Institution: Ulster University		
Unit of Assessment: Architecture, Built Environment and Planning (13)		
Title of case study: Enhanced Quality of Life through Improved Energy Supply using Applied Innovative Solar Technologies: SOLAR		
Period when the underpinning research was undertaken: January 2005 to December 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Dr M Smyth	Reader in Solar Technologies	1999 to present
Dr A Zacharopoulos	Senior Lecturer in Energy	2007 to present
Dr J Mondol	Reader in Architectural Engineering	2003 to present
Dr A Pugsley	Research Associate in Solar Technologies	2017 to present
Mr D McLarnon	Commercial Manager	2008 to present
Period when the claimed impact occurred: August 2013 to December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Impact is through the adoption and application of the innovative solar technologies and relevant practice, producing:

I1: Impact on end user energy use and economic savings, pollution and GHG emissions in Belfast and Botswana.
I2: Impact on education by supporting primary education through solar energy to power laptops and connect to the internet.
I3: Impact on local government decisions and the choice of energy resource deployed by local council (Botswana).
I4: Impact on entrepreneurial activity by providing surplus power to local villagers to provide charging facilities.
I5: Impact on health, social and gender inclusion through setting up a village DESCO (Distributed Energy Service Company).

2. Underpinning research

Research in solar energy and energy efficient buildings has been a core theme of our research unit and Centre for Sustainable Technologies (CST). The research is underpinned by CST's fundamental research in the area of solar materials, novel collector designs, advanced optics and thermal transfer/storage (**R1-R6, G1-G4**).

The CST team (Smyth, Zacharopoulos, Mondol, Pugsley, McLarnon) has developed significant expertise, experience and facilities in the modelling, development and experimental evaluation/characterisation of solar technologies. The underpinning research is centred on research concerning innovative low-cost integrated collector/storage (ICS) solar technologies (**G1**) and hybrid solar thermal/electric collectors (beginning in 2008) with particular attention to their application in Sub-Saharan Africa (SSA) from 2017 to present (**G2-G4**). ICS Solar Water Heaters are simple, low-cost small-scale solar hot water systems ideal for single and multi-family dwellings in low-income communities. One significant issue, however, is their tendency to suffer significant ambient heat loss, especially at night-time and during non-collection periods. The team has extensively published on the evolution and development of ICS systems (**R1**) and has pioneered new research on thermal diodes and double vessel designs and their characterisation (**R2-R3**). The thermal diode innovation is created by incorporating a liquid-vapour phase change material (PCM) in the double vessel cavity at a very low pressure. Research on the forward and reverse heat transfer mechanisms, during collection and non-collection operations respectively, has resulted in significant improvements in collection efficiencies and thermal retention, resulting in new collector designs and formats (**R4**) while maintaining low cost and simplicity. Further enhancements have used different materials and the incorporation of optical reflectors (**R5**).

Solar thermal and Photovoltaics (PV) are complementary technologies. The CST team has conducted significant work in the area of hybrid solar thermal/electric technologies and has understood the relevance of this combined technology for developing nations in SSA (**R6**). By incorporating the solar thermal diode technology in a simple low-cost collector (commercially known as the SolaCatcher), with PV modules tailored to harsh operating environments and connected to simple battery storage, we verified through our research that an 'entry level' standalone solar system that provides a basic level of electrification and hot water is an affordable option for many (**G3, G4**).

The connection between solar energy research at CST and impact is twofold: innovation and applied solar energy. The specific underpinning research that narrates the industrial interaction and commercialisation activities related to novel solar technologies, includes the SolaCatcher. The innovative thermal diode technology that underpins the operation of the SolaCatcher was first investigated in 2007 leading to a PhD project, then to Invest Northern Ireland Proof of Concept funding (**G1**) and several follow-on projects (**G3, G4**). Following the successful completion of this project a University spin out company, SolaForm Ltd, was set up in 2013 and attracted GBP190,000 of investor support to commercialise the SolaCatcher. The team's activities in industry are furthered realised through its work with industry partners and by pushing the boundaries in novel integrated solar technology development since 2014.

