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The diffusion of a renewable energy technology and innovation system functioning: Comparing bio-digestion in Kenya and Rwanda

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ABSTRACT

Lack of access to modern energy services is a daunting development challenge in sub-Saharan Africa. The promotion of renewable energy technologies (RETs) by development partners and government organizations is one way of meeting this challenge. Despite substantial investment of effort, the diffusion of RETs in Africa has been disappointing, leading to a search for more effective policies and approaches. In this paper, we discuss the role of technological innovation system (TIS) in fostering technology diffusion. We argue that the functional build up of TIS shapes technology diffusion levels in least-developed country settings. We report a comparative analysis of the biogas TIS in Kenya and Rwanda by applying the so-called the 'functions approach to innovation systems'. On this preliminary evidence, we argue that patterns of accumulation of TIS functions may determine rates of technology diffusion. We argue that to ensure accelerated diffusion of RETs, policy attention should be paid to improving the functional performance of TIS.

1. Introduction

Poor access to modern energy in sub-Saharan Africa is among the leading development challenges, demanding a multifaceted effort. Almost 80% of the population in this region (not including South Africa) depends on direct combustion of unprocessed firewood, charcoal, crop residues and animal waste for household energy source [1]. This translates to roughly 625 million people living without access to modern fuel in the region [2]. Over-reliance on traditional biomass sources—by using crude and inefficient technologies—has been known to result in health and environmental hazards [1].

Facilitating the adoption of renewable energy technologies (RETs), such as bio-digesters,[1] has been among the preferred policy responses to this challenge. Bio-digesters can produce modern fuel from organic waste, such as cow dung, called biogas. Using biogas can decrease negative health effects of indoor air pollution and improve environmental sustainability [4].

Despite the health, environmental, agricultural and gender-related benefits of biogas technology, its diffusion in sub-Saharan Africa remains extremely low [4,5]. For instance, Mshandete and Parawira [6] reported that Burkina Faso, Zimbabwe and Sudan combined had less than 350 functional bio-digester units as of 2007. A range of factors are believed to explain the limited diffusion of biogas in the region. This includes high initial cost of bio-digesters compared to income of most rural households [7,8]. Even when a household has the capacity to afford a digester and has the minimum required number of cattle for producing dung, adoption of biogas is often limited due to lack of awareness about the benefits of the technology [8,3]. Limited technical capacity is another factor resulting in poor technical design and construction [3,4]. This, coupled with insufficient provision of after-sales services, including routine maintenance, results in large-scale non-functionality of installed digesters [4,9].

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[1] A bio-digester refers to a container that ferments organic substances under anaerobic (air-free) conditions. The result of anaerobic digestion is a combustible gas composed of 50 to 70% methane, 30 to 40% carbon dioxide, traces of hydrogen sulfide (H_2S), ammonia (NH_3) and water vapor called biogas [3].

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Non-functionality of digesters decreases reputation of the technology, further damaging its broader diffusion [8].

This complex situation has initiated, and will continue to require, public intervention from governmental and non-governmental actors over the course of the introduction process of bio-digestion in many African countries. This, includes capacity building initiatives, such as training, financial mechanisms targeted to make digesters affordable, such as subsidies, and so on [7,3]. However, our understanding on how these activities influence the diffusion rate of bio-digesters is limited, so that policies to encourage dissemination and use of biogas plants and other RETs continue to be unfocused.

This paper takes up this key issue by analyzing the institutional aspect of the diffusion of biogas in Kenya and comparing it to that of Rwanda. For this purpose, it starts out with the observation that it is now widely accepted by innovation scholars that the development, diffusion and adoption of technologies involve both collective and individual efforts [10]. What this implies is that innovation processes are influenced not only by techno-economic factors, but also by the prevailing institutional context, such as the capabilities and incentives of actors and the influence of public policies. This context, which comprises interactive actors and institutions around a specific technology, has been called a technological innovation system (TIS) [11].

