreign expertise and support with respect to maintenance hardware and software. The emerging economies more or less serve as consumers of technology and their ability to innovate is severely limited by low capabilities of human resources operating in specific sectors.

### *ii. Actors and capabilities*

Implementation of renewable energy projects in emerging economies is characterized by use of foreign experts whose contracts may not be designed to develop the capability of national and project level counterparts. Projects are usually designed to deliver energy services and learning and development of the skills of project partners fails to put in place appropriate measures for evaluating the level of capacity development that results from project participation. This could be attributed to the design of the contracts which in most cases give the foreign counterparts an upper hand without due regard for building local capabilities. The capability of actors to innovate is severely limited for example developers of wind pumps whose desire to create markets by venturing into electrification systems have not made progress due to technological limitations. Key actors in one function of TIS such as knowledge development which is mainly generated in research institutions may perform a peripheral role in other functions such as resource mobilization.

### *iii. Flows and Interactions*

The flows of knowledge from global to national to project level is designed to maintain the tacit knowledge with the international experts leaving the recipient economy with only the codified knowledge. At firm level, actors operate with competition and are not willing to share knowledge with competitors. The tertiary education system operates in a silo and does not respond to industry demands. The result is that most of the research conducted remains at the level of experiments and innovation towards commercialization is limited. Evidence of learning from existing installations is generally lacking. In a similar manner, policy review fails to draw useful lessons from previous policies. Attempts to harmonise available data sets generated for different purposes such as energy and meteorology are limited with the result that each institution focuses on its mandate without exploring avenues of collaboration to enhance delivery on their mandates.

The objective is to apply the modified TIS framework to the three distinct levels identified by the IREK framework in the developing country context as operating at the global, national and project levels with a view to setting out a research agenda to examine outcomes of international cooperation on low carbon technologies can be shaped and transformed to become efficient in terms of energy production, industrialization and related social inclusion. This is not to imply that these levels operate independently but it takes cognizance of the fact that within each level specific rules and regulations, actors and networks as well as flows and interactions operate and that there are interactions between the levels which vary as the innovation system within the specific sector emerges.

Table 5 presents the inducing and blocking mechanisms based on the IREK framework dimensions.

Table 5: Drivers and barriers for small scale wind in Kenya

| | Indicators | Status of the SWT innovation system in Kenya | Drivers (Inducing) | Barriers (Blocking) |
|---|---|---|---|---|
| Rules and regulations | • Direction of state and donor support | • Leans towards development of wind-diesel hybrids | | ✓ |
| | • Energy Policy support | • Energy Policy support clearly articulated in policy documents | ✓ | |
| | • Setting of targets | • Targets lean towards grid connected electricity | | ✓ |
| | • Policy implementation | • Weak | | ✓ |
| | • National Budgetary support | • Absence of budgets for SWT installation | | ✓ |
| | • Prioritisation of SWT | • Still under-prioritised by the state and donors in comparison with solar | | ✓ |
| | • Presence of a regulatory framework | • Regulatory framework for standalone | | ✓ |

