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Rogers, T.

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

Tom Rogers

Faculty of Science & Technology, The University of the West Indies, Cave Hill campus, Barbados

Corresponding author: Tel.: +1246 417 4158; Email address: thomas.rogers@cavehill.uwi.edu

Highlights

- A detailed review of the Barbados solar water heating development
- Application of a functional analysis approach to capturing a Technological Innovation System
- Current statistics suggest Barbados solar water heating industry is in a period of market stagnation
- The strengthening of stakeholder networks is required to promote future growth

Abstract: Most small island states are under economic pressure to transition from energy systems currently reliant on imported oil, into systems based on clean energy technologies that are often already economically viable due to high energy prices. Guidance on transforming energy systems is limited with very few examples available to policy makers. This paper applies a technological innovation system approach to recording the development of the much-celebrated Barbados solar water heating industry and highlights the reasons for its successful adoption. It also uses a functional analysis approach proposed by Bergek et al (2008) to identify barriers and opportunities for future growth in the local and regional solar thermal market, as well as identify the key actor networks necessary for a successful innovation system for small island states.

Keywords: Innovation systems; solar water heaters; small island developing states.

1 Introduction

Many small island states face an economic crisis due to their expensive energy systems. Imported fossil fuels often comprise over 95 per cent of their primary energy sources, which leads to high electricity bills, lock-in scenarios, diseconomies of scale, weak economies and low levels of energy security [1]. Their susceptibility to the effects of climate change/disruption and low levels of resilience exacerbate this predicament [2]. These islands, mainly located in the tropics, often have substantial indigenous energy resources including solar, wind, geothermal, biomass and marine energy. There have been very few examples of small island states successfully exploiting any of these resources. The case of the Barbados Solar Water Heating (SWH) 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 SWHs, 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$ 25,100 (2013 estimate) [3], and a large solar resource - receiving an annual average daily irradiance of 5.4 kWh/m^2 [4, 5]. The penetration of solar water heating is fourth highest in the world behind Cyprus, Israel, and Austria, and it has the highest penetration in the Caribbean, accounting for 60 per cent of the total installed regional solar water heaters [6]. The island is responsible for 80 per cent of SWH manufacturing in the region. As of September 2012, SWH installations in Barbados were at approximately 50,000 with an estimated penetration rate of 40 per cent [7]. It has been suggested that 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 [4, 7, 8, 9, 10, 11], however, in recent years anecdotal evidence suggests that the SWH industry has experienced slow growth nationally and in the regional export market.

This paper applies a Technological Innovation System (TIS) approach to firstly document the emergence and diffusion of the solar water heater industry in Barbados, and secondly to identify the current key policy challenges and future initiatives for realising longer-term potential in the sector, both nationally and regionally. The paper also seeks to obtain a more accurate assessment of the health of the Barbados SWH by exploring primary sources.

Section 2 provides a review of the technological innovation system concept and the methodology used here. Section 3 then applies the TIS functional dynamics approach. This section outlines the structural components of the Barbados SWH industry, defines the functional framework and highlights the empirical analysis of the evolution of the innovation system. Section 4 identifies the key policy issues to be addressed in order to strengthen the industry.

2 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"* [12]. This was the case for the Barbados solar water heating industry, which emerged in the early 1970s, however the type of system used in Barbados has its origins in North America in the 1950s. Defining a particular Innovation System (IS) requires a macro-level investigation of that innovation, focussing on the transfer of technical knowledge to the layman [13]. The development of an innovation system and its diffusion into general society can be captured by the phrase… *"progress is the path from the primitive to the complex to the simple"*. The aim of an innovation system is to develop, diffuse and utilise 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 categorise the different dimensions so as to aid their definition. These include; national innovation systems, regional innovation systems, sectoral innovation systems and technological innovation systems (TIS). 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*" [14]. Further insight into types of innovation systems can be found in Jacobsson and Bergek (2011) [15].

The TIS 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 TIS, 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 analysed [16]. 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 [17, 18, 19]. 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 [20]. Bergek et al's list of functions was chosen as it best captures the development of the Barbados solar water heating industry [18]. The scheme of analysis for Bergek et al's TIS scheme of analysis is shown in Figure 1 and is described in section 3 in tandem with the analysis of the Barbados SWH innovation system.

