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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)

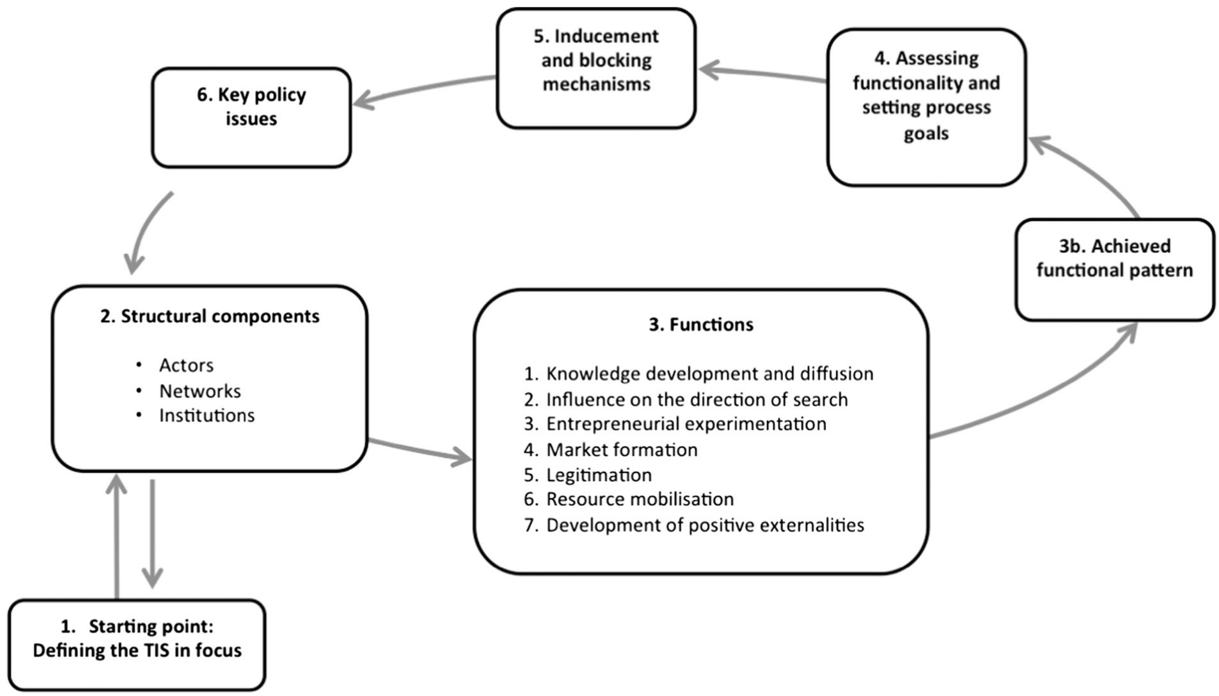

Fig. 1. An overview of Bergek et al.'s scheme of TIS analysis (source: Bergek et al., 2008).

installations. Recent estimates suggest that 60% of the ~100 hotels on the island have installed large-scale solar water heating systems (CHENACT, 2012). Other actors in the commercial sector include the agricultural and food industry, government buildings, restaurants, and bottle recycling.

At the residential level, the solar water heater industry is involved with the installation of new solar water heaters, decommissioning and replacement of old solar water heaters, and maintenance. Installations of new solar water are mainly for new buildings. Competitors in the solar water heater technological innovation system include alternative