| | | | | |
|---|---|---|---|---|
| | | decentralized generation lacking | | |
| | • Policy making process | • Policy making in silos and limited integration with other development sectors | | ✓ |
| | • Data availability | • SWERA Atlas provides indicative wind regimes but does not provide site specific data | ✓ | ✓ |
| | • National buy-into international frameworks for low carbon emission | • Present (UNFCCC, INDC, SE4All) | ✓ | |
| Actors and capabilities | • Number of local firms involved in manufacture | • Limited | | ✓ |
| | • Number of local firms involved in importation | • Limited | | ✓ |
| | • NGO support for decentralized SWT electrification | • Present to a certain extent | ✓ | |
| | • Presence of an association for renewable Energy practitioners | • Kenya Renewable Energy Association but whose members lean towards solar PV) | ✓ | ✓ |
| | • Consultancy firms engaged in SWT research | • Few | | ✓ |
| | • Community awareness on SWT | • Limited | | ✓ |
| | • Capabilities in project planning, design Energy Sector actors at national and project levels | • Limited | | ✓ |
| | • Use of lessons from previous policy implementation | • Limited | | ✓ |
| | • Market focus | • Since 2011, the local providers of wind turbines increasingly shifted their focus toward the emerging market for solar PV | | ✓ |
| | • Presence of local suppliers of wind powered mini-grids on a commercial basis | • Few | | ✓ |
| | • Activity of global lead firms in local market for SWT | • Present but limited | ✓ | ✓ |
| | • Local capability for undertaking site specific assessments manufacture, innovation and aftersales service provision | • Very limited | | ✓ |
| | • Level of domestic knowledge on the functioning of wind powered mini-grid | • Limited | | ✓ |
| | • Presence of coordinated R&D at national and local levels | • Absent | | ✓ |
| | • Knowledge of demand and efficiency in energy consumption sectors | • Limited | | ✓ |
| Flows and interactions | • Costs of competing technologies and practices, especially diesel | • increasing | ✓ | |
| | • Costs of wind turbines globally | • Generally decreasing | ✓ | |
| | • Availability of wind for competitive wind-powered mini-grids in a number of locations | • Good wind resources and possibilities | ✓ | |
| | • Opportunity for standalone wind-powered mini-grids in Kenya | • Good | ✓ | |
| | • Availability of local reference plants, proven technical concepts and business models | • Limited | | ✓ |

| | | | | |
|---|---|---|---|---|
| | • Compatibility of the technology used in large-scale wind-turbine systems with smaller scale-systems | • Limited and thus needs significant reconfiguration | | ✓ |
| | • Knowledge of trends in developed economies | • Inadequate | | ✓ |
| | • Networking among and between actors at local, national and international levels | • Limited | | ✓ |

*Source:* (Hansen, 2017). Modified by Author using IREK Dimensions.

The argument is that conducting the analysis in table 5 at Global, National and Project levels so as to identify the strengths and weaknesses in the innovation system which could provide a better guide of formulating strategies for intervention. This provides good ground for testing four key hypotheses posed under the IREK framework that: 1) Emerging economies are in a particularly strong position to advance relevant and affordable technologies because conditions in BRICs are more similar to those in poor countries; 2) 'Small Is Beautiful' (Schumacher, 1973) whereby it is postulated that small-scale mini-grids are associated with higher learning exponentials than large projects. The low levels of pre-existing technological and organizational capabilities among Kenyan actors limits their involvement in large scale projects. As a result learning tends to take place in less knowledge-intensive activities such as micro- and mini- grids which may provide better opportunities for learning in core activities such as project development, engineering, operation and maintenance; 3) Learning at project level is highly dependent on the degree to which external partners incorporate knowledge transfer as an explicit part of the project through maintenance training, coupled with the absorptive capacity of Kenyan actors through investment in the use of experienced engineers and conducting specific training activities and; 4) Even the most 'relevant' technologies developed abroad may require to undergo a process of transformation to make them both efficient and inclusive in the specific context of Kenya.

Table 1 and Table 5 present two slightly different but interrelated perspectives of analyzing the innovation system for small wind turbines in Kenya. Table 1 uses the TIS framework while Table 5 uses the IREK framework. Both tables however bring out a picture of blocking mechanisms outweighing the inducing mechanisms which is characteristic of an innovation system still in its formative stage despite decades of technological developments in other economies across the globe. This could be a pointer to the limited learning that has occurred in Kenya from other countries such as China, United States and India whose technological pathways for small wind turbine have experienced significant growth over the last one to two decades. Research on the small wind turbine innovation system is thus necessary to explain the time lag of the formative phase of the innovation system.