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

	Hekkert et al (2007) [17]	**Bergek et al (2008) [18]**	**van Alphen et al (2010) [21]**
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

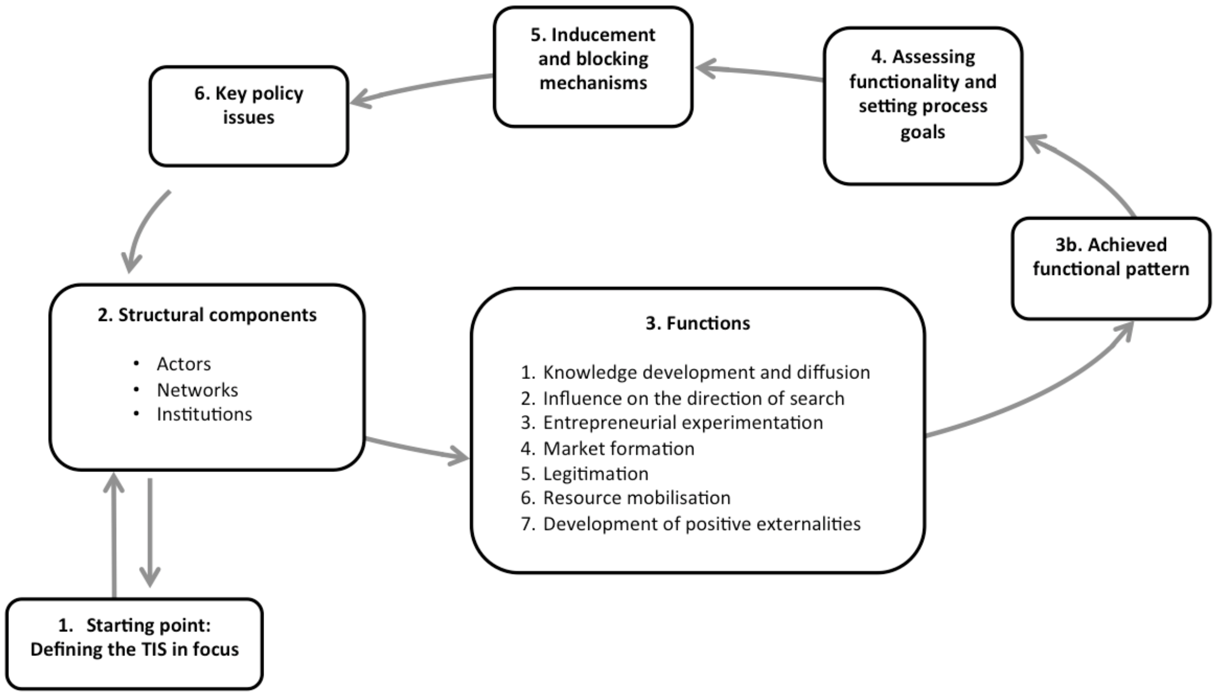

Figure 1. An overview of Bergek et al's scheme of TIS analysis [18].

3 Scheme of analysis

3.1 Step 1: Defining the TIS in focus

A desktop study was first performed in order to define the starting point of the TIS. Researchers made use of the available industry reports, official statistics, and newspaper articles, as well as the increasing volume of journal articles related to innovation systems. Expert interviews were conducted with key stakeholders in order to determine any remaining points. A total of seven stakeholders were contacted, ranging from 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, in most cases, positioned above the solar panel/collector (pumps can be employed when storage tanks are positioned below the level of the solar collector).

3.2 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 of course 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. Some examples of networks include: production supply chains, producergovernment, 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. [18, 20]. The key actors, networks and institutions in the Barbados SWH are presented in Figure 2 and are discussed below.

