Mapping of Solar PV and Wind Energy Markets in Kenya: Current State and Emerging Trends

Ulrich Elmer Hansen
PhD, Senior Researcher
UNEP DTU Partnership, Dept. of Management and Engineering
Technical University of Denmark

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) and African Centre for Technology Studies 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: Hansen, U. E. (2017). *Mapping of Solar PV and Wind Energy Markets in Kenya: Current State and Emerging Trends* (IREK Working Paper No. 1). Copenhagen/Nairobi/Eldoret: AAU, ACTS and MU.

Mapping of Solar PV and Wind Energy Markets in Kenya: Current State and Emerging Trends.

Ulrich Elmer Hansen, PhD, Senior Researcher, UNEP DTU Partnership, Dept. of Management Engineering, Technical University of Denmark.

1. Introduction

Since Kenya has a rural electrification rate of around 7% with a total of 35 million people living without electricity, a key objective for the Kenyan government has been to increase the access to affordable sources of electricity for the rural population located in off-grid areas (IEA and World Bank, 2015). At the same time, the demand for energy has increased rapidly over the past decades due to the general economic development and population growth in Kenya. Increasing the generating capacity thus constitutes a key priority for the energy-related government agencies and regulatory authorities. While the current energy system relies mainly on hydro power, the expansion of renewable energy sources, especially wind and solar power, has been given high priority in national policies (REA, 2009). However, updated information on the development and diffusion of wind and solar technologies in Kenya is currently lacking.

In this context, the Innovation and Renewable Electrification project (IREK) project aims at analyzing the development of solar and wind-powered mini-grids and large-scale, grid-connected plants in Kenya. The present report is prepared as part of this analysis, focusing on addressing the following key research questions:

- What are the current status and trends (across PV and wind) mini-grids and large-scale (grid-connected) market segments?
- What are the main drivers for the observed market trends?
- What are the key drivers and barriers for market development?
- How do wind and solar markets in Kenya differ in terms of development and organization?
- What are the key differences with regard to local industry and business involvement?

These questions will be addressed individually in the sub-sections throughout the report. In addressing these questions, a recurring theme in the report is the question of the role and involvement of European and Chinese actors in the various projects analyzed.

The remainder of the report is organized as follows. The second section will present the so-called sectoral innovation systems perspective, which is applied in the analysis presented in sections 4 and 5. The third section presents the key findings on the state of the market development across the segments and technologies. In the fourth section, the main drivers and barriers for the observed market development trends will be addressed. Section five will describe the sectoral innovation system features across the segments and technologies. Finally, section six will present and discuss the main conclusions of the report.

2. Analytical framework

The analytical perspective guiding the analysis presented in this report is based on the sectoral innovation systems (SIS) perspective, which ascribes importance to learning, knowledge and capability accumulation in the innovation process (Malerba, 2005). The SIS perspective is based on the basic assumption that innovation dynamics are closely related to the specific characteristics of a given sector or industry. Innovation within a sector is seen as a dynamic process, which constantly transforms the structure and boundaries of a given sector. In this report, the focus is on analysing the sectoral innovation systems of solar and wind technologies within Kenya.

While there are profound differences between solar and wind technologies, the differences within each of these two overarching technology categories are equally profound. To give an example, the notion of a 'solar technology' may be used as an umbrella concept to describe solar-powered LED lamps, solar home systems as well as utility-scale solar power plants. Common for these systems is that they make use of solar panels as the underlying source of electricity generation. However, it is clear that there are significant differences between the users, producers, investors, actors, prices, scale, R&D-intensity, value chains, technical characteristics and competing technologies across these systems (Hansen et al., 2015). Each of these technology systems sub-categories may thus more appropriately be considered as sectors in their own right.

Based on this technology understanding, this report distinguishes between small-scale mini-grids and large-scale power plants using solar and wind technologies to generate electricity. Mini-grids are understood as decentralized (off-grid) systems consisting of power generation assets and distribution with power capacity between 0.2 kW and 2 MW connecting two or more individual households (Pedersen, 2016). Large-scale power plants are understood as grid-connected plants owned by utilities and/or private operators with installed capacities above 15 MW.

The above translates into the conceptualisation of four different sectoral innovation systems within Kenya with distinctive sector-specific innovation features, which are explored in the report: (i) wind-powered mini-grids; (ii) large-scale, grid-connected wind power plants; (iii) solar-powered mini-grids, and (iv) large-scale, grid-connected solar power plants. Following the SIS perspective, three main dimensions are used to guide the analysis of these four sectors (Malerba and Nelson, 2011):

- Knowledge and technologies
- Actors and networks
- Institutions

The knowledge and technology dimension focuses on the underlying knowledge bases of a given sector, which can be highly unique to the sector as a result of the interaction across the firms and organisations involved. The knowledge base in some sectors rely mainly on tacit know-how, craft and practical skills, while others depend more on codified knowledge and formal R&D (Asheim and Coenen, 2005). This means that knowledge created within specific sectors may not be easily acquired and transferred across sectors.

The actors and networks within sectoral innovation systems may involve firms as well as non-firm actors and their mutual interaction in the dynamic learning and innovation processes within specific sectors. While firms plays an important role, governments, universities, suppliers, financial institutions and NGOs are examples of other actors that take part in the innovation activities within a given sector (Malerba and Nelson, 2011).

The institutions of a given sector involve the surrounding infrastructure and enabling framework conditions in which innovation takes place. Such institutions can be more or less formal ranging from laws, regulations and standards as formal, tangible institutions to norms, habits and routines as informal institutions resulting from repeated interaction among actors. These institutional conditions shape the involvement and interaction of actors and influences the learning processes leading to knowledge and capabilities accumulation (Malerba, 2005).

These three dimensions will be used to structure the analysis presented in sections 4 and 5 of the report.

3. Market status and trends

This section reports on the status of market development across the mini-grid and large-scale market segments for wind and solar PV technologies, respectively. It seeks to address the first research question put forward initially: *What are the current status and trends (across PV and wind) mini-grids and large-scale (grid-connected) market segments*? In the following, the status for wind-powered mini-grids and large-scale wind power plants at various stages of development will be addressed firstly. Subsequently, the section proceeds by presenting the status for solar-powered mini-grids and large-scale solar power plants. This order of presentation will be maintained throughout the report.

3.1. Wind-powered mini-grids

According to the ESMAP (2016), a total of twenty-one, state-owned mini-grid stations are currently in operation in Kenya, most of which are diesel-fired generators and combined hybrids with solar and wind. Nineteen of these are owned by the Rural Electrification Agency (REA) and operated by the Kenya Power and Lighting Company (KPLC), which include one diesel-wind hybrid plant (Marsabit, 500 kW) and a solar-wind-diesel hybrid plant (Habaswein, 50 kW) (Gichungi, 2014) (see Table 1 and Table 2). The remaining two diesel and heavy fuel oil-fired mini-grids (Garissa and Lamu) are owned and operated by the Kenya Electricity Generating Company (KenGen). The total installed capacity of wind power in these mini-grids are 0.55 MW (ERC, 2015). It should be noted that KenGen has recently announced plans to hybridise the Lamu plant with wind turbines[1].

Table 1. Mini-grids owned and operated by KPLC in Kenya in 2015.

Mini-grid	Type	Nominal Capacity	Effective Capacity	Customers
Baragoi	Diesel	248 kW	138 kW	230
Eldas	Diesel	184 kW	184 kW	80
Elwak	Hybrid Solar	740 kW	610 kW	802
Habaswein	Hybrid Solar and Wind	760 kW	542 kW	1,015
Hola	Hybrid Solar	1,220 kW	660 kW	1,956
Lodwar	Hybrid Solar	2,740 kW	1,480 kW	2,380
Lokichoggio	Diesel	680 kW	500 kW	166
Mandera	Hybrid Solar	2,350 kW	1,480 kW	4,000
Marsabit	Hybrid Wind	2,900 kW	2,800 kW	3,300
Merti	Hybrid Solar	250 kW	170 kW	436
Mfangano	Hybrid Solar	520 kW	390 kW	120
Mpeketoni	Diesel	1,285 kW	950 kW	1,503
Rhamu	Diesel	184 kW	184 kW	2,132
Takaba	Hybrid Solar	244 kW	244 kW	300
Wajir	Diesel	3,400 kW	3,130 kW	4,100
TOTAL		**17,705 KW**	**13,462 KW**	**20,598**

Source: Carbon Africa Limited (2015).