### e. Policy issues raised and research needs

Addressing sustainable energy access has received limited attention within the sphere of most approaches to local governance in Kenya (Batchelor et al., 2015). Despite the devolution of various government services to county level in 2010, some of the roles in energy access are still very national, for example local wind resource assessments and analysis. Batchelor notes that change is vaguely understood since the sources of authority in Kenya changed following devolution and both local and international actors in the SWT innovation system are yet to grasp what these changes mean. The role played by local level actors, often led by non-government actors such as Practical Action Eastern Africa, World Wide Fund for nature particularly on renewable energy, are increasingly being recognised and supported by national and county governments (Batchelor et al., 2015). Specific gaps identified in policy include: the lack of clear county level policy on renewable energy; the absence of a county data-base on energy resources; and limited capacity to enforce standards (Batchelor et al., 2015). Decentralised energy service provision and in particular SWT development and promotion is characterised by a topdown approach whereby wind resource assessment and site specific data collection and analysis is done by the national government through the installation of data loggers with limited involvement of communities whose awareness on the cost of installing viable system is still limited by the few demonstration sites. The tendency of energy sector actors to focus on solar PV has resulted in the side-lining of the potential contribution of SWT to rural and urban areas as demonstrated by the few systems installed. Batchelor et. al., (2015) recognises the need for lobby groups to give 'a voice' to the benefits that SWT diffusion could confer to the communities who have limited or no access to grid connected electricity. Most of the SWT technology in Kenya is imported and thus faces the same complications of corruption that drives the cost of imported products beyond the reach of potential markets dominated by low affordability.

Batchelor et. al., (2015) highlights the constraints faced with regard to entrepreneurship. Renewable energy and in particular the small wind turbine sector has very few actors, is faced with high cost of equipment and installation, limited distribution services, limited awareness on technologies available in the market, poor quality control of products supplied from local and external markets, centralised control of data collection and analysis for energy generation within the Ministry of Energy and Petroleum. The few actors in small wind turbine sector are reported to have limited capabilities, with respect to coordination, promotion and marketing. The absence of a good marketing strategy coupled with the high cost of equipment, energy services and products limits access to small wind turbine technology. County officers dealing with energy issues have limited capacity (Batchelor et al., 2015) in identification and quantification of linkages of energy access with other development sectors and therefore this limits their ability to design viable projects that could facilitate the diffusion of small wind turbines. The countrywide absence of middle level colleges for training on SWT technology implies translates to limited technological capability among actors within the sector.

With respect to flows and interactions, the limited capability of resource centres (Batchelor et al., 2015) such as the energy centres coupled with their absence in some counties limits the level of information exchange and therefore user producer interaction is severely curtailed. According to the Ministry of Energy and Petroleum, the set-up of the Ministry of Energy Centres does not cater for SWT technology diffusion. This results in shrouding of the little information that trickles down to potential technology users. The perception of government as providers of solutions by the community creates a culture of dependency. The limited capability of officers assigned to the energy dockets limits their level of comprehension of community needs which in most cases are basic and immediate and therefore poses issues with regard to matching technology in the market to specific needs (Batchelor et al., 2015).

## 7. Conclusion

The levelized cost of energy fronts wind technology as holding potential and competitive to nuclear and hydro sources. The policy provisions recognize the importance of decentralized energy within the energy supply matrix but the operationalization appears to be weak. Development trends in countries such as Denmark, UK, India, China and the United states indicate a growth in small wind turbine systems. The potential to deploy small wind turbines has been proven from literature. Policy implementation however seems to be focused on large scale wind systems with a view to addressing national industrialization objectives. Social equity issues relating to universal access to clean energy services provision do not appear to be addressed by current policy implementation. The analysis of the SWT based on Hekkert et. al. indicates that the blocking mechanisms outweigh the inducing mechanisms. This forms sufficient justification for a research agenda into the diffusion of small wind turbines in Kenya which could be addressed by the IREK framework. This review and research agenda is an attempt to bring out the complementarity between the IREK and TIS frameworks which overlap to some extent. The IREK framework is used to demonstrate how technology specific analysis can be conducted for better understanding of emerging technology innovation systems.

## 8. References


Alphen K., Hekkert M. P. and Sark W. G.J.H.M (2008). Renewable energy technologies in the Maldives.