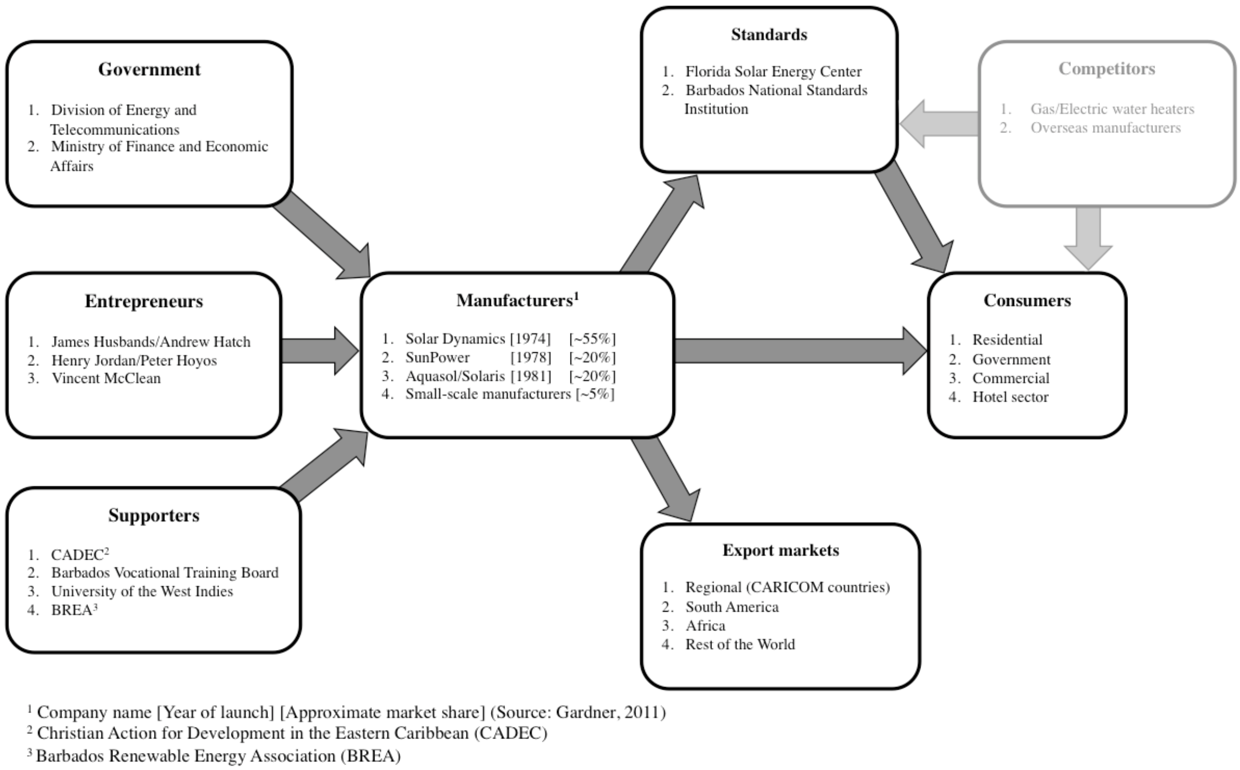

Figure 2. Key actors and their relationships for the Barbados solar water heater TIS.

During its formation, the Barbados SWH industry was very much an entrepreneur driven TIS, 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 TIS network and have been the main drivers of the solar water heating industry, showing proof of concept to Government, product design and development, and legitimisation. 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 ~5 per cent of the market share and therefore play only a supporting role in the network [8].

The main uses of SWH in residential homes are for showering and cooking/cleaning purposes. In the commercial sector, hot water has more uses related to the type of commercial sector. The Barbadian economy is dependent on tourism with hotels estimated to account for ~20 percent of solar water heating installations. Recent estimates suggest that 60 per cent of the ~96 hotels on the island have installed large-

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[1] Solar Dynamics - http://solardynamicsltd.com/ (Accessed 12/08/2014)
[2] Sun Power – http://www.sunpowr.com/ (Accessed 12/08/2014)
[3] Solaris Global Energy- http://solarisenergy.us/ (Accessed 12/08/2014)

scale solar water heating systems [22]. Other actors in the commercial sector include, the agricultural and food industry, government buildings, restaurants, and bottle recycling.

Competitors in the SWH TIS include alternative methods of heating water, namely electric immersion heaters and gas-fired boilers offered by plumbing stores. For comparison, a 66 gallon SWH would cost ~US$2,000, whilst an electric immersion heater system is around US$600 and gas fired water heating system US$800. The high cost of electricity on the island (~US$0.40/kWh) and a 30 per cent import duty applied to electric immersion heaters has meant that customers with the financial means opt for the SWH due to pay-back period of ~2.5 years. Due to the presence of the local SWH 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 [23]. Out of the 78,936 occupied households, 34 per cent had solar water heaters installed, 15 per cent used either gas or electric water heaters, and 52 per cent had no types of water heaters installed.

3.3 Step 3: Mapping the functional pattern of the TIS

The following subsections briefly describe each of the seven functions introduced in section 2 (Figure 1), before ascertaining to what extent each of the functions have been filled in the Barbados SWH TIS.

3.3.1 Entrepreneurial experimentation

Entrepreneurs are central to the formation of a TIS 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 a 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.

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$4,200 of funding from CADEC to set up Solar Dynamics. Solar Dynamics worked to adapt the 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 SWHs 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 [8]. This competition undoubtedly played a significant role in product development, with all three current manufacturers now offering a broadly similar thermosyphon driven design.

3.3.2 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 SWH market is often described in three 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 to regional market [24].

Soon after the creation of Solar Dynamics, they were given the opportunity to demonstrate the advantages of SWH over the incumbent gas and electric water heaters. In 1974, a SWH 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 per cent and Government support for SWHs quickly followed, helping Solar Dynamics move quickly from a niche market to a bridging market. Timely fiscal incentives saw the exemption of raw materials for SWHs from their 20 per cent import duty (which lowered the installed cost by 5-10 per cent), as well as a 30 per cent consumption tax placed on conventional water heaters, and securing a Government contract for 84 SWHs for the Oxnards housing development project [8]. 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 [9]. Government incentives continued to support the innovation system, which saw a steady growth in SWH installations, peaking in 1989 with 2,800 units installed in that year.

Figure 3 shows the market development up until 2002. In addition to the initial SWH incentives mentioned previously (removal of import duty on raw materials and 30 per cent levy on imported electric and gas heaters), a tax amendment in 1980 allowed for the full cost of a SWH to be deducted from income tax. This was in place until 1993 when it was suspended as part of structural economics reforms before being reintroduced in 1996. The notable fall in installations in the early 1980s and early 1990s are explained by the worldwide economic recessions during those periods. The cumulative installations don't take into consideration the lifespan of the SWHs 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 hotels on the island, which highlights the large number of solar water heaters that were inoperable due to insufficient maintenance [22].