Table 2. Key characteristics of the two existing wind-powered mini-grids in Kenya.

	Marsabit	**Habaswein**
Installed capacity wind	Two 250 kW wind turbines	Three 20 kW wind turbines
Total system supplier	Socabelec East Africa Ltd.	
Turbine supplier	Vergnet Groupe[2] (France)	Layer Electronics S.R.L (Italy)
Key component supplier	ABB PowerStore system (500 kW)	
Start date of operation	Scheduled for completion in 2016	

Author's own elaboration

[1] http://www.kengen.co.ke/?q=content/offgrid-stations
[2] http://www.rushydro.ru/upload/iblock/9f8/Eric-Vales_VERGNET.pdf

Beside these publicly-owned mini-grids, there are a number of private companies that offer wind and solar-powered mini-grids to off-grid villages and households on a commercial basis. Anecdotal evidence of the scale of this market in Kenya is provided in a recent report by SE4All (2016;31), which state that "*The private sector and civil society have installed at least a dozen wind/solar/micro hydro/hybrid mini-grids*". AHK (2013) and Carbon Africa Limited (2015) also lists a number of private companies operating in Kenya with expertise and activities in wind-powered mini-grids, which include PowerGen, SteamaCo, Wind for Prosperity Kenya, RIWIK, CraftSkills and WinAfrique (see also Kant et al., 2014). It has, however, not been possible to confirm the exact number of private wind-powered mini-grids in operation in Kenya as plant specific information is generally scarce. Notwithstanding, it appears likely that most, if not all, of the existing mini-grids involve either solar-diesel hybrids or solar-powered mini-grids.

The use of small-scale wind energy for water pumping has been produced and exploited in Kenya since 1986 and by 2005 about 300-350 windmills were in operation. With respect to electricity-producing wind turbines, one local Kenyan manufacturer has been active since the late 1990s, and three foreign manufacturers started activities in 2010–2011 with a small amount of wind turbines installed. From around 2011, however, the domestic wind turbine suppliers have increasingly shifted their focus and activities toward the emerging market for solar-powered mini-grids, such as in the case of the companies WinGen (now called PowerGen) and SteamaCo. To explain this movement, AHK (2013) refer to the limited size of the domestic market for wind turbines compared to the emerging market for solar PV (across market segments) while Vanheule (2016)[3] mention the decrease in the price and the relative ease of installation and maintenance of solar panels (compared to wind systems). Kamp and Vanheule (2015) estimates that around 20 companies currently offer imported wind turbines, but they are predominantly installers of solar PV systems who complement their energy product portfolio with wind turbines. Locally produced wind turbines are typically in the range of 150 W to 3 kW and around 120-150 wind turbines within this range have been installed in Kenya until now (Vanheule, 2012)[4]. Compared to the typical size of commercial solar-powered mini-grid systems currently offered by domestic suppliers in Kenya, which are in the range of 15-100 kW, the locally produced wind turbines are smaller and not well-suited to cater for this market[5]. Imported turbines are in the range of 1-5 kW and their average efficiency and reliability (and price) are generally higher compared to locally produced wind turbines. According to Vanheule (2012), an increasing number of the local manufacturers are offering imported turbines from China, but detailed information about Chinese wind turbines installed in Kenya thus far is limited.

There are currently a number of wind-powered mini-grids at various stages of development from the initial planning and feasibility stage to the final construction and operational stage. AHK (2013) lists five new wind-diesel hybrid mini-grids currently under construction in Kenya with a total capacity of 600 kW. The Kenyan government's rural electrification master plan from 2009 also included support for the retrofitting of existing diesel-based decentralised power stations into hybrid schemes with wind and solar PV (REA, 2009). As part of the implementation of the master plan, 44 new sites are planned to be developed as hybrid mini-grids among which 19 include wind turbines with a total capacity of 1.9 MW (AHK, 2013). The development of mini-grids in Kenya is supported by various donor organisations, such as the World Bank's SREP program, which aims to install 3 MW of wind and solar in hybrid with the existing diesel generators in twelve isolated grids with a total installed capacity of 11 MW (Government of Kenya, 2011). Similarly, DFID and the GIZ provide various kinds of support for the hybridisation of existing diesel-fired mini-grids with wind or solar PV and the development of private mini-grids. It appears, however, that none of these organisations have an explicit focus on wind-powered mini-grids and mainly focus on supporting the development

[3] Personal communication with Lynn Vanheule (Sept. 2016).
[4] To that come a number of local craftsmen producing smaller wind turbines in the range of 30-300 W based on available materials, such as metal scrap and spare parts (Vanheule, 2012).
[5] See, for example, the products provided by CraftSkills: http://craftskillseastafrica.com/turbines.htm

of solar-powered mini-grids[6]. One notable exception is the UNIDO-funded project in 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) (Gollwitzer et al., 2015)[7].

3.2 Large-scale, grid-connected wind power projects

The use of large-scale, grid-connected wind power in Kenya is presently limited to one project, which involves the (25.5 MW) Ngong Power Station (ERC, 2015). The plant is owned by KenGen and was originally a donation from the Belgian government in 1993 starting with only two turbines (IREK, 2015). Subsequently, in 2009 it was expanded to comprise six 850 kW Vestas turbines.

Four additional large-scale wind power projects are currently under development in Kenya, including the (prominent) Lake Turkana project (310 MW), the Kipeto Energy Wind Park (100 MW), The Kinangop Wind Park (60 MW) and the Baharini Electra Wind Farm project (90 MW).

The Lake Turkana project is developed by a consortium of international actors, including the Danish Investment Fund for Developing Countries, Vestas, the Finnish Fund for Industrial Cooperation and KLP Norfund Investments. The project is located in the area around Lake Turkana and involves the installation of 365 (850 kW) Vestas turbines, which will be imported from China (AHK, 2013). When completed, it will comprise the largest wind power project in Africa and will add what corresponds to around 18% of the total installed electricity generation capacity in Kenya. While the power purchase agreement (PPA) was signed with KPLC already in 2010, financial closure has been reached and the project is undergoing construction and is scheduled to start operation in 2017[8] (WinDForce, 2013; Eberhard et al., 2016).

The Kipeto Energy Wind Park is owned by a consortium consisting of the African Infrastructure Investment Fund, Craftskills Wind Energy International Ltd., International Finance Corporation and the Kipeto Local Community Trust. In 2015, the consortium signed a PPA with KPLC, and at the beginning of 2016, the Chinese company, China Machinery Engineering Corp., was contracted as the EPC contractor[9]. The project will include the installation of 60 turbines supplied by General Electric[10]. According to ERC (2015), the PPA has however not been agreed yet and is still undergoing evaluation.

The funding for the Kinangop Wind Park project had originally been provided by the African Infrastructure Investment Fund II and Norfund with debt finance supplied by Standard Bank of South Africa. The project was planned to have been completed in 2015 with 38 turbines supplied by General Electric and Iberdrola as the EPC contractor in cooperation with the Kenyan-based consultancy company Aeolus Kenya Ltd.[11]. The project experienced delays and was eventually cancelled in early 2016 (AHK, 2013). A number of media reports have claimed that the cancelation of

---

[6] See, for example, the recent announcement by the French development agency to "*support the installation of renewable energy generation units (primarily solar photovoltaic [PV], but also in some cases wind turbines) in 23 mini-grids currently powered by diesel generators*" https://www.esi-africa.com/news/france-invests-37m-kenyan-mini-grids/

[7] http://steps-centre.org/2014/blog/microgrids/

[8] http://ltwp.co.ke/

[9] Engineering, procurement, and construction (EPC) contracts is a prominent form of contracting agreement in the construction industry. The EPC contractor will carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct to deliver a functioning facility or asset to their clients.