AWEA (2016).1565215 Denmark Small Wind. Technical University of Denmark Department of Wind Energy Frederiksborgvej

Baker, L., & Sovacool, B. K. (2017). The political economy of technological capabilities and global production networks in South Africa's wind and solar photovoltaic (PV) industries. *Political Geography*, *60*, 1–12. https://doi.org/10.1016/j.polgeo.2017.03.003 (Accessed on 2018-01-12)

Batchelor, A. S., Smith, J., & Fleming, J. (2015). Renewable Energy and Decentralization ( Read ) Working Paper 2 Decentralisation in Sub - Saharan Africa : Prevalence , Scope and Challenges, (August 2014), 1–28.

Bauer, J. M., Lang, A., & Schneider, V. (2012). Innovation policy and governance in high-tech industries: The complexity of coordination. *Innovation Policy and Governance in High-Tech Industries: The Complexity of Coordination*, 1–304. https://doi.org/10.1007/978-3-642-12563-8 (Accessed on 2018-01-12)

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems : A scheme of analysis Analyzing the Functional Dynamics of Technological Innovation Systems : A Scheme of Analysis. *Research Policy*, *37*(37), 407–429. https://doi.org/10.1016/j.respol.2007.12.003

Bozeman B. and Gaughan M.(2003). Knowledge Flows and Knowledge Collectives: Knowledge Flows and Knowledge Collectives: Understanding The Role of Science and Technology Understanding The Role of Science and Technology Policies in Development Policies in Development Volume 1: Knowledge Flows, Innovation, and Volume 1: Knowledge Flows, Innovation, and Learning in Developing Countries Learning in Developing Countries

CarbonAfrica, TecnoAmbiental, T., Africa, R. S., & Netherlands, E. (2015). *Kenya Market Assessment for Off-Grid Electrification Final Report*. Retrieved from http://www.renewableenergy.go.ke/asset_uplds/files/ERC IFC mini-grids - final report - Final.pdf

Cavdar, S. C., & Aydin, A. D. (2015). An Empirical Analysis about Technological Development and Innovation Indicators. *Procedia - Social and Behavioral Sciences*, *195*, 1486–1495. https://doi.org/10.1016/j.sbspro.2015.06.449

Chaminade, C., & Edquist, C. (2005). From theory to practice : the use of systems of innovation approach in innovation policy. *Innovation*.

Cruz-Ros, S., & Gonzalez-Cruz, T. F. (2015). Service firm capabilities and performance: Contingent analysis of customer contact. *Journal of Business Research*, *68*(7), 1612–1621. https://doi.org/10.1016/j.jbusres.2015.02.005

Daniel, M. K. (1999). Bringing power to the people. Environment, 41(5), 10-15+.

Dosi, G., & Grazzi, M. (2009). On the nature of technologies: Knowledge, procedures, artifacts and production inputs. *Cambridge Journal of Economics*, *34*(1), 173–184. https://doi.org/10.1093/cje/bep041(Accessed on 2018-01-12)

ECA, TTA, & Energy, A. (2014). *Project Design Study on the Renewable Energy Development for Off-Grid Power Supply in Rural Regions of Kenya Project no. 30979 Final Report*. Retrieved from http://www.renewableenergy.go.ke/asset_uplds/files/ECA Kenya Minigrids Report - revised final(1).pdf

Edquist, C. (1999). Systems of innovation: theory and policy for the demand side. *Technology in Society*, *21*(1), 63–79. https://doi.org/10.1016/S0160-791X(98)00037-2

Edquist, C., Meeus, M. T. H. H., Oerlemans, L. a. G. G., Hage, J., Roper, S., Love, J. H., … Centre, C. (2014). Forms of knowledge and modes of innovation. *Research Policy*, *31*(1), 145–172. https://doi.org/10.1016/j.rser.2009.11.007(Accessed on 2018-01-12)

Edsand H. E. (2016). Technological Innovation Systems and the Wider Context:A framework for developing countries

Etzkowitz, H., & Ranga, M. (2013). Triple Helix systems: an analytical framework for innovation policy and practice in the Knowledge Society. *Industry and Higher Education*, *27*(4), 237–262. https://doi.org/10.5367/ihe.2013.0165 (Accessed on 2018-01-12)

Feinson, S. (2003). National Innovation Systems Overview and Country Cases, 13–38.

Fichman, R. (1992). Information technology diffusion: A review of Empirical research. *MIT Sloan School of Management*, *9*(2009), 14–23.

