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Understanding the diffusion of domestic biogas technologies. Systematic conceptualisation of existing evidence from developing and emerging countries

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ABSTRACT

Accelerating the diffusion of domestic biogas is considered to be a promising option for reaching the goal of universal access to energy by 2030, particularly for the provision of cooking energy for rural populations in developing countries. The aim of this study is to develop a systematic account of the factors that influence the diffusion of domestic biogas technologies. To achieve this objective, a three step analysis approach is applied. In the first step, a conceptual model is built based on insights from scholars that have been studying the diffusion of energy innovations in rural contexts. In the next step, a qualitative content analysis of scientific literature is undertaken to test and refine the categories proposed by the conceptual model and to systematically organise the empirical evidence of the factors that influence the diffusion of domestic biogas in developing and emerging countries. The systemised evidence is used to identify the components and interactions between the household configurations and socio-economic context that determine both the adoption process at household level and the overall technology diffusion. Finally, in the last step, we reflect on the implications of the resultant systematic conceptualisation regarding the purpose and design of programmes promoting the dissemination of domestic biogas technologies.

1. Introduction

Domestic biogas is considered to be a clean cooking alternative for the rural poor in developing countries. Accordingly, accelerating the diffusion of domestic biogas plants is expected to significantly contribute to achieving the ambitious goal of ensuring universal access to modern energy services by 2030 [1]. Domestic biogas is not, however, a new idea and first initiatives developing practical designs appropriate for single households or farmers can be traced back to the first half of the 20th century.[1] There has even been mass dissemination of the technology in some Asian countries for decades. For example, more than 26 million plants had been installed in China by 2006 [5]; in India around 4.75 million plants were reported to have been installed by 2014 [6]; and from 1992 to 2013 over 260,000 plants were installed in Nepal [7]. These programmes have been dependent on the continuous and long-term political support from central governments and have led to the emergence of nationwide institutional structures. In contrast, installation rates for domestic biogas plants (the main parameter for measuring the diffusion process) are somewhat marginal in countries where such programmes have not been established. However, global interest in broadening the diffusion of domestic biogas has been growing and during the last decade national biogas programmes have been launched in some Asian, African and Latin American countries.

Domestic biogas refers to the application of anaerobic digestion in order to provide an individual household (generally rural) with services such as the treatment of wastewater and the supply of fuel for domestic use (e.g. cooking). The central component of a domestic biogas plant is the digester (also called the biodigester), which is the container where the anaerobic decomposition of organic matter takes place. There are numerous types of digesters, which vary (among other characteristics) in their geometry, construction materials and installation requirements. [8,9] Digesters for domestic applications are commonly no larger than 10 m^3 (see Table 4). In addition to the digester, a biogas plant comprises other components, such as pipes, valves and additional containers (e.g. for feeding purposes and for the storage of treated slurry). [10,11].

Critical assessments of the suitability of such technical configurations to improve the livelihood of the rural poor, as well as of the

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[1] Some examples of early designs and applications include the patented design and its commercialisation by Mr Lo Guo-Rui in the 1930s in China [2], first installations of early designs under real conditions in Indian rural households during the 1950s [3] and the demonstration of the technology at a school in 1955 in Kathmandu, Nepal [4].

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effectiveness of mass dissemination programmes, have been emerging. One notable strand of criticism contests the general assumption that domestic biogas technologies are appropriate for addressing the developmental needs of the poorest. Indeed, the applicability of biogas technologies is constrained by access to specific resources such as water, manure, land and financial capital. Insufficient levels of these resources are more likely to be found in poor households. [3,12,13] Another area of controversy is related to the adequacy and effectiveness of programmes fostering the mass dissemination of the technology. One central concern is the lack of individual motivation in the diffusion process; the high rate of diffusion achieved by successful programmes has been driven by concrete plant installation targets and corresponding subsidy schemes, whereas user commitment and motivation to adopt the technology remains low [14–16]. Related to this, poor user management practices and a lack of follow-up services (e.g. maintenance) are often reported, which lead to malfunction or, in the worst case scenarios, abandonment of the systems [16–20]. The actual number of functional plants (behind the impressive total installation figures) is often unclear. Chen et al. estimate that, "of the 26.5 million biogas digesters in China's rural areas, only 60% ... were operating normally" [5]. In India, the rate of "acceptance" of installed plants varies between 40% and 70%, according to Bhat et al. [16].