[10] http://renewables.seenews.com/news/kipeto-wind-farm-inks-power-purchase-contract-with-kenya-power-527469

[11] http://aeoluskenya.com/index.html

the project was mainly due to local opposition against the project relating to land rights issues (see also (Eberhard et al., 2016)[12].

The Baharini Electra Wind Farm project is financed by the World Bank's International Finance Corporation and will be carried out by Belgian Electrawind in collaboration with the local partner Kenwind. It seems that the project has not advanced beyond the initial feasibility and planning stage. This means that financial closure and a PPA have not been agreed and that technology suppliers and contractors have not been identified yet.

The above projects are being developed under the Kenyan feed-in tariff for wind power projects, which was first introduced in 2008 and later revised in 2012. The current tariff offered for wind power projects in the range 50-100 MW is US$ 0.11/kWh (WinDForce, 2013). The feed-in tariff for wind power projects has attracted interest from a number of private developers as well as donors and development banks, which have provided financial support and advisory services to move the project toward reaching financial closure (Eberhard et al., 2016). This has resulted in a high number of applications submitted under the FIT. WinDForce (2013) reports that until 2013, a total of 236 applications had been submitted under the FIT system out of which 20 was approved (AHK 2013). However, as none of these projects have signed PPA's and progressed into full operation it appears that movement on the ground has been slow. The Lake Turkana project provides an illustrative example, which reached financial closure nine years after its start.

3.3 Solar-powered mini-grids

As shown in Table 1 above, a total of eight state-owned mini-grid stations are currently in operation in Kenya, which involves seven solar-diesel hybrids and the wind-solar-diesel hybrid previously mentioned above (Habsawein). The total installed capacity of these solar-powered mini-grids, which are owned by REA and operated by KPLC, is 0.51 MW (see Tables 2 and 3 below) (Gichungi, 2014). Detailed information on these state-owned, solar-powered mini-grids in Kenya is generally scarce. However, in general, there is a strong presence of European companies in Kenya, especially from Germany, that are specialised in the supply of core solar technology components to mini-grids as well as related engineering and consultancy services. Examples of German-based companies supplying such components, which include panels/modules, inverters, controllers and batteries include Energiebau Solarstromsysteme, Donauer Solartechnik and Juwi AG. These foreign companies are typically closely linked to local project developer companies in Kenya, such as Harmonic Systems Ltd.[13], Dreampower[14] (local subsidiary of an Italian company) and Solar Works Ltd. in the development of the specific projects.

The existing solar PV industry in Kenya includes one local assembly plant entitled Ubbink East Africa Ltd.[15], which supplies solar PV panels with capacities ranging between 13-240 Wp (the bulk of sales is 40 Wp modules) and a number of local battery producer/supplier companies, such as Chloride Exide Ltd. (Byrne 2009; Ockwell and Byrne, 2016). However, it appears that the local industry is mainly focused on serving the Kenyan market for solar home systems and solar smaller scale applications for individual households (Hansen et al., 2015). It seems evident therefore that most of the core system components in the solar-powered mini-grids in Kenya are imported from abroad, typically from renowned European or American companies through local sales offices and wholesale retailers[16] (AHK, 2013). There is limited information about the possible involvement of Chinese technology suppliers in the solar-powered mini-grids in operation in Kenya.

[12] http://africanbusinessmagazine.com/region/east-africa/africas-largest-wind-farm-set-power-kenya/ and http://www.windpowermonthly.com/article/1385206/61mw-kinangop-project-cancelled
[13] http://www.harmonicafrica.com/gallery
[14] http://dp.co.ke/
[15] http://www.ubbink.co.ke/Home.aspx
[16] Relationships between German companies and local partners, for example, include Energiebau and Solarworks as well as Donauer and Harmonics (AHK, 2013)

Table 2. Installed capacities of wind and solar in the existing mini-grids in Kenya.

No.	Station	County	Installed Diesel Capacity (kW)	Installed Wind Capacity (kW)	Installed Solar PV Capacity (kW)
1	Wajir	Wajir	1746	0	0
2	Mandera	Mandera	1600	0	300
3	Marsabit	Marsabit	560	500	0
4	Lodwar	Turkana	1440	0	60
5	Hola	Tana River	800	0	60
6	Merti	Isiolo	128	0	10
7	Habaswein	Wajir	360	50	30
8	Elwak	Mandera	360	0	50
9	Baragoi	Samburu	128	0	0
10	Mfangano	Homabay	584	0	0
Total			7706	550	510

Source: Gichungi (2011) and RECP (2013).

Table 3. Key characteristics of the Mfangano solar-powered mini-grid[17].

Installed solar capacity	40 kWp (no battery)
Total system supplier (EPC)	Dreampower and Juwi AG
Commissioning	2013
Core components	N/A

Source: Dinnewell (2014).

According to AHK (2013), fifteen state-owned, solar-powered mini-grids are currently under construction in Kenya with a total capacity of 2 MW. To that come 9 planned solar-powered mini-grids with a total capacity of 1.8 MW, which are developed as hybrid solar-diesel mini-grids (in existing diesel-fired plants) and an additional 25 plants (with a total capacity of 5.6 MW), which are at the initial proposal stage. Most recently, the REA has announced a call for tenders for the development of twenty-five new solar-powered mini-grids (REA, 2016). There are a number of donor organisations promoting development of solar-powered mini-grids in Kenya. These donors provide financial support to specific projects, such as the development of up to 26 new solar-powered mini-grids (mainly solar-diesel hybrids) by the KfW and GIZ through the German development agency (ESMAP, 2016). Similarly, DFID and the World Bank have provided direct investments for the development of new (greenfield) solar-powered mini-grids while the Spanish Embassy have put forward financing for the development of five new solar-wind-diesel hybrid mini-grids. Other donor-funded projects include the DFID-funded cooperative-based Kitoyni mini-grid[18] (solar-diesel hybrid, 13.5 kWp) and the UNIDO-funded, community-based Olosho Oibor mini-grid (solar-wind-diesel hybrid, 10 kWp) (Pedersen, 2016; Gollwitzer et al., 2015; Gollwitzer, 2016).

A number of private companies are involved in supplying solar-powered mini-grids on a commercial basis in Kenya, which include Powerhive East Africa Ltd., PowerGen, SteamaCo and Talek[19] (Carbon Africa Limited, 2015). Since 2012, these foreign-owned companies have installed 20-

[17] see http://www.th-energy.net/english/special-self-consumption/local-mini-grids/ and http://www.pv-tech.org/news/juwi_trials_battery_less_pv_diesel_hybrid_system_in_kenya

[18] http://www.energy.soton.ac.uk/e4d-first-year-operation/

[19] Talek Power company has been created as a so-called 'special purpose vehicle' by the German development agency GIZ and is set up as a private company in trust (GIZ, 2015; ESMAP, 2016).

30 solar-powered mini-grids in the size of 1.4-10 kW with a few examples of larger systems (20 and 50 kW). Two of the companies have received a formal license to operate and one company has secured financing for establishing a portfolio of another 100 mini-grids (Pedersen, 2016; Harrington, 2016). These companies have already gone through an initial pilot phase and are now in the process of significantly upscaling their activities in Kenya (Earley, 2015). Most of the core components used in these solar-powered mini-grids is sourced from renowned suppliers from Europe or the US either in-house or through external suppliers. It should be noted that SteamaCo has developed a smart metering systems, which is used in a number of the solar-powered mini-grids in Kenya[20] (Ashden, 2015).