Fidel, P., Schlesinger, W., & Cervera, A. (2015). Collaborating to innovate: Effects on customer knowledge management and performance. *Journal of Business Research*, *68*(7), 1426–1428. https://doi.org/10.1016/j.jbusres.2015.01.026

Freeman, C. (1991). Innovation, Changes of Techno-Economic Paradigm and Biological Analogies in Economics. *Revue Économique*, *42*(2), 211. https://doi.org/10.2307/3502005

Gardner, P., Garrad, A., Hansen, L. F., Jamieson, P., Morgan, C., Murray, F., … Fichaux, N. (2009). Part I: Technology. *Wind Energy - The Facts: A Guide to the Technology, Economics and Future of Wind Power*, 29–152. Retrieved from http://www.wind-energy-the-facts.org/images/chapter1.pdf (Accessed on 2017-10-

12)
GOK, & EUEI-PDF. (2014). *EUEI-PDF Kenya 2013 Project Renewable Energy Regulatory Capacity Development Assessment of a net metering programme in Kenya Volume 1: Main report*. Retrieved from http://www.renewableenergy.go.ke/asset_uplds/files/Net Metering Assessment Report Volume 1.pdf
Hanseman, D. J., & Gustafson, E. F. (2014). The MIT Press, *63*(3), 468–470. https://doi.org/10.1086/521238 (Accessed on 2018-01-12)
Hansen, U.E. (2016). Mapping of Solar PV and Wind Energy Markets in Kenya: Current State and Emerging Trends. IREK
Hansen U.E, Gregersen C., Lema R., Samoita D., Wandera F. (2018) Size and shape: A disaggregated perspective on sectoral innovation systems in renewable electrification pathways
Hekkert et. al. (2007).Functions of innovation systems: A new approach for analysing technological change
Hekkert M., Negro S., Heimeriks G., Harmsen (R. 2011) Technological Innovation System Analysis. A manual for analysts
ILO. (2016). *Promoting Decent Work in Global Supply Chains in Latin America and the Caribbean LESSONS LEARNED AND POLICY*. International Labour Organisation.
Islam, N. (2014). New Growth Theories : What Is in There for Developing Countries ? *The Journal of Developing Areas*, *38*(1), 171–212. Retrieved from http://www.jstor.org/page/info/about/policies/terms.jsp%5CnThe Journal of Developing Areas, .
Kabendara, E. (2015). *How Tanzania plans to light up a million homes with solar power*. *The Guardian*. Retrieved from http://www.theguardian.com/environment/2015/oct/29/how-tanzania-plans-to-light-up-a-million-homes-with-solar-power%5Cnpapers3://publication/uuid/1CB4A546-20ED-4BF6-90E4-5BC2F1E98DD2
Kamp, L. M., & Vanheule, L. F. I. (2015). Review of the small wind turbine sector in Kenya: Status and bottlenecks for growth. *Renewable and Sustainable Energy Reviews*, *49*, 470–480. https://doi.org/10.1016/j.rser.2015.04.082
Kandoi, R. K., Ansari, M. Z., Mishra, N. K., Sharma, D., Kiva, E. I., & Kihara Mungai, E. (n.d.). Scaling up of Wind Energy Development Plans in Kenya. Retrieved from https://www.windforce-management.com/uploads/articles/rahul_kumar_kandoi-scaling_up_of_wind_energy_development_plans_in_kenya_963709.pdf (Accessed on 2018-01-12)
Kaplinsky, R. (2013). Inclusive Innovation: Definition and Importance. Policy Brief to the OECD/World Bank.
Kenya: 2020 universal electricity access goal appears promising. (n.d.). Retrieved June 20, 2017, from https://www.esi-africa.com/news/kenya-2020-universal-electricity-access-goal-appears-promising/
Kibet, Y. K., & Korir, M. (2013). Relationship between Complexity and Product Adoption by the Salesperson in Manufacturing Firms in Kenya. *Int. J. Cur. Tr. Res*, *2*(1), 425–429. Retrieved from www.injctr.com
KNBS. (2017). Economic Survey 2017
Kuratko, D. F. (2010). *Corporate entrepreneurship: an introduction and research review*. *Handbook of Entrepreneurship Research*. https://doi.org/10.1007/978-1-4419-1191-9
Lema, R. (2017). Renewable Electrification, Sustainable Industrialisation and Technology Transfer: What can we learn from Innovation and Development Research? IREK
Lewis, J. I. (2007). Technology acquisition and innovation in the developing world: Wind turbine development in China and India. Studies in Comparative International Development, 42(3–4), 208–232. https://doi.org/10.1007/s12116-007-9012-6 (Accessed on 2018-01-12)
Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31
Malerba, F., Nelson, R., Lema, R., Sagar, A., Zhou, Y., Baden-fuller, C., … Creswell, J. W. (2007). Sectoral systems of innovation and production. *Prometheus*, *43*(3), 630–631. https://doi.org/10.1093/scipol/scv049 (Accessed on 2018-01-12)
Manzini, S. T. (2012). The national system of innovation concept: An ontological review and critique. South African Journal of Science, 108(9–10), 1–7. https://doi.org/10.4102/sajs.v108i9/10.1038
Ministry of Energy, Kenya (2008). Updating of the Rural Electrification Master Plan: Final report Vol.3-Background technical studies
MOEP (2013). 5000+MW by 2016. Power to transform Kenya Investment Prospectus, 2013-2016. MOEP.
MOEP(1). (2016). *Sustainable Energy for All Action Agenda*. Retrieved from http://www.renewableenergy.go.ke/asset_uplds/files/SE4All AA Report Final 10 March 2016.pdf
MOEP. (2016). *Sustainable Energy for All Investment Prospectus*. Retrieved from http://www.renewableenergy.go.ke/asset_uplds/files/SE4All IP Report Final 10 March 2016.pdf
Morgan, K. (1997). The learning region: Institutions, innovation and regional renewal. Regional Studies, 31(5), 491-503. Retrieved from http://search.proquest.com/docview/208885991?accountid=172684 (Accessed on 2018-01-12)
Morgan, K. J. (2004). The Exaggerated Death of Geography: Learning, Proximity and Territorial Innovation Systems. *Journal of Economic Geography*, *4*(1), 3–21. https://doi.org/10.1093/jeg/4.1.3
Mostafa, M., Balslev, S., & Haghighi, M. (2015). Determination of Innovation Capability of Organizations : Qualitative Meta Synthesis and Delphi Method. *In Proceedings of RESER2015 - Innovative Services in the*