Although interest in broadening the global diffusion of domestic biogas has been growing, systematic understanding of the particular factors and specific circumstances which result in successful programmes is still lacking. This is relevant because domestic biogas programmes are expected to disseminate the technology under different environmental, social, economic and political conditions. Therefore, the central objective of this study is to develop a systematic description of the factors that influence the diffusion of domestic biogas technologies. The research comprises three stages. (i) In a first stage a conceptual model is developed in order to analyse the diffusion process of domestic biogas in developing and emerging countries. For this aim we build on insights from academics who have studied the diffusion of rural household innovations, particularly the case of energy for cooking, by adapting and complementing their conceptualisations and, thereby, further advancing the concept by taking into account the socio-technical particularities of domestic biogas technologies. (ii) In a second stage the proposed conceptual model is used to organise the empirical observations reported by studies analysing domestic biogas dissemination programmes in different geographical contexts. This step serves two purposes; on the one hand to test and refine the model against available empirical evidence, while – on the other hand – complementing the proposed conceptualisations through the systematisation and description of factors that proved to be particularly influential for the reviewed empirical processes. (iii) In a final stage we reflect on the implications of the resultant systematic conceptualisation regarding the purpose and design of programmes promoting the dissemination of domestic biogas technologies.

2. Conceptual framework–a system perspective on the diffusion of domestic energy innovations

The process by which households in developing countries change their pattern of domestic energy consumption has long been the object of research by scholars from different disciplines. The simplest conceptualisation is the so-called 'energy ladder' hypothesis [21,22]. While the energy ladder was extensively applied by studies on domestic energy transitions in the 1990s and 2000s, evidence highlighting deficiencies of the model accumulated and some scholars started to emphasise the need to abandon the idea of 'fuel switching' (which derives from the straightforward application of the energy ladder hypothesis), as well as other oversimplifications of adopters' behaviour [23–26].

Accordingly, Ruiz-Mercado and her colleagues developed more comprehensive models of the process by which new energy devices and practices are adopted by members of a given social system [27]. Their analysis is focused on the adoption and diffusion of so-called improved cook stoves (ICS), i.e. stoves that allow the use of traditional biomass fuels, like firewood and charcoal, but whose designs reduce the negative impacts linked to cooking with open fires or traditional stoves, particularly indoor pollution, poor health, deforestation and climate change. The basic assumption of their model is that the adoption of a new cooking device is a process which "takes place in a dynamic system with strong interactions between the user, the technology, the fuels and the larger socio-economic and ecological contexts". The introduction of the new stove in a household initially disrupts the existing dynamic system and the adoption is the process by which a new state of equilibrium is achieved. The outcome is a modified set of cooking practices, in which each fuel-stove option available is applied where it performs best as perceived by the user. For instance, the preferred fuel-stove option for boiling might differ to that frying or grilling.

The system perspective proposed by Ruiz-Mercado and her colleagues shifts the focus from the fuels or the stoves to the user's cooking system. The cooking system comprises material components (fuels, stoves, kitchen etc.) and non-material elements (practices, traditions etc.). The goal of preparing cooked meals is achieved through the interaction between these two kind of elements. This model is able to reproduce the coexistence of multiple stove-fuel options – evident from several studies in different countries – and moves the emphasis from the initial adoption of the new device to its actual use over time. In order to apply this system perspective to the case of domestic biogas innovations we propose to broaden the model in two ways; the first relates to the socio-technical differences of the innovations considered and the second aims to generate a more differentiated conceptualisation of what Ruiz-Mercado and her colleagues referred to as 'the larger socio-economic context'.

2.1. Socio-technical differences between ICS and domestic biogas

While the anticipated impacts of the adoption and sustained use of ICSs are diverse, the direct effects on the 'dynamic system' that frames a household's daily life are mostly limited to the domain of cooking practices. The effects of introducing domestic biogas technology into a household are more diverse. Firstly, its application involves not only a new stove in the kitchen, but also the installation and operation of the digester that produces the fuel (the biogas), as well as auxiliary devices for feeding it and handling the effluent, and the pipes for transporting the gas to the kitchen. In other words, as well as becoming the user of a new stove, the user of a domestic biogas system also becomes an energy producer; i.e. the operator of the biochemical process that produces the biogas as well as the 'by products' (liquid effluent and sludge) of the anaerobic digestion. Secondly, domestic biogas is often promoted as a technical solution with a variety of benefits for a household in addition to energy for cooking. The most notable benefits are the provision of biological fertiliser, the adequate treatment of waste water and improvements to sanitation. Therefore, applying the system perspective to the case of domestic biogas requires a more differentiated conceptualisation of the 'dynamic system' in which the user is embedded and in which the new technology is expected to be integrated. Adopting a domestic biogas plant does not only entail adjustments to a household's cooking subsystem. During the process, adjustments between and within the household's other subsystems[2] may be necessary; particularly those related to animal husbandry (which provides the inputs for the anaerobic digester) and crop production (where the use of effluents should generate additional

[2] We opt to use the term 'subsystem' to refer to a set of interacting components which fulfils comprehensible single functions, which in turn contribute to constructing and/or sustaining a household's livelihood. Subsystems can be part of a household's own configuration (e.g. those providing cooked meals or crops) or can be external (e.g. those providing knowledge, training or loans).