3.4 Large-scale, grid-connected solar power projects

Currently, there are four grid-connected solar power plants in operation in Kenya. These include: (I) a 575 kWp plant installed at the UN compound in Nairobi; (ii) a second plant at the SOS Children's village in Nairobi (60 kWp); (iii) a third 72 kWp system installed at a flower farm and (iv) a fourth, 1 MWp plant at a tea-processing facility (AHK, 2013; Hansen et al., 2015). While the first two plants were financed mainly by international donors, the other two were financed by the industrial plant owners. The existing plants appear to have been delivered on a turnkey basis by total system suppliers from abroad in cooperation with local consultancy companies and installation contractors (Dinnewell, 2014). For example, the German company Energiebau Solarstromsysteme GmbH was the turnkey provider of the first-mentioned plant in cooperation with the Kenyan-based company SolarWorks, which included the sourcing of all of the core components mainly from European suppliers[21] (modules from Schott Solar, Kaneka and inverters from SMA Solar Systems) (Hille and Franz, 2011; AHK, 2013). Similarly, the second plant was constructed by the UK-based company Arun Construction Sevices in cooperation with the local company Azimuth Power (modules from Centrosolar AG and inverters from SMA Solar Systems[22] (Hille and Franz, 2011). In the third plant, the tea farm owner commissioned the UK-based company, SolarCentury, to deliver the plant, including import of key components, in cooperation with the Kenyan-based companies East African Solar Ltd. and Azimuth Power (SolarCentury, 2014)[23]. An additional plant at the Strathmore University (0.6 MW), which in 2015 signed a PPA with KenGen, seems to be close to starting operation[24]. In this project, the Kenyan companies Questworks and ReSol have been contracted respectively as the total system provider and installation contractor, and key components will be sourced from European and Chinese suppliers (including panels from JinkoSolar and inverters from Solaredge)[25]. In general, the involvement of additional local companies in the abovementioned plants seems to be limited mainly to local technicians and engineers during the construction stage as well as local contractors of maintenance services during operation.

A number of projects of significantly larger scale seem to be under development in Kenya as part of the feed-in tariff system, which currently offers a tariff of US$ 0.12/kWh for project developers (ERC, 2015) (see Fig. 1). This includes the Samburu project (40 MW), the Garissa project (50 MW), the Greenmillenia Energy project (40 MW), the Nakuru project (50 MW), the Kopere Solar Park project (17 MW), the Witu Solar Power project (40 MW), and the Alten Kenya Solarfarm project

[20] http://steama.co/
[21] http://www.constructionkenya.com/1928/africas-largest-solar-panel-installed-in-nairobi/ and https://www.energiebau.de/Nairobi-Kenya.2295.0.html?&L=1
[22] http://www.arunservices.co.uk/solar-case-studies/ and http://www.theeastafrican.co.ke/news/Giant-solar-power-farm-switched-on/2558-1696158-12ptrwjz/index.html
[23] http://www.solarcentury.com/za/media-centre/changoi-press-release/
[24] Kenya Power. http://constructionreviewonline.com/2016/05/another-40mw-solar-power-plant-in-kenya-to-be-constructed/
[25] http://www.solaredge.com/sites/default/files/solaredge-Case-Study-600kW-Strathmore-University-Kenya.pdf

(40 MW) (Hansen et al., 2015; IREK, 2015). These projects are being developed by foreign technology suppliers and companies specialised in large EPC contracts in the energy sector, such as Stimaken and Martifier Solar. Interestingly, one of the planned projects, the Garissa project, involves a Chinese technology supplier, JinkoSolar, and Chinese project developer, Jiangxi Corporation for International Economic and Technical Cooperation Ltd. Common for these planned projects is that none of them appear to have advanced from the initial expressions of interest and feasibility study stage to reaching financial closure and signing of PPA's[26]. Hence, as the project planning preparation for most of these projects started already in 2012, movement on the ground seems relatively slow and most of the projects seems to be some way before reaching the construction and operational stage (ERC, 2015; Eberhard et al., 2016). Most of the projects are supported by a number of donors and development banks, such as the World Bank and the German development agency. However, it appears that project developers are generally struggling to secure funding and reaching financial closure (Dinnewell 2014; Eberhard et al. 2016).

Fig. 1. Projects approved by the ERC to be developed under the feed-in tariff system (2015).

Technology	No. of Applications	Proposed Capacity (MW)	Approved Capacity (MW)	Resource (%)
Wind	1	50	50	11.8
Hydro	0	0	0	0.0
Small Hydro	13	85.95	85.95	20.3
Geothermal	0	0	0	0.0
Solar	3	120	120	28.4
Biogas	6	167.3	167.3	39.5
Co-generation	0	0	0	0.0
Total	23	423.25	423.25	100.0

Source: ERC (2015). Note: the list only involves projects for which the expressions of interest (EOI) have been approved by the FIT evaluation committee[27].

4. Drivers and barriers across segments and sectors

In this section, some of the main drivers and barriers for the diffusion of wind and solar PV technologies across the mini-grid and large-scale segments will be addressed. The focus is on addressing the following question: *What are the main drivers and barriers for the observed market development trends*? The sectoral system of innovation perspective is used to guide the analysis.

4.1. Drivers and barriers for the development of wind-powered mini-grids

A key driver for the development of hybrid diesel-wind mini-grids in Kenya is the increasing operational costs of the existing diesel-fired mini-grids due to the generally increasing costs of diesel. In parallel with the decreasing costs of wind turbines systems (IRENA, 2015), hybridization with wind (and solar) has increasingly become attractive in order to reduce the operational costs of the existing mini-grids (Moner-girona et al., 2006; Gichungi, 2014). A number of donor programs and national plans also mainly support the development of hybrid wind-diesel mini-grids. However, compared to the support for solar-powered mini-grids, the development of wind-powered mini-grids seems to be somewhat under-prioritised in these initiatives. In a number of locations, especially in the eastern and northern parts of Kenya (such as the area surrounding Lake Turkana) offers particularly

[26] http://www.reuters.com/article/us-africa-solar-idUSKCN10F18I

[27] In the three previous annual reports prepared by the ERC, the number of solar projects listed as 'approved solar PV projects' were 20, 16 and 9, indicating that since 2012/13, 48 solar power projects were approved under the FIT, none of which have been realized nor have a signed PPA as of yet.

favorable wind resources. While the development of wind-powered mini-grids in such locations can become economically viable, optimal location also depends on the local demand (GIZ, 2014).

The development of wind-powered mini-grids in Kenya is prevented by a number of factors related to the existing knowledge base in Kenya and the wind turbine industry. Generally, there is very limited domestic expertise in the development of larger scale (15-100kW), stand-alone wind-powered mini-grids. The domestic industry mainly involves small-scale systems in the range of (150W-3kW) and smaller wind turbines (30-300W) developed by local craftsmen. The two existing state-owned wind-powered mini-grids involve hybridisation of the existing diesel-fired plants via imported wind turbines and examples of wind-powered mini-grids developed on a commercial basis by private operators are absent. This means that there is a lack of local reference plants, technical concepts and business models that have demonstrated technical and economic feasibility, especially with regard to stand-alone plants (AHK, 2013). While wind-powered mini-grids have been developed globally, for example in India, the technical concepts do not seem to be readily available from the global technology (market) shelf and applicable in the local context (Ulsrud et al., 2011). Thus, the development of viable technical concepts and business models will possibly involve significant technical testing and experimentation locally, which has not been undertaken hitherto in Kenya. Regardless, the development of wind-powered mini-grids on a commercial basis will have to compete with the prices and systems offered by suppliers of solar-powered mini-grids in Kenya. The technology used in large-scale wind-turbine systems is not directly compatible with smaller scale-systems and thus needs significant reconfiguration, development and adaptation. However, the general trend in the global wind industry has involved lead firms generally focusing their development efforts on larger and more efficient turbines (up to 8 MW). Therefore, it appears that the Kenyan market for small-scale wind turbines has generally not been considered commercially attractive by industry lead firms.

The table below provides a summary of the above-mentioned drivers and barriers according to the sectoral system of innovation perspective.