*21st Century*.
Muchie, M., Gammelot P., and Lundvall B.A. (2003). Putting Africa first: The making of an innovation system.
Mytelka, L. K., & Smith, K. (2002). Policy learning and innovation theory: an interactive and co-evolving process. *Research Policy*, *31*(8–9), 1467–1479. https://doi.org/10.1016/S0048-7333(02)00076-8
Niosi, J. (2002). National systems of innovations are "x-efficient" (and x-effective): Why some are slow learners, Research Policy, 31.
Perrot, R., 2012. The dynamics of renewable energy transition in developing countries: The case of South Africa and India, Working Paper Series. Maastricht.
Pueyo A. and Linares P. (2012). IDS Working paper. Volume 412
Pueyo, A. (2015). Pro-Poor Access to Green Electricity in Kenya. *IDS Evidence Report 135*, (May). Retrieved from:http://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/6165/ER135_ProPoorAccesstoGreenElectricityinKenya.pdf. Realizing the potentialwww.elsevier.com/locate/rser
Redmond, W. (2016). Innovation, Diffusion, and institutional change, (January). https://doi.org/http://dx.doi.org/10.1108/17506200710779521 (Accessed on 2018-01-12)
Schrempf, B., Kaplan, D., & Schroeder, D. (2013). National, Regional, and Sectoral Systems of Innovation – An overview. Report for FP7 Project "Progress", Progressproject.eu., 32.
Schumacher, F. (1973) Small is Beautiful. London: Blond and Briggs
Straub, E. T. (2016). Understanding Technology Adoption: Theory and future directions of informal learning, (January). https://doi.org/http://dx.doi.org/10.1108/17506200710779521
Suzuki M. (2013). Addressing key issues in technology innovation and transfer of clean energy technologies: a focus on enhancing the enabling environment in the developing countries. Environ Econ Policy Stud (2014) 16:157–169.DOI 10.1007/s10018-013-0059-5.
Tidd, J., Bessant, J., & Pavitt, K. (2005). *Managing Innovation*. *America* (3rd ed.). West Sussex, England: John Wiley & Sons, Ltd. https://doi.org/10.1007/978-3-540-89230-4 (Accessed on 2018-01-12)
Torvanger, A., & Meadowcroft, J. (2011). The political economy of technology support: Making decisions about carbon capture and storage and low carbon energy technologies. *Global Environmental Change*, *21*(2), 303–312. https://doi.org/10.1016/j.gloenvcha.2011.01.017 (Accessed on 2018-01-12)
UNIDO, & UNU-Merit. (2014). Diffusion Strategy of Green Technology and Green Industry in Africa.
www.fusystems.com/index.html?gclid=Cj0KCQjwsZHPBRClARIsAC-VMPBfdJsI-jy5BfiqO1giX5BardDD4KTaQ165JO244pnN_xKvyjAmBnIaAuNEEALw_wcB (Accessed on 2017-11-20)