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 to estimate residential penetration at 34 percent, and the CHENACT report to estimate penetration into the hotel sector at 60 percent, it is estimated that installation of SWH island-wide are approximately 38,000, which represents roughly 35 to 40 per cent overall market penetration [22, 23]. Approximately 75 per cent of installations are installed on domestic properties, whilst hotels make up the most of the remainder. The market share is split 55%, 20%, 20%, and 5% between Solar Dynamics, Sun Power, Solaris, and small independent manufacturers respectively [8].

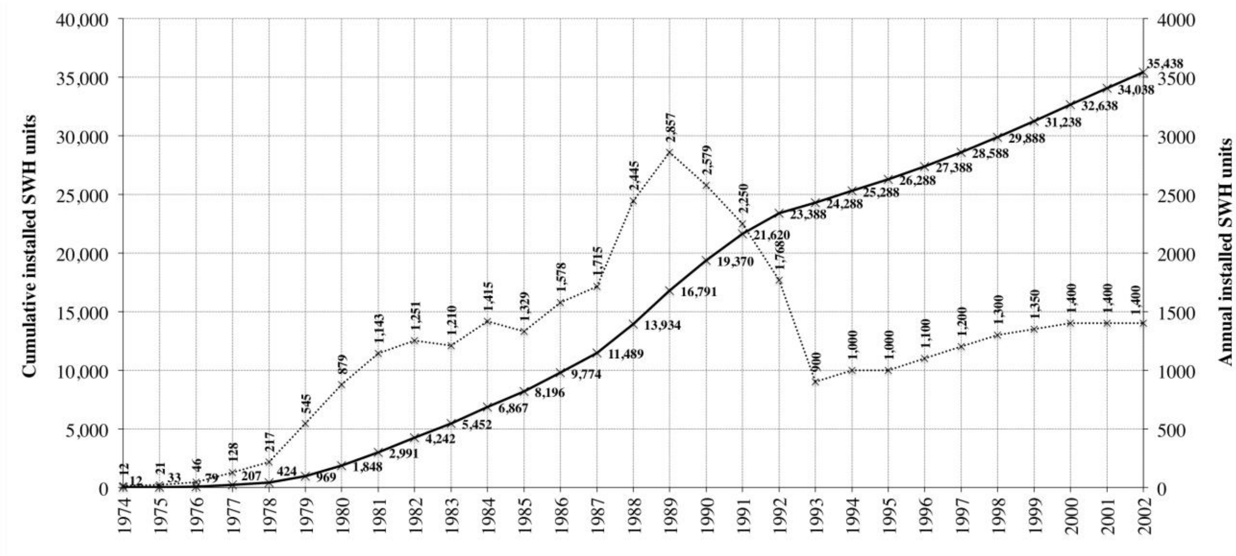

Figure 3. Annual and cumulative installed SWH units in Barbados from 1974 to 2002. Source: Perlack and Hinds (2003) [25]

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 were involved with an unsuccessful joint venture partnership in Nigeria. Solar Dynamics started producing SWHs in neighbouring St Lucia through a successful joint venture. The literature suggests that SWHs originating in Barbados account for ~60 per cent 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 per cent (compared with ~40 per cent in Barbados) [8, 9].

3.3.3 Knowledge development and diffusion

This function of the analysis aims to explain the breadth of the knowledge base within the TIS and how that knowledge has been, and is currently, 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 [18].

In the case of the Barbados SWH TIS, the manufacturers carry out several roles including product development, supply, distribution, installation, training, and sales. If the arrows in Figure 2 are replaced with links, then the figure also represents the knowledge interactions taking place within the TIS. Manufacturers are at the centre 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 labour.

3.3.4 Influence on the direction of search

This function refers to incentives and/or pressures for organisations 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. [18].

Although it was private entrepreneurship that prompted the introduction of SWHs, the Government of Barbados quickly realised the potential of SWHs 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 SWHs on housing projects and communication/promotion of the benefits of SWHs to householders.

3.3.5 Resource mobilisation

This function describes the extent to which actors within the TIS are able to mobilise 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 TIS development [18].

A major challenge for local SWH 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 [4], currently there is only minor support from R&D institutions. With increased focus on sustainable energy at local R&D institutions and abroad, more opportunities are beginning to emerge.

3.3.6 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 [18]. Due to the previously mentioned early support of the Government, legitimation in the SWH 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, scepticism of SWHs 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 solved quickly. 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 SWHs at the Florida Solar Energy Centre (FSEC)[4] [9]. Legitimacy was also strengthened by the suppliers collaborating with credit unions and commercial banks to provide credit to customers over a two year period [8].

3.3.7 Development of positive externalities

Bergek et al (2008) state that through its development, a TIS will generate opportunities for the generation of positive external economies, which can be monetary or knowledge based [18]. "Success breeds success" is a simple way of summarising this function. The generation of positive externalities occur throughout the lifetime of the TIS and functions will impact other functions at different stages of IS development.