Recent insights suggest that TIS facilitates the creation of markets and the development of entrepreneurial activities around technologies by fulfilling key activities and processes. These activities and processes—also known as system functions—create legitimacy, provide resources, generate guidance for potential firms, users and other actors towards a new technology, and so on [12–14]. Through these functions, TIS influences the diffusion and adoption of new technologies into new social and economic settings [15,16]. It follows that diffusion of technologies would be enabled by improved functional performance of the relevant TIS. Few empirical studies have sought to show this link between the functioning of innovation systems and rates of technology diffusion. Hekkert et al. [17] have stated that whereas the functioning of Dutch cogeneration technology explains the diffusion of the technology, "[m]ore case studies are necessary to generalize this observation for technology diffusion in general." Moreover, most TIS research has been done in highly-developed countries; and it is not clear if the theoretical insights of the TIS approach are generalizable to least developed countries. An important difference is that institutions tend to be weak and fragmented in developing countries, and we expect this to influence the emergence of TIS for new technologies. Additionally, these TISs are driven by development assistance from international donors and nongovernmental organizations.[2] The purpose of this paper is to examine how the functioning of TIS in developing countries is related to technology diffusion rates by analyzing the functional evolution of the TIS of bio-digesters in Kenya and Rwanda.

In line with previous analyses of TIS using the concept of the system functions (see for example [15–19]), the analysis in this paper relies heavily on comparison of the two TIS on the basis of assessments of their functions and the level of diffusion they have achieved. The reason for comparing the two cases is the significant differences in achieved installation rates of biodigesters as compared to estimated technical biogas potentials of the two countries.[3] The Rwandan biogas TIS covers a decade of development, ensuring a total installation of about 1400 digesters. This corresponds to an annual installation rate of about 0.12% of the technical potential (which is about 117,000 digesters). In contrast, The Kenyan biogas TIS shows five decades of development. However, in its first four decades of evolution, it achieved a total installation of only 1300 digesters. This corresponds to an annual installation rate of about 0.004% of the technical potential (which is about 800,000 digester units in that period). This difference in outcomes for two less-developed countries without prior biogas experiences (before the studied periods) represents an opportunity to analyze the causes in terms of the evolution and functioning of the two TIS.

We find that the accumulation of functions along with the strength of interaction between functions is related with higher diffusion rates. We also describe the pattern of the build-up of TIS functions. We find that government actions in support of a technology create a signal for engagement of governmental and non-governmental actors. Such guidance leads to the development of other functions. The accumulated functions create economic incentives, social legitimacy, policy guidance, technical capability, awareness, demand and increased commercial experimentation, enhancing the diffusion of technologies.

The paper is organized as follows. In Section 2, a brief explanation on the theoretical approach is given. In Section 3, we describe the methodology employed to analyze the empirical data. In Section 4, the functional evolution of the Kenyan and Rwandan bio-digestion TIS and their performance in terms of installed digester units are described. Section 5 provides a comparative analysis of the two cases and Section 6 finishes with some concluding remarks and policy insights.

2. Theoretical background

Analyses of the (determinants of) diffusion of innovations in least developed countries (LDCs) have historically focused on the techno-economic features of the innovation and communication and individual characteristics of adopters that determine adoption decisions. Thus, research attention was mainly on the (potential) user side to understand the factors influencing adoption decisions; for an overview, see Siegel and Rahman [20] and Jan [21]. However, innovation scholars have increasingly contextualized the diffusion and adoption of new technologies as part of the overall innovation process [12,22–24]. One justification for this is the evidence that adoption of a new technology and its use entails learning, adaptation and capability development among users of a technology [25,26], which often

[2] Given this role, it may be interesting to analyze the interaction between international and national structures and what role this may have on the buildup of TIS. However, in this paper we are not going to analyze this aspect of the systems.

[3] Technical potential of biogas in the context of this paper refers to the number of household digesters that can be potentially installed in a country taking into account of household resource potentials. Therefore, it corresponds to the number of households in a country (at a specific period) that have sufficient resources, such as feedstock, to adopt a family-sized biogas plant.