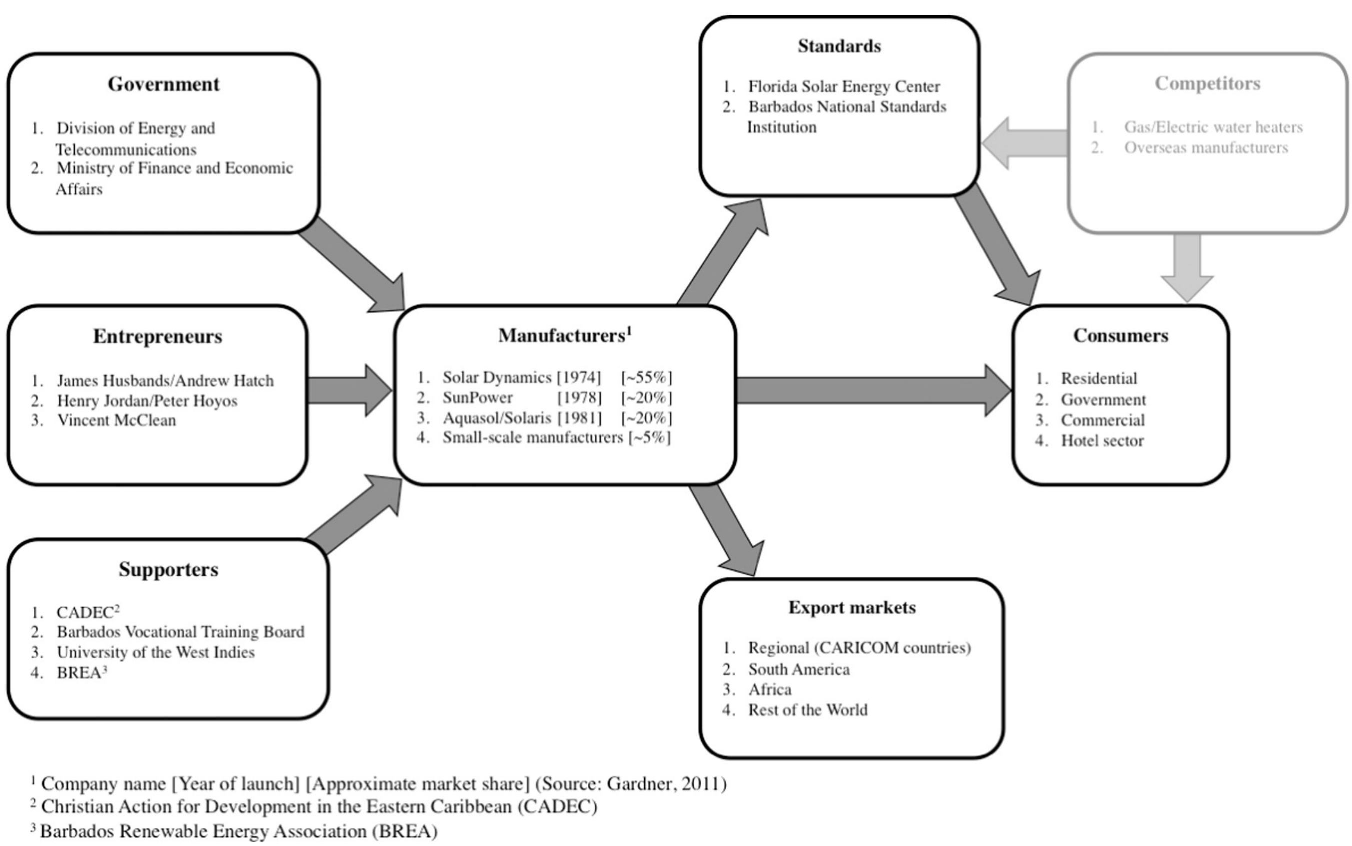

Fig. 2. Key actors and their relationships for the Barbados solar water heater TIS.

methods of heating water, namely, electric immersion heaters and gas-fired boilers offered by plumbing stores. For comparison, a 250 l solar water heater would cost ~US$2000, while a similar sized electric immersion heater system is around US$600 and a gas-fired water heating system US$800. The high cost of electricity on the island (~US$0.30/kWh) and a 30% import duty applied to electric immersion heaters has meant that customers with the financial means opt for the solar water heaters due to payback period of ~2.5 years. Due to the presence of the local solar water heater manufacturers, installers and servicing, competition from overseas manufacturers of solar water heaters is limited.

The 2010 Barbados population and housing census included questions on household appliances, in particular methods of water heating (Barbados Statistical Services, 2013). Out of the 78,936 occupied households, 34% had solar water heaters installed, 15% used either gas or electric water heaters, and 51% had no type of water heater installed.

Step 3: Mapping the functional pattern of the TIS

The following subsections briefly describe each of the seven functions introduced in the "Methodology" section (Fig. 1), before identifying to what extent each of the functions have been filled in the Barbados solar water heater technological innovation system.

Entrepreneurial experimentation

Entrepreneurs are central to the formation of a technological innovation system and a successful innovation system must emerge from what is ordinarily considerable uncertainty in terms of technology, applications, and markets. Construction of solar water heaters had been attempted at the "home experimenter" level in Barbados prior to their commercial production. This was thanks in part to Professor Tom Lawand of the Brace Research Institute, McGill University, who on a visit to Barbados in the 1960s showed proof of concept of a low-cost design constructed from local materials (Husbands, 2012).

During the 1970s oil crisis, Reverend Andrew Hatch of Christian Action and Development in the Eastern Caribbean (CADEC) saw the potential application of this technology and managed to secure US$4200 of funding from CADEC to set up Solar Dynamics. Solar Dynamics worked to adapt the solar water heater design to local manufacturing capabilities and material availability, as well as environmental and climatic conditions. Entrepreneurial experimentation was driven by competition within the local market, which was evident from inception of the innovation system. Solar Dynamics' main competitors, Sun Power Ltd. and Aquasol, which was bought by Solaris Global Energy in 2011, emerged in 1978 and 1981, respectively. Competition and consumer expectations drove the design development of solar water heaters, with a focus on glass with a higher heat tolerance, improved welding techniques, better flow design in the solar collector to combat calcium build-up, and an appreciation of consumer hot water requirements so that systems were sized accordingly (Gardner, 2011). This competition undoubtedly played a significant role in product development, with all three current manufacturers now offering a broadly similar thermosyphon-driven design.