During the emergence of the Barbados SWH industry, the entry of new firms was central to the development of positive externalities and this supports the assertions of Bergek et al (2008) [18]. As a TIS, 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 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 solar photovoltaic market, which is currently a rapidly growing market [26]. A conservative calculation reveals that todays SWH industry saves Barbados as much as US$14.5 million per year from reduced electricity consumption[5].

3.4 Step 4: Assessing functionality

Up to now, the focus has been on describing the different functions of the TIS - 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 TIS, and (2) comparison with other systems [18].

3.4.1 Phase of development

The successful formative development phase of the Barbados SWH TIS occurred in the early-1970s, and the industry then enjoyed a strong growth phase during the mid-1970s and 1980s reaching a peak of 2,857 in 1989 (see Figure 3). System installation then dropped off significantly in the early 1990s due to global recession, falling to around 900 installations in 1993. Sales then began to grow slowly and reached 1,400/year in 2002, when manufacturers stopped voluntarily reporting their sales figures. Indications are that sales figures then continued to rise [25]. Solar water heaters can be expected to have a lifetime of 15 to 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 [27]. The decommission rate of SWHs 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 SWH

[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).

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[6]. 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 SWH penetration at around 30 per cent, significantly less than the largely reported 40-50 per cent[7] and closer to the 35 per cent estimate stated earlier (see section 3.3.2) [7, 8, 9]. Even without considering failure rate, the growth rate of the SWH TIS is believed to have slowed down and reached a fourth 'stagnation' phase.

3.4.2 Comparison between TISs

Comparison of a TIS with similar innovation systems regionally or internationally provides vital insight towards understanding the health of a TIS [18]. A look at the International Energy Agency (IEA) report on solar heating worldwide reveals that Barbados is ranked fourth in the World in terms of installed capacity per capita (see Figure 4) [28]. Interestingly Barbados is the only Caribbean country and indeed Small Island Developing State that features in the top 55 countries detailed in the IEA list. The top five countries in this list: Cyprus, Israel, Austria, Barbados and Greece, share similar SWH 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 25m in height must use SWH to provide domestic hot water [29, 30]. They are also characterised by having a scarcity of fossil fuel resources, good solar resources, and an enterprising SWH manufacturing base.

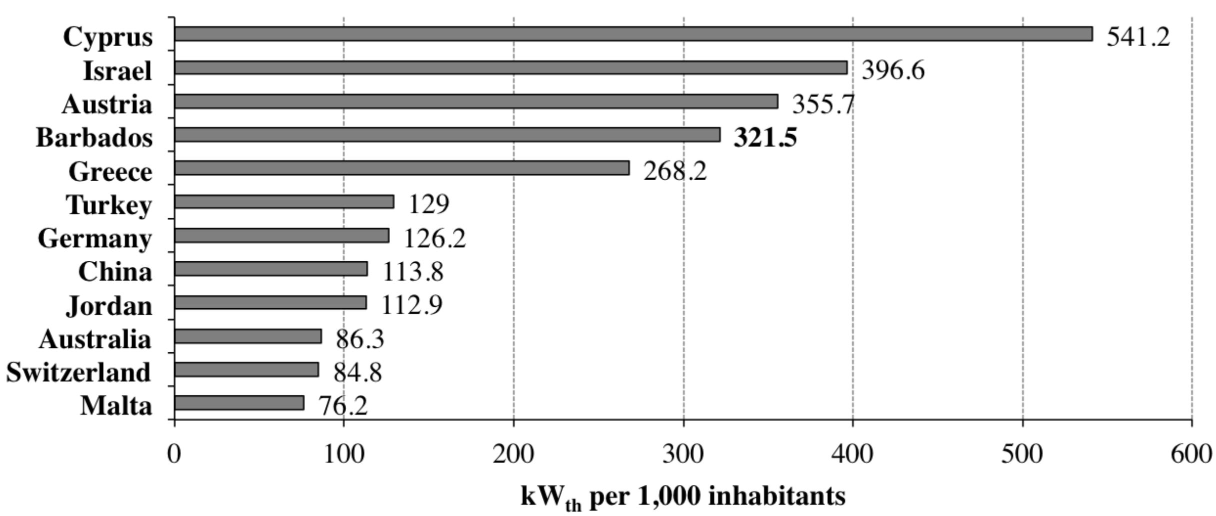

Figure 4. Installed capacity of SWH by end of 2011- top twelve countries Source: IEA [28]

Although far larger than Barbados, perhaps the best SWH market for comparison with Barbados is that of Cyprus. 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 SWH 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 energy due to the absence of natural resources. Cyprus has a very high SWH

[6] An example of the effects of lime scale can be viewed on one manufacturer's website http://www.sunpowr.com/service.html (Accessed 20/11/2013)

[7] This calculation assumes an installation rate of 2,000 systems per year, as reported in Gardner (2011) and a product lifespan of 15 years.

penetration approaching 90 percent and this inevitably means that the local market is saturated with any production meeting demand from new dwellings and decommissions SWH units [31]. It is interesting to note that the SWH penetration rate in Cyprus has contributed a degree of resilience into the country's energy system, which benefitted the country economically during the 2012–13 Cypriot financial crisis. The Cyprus case is further discussed in section **Error! Reference source not found.**.