3. References to the research

The quality of the underpinning research is evidenced through the publication of scientific papers in leading peer-reviewed journals.

R1: Smyth M, Eames PC and Norton B (2006) Integrated collector storage solar water heaters. *Renewable and Sustainable Energy Reviews*, 10 (6), pp. 503-536. 10.1016/j.rser.2004.11.001.

R2: Smyth M, Quinlan P, Mondol JD, Zacharopoulos A, McLarnon D and Pugsley A (2017) The evolutionary thermal performance and development of a novel thermal diode pre-heat solar water heater under simulated heat flux conditions. *Renewable Energy,* 113, pp. 1160-1167. 10.1016/j.renene.2017.06.080.

R3: Smyth M, Quinlan P, Mondol JD, Zacharopoulos A, McLarnon D and Pugsley A (2018) The experimental evaluation and improvements of a novel thermal diode pre-heat solar water heater under simulated solar conditions. *Renewable Energy* 121, pp. 116-122. 10.1016/j.renene.2017.12.083.

R4: Pugsley A, Zacharopoulos A, Mondol J and Smyth M (2019) Theoretical and experimental analysis of a horizontal planar Liquid-Vapour Thermal Diode (PLVTD). *International Journal of Heat and Mass Transfer* 144, pp. 1-34. 10.1016/j.ijheatmasstransfer.2019.118660.

R5: Muhumuza R, Zacharopoulos A, Mondol J, Smyth M, Pugsley A, Francesco Giuzio G and Kurmis D (2019) Experimental investigation of horizontally operating thermal diode solar water heaters with differing absorber materials under simulated conditions. *Renewable Energy* 138, pp 1051-1064. 10.1016/j.renene.2019.02.036.

R6: Smyth M, Mondol J, Muhumuza R, Pugsley A, Zacharopoulos A, McLarnon D, Forzano C, Buonomano A and Palombo A (2020) Experimental characterisation of different hermetically sealed horizontal, cylindrical double vessel Integrated Collector Storage Solar Water Heating (ICSSWH) prototypes. *Solar Energy*, 206, pp 695-707. 10.1016/j.solener.2020.06.056.

The quality of the underpinning research is further evidenced by the succession of prestigious grants from a range of funding sources including EPSRC and Invest NI.

G1: Smyth
A Low cost, easy to install twin vessel Integrated Collector Storage Solar Water Heater using Phase Change Materials and vacuum technology
01/01/2009 - 31/05/2010
Invest NI- Proof of Concept
GBP99,511

G2: Smyth, Zacharopoulos and Mondol

HERD Power – Feasibility study, workshop and partner consortia building
01/04/2017 - 31/07/2018
Department for the Economy
GBP31,856

G3: Mondol, Zacharopoulos and Smyth
SolaFin2Go – Solar Finance to Go
EPSRC (Innovate UK, Energy Catalyst Round 5)
01/04/2018 - 31/03/2019
GBP245,808

G4: Mondol, Zacharopoulos and Smyth
SolaNetwork
EPSRC – Technology Strategy Board (Innovate UK, Energy Catalyst Round 6)
01/07/2019 - 30/06/2021
GBP211,716

4. Details of the impact

The commercialisation of the SolaCatcher solar water heater through Solaform Ltd (2013), an Ulster spin-out company (Directors: Smyth and McLarnon) (**C1**), has supported research in the development of innovative solar technologies and producing IP centred on the thermal diode (**C2**). These technologies have gained international awareness and pre-commercial success, both in the UK and SSA, through their successful deployment (**G3**), impacting end user and community energy use, and providing social, economic and environmental benefits.

