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Development of innovation systems for small island states: A functional analysis of the Barbados solar water heater industry

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ABSTRACT

Most small island states are under economic pressure to transition from energy systems dominated by imported oil, into systems based on clean energy technologies, which are often already economically viable due to local high energy prices. Guidance on transforming energy systems is limited with few examples available to policy makers. This paper applies a technological innovation system approach to recording the development of the much-lauded Barbados solar water heating industry and applies Bergek et al.'s (2008) functional analysis approach to put forward reasons for its successful adoption. The research concludes that the Barbados solar water heater industry actually appears to be in a state of market stagnation (at around 35% penetration) and using functional analysis identifies barriers and opportunities for future growth in the local and regional solar hot water heater market, as well as proposing the key actor networks necessary for success in sustainable energy technology based innovation system for small island states.

Introduction

Many small island states across the world face an economic crisis due to their expensive energy systems. Imported fossil fuels often comprise over 95% of their primary energy sources, which leads to high electricity bills, lock-in energy system scenarios, diseconomies of scale, weak economies, and low levels of energy security (Weisser, 2004; Auth et al., 2012). Their susceptibility to the effects of climate disruption and low levels of resilience often exacerbate their predicament. These islands, mainly located across the tropics, often have substantial indigenous renewable energy resources including solar, wind, geothermal, biomass, and marine energy. To date, there have been very few examples of small island states successfully exploiting any of these resources. The case of the Barbados solar water heating sector is an exception and provides an example of an innovation system that grew relatively quickly from an emerging innovation system in the early 1970s, into a mature and entrenched technology that, by the 1980s, competed within, and indeed was the major actor, in the Barbados water heating market – prior to solar water heaters, electric immersion heaters and gas-fired heaters were the norm.

The island of Barbados is located in the eastern Caribbean and has a population of approximately 290,000, a GDP per capita of US$16,200 in 2014, and a large solar resource; it receives an annual average daily irradiance of 5.4 kWh/m^2 (Headley, 1998). Its penetration of solar water heating is the fourth highest in the world, behind Cyprus, Israel, and Austria, and it has the highest penetration in the Caribbean, accounting for 60% of the region's total installed solar water heaters (REN21, 2014). The island is also responsible for 80% of solar water heater manufacturing in the region. The solar water heating market has delayed the requirement for the addition of new generation capacity by the countries monopoly power company, Barbados Light & Power (BL&P), due to the technology's displacement of electric immersion water heaters. The emergence and success of Barbados's solar water heating industry has been well documented (Bugler, 2012; Gardner, 2011; Epp, 2009; Langniß and Ince, 2004; Headley, 1998). According to Bugler (2012), solar water heater installations in Barbados were at approximately 50,000 with an estimated penetration rate of 40%. Data retrieved by the author from the 2010 Barbados population and housing census suggests the penetration rate to be lower than this, 34%. And in recent years, anecdotal evidence suggests that the SWH industry has experienced slow growth nationally and in the regional export market.

This paper attempts to investigate this anecdotal evidence by applying a technological innovation system (TIS) approach to firstly document the emergence and diffusion of the solar water heater industry in Barbados and secondly identify the current key policy challenges and future initiatives for realizing longer-term potential in the sector, both nationally and regionally. The paper also seeks to obtain a more accurate assessment of the current state of the Barbados solar water heater sector by exploring primary data sources.

The "Methodology" section provides a review of the technological innovation system concept and the methodology used here. The "Scheme of analysis" section then applies the technological innovation system functional analysis approach. This section outlines the structural components of the Barbados solar water heater industry, defines the functional framework, and highlights the empirical analysis of the

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Table 1
Lists of functions for technological innovation systems found in the literature.

	Hekkert et al. (2007)	Bergek et al. (2008)	van Alphen et al. (2010)
Function 1	Entrepreneurial activities	Knowledge development and diffusion	Creating adaptive capacity
Function 2	Knowledge development	Influence on the direction of search	Knowledge diffusion through networks
Function 3	Knowledge diffusion	Entrepreneurial experimentation	Demand articulation
Function 4	Guidance of the search	Market formation	Creation of legitimacy
Function 5	Market formation	Resource mobilization	Resource mobilization
Function 6	Resource mobilization	Legitimacy	Market formation
Function 7	Counteracting resistance to change	Development of positive externalities	Entrepreneurial activities

evolution of the innovation system. The "Conclusions" section suggests key policy issues to be addressed in order to strengthen the region's solar water heater industry.

