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Technological shape and size: A disaggregated perspective on sectoral innovation systems in renewable electrification pathways

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ABSTRACT

The sectoral innovation system perspective has been developed as an analytical framework to analyse and understand innovation dynamics within and across various sectors. Most of the research conducted on sectoral innovation systems has focused on an aggregate-level analysis of entire sectors. This paper argues that a disaggregated (sub-sectoral) focus is more suited to policy-oriented work on the development and diffusion of renewable energy, particularly in countries with rapidly developing energy systems and open technology choices. It focuses on size, distinguishing between small-scale (mini-grids) and large-scale (grid-connected) deployment paths in renewable energy. We explore how the development and diffusion of solar PV and wind technology evolve in these sub-sectoral systems. We find that innovation and diffusion dynamics differ more between small and large than between wind and solar. This has important analytical implications because the disaggregated perspective allows us to identify trajectories that cut across conventionally defined core technologies. This is important for ongoing discussions of electrification pathways in developing countries. We conclude the paper by distilling the implications of these findings in terms of the requirements and incentive mechanisms that shape different pathways.

1. Introduction

Kenya, like many other countries around the globe, is currently facing momentous energy decisions. With a low rural electrification rate and a large proportion of the population currently lacking access to electricity, increasing generating capacity and achieving 100% energy access is a key priority for the government. While the current electricity system relies mainly on hydropower, the expansion of renewable energy (RE) sources, especially wind and solar power, has been given a high priority in national policies such as the national development strategy Vision 2030 and the rural electrification master plan [1,2].

Within the context of a rapidly developing energy system, Kenya faces a number of important technological choices in terms not only of which technologies to prioritise, but also how to deploy them. The current policy frameworks have enabled a combination of government and private sector developments in the energy sector.

The concept of sectoral innovation systems (SIS) has been used to illuminate the factors affecting innovation dynamics within and across sectors. The SIS perspective is particularly concerned with highlighting sector-specific characteristics of industrial evolution [3]. From the sectoral perspective, increasing attention is paid to RE sectors and their development. In this paper, we argue that it is crucial to take a closer look at the RE sector and what constitutes such a sector in order to push further the disaggregation of trends in the sub-sectors of wind and solar PV. In examining differences in terms of size and shape across and between these sub-sectors, we raise questions regarding the definitions and boundaries of these renewable energy 'sectors'.

Thus the key research question of this paper is: *How do wind and solar markets in Kenya differ in terms of development and organisation, both across and within sectors*? We answer this question by mapping out current status and trends across the mini-grid and large-scale market segments for wind and solar PV technologies respectively. Then we use the SIS perspective to describe the characteristics of each sub-sector, their drivers and barriers, and discuss the similarities and differences between them. As detailed and up to date information on the development and dynamics of the solar and wind markets in Kenya were found to be lacking, this paper seeks to bring together preliminary insights from research conducted in 2015–2016.

The paper is structured as follows. Section 2 introduces the sectoral innovation systems approach and its three main dimensions, which are

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used as the analytical framework for the research. Section 3 briefly introduces the research methods. Section 4 presents the results in the form of a mapping of current status and trends across the mini-grid and large-scale market segments for wind and solar PV in Kenya. Section 5 then describes each of the four disaggregated sectoral innovation systems and their characteristics, drawing on the dynamics presented in Section 4. Section 6 discusses the similarities and differences across these sectors using the three main dimensions of the SIS approach as vectors. Finally, Section 7 pulls together the key findings of the research and provides a discussion of how the disaggregated SIS analysis can highlight the coexistence of different innovation systems within broadly defined sectors. It sums up by drawing insights for policy-makers and future research on shaping electrification pathways in countries where the process of electrification is ongoing. Our findings have wider significance because the size and shape of these pathways add-up as defining features of alternative electrification paradigms.

2. Disaggregating the innovation systems approach

Innovation systems approaches are increasingly used for the analysis of development problems, including development problems in Africa [4,5]. The sectoral systems perspective ascribes importance to learning, knowledge and capability accumulation in the innovation process [6]. The SIS perspective is based on the underlying assumption that innovation dynamics are closely related to the specific characteristics of a given sector or industry. Innovation within a sector is a dynamic process, which constantly transforms the structure and boundaries of a given industry. In this paper, the focus is on analysing two low carbon technologies, namely solar PV and wind technologies in Kenya.

