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A system of innovation? Biomass digestion technology in Tanzania

Astrid Szogs[a,*], Lugano Wilson[b]

[a]*Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Lund University, MNO-huset, Sölvegatan 16, Box 117, SE-22100 Lund, Sweden*

[b]*Energy Engineering Department, Faculty of Mechanical and Chemical Engineering, University of Dar es Salaam, P.O. Box 35131, Dar es Salaam, Tanzania*

Abstract

If least-developed countries (LDCs) are to participate effectively in the bio-economy, several key areas need to be developed, including market access, international biotech alliances, protection and regulation, and risk management. Using a case-study approach, we identify and map the players in the field of biomass digestion technology in Tanzania and analyze to what extent a system of innovation can be identified. Specifically, the collaborations, markets, and technological capacity in the field of biomass digestion technology are examined. Through an in-depth analysis of two cases, we find that a system of innovation can be identified, and that major challenges exist with respect to financing and supportive policies. Whether this is a common characteristic for creating systems of innovation in developing countries needs to be further researched.

Keywords: System of innovation; Innovation; Biomass digestion technology; Policy enforcement; Least developed countries; Tanzania; Digestion; Risk management; Biotech; National systems of innovation

1. Introduction

The aim of this paper is to determine the extent to which we can identify a system of innovation for biomass digestion technology in Tanzania. We analyze existing alliances and technological networks in biomass digestion technology. We also examine options for market access and existing and potential policy frameworks in Tanzania for this specific sub-field of biotechnology. Despite numerous scientific advances in biotechnology in industrialized countries, several factors can be identified that allow developing countries to participate in biotechnology. Among them are:

- A growing recognition that current patterns of globalization are not achievable if they do not include developing-country products. Most of these countries depend on industries that are based on natural

*Corresponding author. Tel.: +46 222 0298; fax: +46 222 4161.
E-mail address: astrid.szogs@innovation.lth.se (A. Szogs).

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resources (particularly agriculture), which can add increased value to their products by using modern biotechnology.

- Many of the techniques used in biotechnology research are becoming more readily available because of scientific familiarity; therefore, they are relatively easy to acquire through sustained capacity and enterprise development efforts.
- Much of the initial R&D expenditures have already been made by industrialized countries; what is needed is effective international technology partnerships [1].
- Biotechnologies have a key role in meeting obligations under the Kyoto Protocol, and developing countries offer a potential supply chain [2].

The extent to which developing countries can take advantage of these opportunities depends on the level of domestic technological capacity[1] and the "global biotechnology governance system that emerges from the current policy debates," one that "provides opportunities for market access will help foster the commercialization of new technologies" [1]. Furthermore, innovative local biomass policies are needed in order to realize emerging opportunities.

Participation in the biotech sectors of least-developed countries (LDCs) will be limited to countries that invest in the requisite technological development. In light of this, we chose to examine the state of biomass technology in Tanzania with respect to its potential for becoming a global player. We also sought to map state-of-the-art biomass technologies in Tanzania.

Our decision to investigate biomass digestion technology came about because of earlier research in other areas where

> … much of the research on policy aspects of biotechnology has focused on agricultural and pharmaceutical biotechnology. The field of industrial and environmental biotechnology remains understudied. Industrial biotechnology covers two distinct areas. The first area is the use of renewable raw materials (biomass) to replace raw material derived from fossil fuels. The second is the use of biological systems such as cells or enzymes (used as reagents or catalysts) to replace conventional, non-biological methods [1].

Industrial biotechnology has received less public policy attention than biotechnology in other sectors.

Tanzania is the largest country in East Africa and also among the poorest countries in sub-Saharan Africa. Following its independence from Britain in 1961, Tanzania inherited a small and unvaried industrial structure dominated by simple consumer goods and primary processing activities. Although there is today an awareness of the importance of research and development for future development, the impact of policies in the Tanzanian industrial sector is still weak, and the rate of commercialization and utilization of the few R&D results has been insignificant [4]. Also, a shortage of industrial skills, as well as institutional weakness, are factors that hamper industrial development [5].