Levring (2018). https://www.bloomberg.com/news/articles/2018-01-11/naysayers-caught-in-losing-bet-against-wind-power-denmark-warns (Accessed on 2018-01-11)

**Annex 1: Technological Innovation Systems Framework (Hekkert et. al.)**

| | Function | Focus | Diagnostic questions |
|---|---|---|---|
| 1. | Entrepreneurial experimentation and production | Actors present in industry | • Are these the most relevant actors?<br>• are there sufficient industrial actors in the innovation system?<br>• do the industrial actors innovate sufficiently?<br>• do the industrial actors focus sufficiently on large sale production?<br>• Does the experimentation and production by entrepreneurs form a barrier for the Innovation System to move to the next phase? |
| 2. | Knowledge Development | Knowledge development institutions | • Is the amount of knowledge development sufficient for the development of the innovation system?<br>• Is the quality of knowledge development sufficient for the development of the innovation system?<br>• Does the type of knowledge developed fit with the knowledge needs within the innovation system<br>• Does the quality and/or quantity of knowledge development form a barrier for the TIS to move to the next |
| 3. | Knowledge exchange, | Type and amount of network | • Is there enough knowledge exchange between science and industry?<br>• Is there enough knowledge exchange between users and industry?<br>• Is there sufficient knowledge exchange across geographical borders?<br>• Are there problematic parts of the innovation system in terms of knowledge exchange?<br>• Is knowledge exchange forming a barrier for the IS to move to the next phase? |
| 4. | Guidance of the search, | Regulations, visions and expectations of Government and key actors | • Is there a clear vision on how the industry and market should develop?<br>• In terms of growth<br>• In terms of technological design<br>• What are the expectations regarding the technological field?<br>• Are there clear policy goals regarding this technological field? - Are these goals regarded as reliable?<br>• Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties?<br>• Does this (lack of) shared vision block the development of the TIS? |
| 5. | Formation of markets, | Projects installed (e.g. wind turbines planned, site allocation and constructed) | • Is the current and expected future market size sufficient?<br>• Does market size form a barrier for the development of the innovation system? |
| 6. | Mobilization of resources, | • Physical resources (infrastructure, material etc),<br>• Human resources (skilled labour),<br>• Financial resources (investments, subsidies etc) | • Are there sufficient human resources? If not, does that form a barrier?<br>• Are there sufficient financial resources? If not, does that form a barrier?<br>• Are there expected physical resource constraints that may hamper technology diffusion?<br>• Is the physical infrastructure developed well enough to support the diffusion of technology? |
| 7. | Counteracting resistance to change | Resistance | • Is there a lot of resistance towards the new technology, the setup of projects/permit procedure?<br>• If yes, does it form a barrier? |