3.5 Step 5: Identify Inducement and blocking mechanisms

Here we identify the drivers and barriers to the future growth of the Barbados SWH sector. The analysis focuses on the functions that were mapped in section 3.3. Figure 5 illustrates the various inducement and blocking mechanisms and links them to their associated function. The main issue with the SWH sector is that the market penetration of SWH into the Barbados market has remained at ~35 per cent 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 and they typically heats water to around 60°C, which and is well suited for domestic purposes and for use in hotels. An 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 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 process 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 manufacture is offering such a collector.

There are a number of reasons for the widely acknowledged belief that the SWH market formation 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 per cent of homeowners. Consumer confidence in the technology can sometimes be 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 leakage [8]. Although designs have improved significantly and manufacturers now emphasise the need for careful sizing of the systems, consumer confidence can 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 SWHs – which have a typical payback period of around two years. Lastly, the split-incentive issue is seen as a barrier to further market penetration. A large section of the Barbados housing sector is comprised of rented property, which is occupied either by local tenants or by the tourist sector – the 2010 Population and Housing Census indicates that ~20 per cent of houses in Barbados are rented [23]. Even though electricity bills may be high, tenants are reluctant to invest in SWHs for a property that isn't theirs. And property owners have no reason to install a SWH 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 SWH market including the progressive rise in global energy prices; improved resilience to future energy market shocks; and potential Caribbean and Latin American markets which currently have low SWH penetration rates - Brazil, Mexico and Chile are all increasing their manufacturing capabilities [6].

The lack of statistical reporting within the SWH sector inhibits the 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 unit installs 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 to 6 percent of total annual carbon emissions from Barbados [25]. It is 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 centre 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 been researched elsewhere and their manufacture and application in Barbados could be explored [32].