It has been argued that at least five key areas of governance systems need to be adjusted if developing countries hope to participate effectively in the bio-economy. These are: market access, international biotechnology alliances, intellectual property protection, regulation, and risk management [1]. Therefore, it is important to view activities in this field from a systemic perspective, and to investigate which parts of the innovation system are well-integrated and functioning properly and where the system is fragmented and still developing. Using an innovation system approach, we examine and identify key possibilities as well as challenges and constraints with respect to these five key areas.

1.1. Objectives and research questions

Our objective is to map the biomass digestion technology situation in Tanzania, and analyze to what extent we can identify a system of innovation. This objective includes to map key players in the field as well as to identify primary applications of biomass digestion technology in Tanzania.

[1]Technological capacities include "the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages" [3].

Research questions therefore are the following:

- What are the main players in biomass digestion technology in Tanzania?
- What constitutes the innovation system?

1.2. Methodology

Our research was designed using a case-study approach. The rationale for this choice rests mainly on the qualitative nature of the research questions, as a case-study approach is believed to be essential for answering such questions. According to Yin [6], a case-study approach is suitable when the objective is to explain how-and-why questions that consider specific developments that occur.

Generally, case-study research strategies are suitable when the research aims to offer a description, to test, or to generate theory [7]. To offer a description is part of the aim of this research work.

Concerning sources for data collection, Yin [6] argues that a case-study approach needs to be understood as a comprehensive research method that deals with a range of different sources of evidence, for instance interviews, documents, surveys, and observations. By including documents, interviews, and observations in the study, an easier construction of study validity can be provided. Hence, this study draws on a number of sources of evidence, including policy documents, opinions, statements, regulatory texts, and interviews. More specifically, the documentary research is based on systematic searches of scientific literature, and primary source materials on biomass digestion technology that originated from players in the field.

1.3. The technology

In this paper, ''biomass digestion technologies'' refers to biomass thermochemical conversion processes that are commonly used to extract useful energy and fuels from biomass streams. To achieve this, the processes deploy combustion, gasification, or pyrolysis. Among these, biomass combustion has a wide application in Tanzania both at the household level and for industrial applications.

Biomass combustion technologies that have undergone considerable innovation in Tanzania are improved stoves and biogas technologies for household energy use, and the application of co-generation (the simultaneous production of electricity and process steam or another secondary thermal energy) for the industrial energy supply. This paper focuses on improved stoves and co-generation digestion technologies. While individual firms have implemented co-generation, improved stove technologies have benefited from a collaborative effort that includes the government, non-government organizations (NGOs), community-based organizations (CBOs), research institutions, universities, and the private sector. These form a network of innovation, which we will consider.

2. Theoretical framework

We investigate whether a system of innovation for biomass digestion technology in Tanzania can be found, and if so, map the players in such a system. Therefore, a framework is needed that explicitly addresses innovation and innovation systems. In the following, we briefly define innovation and introduce the concept of innovation systems. We also discuss the possibility of applying this concept in developing countries.

In its broadest sense, innovation can be described as ''the first application of knowledge in a new way, with commercial success'' [8]. Another important feature of innovation is its process nature, as illustrated by Kline and Rosenberg's interactive model [9]. They emphasize the dynamic exchanges between internal and external sources of knowledge, and indicate the importance of interactions between different players in the field. Interactions are accomplished through different learning processes, that is, the interactions are channels for various kinds of learning. The innovation system approaches view innovation as emerging out of an interactive process that takes place between firms and institutions. This fits well for purposes of this paper; hence, the conceptual foundation for our analysis lays in the national systems of innovation (NSI) approach.

Innovation systems are defined as "a network of institutions, public or private, whose activities and interactions initiate, import, modify, and diffuse new technologies" [10]. This implies that successful technological change is determined by factors such as the institutions surrounding the firm that is developing and adopting new technologies. Innovation is not seen as a linear process from basic research to product development, but is characterized as an interactive and dynamic process that evolves over time. Therefore, the interconnections among institutions, and how they interact, are crucial for investigating and building an innovation system. These interactions may be technical, commercial, legal, or financial, with the overall goal being the financing, development, protection, and/or regulation of new science and technology [11].

