Institution: Aston University		
Unit of Assessment: 12 Engineering		
Title of case study: Seawater Greenhouse – impact on sustainable food production in arid climates		
Period when the underpinning research was undertaken: 2005 to 2018		
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 Philip Davies	Reader	Jul 2005 – Oct 2018 (from Nov 2018, Professor at University of Birmingham)
Dr S C Generalis	Reader Lecturer	Aug 2011 - present Oct 1998 – Jul 2011
Period when the claimed impact occurred: 2014 to present		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Aston University research in thermodynamic modelling and turbulent fluid flow has contributed to establishing a viable design for a greenhouse that uses seawater for cooling and irrigation. This has enabled the development of commercial food production facilities in arid, coastal regions including those in less economically developed locations. The impacts reported in this case study are:

1) Commerce and Economy – Seawater Greenhouse Limited has increased its capabilities and capacity to provide design, consultancy and project management services in the development of Seawater Greenhouses
2) Impacts on production – demonstration of seawater greenhouse designs to become commercially viable in the production of fresh vegetables in arid, coastal environments.

2. Underpinning research

Research at Aston University into seawater greenhouse technology was initiated by Davies who joined Aston in 2005 after completing a Royal Society Industry Fellowship at University of Warwick (2003-2005) with sponsorship by Seawater Greenhouse Ltd (https://seawatergreenhouse.com/). A programme of applied research was established at Aston, in continued collaboration with the company. Investigating the psychrometric properties of concentrated seawater was the starting point to develop a better understanding of seawater cooling and humidity control for agricultural greenhouses. As part of Davies' start-up package, Aston supported a PhD student to work on seawater cooling technology through thermodynamic modelling and experimental work. Facilities were set up for measuring the key properties of seawater and seawater brines, enabling several useful semi-empirical correlations to be obtained for engineering design work **[R1]**. This was strengthened by collaboration with the Sfax solar salt works in Tunisia that supplied samples of seawater brines for analysis and testing **[R2]**. The PhD project included the construction of bench models and validation of models for the design of cooling systems **[R3]**.

In 2007, in parallel to the above PhD project, EPSRC awarded £712k under the programme 'Energy and International Development' with Davies as PI **[G1]**. The project investigated enhanced biomass production and energy conversion in rural, water-scarce communities in India. A key outcome was a new highly efficient desalination concept that was well suited to treatment of brackish groundwater where energy is available as heat (e.g. from solar or waste heat sources). The concept results in minimal waste product, a concentrated brine, that can be used to cool greenhouses, enabling water efficient crop cultivation, and producing salt as a by-product. The research developed prototype solar-driven desalination and fan ventilation systems, that were tested over several months at Aston University **[R4]**. A pilot greenhouse later installed at GB Pant University of Agricultural Technology in India demonstrated for the first the use of desalination reject brine to cool a greenhouse **[R5]**.

An Innovate UK-DFID project was awarded in 2015 to Davies and Generalis under the Agri-Tech Catalyst programme **[G2]**, in collaboration with Seawater Greenhouse Ltd and Pastoral and Environmental Network in the Horn of Africa (PENHA). The aim of this project was to simplify and improve the technology for use in developing countries for which the level of investment required by the earlier systems would not be feasible. The simplified design made use of wind-driven ventilation and low-cost net cladding, in place of polythene or glass greenhouse cladding. Due to the bimodal climate in Somaliland, the prevailing winds blow mainly from two opposing dimensions and the design had to accommodate this. The complex wind pattern and permeable cladding gave rise to a challenging modelling and design problem that was a addressed using numerical techniques developed by Generalis and Akinaga, who created bespoke code for fast execution of year-round modelling using weather data as inputs, making use of expertise from Generalis and Akinaga in solving Navier-Stokes equations representing turbulent flows **[R6].**

3. References to the research – Aston authors in bold

R1 G. Lychnos, J. Fletcher and **P. A. Davies**, Properties of seawater bitterns with regard to liquid-desiccant cooling, Desalination, 250, 172-178 (2010). DOI: https://doi.org/10.1016/j.desal.2008.11.019

R2 G. Lychnos, R. Amdouni and **P. A. Davies**: Concentrated seawater brines for use in solar-powered desiccant cooling cycles, RSC Advances, 2, 7978-7982 (2012). DOI: 10.1039/C2RA21414H

R3 G. Lychnos and **P. A. Davies**, Modelling and experimental verification of a solar-powered liquid desiccant cooling system for greenhouse food production in hot climates, *Energy*, 40 (2012) 116-130 DOI: https://doi.org/10.1016/j.energy.2012.02.021

R4 P. A. Davies and A. K. Hossain, Development of an integrated reverse osmosis-greenhouse system driven by solar photovoltaic generators, Desalination and Water Treatment, 22, 1-13 (2010). DOI: https://doi.org/10.5004/dwt.2010.1393

R5 P. A. Davies, R. Srivastava, B. Kaphaliya, A. K. Hossain, O. Ngoye Igobo, and G. Garantziotis: A greenhouse integrating desalination, water saving and rainwater harvesting for use in salt-affected inland regions, Journal of Scientific and Industrial Research, 70, 628-633 (2011) Available via: http://publications.aston.ac.uk/id/eprint/17953/

R6 T. Akinaga, **S.C. Generalis**, C. Paton, O.N. Igobo, **P.A. Davies**, Brine utilisation for cooling and salt production in wind-driven seawater greenhouses: Design and modelling, Desalination, 426 (2018) 135-154, DOI: https://doi.org/10.1016/j.desal.2017.10.025

Related Grants

G1 EPSRC Grant EP/E044360/1 - Enhanced biomass production and energy conversion for use in water-scarce areas of India, £712,038

G2 Innovate UK (Agritech Catalyst) 102275 - Sustainable intensification of agriculture in the Horn of Africa, £170,925

Evidence of research quality is the publishing of research results in peer reviewed journals and securing research funding through peer-reviewed competition.