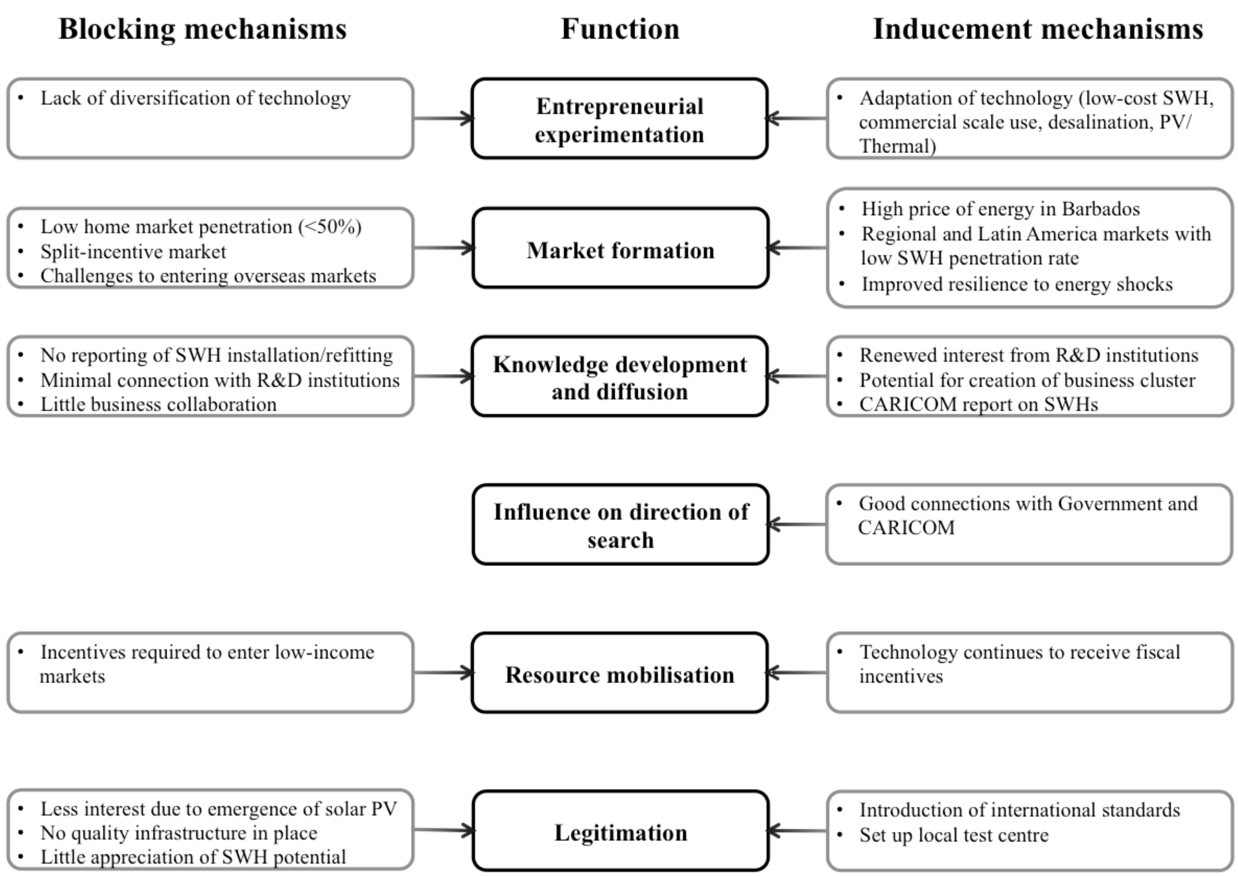

Figure 5. Inducement and blocking mechanisms to growth of the Barbados SWH sector

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). When the Barbados SWH industry approaches market saturation, overseas export markets may be better pursued if manufacturers were to form a business cluster. The Cyprus SWH industry faced a similar scenario with a penetration rate approaching 90%. In their paper, Maxoulis et al present the potential benefits of local SWH 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 [31]. Similar to Barbados, the high local penetration of SWH systems in Cyprus has provided a sense of comfort and security amongst manufactuers 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 recognise the importance of collaboration among each other and find ways to build relationships of trust [31]. 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.

4 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 SWHs in 2005, suggesting an installation target of ~54,000 SWHs by 2025 [25]. 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.

The work presented here maps the functional patterns of the Barbados solar water heating industry and results shows 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. This data will allow researchers and policy makers to better tailor financial incentives and identify areas of future technology improvements/developments. With 15 per cent of households using either gas or electric water heaters, there is still a substantial domestic market for solar water heaters on the island. There is also a need to better understand why 52 per cent of households do not employ any type of water heater [23]. 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 TIS approach adopted here has allowed a structured approach to the mapping of the Barbados solar water heating industry and 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 worldwide. It highlights the benefits of strong government support for emerging technologies, in particular the need for clear incentives and a long-term commitment. Further work is recommended to apply functional analysis 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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6 References

[1] Weisser, D. (2004). On the economics of electricity consumption in small island developing states: a role for renewable energy technologies? *Energy Policy*. Vol 32. Iss 1. pp 127–140

[2] Chmutina, K. Bosher, L. (2014). Construction in Barbados: keeping natural hazards in mind? *Disaster Prevention and Management*. Vol 23. Iss 2. pp 175-196

[3] Central Intelligence Agency. Barbados. The World Factbook. Available at https://www.cia.gov/library/publications/the-world-factbook/geos/bb.html (Accessed 11/08/2014)

[4] Headley, O. 1998. Solar Thermal Applications in the West Indies. *Renewable Energy.* Vol 15. pp 257–263

[5] Moore, W., Alleyne F., Alleyne Y., Blackman K., Blenman C., Carter S., Cashman A., Cumberbatch J., Downes A., Hoyte H., Mahon R., Mamingi N., McConney P., Pena M., Roberts S., Rogers T., Sealy S., Sinckler T., Singh A. 2012. Barbados Green Economy Scoping Study – Synthesis Report. Government of Barbados, University of West Indies - Cave Hill Campus, United Nations Environment Programme, 55p.

[6] REN21. (2014). Renewables 2014 Global Status Report (Paris: REN21 Secretariat). Available at www.ren21.net/gsr (Accessed 20/11/2013)

[7] Bugler, W. (2012). Seizing the sunshine: Barbados' thriving solar water heater industry. *Climate and Development Knowledge Network*. Iss. September 2012. Available at http://cdkn.org/resource/cdkn-inside-story-seizing-the-sunshine-barbados-thriving-solar-water-heater-industry/ (Accessed 11/08/2014).

[8] Gardner, D. (2011). Development and implementation of a strategy for the promotion of solar water heating in CARICOM countries. Caribbean Renewable Energy Capacity Support (CRECS) project. http://cipore.org/wp-content/uploads/downloads/2013/02/Final-Report-Solar-Water-Heating-Strategy-CC-Countries-Devon-Gardner.pdf (Accessed 27th June 2013)

[9] Epp, B. (2009). The Barbados model: A success story in three acts. *Solar Thermal World*. Published online at http://solarthermalworld.org/content/barbados-model-success-story-3-acts (Accessed 11/08/2014)

[10] Langniß, O. Ince, D. (2004). Solar Water Heating – A Viable Industry for Developing Countries. *Refocus*. Vol May/June 2004. pp 18–21

[11] Husbands, J. (2012). The Development of Barbados' Renewable Energy Industry. *Business Barbados*. Available at http://businessbarbados.com/trending/green-business/development-barbados-renewable-energy-industry/ (Accessed 11/08/2014)

[12] Shama, A. (1982). Speeding the diffusion of solar energy innovations. *Energy (OXFORD)*. Vol 7. Iss 8. pp 705–715

[13] Freeman, C. (1987) Technology Policy and Economic Performance: Lessons from Japan, Pinter Publishers Ltd, London.