While there are profound differences between low carbon technologies [7], the differences within solar PV and wind energy overarching technological categories are equally profound. To give an example, the notion of a ‘solar technology' may be used as an umbrella term to describe solar-powered LED lamps, solar home systems and utility-scale solar power plants. Common to these systems is the fact 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 respective users, producers, investors, actors, prices, scales, R&D intensities, value chains, technical characteristics and competing technologies of these systems [5]. As noted by Stephan et al. [8], understanding such differences in sectoral configurations helps identify dynamics that otherwise go unnoticed. As a result, each of the subcategories of these systems of technology may more appropriately be considered units of analysis in their own right. In the delineation of specific sectors, a key question therefore concerns the selection of an appropriate level of aggregation in the analysis. Accordingly, the case of solar and wind technologies examined in this paper are understood as sub-sectors of the wider renewable energy sector, which in turn is considered a subset of the broader energy sector, and so forth. Initially, Malerba defined SISs broadly as “a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products” [9]. While this broad definition was developed with the intention to be able to cover research conducted at various level of aggregation, most empirical studies in this field focuses on a highly aggregated level of analysis covering the entire pharmaceutical, chemical, telecommunications or biotechnology sectors [6]. In this paper, we adopt a more disaggregated level of analysis in order to uncover in further detail the innovation dynamics within such overarching and broadly defined sectors.

Based on this understanding of technology, this paper distinguishes between small-scale mini-grids and large-scale power plants using solar and wind technologies to generate electricity. Mini-grids are understood as decentralised (off-grid) systems consisting of power-generating assets and distribution with power capacities of between 0.2 kW and 2 MW connecting two or more individual households [10]. 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 description translates into the conceptualisation of four different SISs in Kenya with distinctive sector-specific innovation features, which are explored in the paper: (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 [3]:

- 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 interactions between the firms and organisations involved. The knowledge base in some sectors relies mainly on tacit know-how, craft and practical skills, while others depend more on codified knowledge and formal R&D [11,12]. This means that knowledge created within specific sectors may not be easily acquired and transferred across sectors.

The actors and networks within SIS 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 play an important role, governments, universities, suppliers, financial institutions and NGOs are examples of other actors that take part in the innovation activities of a given sector [3].

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 interactions among actors. These institutional conditions shape the involvement and interactions of actors and influence the learning processes that lead to the accumulation of knowledge and capabilities [6].

Using the SIS approach as an analytical framework also prompts bigger questions as to its strengths and drawbacks. As noted by Kern [13], one criticism of the innovation systems approach is the apolitical nature of its analyses, and while some aspects of politics may be covered by, for example, the institutional dimension of the framework used in this paper, others view the politics as pervasive across all the dimensions and functions of innovation systems. Although an explicit analysis of the agents of change that may reveal the relative differences and similarities of the four sectors is not included, the framework does explore the drivers and barriers for each sector. Revealing the differences and similarities of the dynamics across sectors makes possible a discussion of how policy-makers and stakeholders can take more informed decisions regarding how to nurture renewable energies across complementary sub-sectors. It is important to note here that the under- or over-prioritisation of certain sectors in relation to others is not simply based on technical decisions, but essentially involves political choices and prioritizations. Large-scale solar and wind-energy projects are essentially large infrastructure projects that are typically highly political in nature and that involve a multitude of actors with competing interests and negotiations across various levels. For example, some argue that the push for RE in Kenya is not necessarily being driven by environmental concerns, but rather by the need to provide access to electricity to the highest number of people within the shortest time possible [14]. These authors highlight the tensions that come from pursuing the multiple objectives of ‘growth’, ‘inclusiveness’ and ‘sustainability’ [15]. Few studies have addressed the political economies of the RE sector in Kenya with the exception of Newell and Phillips, who look at transitions in the energy sector more broadly [16].[1] By unpacking the innovation

[1] See also Ahlborg [55].