Working with our partners in Northern Ireland (Grove Housing Association), the SolaCatcher was successfully installed into social housing in the Greater Belfast area, providing solar pre-heated water to low-income families, achieving *significance* by alleviating fuel poverty. In Botswana, through regional stakeholders (Empowered Pty, Botswana Housing Corp, Botswana Institute for Technology Research and Innovation (BITRE), Ministry of Tertiary Education, Research, Science and Technology (TERST) and Francistown Council), SolaForm Ltd (with Ulster and dpSun Ltd) and Innovate UK Grants (SolaFin2Go and SolaNetwork) (**G3-G4**), the SolaCatcher (and SolaFin2Go technology) was installed in the village of Jamataka. This innovative integrated PV/thermal approach provides a wider *reach* through addressing Sustainable Development Goals (SDGs) associated with environmental sustainability, delivery of public services and poverty eradication related to the 2030 Agenda for Sustainable Development and specifically SDG 7.

I1 Impact on end user energy use and economic savings, pollution and GHG emissions in the Belfast (a) and Botswana (b) regions

(a) The SolaCatcher concept developed by the CST team was installed into social housing in North Belfast (2014 and 2015) to supplement domestic hot water production. The near commercial units deployed were borne out of years of underpinning research, specifically evaluating the merits of vertical vessel designs and associated feature/component development for mass production (**R2**). The units were designed to improve solar collection, thermal stratification and storage in order to maximise the solar saving fraction (SSF) for domestic dwellings with traditional hot water infrastructures to specifically help alleviate fuel poverty (**C3**). Through energy metering it was shown that each unit provided up to 15% (measured average of 291 kWhrs equivalent to 0.14 tonnes of CO_2 pa per dwelling) saving on the domestic hot water needs for these families, leading to reduced economic and environmental costs. This work led to the SolaCatcher technology being deployed in Botswana.

(b) The SolaCatcher units installed in Jamataka village, Botswana evolved from many years of underpinning research that evaluated the merits of different vessel designs for operation in the SSA climate (**R6**). Furthermore, the SolaCatcher was integrated and incorporated into a more inclusive ‘entry level’ solar system: the SolaFin2Go technology. The combination of PV and electrical storage with the solar thermal SolaCatcher, developed by the CST team in 2018, enabled a more complete provision of energy for village users than what might be supplied through other competing, traditional solar technologies. Jamataka, Botswana is a socio-economically diverse rural village where electricity and hot water consumption is limited by a combination of unavailability and unaffordability. Prior to installing the SolaFin2Go prototypes, the primary school relied entirely on natural lighting, passive ventilation, and a 4kW petrol generator used occasionally to power a photocopier. While the school has several computers, these were rarely used owing to excessive fuel costs. Household electricity consumption in Jamataka typically relates to mobile phones (charged at local shops by solar PV or petrol generator - the nearest fuel supply is over 20km away), torches and radios (powered by disposable batteries) and solar lanterns. Outdoor wood fires are used for cooking and hot water production throughout the village, with some LPG use.

Ulster's SolaFin2Go technology and its real-life application in Jamataka has been improving the day to day lives of the villagers while having commercial implications for the solar supply chain and professionals involved in their deployment, along with policy/regulation, operations and management. On-site measurement had shown that the typical total consumption for the school office is 1400 Wh/day, which was met by running the 4kW petrol generator. Integrating the solar system offset 0.98 litres of petrol, equivalent to £0.67 and 2.3kg CO_2 per day. The households use ~650Wh/day (equivalent to 0.45 litres of petrol, equivalent to £0.31 and 1.06kg CO_2) and typically 30L/day hot water consumption (equivalent to burning 0.48kg of local wood).

I2 Impact on education by supporting Jamataka Primary School through solar energy to power laptops and connect to the internet

The activities of the CST team and the deployment of the SolaFin2Go technology have resulted in end user energy behaviour change and has improved community access. The school **(C4)** was able to participate for the first time in Africa Code Week (Oct 2018), using solar energy to power laptops and the technology's communication network to connect to the internet **(C5)**. Prior to the installation, the school had no internet and electricity used to power the school laptops needed the 4kW petrol generator with related fuelling, noise and safety risk issues. The head teacher stated, *"the impact upon the school and pupils has been transformative, providing reliable, sustainable and modern energy, introducing coding skills and digital literacy to the pupils through power and communications delivered by the SolaFin2Go technology"* (**C4**). Most of the children had previously not seen the laptops working and certainly had never experienced programming.