	Drivers (enabling conditions)	**Barriers (disenabling conditions)**
Knowledge and technologies	• The increasing costs of competing technologies and practices, especially diesel • Generally decreasing costs of wind turbines globally • Good wind resources and possibilities for competitive wind-powered mini-grids in a number of locations	• Very limited domestic expertise in the development of larger scale (15-100kW) stand-alone, wind-powered mini-grids • Lack of local reference plants, proven technical concepts and business models for standalone wind-powered mini-grids in Kenya • The technology used in large-scale wind-turbine systems are not compatible with smaller scale-systems and thus needs significant reconfiguration • General trend in the global wind industry involves focusing development efforts on developing larger and more efficient turbines and not for small-scale plants
Actors and networks		• From around 2011, the local providers of wind turbines increasingly shifted their focus toward the emerging market for solar PV • Absence of local suppliers of wind-powered mini grids on a commercial basis • Global lead firms not active on the local market for small-scale wind turbines and wind-powered mini-grids in Kenya
Institutions	• State and donor support for the development of wind-diesel hybrids	• Wind-powered mini-grids appears under-prioritized by the state and donors in comparison with solar

4.2. Drivers and barriers for the development of large-scale, grid-connected wind power projects

As described above, the financial and advisory support provided by various donor organisations has contributed to creating an enabling environment for the development of large-scale wind power projects in Kenya. The tariff offered by the state for wind power projects through the feed-in-tariff system is complementary to these supportive activities. Government support for large-scale wind (and solar) power is part of a broader objective to attract foreign investment in Kenya by offering the possibility of including private, independent power producers (IPP) in the energy sector (SE4All, 2016). With the increasing domestic demand for electricity and the continued decreasing costs of wind turbines globally, the development of wind power projects has become an attractive option for the government to expand generation capacity in a cost-efficient manner. These supportive incentives have contributed to attract a number of international actors to invest in wind power projects in Kenya, especially international donor agencies and European development banks. The technical nature and scale of the wind power projects under development in Kenya seem to be aligned with the competences and strategic orientation of the globally leading wind turbine suppliers. Consequently, globally leading wind turbine suppliers, such as Vestas and General Electric, as well as international EPC contractors and construction companies are also involved in these projects. The development of such projects in Kenya may thus be considered as part of a global expansion of the ongoing technology development and activities into new markets of these industry lead firms. The above entails that the development of large-scale wind power projects in Kenya is generally characterised and encouraged by a high degree of foreign expertise and well-proven technological concepts.

There has been no shortage of ambitious goals and targets for the development of large-scale wind power projects in Kenya in successive national policies and plans. A recent example is the Medium Term Plan adopted in 2015, which sets a target for the installed capacity of wind power to reach 650 MW in 2020 (from 25 MW in 2015) (ERC, 2015). Similarly, the Kenyan government's Vision 2030 aims at expanding the total installed capacity of wind power to 2 GW by 2030. However, the feed-in tariff system is the only incentive structure currently in place to achieve these targets. Hence, a key factor impeding the achievement of the targets for wind power projects is the lack of a more comprehensive and detailed plan with milestones and additional incentives. Indeed, according to Eberhard et al. (2016), the political rhetoric promoting the development of wind power projects in Kenya has not been followed up by the adoption of a more concrete enabling regulatory framework. To this comes the lengthy approval and PPA negotiation processes experienced by project developers and the associated transaction costs. This circumstance reflects that projects are essentially large infrastructure projects, which are typically highly political in nature and involve a multitude of actors with competing interests and negotiations across various levels. The withdrawal of support and necessary guarantees from the World Bank in the Lake Turkana project in 2012 provides an illustrative example of disagreements in the projects[28]. The opposition from local communities and interest groups against a number of the projects has also been found to comprise a key barrier for project developers. In addition, due to the high capital investments needed, it remains a challenge for most project developers to secure sufficient funding from foreign investors in order to reach financial closure. Finally, the lacking ability of the existing grid and its management to absorb and handle the incorporation of wind power into the system constitutes a main challenge for project development (AHK, 2013).

The table below provides a summary of the above-mentioned drivers and barriers according to the sectoral system of innovation perspective.

	Drivers (enabling conditions)	Barriers (disenabling conditions)

[28] http://www.businessdailyafrica.com/Kenya-Power-deal-that-forced-World-Bank-out-of-wind-farm-/539546-1538602-4chhx1/index.html

Knowledge and technologies	• Alignment between the demand for large-scale wind power projects and the competences and strategic orientation of global wind turbine lead firms • Generally decreasing costs of wind turbines globally • Good wind resources in a number of locations	• The inclusion of wind power into the existing grid is problematic
Actors and networks	• Involvement of foreign expertise in the design, construction and management of large-scale wind power projects (EPC contractors, construction companies and consultancy firms) • Involvement of globally-leading wind turbine suppliers (providing well-proven technological concepts)	• Local communities and interest groups opposing against the development of wind power projects
Institutions	• Financial and advisory support from international donors and development banks • Feed-in tariff for wind power projects • Increasing demand for electricity and appertaining need for expanding the generating capacity	• Lengthy approval process • Difficulties in securing sufficient funding from foreign investors and reaching financial closure • Lack of a comprehensive plan and detailed regulatory framework

4.3. Drivers and barriers for the development of solar-powered mini-grids

The development of solar-powered mini-grids in Kenya is generally encouraged by a number of state-driven initiatives to hybridize the existing diesel-fired mini-grid stations with solar, as laid out initially in the rural electrification master plan (REA, 2009). With the generally decreasing costs of solar panels and other core components (such as batteries and inverters), the development of solar-diesel mini-grid hybrids has come to be considered by the government as an attractive option to reducing costs (IRENA, 2016). These initiatives are complemented by financial support provided by a number of donor organizations for the development of hybrid solar-diesel mini-grids. These supportive state and donor-driven initiatives have contributed to creating an enabling environment conducive for the development of solar-powered mini-grids. In addition, within the past 4-5 years, a number of private companies have begun to supply stand-alone, solar-powered mini-grids on a commercial basis to the rural population living in off-grid areas. These private mini-grid suppliers are in the process of driving the establishment of a commercial market for the sale of electricity services to rural communities. This private-sector approach to the provision of rural electrification via mini-grids seems to be unprecedented in Kenya and in East Africa. While there are indeed differences across these companies, they have all been able to attract significant funding from foreign investors to support their start-up and to expand and upscale their activities. Most of the companies have been started by foreign expatriates with significant experience in business start-up, engineering, renewable energy consultancy, telecommunications and donor organizations. This means that the companies have brought into Kenya a high level of technical and organizational expertise and management systems. The technical concepts and business models used by these companies are built around the emergence of the so-called pay-as-you-go (PAYG) model. The PAYG model allows the mini-grid suppliers to offer customers the opportunity to purchase electricity when needed, on a daily basis, thereby avoiding high upfront costs. The emergence of the PAYG model has been enabled by two crucial preconditions. The first relates to the diffusion of mobile phones and the development of the M-PESA mobile payment scheme in Kenya. The second is related to the introduction of smart metering and monitoring technologies, which enable instant monitoring and regulation of electricity use[29].

The private suppliers of solar powered mini-grids in Kenya have pursued different development paths and strategies, some of which include total system suppliers, subcontracting and service providers for other project developers. While the business model in such activities relies on a continual revenue stream and client relations to obtain new project orders, others rely more on securing equity funding from foreign investors to support their activities. Regardless of the strategy adopted, securing continued funding and project investments is crucial at this point in time as the companies are in the process of up-scaling their activities (GVEP, 2014). Another challenge is related to the lack of regulatory framework for the development of commercial mini-grids in Kenya. The private companies are involved in various activities to promoting regulatory changes in favor of creating an enabling framework for the development of commercial mini-grids. Bilateral negotiations between the companies and key government agencies related to obtaining operational licenses and approval of end-user tariffs have shown to be challenging and lengthy (ESMAP, 2016). The prolonged negotiation process is partly related to different objectives of the government agencies and the private operators. The commercial tariff proposed by the private companies is significantly higher than the universal tariff offered by the government through the conventional grid extension programs to support rural electrification. The regulatory authorities are generally hesitant to accepting the inclusion of private operators who are operating with business models based on low connection fees and high usage rates. Hence, while two companies have obtained an operational license the commercial tariffs suggested by these companies have not been approved (GIZ, 2015; ESMAP, 2016)[30].

The table below provides a summary of the above-mentioned drivers and barriers according to the sectoral system of innovation perspective.