The NSI concept gained considerable attention from researchers in institutional economics and innovation and from policy makers [12–18]. It is a suitable framework for analyzing the activities and players that are working together in the production, diffusion, and adaptation of new technical knowledge. This concept also allows us to examine how efficiently the systems are working with respect to promoting new scientific knowledge into society and its ensuing commercialization. The innovation system approach [18–20] deals with the strategic use of interactive learning and economically useful knowledge. The strategic use and sale of innovations and knowledge is becoming increasingly popular, and they represent a new investment trend toward economic liberalization in developing countries. Innovation system approaches have emerged out of the general recognition that there supposedly exists a connection between innovation and the economic performance of firms, industries, and nations.

When investigating whether there is an innovation system for biomass digestion technology in Tanzania, we will apply the innovation system concept in a developing-country context. To do this, however, a few factors must be considered. First, this concept generally has been applied to and emerged from developed countries that have strong and well-developed systems that adequately support the innovative activities taking place. The inadequacy and inappropriateness of the institutional infrastructure and physical and human resources in LDCs requires researchers to question whether this approach is useful in the context of LDCs. Investigators also need to be aware that the technology environment in the sub-Saharan South (excluding South Africa) differs greatly from that of the countries north of the Sahara when it comes to formal structures and institutions. There is an immense technological gap between developed and developing countries, with the technological capacity of the developing countries being quite low,[2] and most of the sub-Saharan African countries have so far been unable to narrow the gap. In industrialized countries, the system concept refers to the integrated nature of the interactions that are taking place. However, as Narula [22] argues, systems can be "incomplete" or "unbalanced" in the sense that "some aspects of the systems are inefficient or simply nonexistent."[3]

With respect to the validity or applicability of an innovation system view of investigating learning and innovative activities in a developing country, important contributions have recently been published in a book on *The Making of African Innovation Systems* [23]. As the title indicates, an important finding in the present state-of-the-art innovations in developing countries is that researchers are often not yet in a position to analyze existing innovation systems. In many countries, they can only observe the state of building the innovation systems. In the same book, the authors acknowledge that "doubts may be raised about the very existence of national systems of innovation on the African continent," and there is an awareness that "innovation in the sense of radical innovation in products and processes is a scarce phenomenon in Africa especially if we hereby imply innovations new to the world market" [24]. One can also argue that "the NSI is more relevant in the African context precisely because the nation along with the innovation, and the systems, are yet to be made" [25].

Taking in account the various realities regarding technological development and innovation in Africa, it becomes obvious that some rethinking of the NSI concept may be necessary. Our empirical findings certainly confirm this need. Johnson and Lundvall [24] have suggested several aspects that are crucial if the NSI concept is to be made relevant in an African context. These are: including all sectors in the analysis; including all

[2]Technological capacity represents the stock of technology-producing assets (e.g., R&D laboratories, learning institutions, scientists and engineers, the accumulated experience of public and private institutions, and the knowledge of managers and workers [21]).

[3]This does not mean that once systems are well established and complete, they will continue "*ad infinitum*" with this "happy state of affairs" [22].

aspects of innovation, meaning to include "diffusion, imitation, and use of new technologies together with all forms of competence building—spanning from learning at the job by workers and farmers to the formal training of scientific personnel" [24]. Moreover, it is argued that "we need to change the focus from the reproduction of the system to its construction" and finally the "wider living conditions and how they affect learning and innovation" needs to be considered [24].

Factors that determine industrial success in developing countries have also been referred to as comprising a "national industrial learning system," whereby the "main elements interact with each other in a systemic way to influence enterprise capability development" [26]. Lall uses this concept as being similar to that of NSI but prefers the use of "national learning systems" in order to accent the focus of developing countries on mastering and using existing technologies rather than with innovations. Lall sees a well-working industrial learning system as one in which companies manage to "access, absorb, master, adapt and deploy in production modern technologies and over time, develop innovative activities" [26]. Increasing interactions between firms, R&D institutes, and technology and training institutions characterize the new technological setting, which is observed more and more in developing countries.

