Writing Sample: As part of my role with environmental think-tank, su-re.co, I served as chapter lead author for a handbook on climate change management. The following is an excerpt from this chapter.

Frugal Innovation for Addressing Climate Change in Developing Countries through Technological Innovation Systems

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1 Introduction: Addressing Climate Change in Developing Countries through Frugal Innovation and Technological Innovation Systems

Every continent is under serious threat of climate change, with developing countries being under enormous risk. It is widely acknowledged that developing countries suffer some of the greatest impacts of climate change due to their strong dependence on natural resources, lack of finance and limited infrastructure for adaptation (McSweeney et al., 2010). These countries also have their respective Nationally Determined Contributions (NDC) to achieve from the Paris Agreement, yet the majority of countries are rated as highly insufficient in meeting the Paris Agreement 2.0 target. Many countries need to simultaneously lower emissions and improve well-being for solutions to be sustainable. Thus, the need emerges for technological innovation to support both mitigation and adaptation actions that consider the specific needs of individuals and communities.

Frugal innovation presents a way in which developing countries can promote economic growth, whilst taking mitigation and adaptation measures against climate change. Frugal innovation provides a way to reduce the complexity and cost of a technology and its production when introducing it into an emerging market. Many low-cost technological innovations struggle at implementing universal uptake, such as innovations in cookstoves in African countries (Takama et al., 2011). These challenges in implementation may be a result of, among other reasons, the insufficient understanding of local cultures and their institutional capacities for a pervasive adoption of new technologies (Numminen and Lund, 2017). Recent insights in innovation studies suggest that the success chances of technological innovations are, to a large extent, determined by how the surrounding system—the innovation system—is built up and how it functions (Wieczorek et al., 2013). The use of Technological Innovation Systems (TIS), which consists of networks of actors, institutions and technologies with an emerging technology embedded, provides a list of system functions for the analysis of the development of a technology (Bergek et al.,

2015). This analysis provides a framework that can be used to foster emerging technology into successful market diffusion by determining what fundamental elements need to be strengthened in a technological innovation for it to properly diffuse into a mainstream market. Although ample literature exists for both frugal innovation and TIS respectively, the intersection between the two concepts is rarely explored or documented in literature. The TIS framework has often been applied to renewable energy technologies, but with few applications in the case of emerging economies.

This chapter presents frugal innovation cases that have emerged to help developing countries adapt to and mitigate climate change through the lens of TIS. The aim of this paper is twofold: 1) to explore the complexities of the frugal innovation of biogas in Bali, Indonesia using TIS as an analytical framework and 2) to review the advantages and limitations of TIS as a framework to analyze the nature of frugal innovation. First, the TIS approach will be used to analyze the frugal innovation of biogas in Bali, Indonesia to determine which TIS functions are insufficient and hinder the project from reaching mainstream market diffusion. In this study, we define the successful uptake of innovation as the expansion and diffusion of the frugal innovation from a smaller market— niche market —to a mainstream market. This chapter discusses how frugal innovations in Bali, Indonesia and Malawi have been created, developed, and initially deployed within a niche market. Second, the key TIS functions needed for successful frugal innovation uptake identified in the Bali case study will be cross-examined with the functions found in the supplementary case study in Malawi. The Malawi case study is a supporting case whose purpose is to reinforce the key elements that lead to successful market expansion and uptake of frugal innovation. In undergoing this examination, pathways to success will be identified to understand what important elements must be considered by future frugal innovations during their creation and deployment. Answers to a set of diagnostic questions provide a basis for evaluating the quality of the functions.

This chapter begins with defining frugal innovation as well as the TIS scheme of analysis, including the seven system functions that will be analyzed and diagnostic questions that will be evaluated. Next, in Section 2, background will be given on each case study. In Section 3, TIS functions will be analyzed as they relate to the frugal innovation of biogas development in Bali, Indonesia. In Section 4, the TIS functions that were sufficient or lacking will be identified in each frugal innovation case study and the usefulness of TIS framing in the context of frugal innovation will be discussed. Finally, Section 5 will explore how the innate characteristics of frugal innovations are advantageous for project success and what this means for future use of TIS assessment for the success of frugal innovations in developing nations.