Market formation

The factors driving market formation include the articulation of demand from customers, institutional change, and change in price/performance. Market formation often runs through various stages, starting with "nursing" or niche markets, bridging markets, and eventually mass markets. Following proof of concept, the development of the Barbados solar water heater market can be described in three distinct phases: (1) public and commercial sector working together to support the fledgling industry, (2) continued market support to communicate its benefits and maintain growth to become a self-sufficient market, and (3) translation of market successes to export into regional market (Epp, 2009).

Soon after the creation of Solar Dynamics, the company was given the opportunity to demonstrate the advantages of solar water heater over the incumbent gas and electric water heaters. In 1974, a solar water heater was installed at the home of Tom Adams, the then prime minister of Barbados. Following installation, the gas consumption at the prime minister's residence dropped by 70% and government support for solar water heaters quickly followed, helping Solar Dynamics to develop quickly from a niche market to a bridging market. Timely fiscal incentives saw the exemption of raw materials for solar water heaters from their 20% import duty (which lowered the installed cost by 5–10%), as well as a 30% consumption tax placed on conventional water heaters, and securing a government contract for 84 solar water heaters for the Oxnards housing development project (Gardner, 2011). Following initial difficulty, financial backing for securing raw materials for the Oxnards project was eventually secured from the Barbados Institute of Management and Productivity (BIMAP) and the technological innovation system was on its way to market maturity. Manufacturers at the time went door to door to inform persons of the benefits of solar water heating and their potential payback period compared to electric and gas water heaters (Epp, 2009). Government incentives continued to support the innovation system, which saw a steady growth in solar water heater installations, peaking in 1989 with 2800 units installed in that year.

Fig. 3 shows the market development up until 2002. In addition to the initial solar water heater incentives mentioned previously (removal of import duty on raw materials and 30% levy on imported electric and gas heaters), a tax amendment in 1980 allowed for the full cost of a solar water heater to be deducted from income tax. This was in place until 1993 when it was suspended as part of structural economic reforms, before being reintroduced in 1996. The notable fall in installations in the early 1980s and early 1990s is explained by the worldwide economic recessions during those periods. The cumulative installations don't take into consideration the lifespan of the solar water heaters and the fact that a share of those installations will almost certainly have stopped working. Manufacturers stated that many customers neglect to properly maintain their solar water heaters leading to early system failure. This is supported by evidence from the CHENACT study of energy use in hotels on the island, which highlighted the large number of solar water heaters that were inoperable due to insufficient maintenance (CHENACT, 2012).

Since 2002, manufacturers have suspended their voluntary reporting of installation statistics on account of intense rivalry between competitors. Using the results of the 2010 census (Barbados Statistical Services, 2013) to estimate residential penetration at 34%, and the CHENACT report to estimate penetration into the hotel sector at 60% (CHENACT, 2012), it is estimated that installation of SWH island-wide is now approximately 38,000, which represents roughly 35–40% overall market penetration. Approximately 75% of installations are installed on domestic properties, while hotels make up most of the remainder. The market share is roughly split 55%, 20%, 20%, and 5% between Solar Dynamics, Sun Power, Solaris, and small independent manufacturers, respectively (Gardner, 2011).

During the 1980s and 1990s, all three manufacturers explored exporting their products to overseas markets. Aquasol (now Solaris Global Energy) set up a franchise manufacturing plant in Trinidad and was involved with an unsuccessful joint venture partnership in Nigeria. Solar Dynamics started producing solar water heaters in neighboring St Lucia through a successful joint venture. The literature suggests that solar water heaters originating in Barbados account for approximately 60% of the solar water heaters in the Caribbean, which suggests that their marketing strategy has been successful. However, as far as regional market penetration is concerned, there is significant potential for market expansion – with a regional penetration rate of ~8% (compared with ~40% in Barbados) (Gardner, 2011; Epp, 2009).