Based on this theoretical framework, the main goal for the case studies that follow is to show whether we find interactions between players in the biomass digestion technology field, and whether these interactions constitute a system of innovation.

3. Case studies

We present two cases that involve biomass digestion technologies in Tanzania, while also providing information on the policy and legal frameworks in the country.

The first case for analysis is improved stove technology, which is being disseminated by Tanzania Traditional Energy Development and Environment Organization (TaTEDO), a NGO based in Dar es Salaam, Tanzania. TaTEDO develops and disseminates improved stoves in both rural and urban Tanzania.

The second case involved biomass co-generation, which is being deployed by a tannin processing plant known as Tanganyika Wattle Company (TANWAT) and two sugar processing companies namely Kilombero and Mtibwa. TANWAT uses wood logs in its co-generation plant whereas the sugar companies utilize bagasse. However, the wood logs and bagasse generate process residues that could lead to high disposal costs or pose an environmental problem when disposed of by means such as open-air burning.

3.1. Improved stove technologies

Since the early 1980s, the government of Tanzania has been at the forefront in developing and disseminating household biomass energy technologies throughout the country. This is done through the Ministry of Energy and Minerals. Programs are financed by international donor agencies such as the International Development Association (IDA), a World Bank institution. Local projects are implemented by groups such as TaTEDO, the Centre for Agricultural Mechanization and Rural Technology (CAMARTEC), Sokoine University of Agriculture (SUA), Miradi ya Gesi ya Samadi Dodoma (MIGESADO), Small Industry Development Organization (SIDO), and various religious organizations. This has resulted in increasing adoption of biomass digestion technologies, so that today Tanzania is a leader among African countries in the use of biogas technology, having installed over 4000 units for both domestic and commercial applications [27].

TaTEDO was among the first agencies to implement the government's program on biomass digestion technology in Tanzania, and it is now actively involved in developing and disseminating improved stove technologies. Its main objectives are to increase biomass fuel conversion efficiency from about 10% with traditional stoves to over 25% using improved stoves. Consequently, the rate of adoption of the improved stoves is a measure of environmental conservation, while also reducing indoor air pollution and the associated harmful health effects.

Besides the government, other TaTEDO collaborators include the donor community, foreign collaborators, NGOs, CBOs, R&D organizations, universities, local governments, and the private sector. In particular, the government, donor community and foreign collaborators have been responsible for financing TaTEDO projects and providing the necessary technical know-how. In addition, research organizations such as

Tanzania Industrial Research and Development Organization (TIRDO) and the University of Dar es Salaam, support TaTEDO in technical issues while developing specific biomass digestion technologies, and evaluating the performance of improved stoves [28–30].

When implementing its projects, TaTEDO interacts with NGOs, CBOs, local governments, and the private sector. These are either the project beneficiaries or are undertaking a specific project role. For instance, TaTEDO collaborated with an NGO based in Shinyanga region known as Hifadhi Ardhi Shinyanga (HASHI) to disseminate improved stoves in semi-arid, rural Shinyanga areas [31]. TaTEDO is also collaborating with a private company based in Arusha known as Kampuni ya Kusambaza Tekinolojia (KAKUTE), which is developing a wick stove that utilizes *jatropha culcas* oil and targets its application in semi-arid, rural Arusha areas [32].

Such technological collaboration includes interactive learning processes between the players. For instance, while TaTEDO obtains access to technology and know-how, the government and donor community become better informed on biomass digestion technologies and their adoption in areas of interest. They further benefit by meeting the specific objectives of the projects being implemented. R&D organizations and universities foster knowledge in the community by participating in these projects. Generally, the community benefits from using products that have been developed and information from reports and publications. The source of knowledge is from project owners (i.e., donors, foreign companies, and the government) as well as from input by the university and R&D institutions. It is important to understand that the knowledge source in some cases takes on a dynamic character since, even when foreign knowledge is applied, it must be adapted to local conditions in order to achieve the best output. For instance, while disseminating improved clay stoves in Shinyanga region, HASHI needed to adopt local knowledge about suitable clay availability and treatment; at the same time, the project introduced appropriate stove designs, knowledge of the sand-to-clay ratio technique, a chimney, and efficient clay firing kilns.