[14] Carlsson, B. Stankiewicz,R. (1991) On the nature, function and composition of technological systems. *Journal of Evolutionary Economy*. Vol 1. Iss 2. Pp 93–118

[15] Jacobsson, S. Bergek, A. (2011). Innovation system analyses and sustainability transitions: Contributions and suggestions for research. *Environmental Innovation and Societal Transitions*. Vol 1. pp41–57

[16] Malerba, F. (2002). Sectoral systems of innovation and production. *Research policy*. Vol 31. Iss 2. pp 247–264

[17] Hekkert, M. P., R. A. Suurs, et al. (2007). "Functions of innovation systems: A new approach for analysing technological change." *Technological Forecasting and Social Change*. Vol 74. Iss 4. pp 413–432

[18] Bergek, A. Jacobsson, S. Carlsson, B. Lindmark, S. Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*. Vol 37. pp 407–429.

[19] Gebreeyesus, M. Iizuka, M. (2010). Discovery of the flower industry in Ethiopia: experimentation and coordination. *UNU-Merit - Working Paper Series*. Available at http://www.merit.unu.edu/publications/wppdf/2010/wp2010-025.pdf (Accessed 11/08/2014)

[20] Kroesen, JO. Kamp, LM. (2010). Energy innovation systems in developing countries – experiences with the implementation of PV in Kenya. Knowledge Collaboration & Learning for Sustainable Innovation ERSCP-EMSU conference, Delft, The Netherlands, October 25-29, 2010.

[21] van Alpen, K. Hekkert, MP. Van Sark, WGJHM. (2008). Renewable energy technologies in the Maldives— Realizing the potential. *Renewable and Sustainable Energy Reviews*. Vol 12. pp 162–180

[22] CHENACT - Caribbean Hotel Energy Efficiency Action Programme (2012). CHENACT Final Report. Energy Efficiency and Micro-Generation in Caribbean Hotels Consultancy. Available at http://www.caribbeanhotelandtourism.com/downloads/CHENACT-Final-Report.pdf (Accessed 11/12/2014)

[23] Barbados Statistical Services. (2013). 2010 Population and Housing Census. Available at http://www.barstats.gov.bb/files/documents/PHC_2010_Census_Volume_1.pdf (Accessed 11/08/2014)

[24] Epp, B. Solar industry in upheaval. *Sun & Wind energy*. Issue 12/2012. pp 28–39. Available at http://www.solrico.com/fileadmin/medien/pdf/SWE_industry_in_upheaval.pdf (Accessed 11/08/2014)

[25] Perlack, B. Hinds, W. (2003). Evaluation of the Barbados solar water heating experience. Available at http://solardynamicsltd.com/wp-content/uploads/2010/07/SWH-report1-2.pdf (Accessed 11/08/2014)

[26] Rogers, T. Chmutina, K. Moseley, LL. (2012). The potential of PV installations in SIDS–an example in the island of Barbados. *Management of Environmental Quality: An International Journal*. Vol 23. Iss 3. pp 284–290

[27] NREL. (1996). Solar water heating. US Department of Energy. DOE/GO-10096-050 FS 119. Available at: http://www.nrel.gov/docs/legosti/fy96/17459.pdf (Accessed 11/08/2014)

[28] Mauthner, F. Weiss, W. (2013). Solar heat worldwide – markets and contributions to the energy supply 2011. *Solar heating and cooling programmes – International Energy Agency*. Available at: http://www.iea-shc.org/solar-heat-worldwide (Accessed 11/08/2014)

[29] Menanteau, P. (2007). Policy measures to support solar water heating: information, incentives and regulations. LEPII. Available at: http://www.worldenergy.org/documents/solar_synthesis.pdf (Accessed 11/08/2014)

[30] Wei, L. (2013). Comparing Solar Water Heater Popularization Policies in China, Israel and Australia: The Roles of Governments in Adopting Green Innovations. *Sustainable Development*. Vol 21. pp 160–170

[31] Maxoulisa, CN, Charalampousb, HP. Kalogirouc, SA. (2007) Cyprus solar water heating cluster: A missed opportunity? *Energy Policy*. Vol 35. pp 3302–3315

[32] Hudon, K. Merrigan, T. Burch, J. Maguire, J. (2012). Low-Cost Solar Water Heating Research and Development Roadmap. *National Renewable Energy Laboratory (NREL)*. US Department of Energy. Available at: http://www.nrel.gov/docs/fy12osti/54793.pdf (Accessed 20/11/2012).

[33] International Network for Energy and Environmental Sustainability (INEES). http://www.uni-flensburg.de/projekte/inees (Accessed 20/11/ 2013)