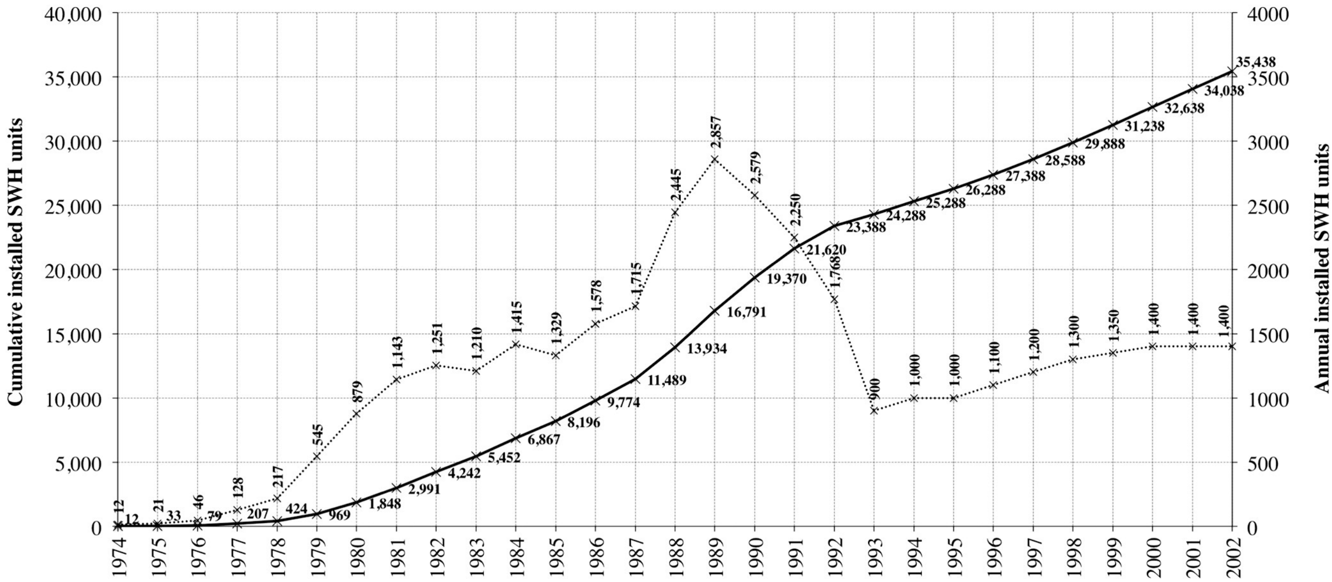

Fig. 3. Annual and cumulative installed solar water heater in Barbados 1974–2002. Source: Perlack and Hinds (2003).

Knowledge development and diffusion

This function of the analysis aims to explain the breadth of the knowledge base within the technological innovation system and how that knowledge has bee and is currently being, developed, diffused, and combined into the system. Technological learning relies hugely on the networks between the main actors within an innovation system. Ordinarily, these include suppliers of inputs or capital goods, manufacturers, distributors, competitors, consultants, and technology suppliers. Externalities and inter-linkages can also occur with firms in unrelated industries, research institutes, and universities, industry associations and training institutions, as was found in Gebreeyesus and Iizuka's functional analysis of the discovery of the Ethiopian Flower Industry (Gebreeyesus and Iizuka, 2010).

In the case of the Barbados solar water heater technological innovation system, the manufacturers carry out several roles including product development, supply, distribution, installation, training, and sales. If the arrows in Fig. 2 are replaced with links, then the figure also represents the knowledge interactions taking place within the technological innovation system. Manufacturers are at the center of the knowledge development and diffusion network, and their strongest interactions are between the government, and their customers. Technical knowledge diffusion, or capacity building, takes place via training (in-house "on-the-job" and externally through the Barbados Vocational Training Board) and through the mobility of skilled labor.

Influence on the direction of search

The function relating to the influence on the direction of search refers to incentives and/or pressures for organizations to enter a technological field. These may come in the form of visions, expectations of growth potential, regulation, articulation of demand from leading customers, crises in current business, etc. (Bergek et al., 2008). Although it was private entrepreneurship that prompted the introduction of solar water heaters, the government of Barbados quickly realized the potential of solar water heaters to reduce the country's dependence on import fossil fuels. Through the initial vision of Prime Minister Tom Adams and continued support of subsequent governments to date, the government became hugely influential on the direction of search by providing support through fiscal incentives, the use of solar water heaters on housing projects, and communication/promotion of the benefits of solar water heaters to householders.

Resource mobilisation

This function describes the extent to which actors within the technological innovation system are able to mobilize human and financial capital as well as complementary assets such as network infrastructure – a range of different resources are required at different stages of the technological innovation system development (Bergek et al., 2008). A major challenge for local solar water heater manufacturers was accessing start-up capital, as financial institutions were reluctant to provide funding – especially with a new company offering an unknown technology as its product. As far as training is concerned, initial impetus was borne from training workshops and seed capital provided by Church and Christian Action for Development in the Eastern Caribbean (CADEC). These days, training is conducted in-house by manufacturers as well as the Barbados Vocational Training Board (BVTB), which provides registered apprentices with the skills and competencies required by technicians in the solar water heating industry. Although historically, there has been technological research involvement from the island's university (Headley, 1998), currently there is only minor support from R&D institutions. However, with increased focus on sustainable energy at local R&D institutions and abroad, more opportunities are beginning to emerge.

Legitimation

This function deals with the fact that a new technology and its proponents need to be considered appropriate and credible by relevant actors, in order for resources to be mobilized, for demand to emerge, and for the actors in the new innovation system to acquire political strength (Bergek et al., 2008). Due to the previously mentioned early support of the government, legitimation in the solar water heater industry developed quickly. Manufacturers spent considerable time and resources communicating the benefits of their products to potential customers, in particular approaching project developers and policy makers.