	Drivers (enabling conditions)	Barriers (disenabling conditions)
Knowledge and technologies	• Expertise in business start-up, engineering renewable energy consultancy, telecommunications • Introduction of smart metering and monitoring technologies, mobile payment schemes and the widespread use of mobile phones (enabling the emergence of PAYG business models) • The increasing costs of competing technologies and practices, especially diesel • Price/performance improvements in core technology components (panels, batteries and balance-of-system components)	
Actors and networks	• Highly specialized foreign-owned companies some of which are vertically integrated firms with headquarters abroad • Rural consumers able to purchase electricity on a daily basis depending on need	• KPLC have objected to new license applications
Institutions	• State and donor initiatives promoting the hybridisation of existing diesel-fired mini-grids with solar • Significant funding provided from foreign investors to private suppliers of mini-grids	• Business models of private mini-grid suppliers dependent on securing continued funding and project orders • Lack of regulatory framework and

[29] The data obtained from the monitoring systems is currently in the process of becoming integrated into development of large databases based on which further optimisation of the systems will be undertaken by the companies.
[30] Since the tariff rates have not been approved by the ERC, their formal status is still at the pilot stage.

	• GIZ directly involved in promoting mini-grids in Kenya through the company Talek • Private suppliers of solar-powered mini-grids promoting regulatory changes in favour of commercial mini-grids (license and tariff system)	clear policy concerning tariffs for commercial mini-grids (lengthy negotiation and approval process) • Lack of framework for future integration with national grid should it arrive at a mini-grid site

4.4. Drivers and barriers for the development of large-scale, grid-connected solar power projects

A key driver for the development of large-scale solar power plants is the rapidly decreasing costs of solar panels particularly during the past 4-5 years where the economics of solar PV has improved significantly[31]. This has led to a situation in which electricity produced by large-scale solar PV has reached grid parity in a number of markets in Africa. For example, the price level of PV-produced electricity from large-scale solar power projects in Zambia has seen competitive bid tariffs proposed by project developers in the range from 6.02 to 10.6 USc/kWh[32](IRENA, 2016). In Kenya, this means that in a number of locations with high levels of solar radiation, solar power can become economically viable (Oloo et al., 2016). With the introduction of the feed-in tariff for solar in Kenya, this has attracted a number of international investors and leading suppliers of solar power plants to start the development of large-scale solar power plants in Kenya. Indeed, in 2014 a government official announced that 25 projects with a total installed capacity of 750 MW were proceeding from the initial feasibility stage towards the power purchasing agreement stage under the FIT policy[33]. According to the National Energy Policy from 2012, the Kenyan government (ambitiously) expects installed solar power capacity to grow as follows: to 100 MW by 2016, 200 MW by 2022 and 500 MW by 2030 (Government of Kenya, 2012). The plants currently under development in Kenya are of a substantially larger scale compared to the existing, operational plants, which may reflect the generally improvement in the economic viability with the size of the plants (IRENA, 2016). Technology designs for large-scale solar power plants are generally well-proven globally, requiring only minor design and construction modifications to adapt to local conditions. Hence, the design and construction period required by technology suppliers and contractors to construct and put into the plants is relative limited[34].

The development of large-scale solar power plants is generally prevented by the difficulties for project developers to attract financing from foreign investors in order to reach financial closure. Some observers have raised concerns that the feed-in tariff for solar may be too low to significantly incentivize foreign investments (Hansen et al., 2015). Another element of the difficulties in attracting funding is related to the unclear policy signals and ongoing discussions concerning the possible introduction of new incentive structures and regulatory models. Since the FIT system was revised in 2012 into its current form, a number of alternative models, such as an auction system, competitive bidding and a net metering system (for smaller grid-connected projects) have been discussed (Hankins, 2014; Ondraczek, 2014). This may reflect a broader trend across African countries, such as Ghana and South Africa involving a move from initial FIT systems toward other types of more competitive approaches to promoting large-scale solar power plants[35]. Since a final political decision has not been taken in Kenya on the preferred model, this appears to have made foreign investors hesitant to proceed with project investments. This has in turn translated into prolonged negotiations concerning PPA contracts and project approvals under the FIT system (ERC, 2015).

[31] Solar panels comprise around 50% of the total investment costs of large-scale solar power plants (IRENA 2016).
[32] http://ifcextapps.ifc.org/IFCExt/Pressroom/IFCPressRoom.nsf/0/6132DA44B2D2780185257FC30046CC96
[33] http://www.pv-tech.org/news/kenyas_fit_approved_solar_pipeline_reaches_750mw
[34] This short project cycle can be illustrated in the case of the recent 15 MW solar power plant put into operation in 2016 in Mauretania, which only required a construction period of one month.
[35] http://www.africaoutlookmag.com/news/implementing-the-right-mix-of-renewable-energy-projects-in-sub-saharan-africa

The table below provides a summary of the above-mentioned drivers and barriers according to the sectoral system of innovation perspective.

	Drivers (enabling conditions)	Barriers (disenabling conditions)
Knowledge and technologies	• Generally decreasing costs of solar panels globally • Solar radiation offer favorable conditions for solar power in a number locations • Tested and well-proven technology globally only requiring minor adaptation (short project cycle)	
Actors and networks	• Local presence of a number of renowned European technology suppliers and contractors • Local labor used during construction and operation (reducing investment and operational costs)	
Institutions	• Financial support from international donors and development banks • Feed-in tariff for solar power projects • Increasing demand for electricity and appertaining need for expanding the generating capacity	• Difficulties in securing sufficient funding from foreign investors and reaching financial closure • Uncertainties concerning future policy framework • Lengthy PPA negotiation and approval process

5. Comparing sectoral innovation systems for wind and solar in Kenya

In this section, the sectoral innovation system perspective is used to address the following two research questions put forward in the beginning: (i) *How do wind and solar markets in Kenya differ in terms of development and organization*? and (ii) *What are the key differences with regard to local industry and business involvement?*

5.1. Sectoral innovation system characteristics of wind-powered mini-grids

The existing knowledge and technological base in the domestic industry for wind turbines in Kenya is characterised by relatively simple and small-scale technologies manufactured locally. Such small-scale systems can be tailored to different local contexts and manufactured from a range of locally available materials while still being relatively robust. The turbines are typically produced by smaller manufacturers, universities or NGOs involved in community projects and thus does not require advanced engineering knowledge or skills. Thus, as opposed to formalized R&D, the domestic industry for small-scale wind turbines is generally characterized by a high level of informal knowledge and learning in the way that local craftsmen and blacksmiths tinker with various designs based on available equipment and materials. While the wind turbines are produced and diffused at relatively low costs, the final performance and standards resulting from this kind of manufacturing tend to vary greatly. The locally-produced systems are contrasted with the imported turbines used in the existing hybrid wind-diesel mini-grids, which are generally of a higher performance and price level (Vanheule, 2012). Due to the lack of experimentation with wind-powered mini-grids and related technical concepts and commercial applications, limited specialisation and experience has been accumulated in this area. The main actors involved in the domestic industry are local wind turbine manufacturers, NGOs and local community entrepreneurs involved in various small-scale projects typically implemented by donors in rural villages (Harries, 1997; Bergès, 2009). A number of these projects include individual engineers and NGOs from abroad involved in testing a specific technical design for rural applications (Ferrer-Martí et al., 2012). The local manufacturers rely on local supply chains and distribution networks and typically make use of connections in the local environment for sourcing materials and related know-how. Government agencies promoting rural electrification in off-grid areas are typically also involved in specific projects either directly or indirectly via technical support. Local universities sometimes provide highly applied research input to specific projects, but formalized R&D activities at universities focusing specifically on small scale wind is largely absent in Kenya. The main supportive conditions promoting the development of wind-powered mini-grids are related to the initiatives adopted as part of the rural electrification master plan to hybridize the existing diesel-fired mini-grids with wind and solar (REA, 2009). These initiatives are supported and complemented by various donor programs.