1.1 Frugal Innovation

Frugal innovation emerged as a promising solution to tackle the poverty gap[1] by providing affordable products and services for people in developing countries and emerging economies to improve their quality of life (Numminen & Lund, 2017 and Albert, 2019). The first global scholarly debut of frugal innovation was in a relatively small section of a book about economic development strategy in China and India by Gupta & Wang (2008). They defined frugal innovation as “innovation that strives to create

[1] The OECD defines the poverty gap as "…the ratio by which the mean income of the poor falls below the poverty line. The poverty line is defined as half the median household income of the total population” (OECD, 2020).

products, services, processes, and business models that are frugal on three counts: frugal use of raw materials, frugal impact on the environment, and extremely low cost." Gupta & Wang (2008) further stated that the rapid rise of emerging markets is the prime mover behind the critical need for all three types of frugality. This was followed by substantive coverage in a special report by *The Economist* in 2010, which described frugal innovation as "…not just a matter of exploiting cheap labor, it is a matter of redesigning products and processes to cut out unnecessary costs" (Bhatti et al., 2018).

The core characteristics of frugal innovation, as found by Numminen and Lund (2017), are engineered simplifications such as minimizing the use of raw materials and other resources, which result in lower manufacturing costs. Product simplifications could lead to considerable energy savings as well. Secondly, frugal technologies should be robust and durable, especially when products are used in remote areas. Frugal innovations differentiate themselves from other available technologies often through some novel technical feature or business model that is tailored to fit the target environment, as opposed to a cheaper product that is sellable to the mass market (Zeschky, Winterhalter, and Gassmann, 2014). Hence, the needs of local communities are addressed through a product that is user-friendly, accessible, and affordable. This includes accounting for the availability of skills in the area to ensure consistent and stable maintenance by end-users. Thirdly, the product utilizes local renewable resources. Finally, the frugal principle is also applied to energy usage, having modest energy output levels that are monitored (Numminen and Lund, 2017). Given the practice is based on an optimization problem, frugal innovation has the potential to simultaneously cater to the community's needs and enable economic growth (Albert, 2019).

Such innovations have become of great interest to national governments and international development organizations in aiding social and ecological sustainability, due to their minimization of resources, affordability, and better accessibility than conventional innovations. In comparison to conventional innovations, frugal innovation resources, such as raw materials, production materials, energy, fuel, water, waste, etc. are conserved or reduced given that more sustainable and local resources are used. Further, frugal innovation improves energy and material efficiency, and substitution (with local and renewable materials and processes), as well as sufficiency, are described as part of the ecological sustainability of frugal innovation (Albert, 2019). Moreover, frugal innovation creates value from waste (waste as a resource) by reusing existing technological components and recycles materials instead of sourcing new ones. Also, due to ease of repair, the effective life of frugal innovation is extended compared to conventional innovations. In relation to the greenhouse gas (GHG) emissions, frugal innovation minimizes the impact on the environment by having a lower carbon footprint or a smaller ecological footprint compared to conventional technologies (Albert, 2019).

However, frugal innovations are not always the more environmentally or ecologically sustainable option. Various reviews (Rosca et al., 2017; Wohlfart et al., 2016; Sharma & Iyer, 2012; and Weyrauch & Herstatt, 2017) show from an empirical point of view, frugal innovation does not always have an inherent sustainability impact. The ecological impact of frugal innovation can be a spill-over effect (Rosca et al., 2017) and environmental sustainability may be more of a side-effect than an upfront impulse for frugal initiatives (Wohlfart et al., 2016). Further, frugal innovation can pose some threats to sustainability, such as the unsustainable extraction of raw materials (due to characteristics of resource-constrained environments) and unsustainable low-cost manufacturing and production. Additionally, by offering a more affordable innovation, more people will be able to buy and use the technological innovation, and thus an increased consumption may result in even more environmental damage

(increasing material use, energy use, and waste generation). Furthermore, frugal innovation can lead to the disposal of old and superannuated goods in the end-of-life-stage, which can cause ecological problems by improper disposal (Albert, 2019). In this case, there may be a tradeoff between ecological degradation due to increased demand and improved social sustainability, such as greater inclusiveness, improved wellbeing and health, better livelihood options, and poverty reduction.

This chapter will explore the case of biogas in Bali in depth and refer to cook stoves in Malawi as a comparative case study. Both innovations are considered to be frugal innovations due to their use of raw materials and their low cost in both production and manufacturing. Further, these innovations have been designed with efficiency and simplicity in mind and are tailored to the local needs of individuals and communities in developing countries. These solutions have also been deployed to support specific climate change adaptation needs and to improve the overall quality of life of the technology end-users.

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