Legitimacy is not a constant and once acquired, it can be lost if any arising consumer concerns are not addressed. During the early years of their development in Barbados, skepticism of solar water heaters was rife and this was exacerbated by some installations being incorrectly sized. If a customer opted for a system that was too small to cope with the demand of that dwelling, hot water quickly ran out, often leading to no hot water by the morning. This is where the local presence of suppliers helped as the local companies were more connected to the customers and issues were quickly solved. Consumer risk was reduced by offering certain assurances at point-of-sale, such as temperature guarantees, energy audits to determine household water usage, and 4 year warranties. Another confidence builder was the voluntary independent testing of solar water heaters at the Florida Solar Energy Centre (FSEC)[4] (Epp, 2009). Legitimacy was also strengthened by the suppliers collaborating with credit unions and commercial banks to provide credit to customers over a 2 year period (Gardner, 2011).

Development of positive externalities

Bergek et al. (2008) state that through its development, a technological innovation system will generate opportunities for the generation of positive external economies, which can be monetary or knowledge based – "Success breeds success" is a simple way of summarizing this function. The generation of positive externalities occur throughout the lifetime of the technological innovation system and functions will impact other functions at different stages of innovation system development. During the emergence of the Barbados solar water heater industry, the entry of new firms was central to the development of positive externalities and this supports the assertions of Bergek et al. (2008). As a technological innovation system, the Barbados solar water heating innovation system has created a relatively closed set of actors and networks. Manufacturers play many roles including suppliers, servicing, training, and lobbyists. Due to the ad hoc nature of the industry, which can be expected given the size of the available market and associated competition, there is a lack of supportive players such as provision of quality infrastructure and research and development, which has led to limited opportunities for positive externalities. One of the major benefits of the Barbados solar water heating experience has been as an example of the possible benefits of renewable energy technologies in the region. Nowhere is this more noticeable than with the introduction of solar photovoltaic systems, which is now a rapidly growing market (Rogers et al., 2012). A conservative calculation reveals that today's solar water heater industry saves Barbados as much as US$14.5 million per year from reduced electricity consumption.[5]

Step 4: Assessing functionality

Up to now, the focus of this paper has been on describing the different functions of the technological innovation system – understanding how each function emerged, and its current level of development. The next step in functional analysis attempts to ascertain how well the system is functioning – i.e. not "how" but "how well." Two bases of assessment are proposed: (1) the phase of development of the technological innovation system and (2) comparison with other systems (Bergek et al., 2008).

Phase of development

Solar water heaters can be expected to have a lifetime of 15–40 years depending upon levels of servicing so it is not clear what the precise penetration in Barbados currently is given that some systems will have been decommissioned due to age and general wear and tear (NREL, 1996). The decommission rate of solar water heater is exacerbated by the fact that Barbados is a coral limestone island and therefore lime scale build-up can be a significant problem for system designers. Modern solar water heater systems are fitted with a sacrificial magnesium anode for cathodic protection that will have a lifespan of ~4 years. However, once anodes are depleted, the systems can be expected to fail within a few years. Consumers also have the option to install water-softening devices into their plumbing. When the failure of existing SWH systems due to aging are considered, a simple calculation puts the current level of solar water heater penetration at around 30%, significantly less than the largely reported 40–50% (Epp, 2009; Gardner, 2011; Bulger, 2012)[6] and closer to the 35% estimate stated earlier (see "Market formation" section). Even without considering failure rate, the growth rate of the solar water heater technological innovation system is believed to have slowed down, and due to market saturation in Barbados, it is widely believed to have reached a fourth "stagnation" phase.

Comparison between technological innovation systems

Comparison of a technological innovation system with similar innovation systems regionally or internationally provides vital insight toward understanding its health. A look at the International Energy Agency (IEA) report on solar water heating worldwide reveals that Barbados is ranked fourth in the World in terms of installed capacity per capita (see Fig. 4) (Mauthner and Weiss, 2013). Interestingly, Barbados is the only Caribbean country and indeed Small Island Developing State that features in the top 55 countries detailed in the list. The top five countries in this list, Cyprus, Israel, Austria, Barbados, and Greece, share similar solar water heater success stories thanks largely to sustained and successful policy promotion throughout their history. In Israel, for example, government regulations decreed that all new build properties under 25 m in height must use a solar water heater to provide domestic hot water (Menanteau, 2007; Wei, 2013). Top users of solar water heater are also characterized by having a scarcity of fossil fuel resources, good solar resources, and an enterprising solar water heater manufacturing base.

Although far larger than Barbados, Cyprus provide the best solar water heater market for comparison with Barbados. Like Barbados, Cyprus gained independence from the United Kingdom in the 1960s and has a record of strong growth, full employment, and external and internal stability. Throughout the development of their solar water heater industries, the economies of Barbados and Cyprus have been relatively stable, driven primarily by their tourism and service sectors, but at the same time highly dependent on imports of raw materials, capital goods, and fossil fuels due to the absence of indigenous resources. Cyprus has a very high solar water heater penetration approaching 90% and this inevitably means that the local market is saturated with any production meeting demand from new dwellings and decommissions solar water heater units (Maxoulisa et al., 2007). It is interesting to note that the solar water heater penetration rate in Cyprus has contributed a degree of resilience into the country's energy system, which helped benefit the country economically during the 2012–13 Cypriot financial crisis.