To date, Tanzania has an acceptable capacity of local technology regarding improved stove technology. There is also a growing local market for emerging new products. However, both the capacity and the market are localized in urban centers, but their diffusion in needy rural areas remains limited [33] because of limited dissemination programs and the absence of incentives that encourage their applications.

3.2. Biomass co-generation technology

Biomass co-generation technology has the potential to utilize abundantly available biomass residues to generate heat and electricity. As biomass is a renewable resource, the technology is environment friendly compared to petroleum-based fuels. By providing a decentralized energy and power supply, biomass co-generation has important potential for rural electrification, and is a tool that can be used to enhance social and economic development.

The TANWAT co-generation plant produces steam energy and electrical power (2.5 MW) to run the tannin processing plant, and the excess power (40%) is sold to the national grid under a power purchase agreement with the electrical utility provider, Tanzania Electric Supply Company Limited (TANESCO). Similarly, Kilombero and Mtibwa sugar companies produce process steam and electrical power amounting to 32.3 MW [27].

These co-generation plants are privately owned. Because they are financed on a recourse basis, all project risks are borne by the owners. In order for these plants to become independent power producers, they need to be financed on a non-recourse or limited-recourse basis in which the debt is secured against a commercial contract arranged for the project duration. Besides the power purchase agreement, contracts include a fuel supply agreement, a site lease agreement, an operating license, a water supply agreement and, in the case of a co-generation plant, a steam-supply agreement [34]. These agreements must be finalized prior to closure of financing, and all project risks are allocated. Since biomass digestion technologies are usually allocated for harnessing abundantly raw materials, it means that the associated costs of collection and transport are minimal. Because these kinds of innovative financing arrangements are not yet available, few co-generation opportunities can be found in Tanzania. However, the potential is there: Tanzania has an estimated biomass co-generation potential of 157 GWh, of which only 9% had been developed by 1995 [35].

3.3. Policy and legal framework

The application of cleaner technologies that utilize indigenous raw materials has been acknowledged in major policy documents, including the National Energy Policy of Tanzania [36], the National Science and Technology Policy for Tanzania [37], the Development Vision 2025 [38], and the National Environmental Policy [39]. However, all lack specific mandates for the application of biomass digestion technologies. Consequently, adoption of these technologies will occur only on the merits of the end users. Conducive policies and enforcements with targeted incentives are necessary in order to accelerate the application of biomass digestion technologies.

4. Analysis

We applied the concept of innovation systems in an LDC context to ascertain whether the key players in the field of biomass digestion technology in Tanzania are linked with each other through various activities, or if they are operating in isolation and no systemic interactions have yet been developed. Due to poor national infrastructure, we found that the nature of the system is more fragmented than what would be expected in industrialized countries with well-established systems and an adequate socio-economic infrastructure with institutions that support innovative activities taking place within the system.

We identified and mapped the players, and then examined how well they interact; also where challenges or hindrances exist that could hamper further development of technologies in the field of biomass digestion technology. We found that the key players in the field of biomass digestion technology are local players in both the public and private sectors. We found international developers of the technology and users in the local domain. Foreign players also play a role in financial matters.

Analyzing this empirical material, we found one case involving an NGO, and one where a private player is the main developer of the technology. Accordingly, we also found that financing of the projects was different, with the NGO being financed by an international donor and government, while co-generation companies are self-financed.

Both cases found that improved stove technologies have, with the financial help of international donors, been developed by local players in Tanzania. Currently, considerable local technological capacity exists, and from a technical point of view the cases showed that Tanzania has invested (partly through foreign aid) in the development of improved stoves technologies. Financial support helped develop improved stove technologies, which was achieved by local players. More specifically, some stove design was international and adopted locally, while some new designs also emerged.

The market for these improved stove technologies is households in rural and urban Tanzania—mainly a domestic market. With current technologies and today's market, it seems that Tanzania will develop further in this area and expand its domestic market, perhaps even becoming a global player. Given that there is noticeable innovation, it is possible to develop designs that will attract international or regional markets in the near future.