5.2. Sectoral innovation system characteristics of large-scale, grid-connected wind power projects

The knowledge and technology base underlying the development of advanced large-scale wind turbines has developed into a highly research and capital-intensive process involving continuous development of new materials, designs and production methods. Thus, the development of utility-scale wind turbines involves both internal R&D carried out within the industry lead firms as well as formalized R&D undertaken by research centers at universities or public research organizations. These R&D activities mainly draw on technical disciplines and engineering-based knowledge. The ongoing development efforts focuses on improving the price and performance of wind turbines in order to increase the competitiveness of wind power compared to conventional sources of energy for power generation. As the economic feasibility generally increase with the size of the wind turbines, the general trend in the industry has involved the development of gradually increasing scale of wind turbines. The development of large-scale wind power projects also draw on a broader set of organizational and administrative competences, including the skills and systems for turbine component manufacturing (e.g. supply chain management) and the knowledge required for EPC contracting and the incorporation of third party consultants (legal advice and engineering consultancy). In the projects under development in Kenya, the main contractors and wind turbine suppliers have drawn upon a range of such knowledge bases and areas of expertise during project development. International actors, such as pension funds, development banks, donors and other types of financial institutions, play an important role in providing financing for the development of the projects. Due to the high national relevance of the projects (as large infrastructure investments), national policy makers, regulatory bodies and government agencies are also involved in the development of the projects. While direct involvement includes bilateral negotiations between project developers and relevant authorities, indirect involvement include political advocacy influencing the projects. While not being directly involved, local community and actor groups have been found to exert a strong indirect influence on the development of the projects mainly due to disagreements on land rights issues. The main supportive instruments promoting the development of large-scale wind power plants in Kenya is the feed-in tariff, which applies to projects larger than 50 MW.

5.3. Sectoral innovation system characteristics of solar-powered mini-grids

The knowledge base underlying the development of solar-powered mini-grids in Kenya draws on a variety of disciplines and relies particularly on foreign expertise. In the state-owned solar-diesel hybrids, the main expertise needed is mainly in the area of turnkey contracting. The necessary technological skills of the total system suppliers are mainly related to the capacity to design the plants, to manage the sourcing of key components and to undertake the construction and final commissioning of the plants. Since this expertise is not currently available from domestic suppliers in Kenya, the development of these plants are dominated by European companies with significant experience in turnkey contracting and related engineering tasks. Despite of the technical capacity and knowledge accumulated in the domestic industry for solar home systems (Byrne, 2009), the local suppliers of core components (such as panels and batteries) seems to be disconnected from the development of solar-powered mini-grids. The private companies from abroad supplying solar-powered mini-grids on a commercial basis in Kenya draws mainly on engineering-based knowledge in the ongoing technical experimentation efforts to optimize their mini-grid systems. Experience from the telecommunications industry has also provided input into the development of a PAYG-based business models specifically developed to target poor customers in rural, off-grid areas. This business model draws on knowledge about IT and software solutions and related data analysis and optimization systems as well as the use of smart metering and monitoring technologies. Some of these companies are engaged in client relations with (private) investors of solar-powered mini-grids some of which include philanthropic foreign investors[36]. There are collaborative networks established across a number of these companies as well as linkages to foreign investors, headquarters and component suppliers in Europe and the US. The enabling environment for the development of solar-powered mini-grids in Kenya is greatly influenced by a number of state and donor-funded programs to hybridize the existing diesel-fired mini-grids. However, the existing regulatory framework for rural electrification, which focuses on conventional grid extension programs, continues to play an important role for the development of commercial solar-powered mini-grids, resulting in lengthy approval and negotiation processes for project developers[37].

5.4. Sectoral innovation system characteristics of large-scale, grid-connected solar power projects

The knowledge and technological base underlying the development of large-scale solar power plants in Kenya draws greatly of foreign expertise in the delivery of plants on a turnkey basis. European companies with substantial experience in turnkey plant engineering, component sourcing and commissioning have thus delivered the existing plants in cooperation with locally-based consultancy companies. Due to the larger scale of the solar power plants currently under development in Kenya, their development draws on additional knowledge on EPC contracting and the related organisational expertise to manage the development of large infrastructure projects. Consequently, international contractors and technology suppliers with the technical expertise and the management skills to develop an integrated plant design and to install and operate the system effectively have been involved in the planning and development of the projects. To this come additional competences in the area of PPA contract negotiations, legal aspects and detailed engineering tasks. While the development of the existing solar power plants have included industrial users and donors as the project owners, the larger scale solar power plants under development include direct involvement from international investors, including development banks and donor organisations. The regulatory framework promoting the development of large-scale solar power is limited to the feed-in tariff system in Kenya.

Distinguishing sectoral innovation system features of across market segments and technologies

	Wind mini-grids	**Large-scale Wind**	**Solar mini-grids**	**Large-scale solar**

[36] http://www.aiche.org/chenected/2016/02/new-smart-solar-microgrids-speed-rural-electrification-kenya

[37] An example of the continued focus of the grid operator and energy planning agencies in Kenya on grid-extension to promote enhanced access to electricity for the rural population is the so-called 'Last Mile Connectivity Project' (see e.g. http://www.afdb.org/en/projects-and-operations/project-portfolio/project/p-ke-fa0-010/).

Knowledge and technologies	Domestic wind turbine industry characterized by: • Small-scale and simple wind turbines • Informal learning and knowledge • Local craftsmen and engineers • Limited knowledge in wind-powered mini-grids • Absence of formalized R&D activities carried out at universities in small-scale wind turbines • Import of higher standard wind turbines	• Formalized R&D in large-scale wind turbines • Technical and engineering-based disciplines • Complex and capital-intensive capital goods • Experience in EPC contracting and planning of large-scale plants • Expertise in PPA contract negotiation and legal aspects • Design of project tailored to local conditions	• Engineering-based knowledge • Telecom expertise (mobile payment schemes, PAYG models) • Smart metering and monitoring systems • Data management and software optimization tools • Consultancy and donor experience	• Engineering-based knowledge • Experience in turnkey contacting • Experience in EPC contracting and planning of large-scale plants • Knowledge System design integration and operation
Actors and networks	• Donors, NGOs, local manufacturers involved in small-scale development projects • Actors embedded in local and regional supply chains and distribution networks • Universities involved in practical and hands-on applied research in specific projects • Absence of private suppliers of wind-powered mini-grids • Importers of foreign wind turbines	• Industry lead firms, such as Vestas and General Electric • International investors, including development banks, donors and pension funds • National policy makers and key government agencies (e.g. via direct negotiation with project developers) • Local community groups (opposing projects)	• European turnkey contractors • Local engineering and consultancy firms • Private suppliers of mini-grids owned by foreign expatriates • Foreign investors (direct plant investments and equity investments) • Foreign component suppliers • Examples of cooperatives and community-based solar mini girds	• International EPC contractors • Technology suppliers • International investors, including development banks and donors • Industrial users
Institutions	• State and donor support for hybridization of the existing diesel-fired mini-grids	• Feed-in tariff for wind power projects	• State and donor support for hybridization of the existing diesel-fired mini-grids	• Feed-in tariff for wind power projects

6. Discussion and conclusion

With the persistent low rural electrification rates and the urgent need to increase the generating capacity in Kenya, the diffusion of wind and solar technologies has been given high priority by the government as means to contribute to solve these energy-related challenges. This report set out to take stock and analyse the state of the market for the development and diffusion of wind and solar technologies in Kenya.

Based on the sectoral innovation systems perspective adopted in the report, it is clear that there are not only profound differences between solar and wind technologies, but equally important also within these technologies. When comparing wind-powered mini-grids with large-scale wind power plants, it appears obvious that these sectors differ fundamentally with regard to their underlying knowledge base, the technologies used, the main actors involved and the institutional conditions in which their development and diffusion take place. A similar picture emerges with regard to the differences between solar-powered mini-grids and large-scale solar power plants.

When comparing the relative development of the market for wind and solar technologies, a number of findings stand out. The development of wind-powered mini-grids have only made very limited progress when compared with the development of large-scale wind power plants at least in terms of installed capacity. In turn, the development of large-scale wind power plants is driven by a limited number of very large-scale projects, such as the Lake Turkana project, which will singlehandedly, add 18% to the total installed generating capacity in Kenya. The opposite picture seems to be case with regard to the diffusion of solar technologies. While the development of solar-powered mini-grids has gained significant traction recently, especially with the emergence of private mini-grid suppliers, the development of large-scale solar power plants has been very limited.