Step 5: Identify inducement and blocking mechanisms

Here we identify the drivers and barriers to the future growth of the Barbados solar water heater sector. The analysis focuses on the functions that were mapped in the section "Mapping the functional pattern of the TIS." Fig. 5 illustrates the various inducement and blocking mechanisms and links them to their associated function. The main issue with the Barbados solar water heater sector is that the market penetration has remained at ~35% in recent times. Regarding entrepreneurial experimentation, the typical Barbados solar water heater has settled on a design that lies within local manufacturing capabilities and meets the demands of consumers and the environment. This design is the flat plate solar collector, which typically heats water to around 60 °C and is well suited for domestic purposes and for use in hotels. A common alternative collector design is the evacuated tube collector, which can heat water to around 100 °C, and has a significantly higher energy gain than flat plate collectors. This makes them more

[4] FSEC are the nearest accreditation body that offers testing and certification of solar products and equipment (http://www.fsec.ucf.edu/). Results for Solar Dynamics Ltd. and Sun. Power Ltd. can be found at: http://www.fsec.ucf.edu/en/publications/html/fsec-gp-14-81/tprdhws.htm (Accessed 20/11/2013).

[5] Estimate based on data from (Epp, 2009).

[6] This calculation assumes an installation rate of 2000 systems per year, as reported in Gardner (2011) and a product lifespan of 15 years.

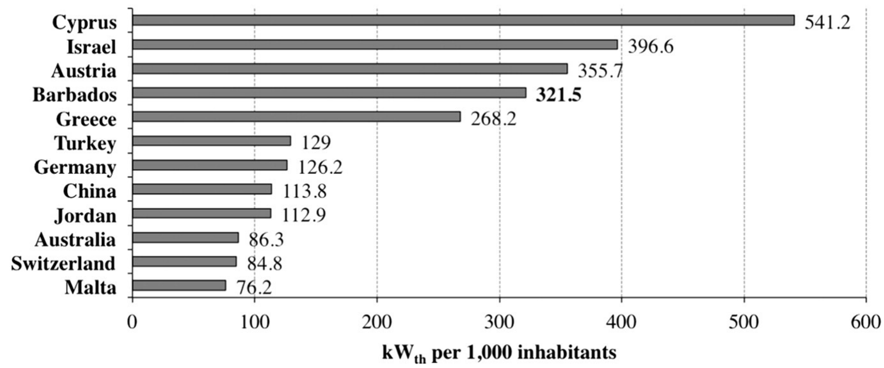

Fig. 4. Installed capacity of solar water heater by end of 2011 – top twelve countries (Mauthner and Weiss, 2013).

suited for situations that require either high-temperature water or lots of warm water; this includes the food processing industry (of which there are many on Barbados), hospitals, and industrial processes requiring the input of heat. Solar collectors can be used to pre-heat water and make substantial energy savings in the process. Solar cooling requires high-temperatures to drive a refrigeration cycle, which can be met by the use of evacuated tube collectors. To date, only one manufacturer in Barbados is offering such a collector.

There are a number of reasons for the widely acknowledged belief that the solar water heater market in Barbados has stagnated. As Barbados has a tropical climate with no cold season, the purchase of a solar water heater may simply be seen as a luxury item to the remaining 50% of homeowners. A detailed assessment should be performed of the water demand from the remaining 50% plus of homes that currently do not have solar water heaters. Split-incentives is mentioned here, as is the targeting of the low-income sector and wider process-heating opportunities in the commercial sector. However, it is possible that many households without solar water heaters do not think it necessary to invest in a solar water heater. It is simple to provide hot water for the kitchen and occasional cleaning elsewhere using only a stove, and the need for regular hot showers and hot water for laundry may be very small or even negligible. Without a need for a product, the value of innovation substantially decreases, although development of a perceived need should be part a of the innovation process. Raising the awareness amongst householders of the level of daily hot water demand at which solar water heaters become worthwhile would be one way to raise public awareness of their worth.

Consumer confidence in the technology is sometimes found to be low – during the early years, defects in the design and incorrectly sized systems led to low efficiency, high cost, and operational difficulties such as system leaks (Gardner, 2011). Although designs have improved significantly and manufacturers now emphasize the need for careful sizing of the systems, consumer confidence may still be low today due to previous bad experiences. There may also be a lack of awareness about the cost of existing electric immersion and gas heaters, and the potential savings from solar water heaters – which have a typical payback period of around 2.5 years. Lastly, the split-incentive issue is seen as a barrier to further market penetration. A large section of the Barbados housing sector is composed of rented property, which is occupied either by local tenants or by the visiting tourists – the 2010