Methodology

Shama (1982) states that "an innovation is any product, idea, service, or a practice that is perceived as new by the consumer", and goes on to say that "it may well be accepted by a group of consumers and still be regarded as an innovation by others." This was the case for the Barbados solar water heating industry, which emerged in the early 1970s, even though the type of system employed in Barbados had its origins in North America in the 1950s. The aim of an innovation system is to develop, diffuse, and utilize innovations. The main reason for applying the technological innovation system methodology to a particular innovation is as a tool to determine system weaknesses, which once highlighted can drive policy development.

The concept of innovation systems emerged in the 1980s. Since then, a range of different innovation systems has been identified that categorize different dimensions so as to aid their definition. These include national innovation systems, regional innovation systems, sectoral innovation systems, and technological innovation systems. Carlsson and Stankiewicz (1991) defined a "technological innovation system" as "a network of agents interacting in the economic/industrial area under a particular institutional infrastructure (...) and involved in the generation, diffusion, and utilization of technology." Further insight into types of innovation systems can be found in Jacobsson and Bergek (2011).

The technological innovation system approach is most suited to the characteristics of the Barbados solar water heating industry. The existing literature provides a number of approaches that can be used to define a technological innovation system (Malerba, 2002), all of which revolve around a similar system design, namely, the determination and coevolution of the actors, networks, and institutions that are connected to the technology being analyzed. Recent work in this area places emphasis on the strength of the linkages and processes between the actors, networks, and institutions, termed "functions," that are important for a well-performing innovation system (Hekkert et al., 2007; Bergek et al., 2008). Three lists of functions have been proposed in the literature, which are shown in Table 1, and a description of each can be found in Kroesen and Kamp's paper (Kroesen and Kamp, 2010). Bergek et al.'s list of functions is used here as it best captures the development of the Barbados solar water heating industry. The scheme of analysis for Bergek et al.'s TIS scheme of analysis is shown in Fig. 1 and is described in the "Scheme of analysis" section in tandem with the analysis of the Barbados SWH innovation system.

Scheme of analysis

Step 1: Defining the technological innovation system in focus

A desktop study was first performed in order to define the starting point of the technological innovation system. This study made use of available industry reports, official statistics, and newspaper articles, as well as the increasing volume of journal articles related to innovation systems. Interviews were conducted with key industry stakeholders in order to determine any remaining points. A total of seven stakeholders were contacted, ranging from within the manufacturing sector, industry associations, government, and research institutions.

The technology at the heart of the Barbados SWH innovation system is the simple and commonly used flat-plate solar collector, thermosyphon water heating system. A thermosyphon solar water heater works on the principle that hot water rises, hence the storage tank is positioned above the solar panel/collector (pumps can be employed when storage tanks are positioned below the level of the solar collector). Worldwide, there are over 212 flat-plate solar collector manufacturers, with the industry's key players based in Europe (REN21, 2014).

Step 2: Structural components (actors, networks, and institutions)

A technological innovation system usually comprises a broad set of actors including innovators, entrepreneurs, manufacturing firms, government departments, research institutes, accreditation bodies, standards institutes, regulators, consumers, suppliers, funders, interest supporters, industry associations, and competing innovation systems. Networks develop between these actors and the degree of understanding and collaboration in these networks gives a strong indication of the strength of the innovation system as a whole (Bergek et al., 2008). Some examples of networks include production supply chains; producer–government, producer–consumer, and producer–quality infrastructure institution relationships; and university–industry links. Institutions include formal laws, standards, and regulations, as well as less formal norms, routines, and culture, e.g. common law, cultural aspects, tradition, practices, etc. (Bergek et al., 2008, Kroesen and Kamp, 2010). The key actors, networks, and institutions in the Barbados SWH are presented in Fig. 2 and are discussed below.

During its formation, the Barbados solar water heater industry was very much an entrepreneur-driven technological innovation system, subsequently supported by timely belief and support from government. Entrepreneurs, present at the industry inception, remain in key positions as heads of the existing three main manufacturing companies, namely, Solar Dynamics,[1] SunPower,[2] and Solaris[3] (formerly AquaSol). These companies form the focal point for the technological innovation system network and have been the main drivers of the solar water heating industry, showing proof of concept to government, product design/development, and legitimization. These three companies are involved in the whole supply chain, including manufacturing, distribution, and installation. Other small-scale manufacturers do exist and they account for around 5% of the market share and therefore play only a supporting role in the network (Gardner, 2011).

The main uses of solar water heaters in residential homes are for showering and cooking/cleaning purposes. In the commercial sector, hot water has more uses depending upon the type of business. The Barbadian economy is dependent on tourism with hotels, guest houses and holiday rentals estimated to account for ~20% of solar water heating

[1] Solar Dynamics - http://solardynamicsltd.com/(Accessed 06/01/2016)
[2] Sun. Power – http://www.sunpowr.com/(Accessed 06/01/2016)
[3] Solaris Global Energy- http://solarisenergy.us/(Accessed 06/01/2016)