The case of biomass co-generation shows that local companies are utilizing technologies that were developed at the international level. These companies financed the technology on their own initiative, and thereby they bear all the project risks. In this case, in the areas of technology development and dissemination, financing, and protection, local players are fragmented. Although the biomass co-generation technology has the potential to boost rural electrification for developing countries like Tanzania, the adoption rate of the technology is still quite low.

It was stated earlier that the overall goal of an innovation system is "the financing, development, protection, or regulation of new science and technology" [11]. In the case of improved stoves, financing has worked reasonably well compared to co-generation. It is clear, however, that financing is crucial for bringing about additional innovations. Further development of an improved stove technology has worked well and a well-developed system is in place, even though challenges remain in the area of enforcement policies. In contrast, the biomass co-generation system is still fragmented in most areas.

We were able to identify various interactive learning processes that form innovative linkages between some of the players in the field of improved stoves. We found clear evidence of systemic interactions between some

of the players, and interactive learning occurs. With regard to policies, however, there are still gaps in the system. For instance, innovative local biomass policies are still needed in order to realize additional opportunities in biomass co-generation, and more enforcement is crucial for further uptake of the developed improved stove technologies. Without such policies in place, the potential of emerging biomass technologies cannot be realized.

5. Conclusion

Our intention was to identify key players in the field of biomass digestion technology in Tanzania and to investigate whether a system of innovation exists. Our research found that the various identified players in the field of improved stove technologies are interlinked with each other, and that interactive learning takes place between them. The linkages led to innovative activities and outcomes. Thus, our systemic approach to activities in this field confirmed that a system of players does exist, and that development of new technologies and knowledge takes place. The system is highly efficient in terms of mutual learning between developers of the technology and the users. However, major gaps could be identified on the area of enforcing policies. The lack of efficient policies hinders the full realization of the potential of some of the technologies. We saw clearly how a mismatch between state-of-the-art developed technologies in the field and supporting policies constrains innovation. To fully develop an innovation system that works well and supports innovative activities, greater emphasis is needed in the area of policies.

We found that biomass co-generation has received only fragmented support, and key players (i.e., private companies) act independently. Therefore, dissemination of the technology is low, and financing is not well established. Innovative policies are needed to disseminate and support the development of biomass co-generation technology.

Applying the NSI approach enabled us to understand and map a variety of collaborations in the field of biomass digestion technology. This revealed that in the case of co-generation technology, weak support is given and innovations are poor. In contrast, in the case of improved stoves we found strong evidence that some innovation is taking place due to existing collaborations between the players, combined with a beneficial financing situation.

We conclude from the case studies that financing is the major issue. However, this is clearly linked with an existing, insufficient institutional arrangement that gives little security to high investment—even though these investments would be environmentally, socially, and economically attractive. It may be valid to generalize from our findings that financing plays a crucial role. It is even more important to understand this as interlinked with policies, hence, the need to work on supportive policies. However, further research is needed to back up this observation.

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Astrid Szogs is currently a Doctoral Candidate at the Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE) at Lund University, Sweden. She is being trained by leading scholars in the development of systems of innovation. In her current research, Ms. Szogs is investigating the role of institutions in emerging fields of biotechnology. She also has specialized in understanding science, technology, and innovation in a developing-country context. She has conducted research in Africa, and published articles on the emergence and characteristics of systems of innovation in Tanzania.

Lugano Wilson is a Research Assistant in renewable energy with the Department of Energy Engineering, Faculty of Mechanical and Chemical Engineering at the University of Dar es Salaam, Tanzania. He previously served as Senior Research and Development Engineer,

as well as Head of Energy and Environment Technologies Division at Tanzania Industrial Research and Development Organization (TIRDO). While with TIRDO for over 14 years, Mr. Wilson supervised and implemented projects in the fields of industrial energy auditing, renewable energy technologies, and environmental management. The principal focus of his work in biomass technologies is design and development, performance testing, and dissemination of the technologies in rural Tanzania. Mr. Wilson has also served as a consultant in energy and environment, and has written and presented over 40 papers and technical writings.