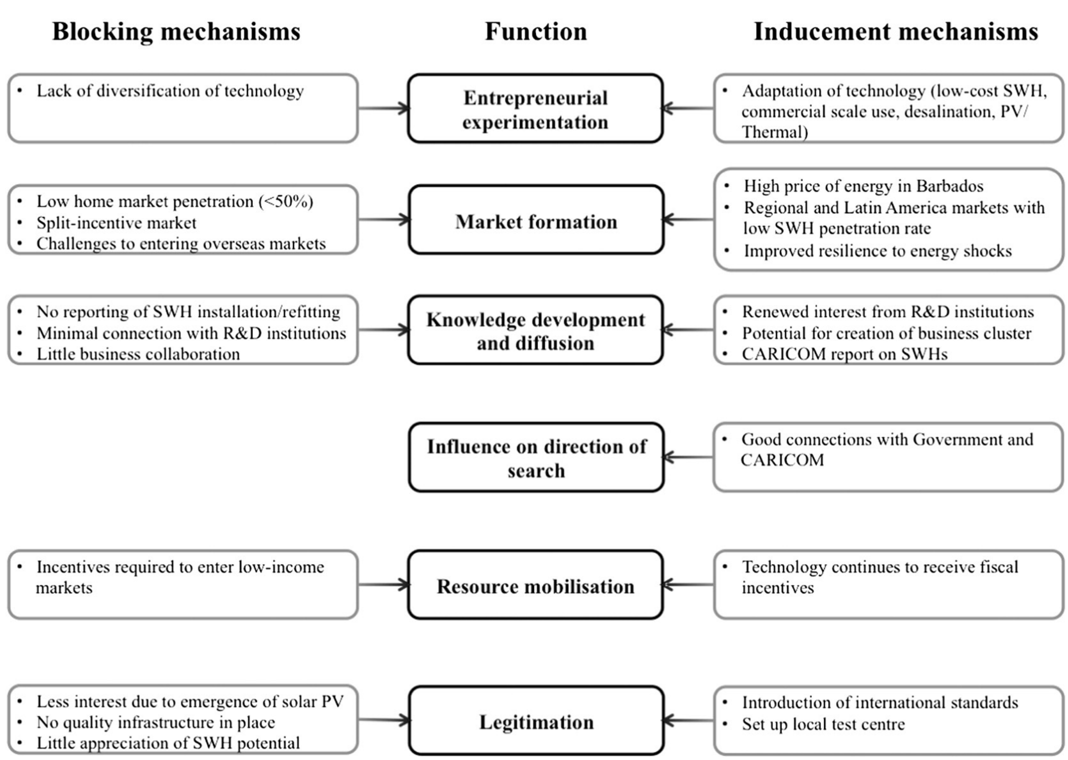

Fig. 5. Inducement and blocking mechanisms to growth of the Barbados SWH sector.

Population and Housing Census indicates that ~20% of houses in Barbados are rented (Barbados Statistical Service, 2013). Even though electricity bills may be high, tenants are reluctant to invest in solar water heaters for a property that isn't theirs. And property owners have no reason to install a solar water heater on a building that will not benefit them directly. The same is also true of commercial buildings where the building owner is not the one paying the energy bills. There are clear inducement mechanisms to the future growth of the solar water heater market including the progressive rise in global energy prices, improved resilience to future energy market shocks, and potential Caribbean and Latin American export markets which currently have low solar water heater penetration rates, noting that they should have climates where thermosyphon system are able to operate effectively. Brazil, Mexico, and Chile are all increasing their manufacturing capabilities (REN, 21).

The lack of statistical reporting within the solar water heater sector inhibits knowledge development and diffusion within the sector. More accurate reporting on unit manufacture, sales, repairs, and exports would allow a better understanding of the current status of the industry and allow analysts and policy makers to better support the sector by understanding which fiscal incentives work best and what adjustments to the industry would stimulate future growth. Due to the voluntary reporting of installations by manufacturers up until 2002, Perlack and Hinds (2003) were able to accurately calculate the fossil fuel and carbon emission savings to Barbados from the industry, respectively US$150 million (compared to tax incentive costs of US$12 million) and 4.3–6% of total annual carbon emissions from Barbados. It is perhaps surprising to learn that manufacturers are not required to report operating statistics given the support that the industry receives through government fiscal incentives.

There has been only minimal contact and cooperation between manufacturers and research institutions. The local university is currently expanding its research capacity within the field of renewable energy and there is clearly potential to increase the amount of R&D into the use of solar thermal applications on the island and regionally. The creation of a local testing center would enable manufacturers to accurately test the operation of their products and would provide a powerful development tool. There is significant R&D potential for technological progress including the use of evacuated tube collectors for industrial purposes, the use of solar collectors for solar cooling applications, high-temperature desalination, and the design of a low-cost SWH. Low-cost SWHs are currently being researched elsewhere and their manufacture and application in Barbados should be explored (Hudon et al., 2012).