I3 Impact on local government decisions and the choice of energy resource deployed by local council (Botswana)

The British High Commissioner for Botswana (**C10**) who officially gave the opening address at the SolaFin2Go commissioning event, recognised the impact that the SolaFin2Go project has had on the village of Jamataka in providing clean and affordable modern energy access (a key pillar of SDG 7) and transforming the quality of life for the Jamataka community. The support of such a high-profile dignitary has impact and the follow up coverage on the SolaFin2Go project and the work done in Jamataka was widely published and disseminated. The SolaFin2Go project also had the full backing of Botswanan Minister of Basic Education (and local MP), Botswana Government and local Tonota Sub District Council, Francistown, Botswana. With such a notable body of support, the activities of the team have been acknowledged by the local council (**C6**) to have helped build the case for the council to secure government funding (2019) though the Revised National Policy on Education, to enable the installation of a much larger standalone PV installation in the school campus (installed in 2020).

I4 Impact on entrepreneurial activity by providing surplus power to local villagers to provide charging facilities

The Jamataka project has had significant media/government interest (**C7**) and has high level acceptance by the local community, from the Kgosi (chief) (**C8**) to individual villagers (**C9**). The Kgosi acknowledges his close working relationship with the CST team and the impact of the project on his village, providing the possibility of extensive access to affordable, reliable, sustainable and modern energy. This has led to a series of social/gender inclusion and entrepreneurial activities. 'Powered' villagers have developed battery charging services for other villagers using surplus power from the installed solar systems. One female head of a household is charging 2 or 3 mobile phones, augmenting her family income by a few Pula (**C9**). The installation and its social benefits were nationally recognised and the British High Commissioner for Botswana (**C10**) commented on the project having an immediate and transformative impact on the quality of life, access to basic services and livelihoods in the village.

I5 Impact on health, social and gender inclusion – delayed by COVID 19

SolaNetwork (2020) **(G4)**, a follow-on project from SolaFin2Go, is curating an integrated set of affordable solar energy access solutions for socio-economically diverse SSA rural communities and scaling-up deployments of SolaFin2Go technologies interconnected to form virtual and physical node-to-node networks. A DESCO will operate and maintain the stand-alone units and grid network; manage and administer electricity trading between community prosumers; and deliver targeted training to promote off-grid solutions and develop local capacity in the sector. The ongoing work of the SolaNetwork project with Jamataka has led to the establishment of the village's first DESCO. The project has encouraged village participation in the operations and management of the solar infrastructure, with subsequent influence in the creation and content of a development strategy and training programme. A village-wide survey (2020) with project partners has helped the team identify DESCO champions who will be trained on a social- and gender-inclusive basis. Impact is still ongoing through creating villager awareness, understanding/learning and participation. COVID-19 has adversely influenced the project and significantly curtailed progress towards the anticipated social and gender impacts.

5. Sources to corroborate the impact

The scope of the impacts arising from the case study research is evidenced by a range of sources detailed below.

C1: SolaForm Ltd, Company Number NI619528, Registrar of Companies for Northern Ireland, Companies House, Belfast, 26th July 2013.
C2: Patent WO2014/020328 - SOLAR WATER HEATER.
C3: Corroborating Statement – The General Manager, Grove Housing Association.
C4: Corroborating Statement – The Head teacher, Jamataka Primary School.
C5: Africa Code Week visit Jamataka primary school 31/10/2018 using SolaFin2Go power to teach children computer coding. 9 Tweets, seen 5,568 times with 218 engagements.
C6: Corroborating Statement – Assistant Council Secretary for Tonota Sub District Council, Francistown, Botswana, communicated the councils' gratitude in providing solar power to their priority village – Jamataka.
C7: Botswana official government statement.
C8: Corroborating Statement – The Kgosi (village chief) communicated his close working relationship with the team and the impact of the project on his village.
C9: Corroborating Statement – Villager and local teacher provides evidence for the additional activities brought about by the PV power.
C10: Corroborating Statement – The British High Commissioner for Botswana recognised the impact that the SolaFin2Go project had on the village of Jamataka.