While some of the drivers and barriers identified were common across the four sectors, some were specifically related to the sector in question. Enabling factors across sectors include the generally decreasing costs of the core technology components, the increasing costs of alternative technologies and the support provided by states and donors. Some of the main constraining factors identified across sectors include the difficulties in securing financing and the lengthy project negotiation and approval processes.

References

AHK, 2013. *Target Market Study Kenya Solar PV & Wind Power*, Delegation of German Industry and Commerce in Kenya.

Ashden, 2015. *Winner Case Study Summary: SteamaCo, Kenya*, Ashden Award for Business Innovation.

Asheim, B. & Coenen, L., 2005. Knowledge Bases and Regional Innovation Systems: Comparing Nordic Clusters. *Research Policy*, 34(8), pp.1173–1190.

Bergès, B., 2009. Case study of the wind-based rural electrification project in Esilanke primary school, Kenya. *Wind Engineering*, 33(2), pp.155–174.

Byrne, R.P., 2009. Learning drivers: rural electrification regime building in Kenya and Tanzania. *October*, p.288. Available at: http://sro.sussex.ac.uk/6963/.

Carbon Africa Limited, 2015. *Kenya Market Assessment for Off-Grid Electrification*, Carbon Africa Limited.

Dinnewell, L., 2014. Solar energy opportunities in East Africa. Available at: http://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Solar_Energy_Opportunities_in_East_Africa_v2.pdf.

Earley, K., 2015. Phones4Power: Using mobile phones to run micro-grids in Africa. Available at: https://www.theguardian.com/sustainable-business/2015/jun/19/phones4power-using-mobile-phones-to-run-micro-grids-in-afri.

Eberhard, A. et al., 2016. *Independent Power Projects in Sub-Saharan Africa Lessons from Five Key Countries*, World Bank Group.

ERC, 2015. Annual Report. Financial statements 2014/2015.

ESMAP, 2016. *Current activities and challenges to scaling up mini-grids in kenya*, Energy Sector Management Assistance Program (ESMAP).

Ferrer-Martí, L. et al., 2012. Evaluating and comparing three community small-scale wind electrification projects. *Renewable and Sustainable Energy Reviews*, 16(7), pp.5379–5390.

Gichungi, H., 2014. Mini Grid PV Business Opportunities in Kenya.

Gichungi, H., 2011. *Progress Report on Use of Renewable Energy in Off-Grid Areas*, pp. 24.

GIZ, 2015. *How do we license it? A guide to licensing a mini-grid energy service company in Kenya*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

GIZ, 2014. *Where shall we put it? Solar mini-grid site selection handbook*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Gollwitzer, L., 2016. *All Together Now : Institutional Innovation for Pro-Poor Electricity Access in Sub-Saharan Africa*. University of Sussex.

Gollwitzer, L., Ockwell, D. & Ely, A., 2015. *Institutional Innovation in the Management of Pro-Poor Energy Access in East Africa*, SPRU Working Paper Series SWPS 2015-29 (Nov.).

Government of Kenya, 2012. National energy policy: third draft.

Government of Kenya, 2011. *Scaling-up Renewable Energy Program (SREP): Investment Plan for Kenya*, Climate Investment Funds.

GVEP, 2014. *Financing Mini-Grids in East Africa*,

Hankins, M., 2014. On the lookout: Grid connect solar PV in East Africa. *RE Trends East Africa*, (3), pp.1–8.

Hansen, U.E., Pedersen, M.B. & Nygaard, I., 2015. Review of solar PV policies, interventions and diffusion in East Africa. *Renewable and Sustainable Energy Reviews*, 46, pp.236–248. Available at: http://dx.doi.org/10.1016/j.rser.2015.02.046.

Harries, M., 1997. Disseminating Windpumps in Rural Kenya - Meeting Rural Water Needs using Locally Manufactured Windpumps. *Energy Policy*, pp.1–18. Available at: http://gamos.org/publications/Disseminating Windpumps in Rural Kenya - Meeting Rural Water Needs Using Locally Manufactured_Energy Policy.pdf.

Harrington, K., 2016. New Smart Solar Microgrids Speed Up Rural Electrification in Kenya. Available at: http://www.aiche.org/chenected/2016/02/new-smart-solar-microgrids-speed-rural-electrification-kenya.

Hille, G. & Franz, M., 2011. *Grid Connection of Solar PV Technical and Economical Assessment of Net-Metering in Kenya*, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

IEA & World Bank, 2015. *Sustainable Energy for All 2015 - Progress Toward Sustainable Energy*, Available at: http://www.worldbank.org/content/dam/Worldbank/Event/Energy and Extractives/Progress Toward Sustainable Energy - Global Tracking Framework 2015 - Key Findings.pdf.

IREK, 2015. A desk assessment on the overviews of current solar and wind energy projects in Kenya. , X(January), pp.1–24.

IRENA, 2015. *Renewable Power Generation Costs in 2014*, International Renewable Energy Agency (IRENA).

IRENA, 2016. *Solar PV in Africa: Costs and Markets*, International Renewable Energy Agency (IRENA).

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, pp.470–480. Available at: http://dx.doi.org/10.1016/j.rser.2015.04.082.

Kant, A., Masiga, H. & Veenstra, E., 2014. *Market Study to Strengthen Economic Cooperation in the Energy Sector*, Triple.

Malerba, F., 2005. Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technology*, 14(1–2), pp.63–82.

Malerba, F. & Nelson, R., 2011. Learning and catching up in different sectoral systems: evidence from six industries. *Industrial and Corporate Change*, 20(6), pp.1645–1675. Available at: http://icc.oxfordjournals.org/cgi/doi/10.1093/icc/dtr062 [Accessed November 17, 2014].

Moner-girona, M. et al., 2006. Decreasing PV Costs in Africa. *refocus*, (February), p.5.

Ockwell, D. & Byrne, R., 2016. *Sustainable Energy for All. Innovation, technology and pro-poor green transformations*, Routledge, New York.

Oloo, F., Olang, L. & Strobl, J., 2016. Spatial Modelling of Solar Energy Potential in Kenya. *International journal of sustainable energy planning and management*, 6, pp.17–30.

Ondraczek, J., 2014. Are we there yet? Improving solar PV economics and power planning in developing countries: The case of kenya. *Renewable and Sustainable Energy Reviews*, 30, pp.604–615. Available at: http://dx.doi.org/10.1016/j.rser.2013.10.010.

Pedersen, M.B., 2016. Deconstructing the concept of renewable energy-based mini-grids for rural electrification in East Africa. *Wiley Interdisciplinary Reviews: Energy and Environment*.

REA, 2016. for Design , Supply , Installation , Testing and Commissioning of 25No . 60 Kw Solar Pv-Diesel Hybrid Plants in 25No . Trading Centres in Off-Grid Areas.

REA, 2009. *Rural Electrification Master Plan: Electrification Action Plan 2009-2013*, Rural Electrification Authority (REA).

RECP, 2013. *Mini-Grid Policy Toolkit*,

SE4All, 2016. Sustainable Energy for All (SE4All). Kenya's Investment Prospectus. , pp.1–63.

SolarCentury, *Williamson Tea 1 MWp solar farm*, Available at: http://www.solarcentury.com/za/wp-content/uploads/sites/6/2014/05/Williamson-Tea-Changoi-CS-web.pdf.

Ulsrud, K. et al., 2011. The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems. *Energy for Sustainable Development*, 15(3), pp.293–303. Available at: http://dx.doi.org/10.1016/j.esd.2011.06.004.

Vanheule, L., 2012. Small Wind Turbines in Kenya - An Analysis with Strategic Niche Management. *Department of Technology Dynamics & Sustainable Development*, Sustainabl(March).

WinDForce, 2013. *Wind Sector Prospectus: Kenya. Wind Energy Data Analysis and Development Programme*, WinDForce.