Competition between Barbados manufacturers has historically been high, and this is one of the reasons for the success of the industry (a quick view of the manufacturer websites will testify to the fierce competition in the industry[7,8,9]). When the Barbados solar water heater industry approaches market saturation, overseas export markets may be better pursued if manufacturers were to form a business cluster. The Cyprus solar water heater industry faced a similar scenario with a penetration rate approaching 90%. In their paper, Maxoulis et al. present the potential benefits of local solar water heater manufacturers forming a business cluster, which include better economies of scale in the purchase of raw materials, the ability to expand research activities into the development of new solar thermal technologies, and possibilities for investment in more technically advanced manufacturing techniques (Maxoulis, 2007). Similar to Barbados, the high local penetration of solar water heater systems in Cyprus has provided a sense of comfort and security among manufacturers who are, to a certain degree, able to survive off servicing existing systems. As Maxoulis et al. state, in order to remedy this weakness, both managers and policy makers must recognize the importance of collaboration among each other and find ways to build relationships of trust. These relationships will allow firms to jointly identify regional and potentially international opportunities. In addition, this level of collaboration and focus will exert pressure on supporting institutions (R&D, training, standards, accreditation, government) to better complement and add more value to the industry.

Continuing with knowledge development and diffusion, national and regional institutions can have an impact on the awareness of the technology, both by consumers and businesses. Actions such as the Caribbean Renewable Energy Capacity Support (CRECS) report on "Development and implementation of a strategy for the promotion of solar water heating in CARICOM[10] countries" have a valuable part to play in increasing regional awareness of the benefits of solar thermal technologies (Gardner, 2011). These reports would be further strengthened by the provision by manufacturers of accurate industry statistics.

The merit of manufacturers testing their products at overseas accreditation institutions has been mentioned previously (see the section "Legitimation"), and clearly this is an effective way of providing legitimation. Further legitimation of the solar water heater sector through the provision of quality infrastructure (QI) will help improve local consumer confidence and, more importantly, aid the ability of manufacturers to access overseas markets. The Barbados National Standards Institute (BNSI) has explored the creation of solar water heater standards through adopting international standards. These could then feed into regional standards via Caribbean Regional Organisation for Standards and Quality (CROSQ).[11] Manufacturers wanting to increase export revenues might also explore the adoption of international standards related to quality management systems within their organizations such as the ISO90000 family. An example of the importance of standards can be seen in the emergence of the Cyprus solar water heater industry, where standardization was seen as important for two reasons. Firstly, it offered a common platform for collaboration between local manufacturers, and secondly, because it introduced scientific methods for testing the solar water heater, thereby facilitating the Cypriot industry to improve its products (Maxoulis, 2007).

Conclusions

The National Strategic Plan of Barbados for 2005–25 was designed to eliminate the country's reliance on fossil fuel. To help ensure an efficient and reliable energy sector, one of its targets is to increase the number of household solar water heaters by 50% by the end of 2025. According to Perlack and Hinds (2003), there were approximately 36,000 solar water heaters in 2005, suggesting an installation target of ~54,000 solar water heaters by 2025. Research presented here indicates that the number of installations in 2010 was ~37,000, suggesting that the market is indeed in a period of stagnation and urgent action is required if future targets are to be met.

This paper maps the functional patterns of the Barbados solar water heating industry and results show that there are several weaknesses in the innovation system, which if strengthened would lead to a stronger, more resilient industry. There is a need to reinstate the collection of manufacturing statistics by the Government Statistical Department. These statistics should include data on the number of new installations (and whether they are residential or commercial), the number of replacements (distinguishing between collector panels and storage tanks), as well as figures detailing the number of sales for export. These data will allow researchers and policy makers to better tailor financial incentives and identify areas of future technology improvements/developments. With 15% of households using either gas or electric water heaters, there is still a substantial domestic market for solar

7 Solar Dynamics - http://solardynamicsltd.com/ (Accessed 06/01/2016).
8 Sun Power – http://www.sunpowr.com/ (Accessed 06/01/2016).
9 Solaris Global Energy- http://solarisenergy.us/ (Accessed 06/01/2016).
10 Caribbean Community (CARICOM) is an organisation of 15 Caribbean nations and dependencies.
11 Caribbean Regional Organisation for Standards and Quality (CROSQ) http://www.crosq.org/(Accessed 20/11/2013).

water heaters on the island. There is also a need to better understand why 52% of households do not employ any type of water heater technology (Barbados Statistical Services, 2013). Closer inspection of the 2010 population and housing census shows that it is primarily the lower-cost houses that do not have water heaters installed. This suggests that the development of a low-cost solar water heater design would help increase market penetration.

The technological innovation system approach adopted here has allowed a structured approach to the mapping of the Barbados solar water heating industry and has proved to be a useful tool to identify the strengths and weakness of this innovation system. This paper has implications for the development of the fast emerging solar PV industry and other renewable energy technologies on Barbados and for other small island states around the world. It highlights the benefits of strong government support for emerging technologies, in particular the need for clear incentives and long-term commitment. Further work is recommended to apply Bergek et al.'s technological innovation system functional analysis approach to other innovation systems in the Caribbean (for example, the Barbados telecommunications sector or the Jamaica pig farming industry) in order to better understand, and further refine, the key functional patterns that lead to successful innovation systems in small island states.

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