4. Details of the impact

Seawater greenhouses are enabling sustainable crop cultivation in arid world regions. They use seawater for both cooling and irrigation making them independent of freshwater resources. They are powered by renewable energy so are not dependant on fossil fuels. Seawater greenhouse technology is helping address food security, climate change resilience, resource scarcity and population expansion. The following impacts arising from Aston research are claimed.

Impacts on Commerce and the Economy – supporting improved capacity/capability to deliver design services (Seawater Greenhouse Ltd - https://seawatergreenhouse.com/)

Seawater Greenhouse Ltd has benefitted from many years of research collaboration **[S1,S5,R1-R6]** with Dr Philip Davies and, in more recent years, Dr Sotos Generalis that have supported the company "*to offer consultancy, design, construction and project management services in their construction"* **[S1]**. During the current REF period, this culminated the development of design tools embedding Aston-developed modelling algorithms which eliminates the "*long process of trial and error"* from the design of greenhouses **[S1]**. This was first deployed in the design options for the seawater greenhouse in Somaliland (see below). The tool enables the design of facilities to take account of local conditions by using as modelling inputs location specific data such as wind direction and velocities. The "*design of seawater greenhouses for each locale is accelerated from months to minutes"* and "*enabled deployment of Seawater Greenhouse technology in less economically prosperous countries"* **[S1]**.

Impacts on Production - demonstrating economically viable food production facilities in arid countries (Sundrop Farms, Pastoral and Environmental Network in the Horn of Africa (PENHA), Red Sea Farms)

Sundrop Farms (https://www.sundropfarms.com/): The experience gained in the EPSRC project with photovoltaic powered-fans combined with evaporative cooling was applied to the design of a project for Seawater Greenhouse Ltd, in a joint venture with Seawater Greenhouse Australia, through a consultancy arrangement **[S1]**. This project was to construct an initial pilot seawater greenhouse covering 2000m^2 at Port Augusta, Australia [**S2**], which was taken forward by Sundrop Farms which established itself in 2012 as an independent company at which time the joint venture with Seawater Greenhouse Ltd was discontinued **[S1, S2].** In 2014, Sundrop Farms scaled up its operations in attracting investment of $US100 million enabling the construction of a 20-hectare commercial greenhouse that incorporates seawater cooling. In their total $AUS200 million **[S3]** facility, Sundrop farms now produce 10-15% (350 tonnes/week; 17,000 tonnes/year) of Australia's truss tomatoes and employing 150 workers **[S3, S4, S5]**.

PENHA (https://www.penhanetwork.org/): The Horn of Africa is the most food-insecure region of the world - some 40% of world food aid goes to the region costing the EU alone more than 1 billion euro p.a. By 2050, the population is predicted to increase by 150%. The Seawater Greenhouse process uses solar energy and seawater to provide a new source of fresh water and a cooler and more humid climate, enabling high crop yield with optimised water use efficiency as evaporative cooling typically reduces crop water demand by 60-80%, compared to open-field cultivation.

As a result of the findings from the Innovate UK-sponsored research, construction costs have been lowered from $US100 to $US20 per square metre of cultivated area **[S1]**, demonstrated by the seawater greenhouse commissioned in Somaliland in 2017. In 2018 the facility reported its first harvest **[S6];** see also https://mailchi.mp/d56cf06c0ac8/penha-newsletter-june-2018. This project also involved the development by Aston of a Decision Support Tool that incorporated turbulent fluid flow modelling and simulation algorithms. Local data on wind speeds and directions are used as an input to the tool with the outputs being data that enables key design parameters for the greenhouse to be identified. The Somaliland system makes use of integrated desalination and salt production as proposed in earlier research at Aston **[R6].**

Red Sea Farms (https://redseafarms.com/): Researchers at the King Abdullah University of Science and Technology (KAUST) spun out a company to develop saltwater greenhouse technologies to encompass new build and retrofit applications as well as provide consultancy services on saltwater and desert agriculture. Davies was invited to KAUST in 2012, and three times subsequently, to advise on desalination strategies for a design study on commercial saltwater greenhouse facilities for food production. In 2018 Red Sea Farms was spun out of KAUST and attracted $US1.9 million funding to build a 2,000m^2 greenhouse to scale up production aiming to produce 50 tonnes/year of tomatoes annually by 2021 **[S7]**. Red Sea Farms also operates several production facilities producing fresh tomatoes to seven markets in Jeddah, Saudi Arabia (https://redseafarms.com/produce/).

Recognition for this and preceding projects was given by the national Shell Springboard prize for low-carbon businesses (£150k) which was awarded to Seawater Greenhouse Ltd in May 2018 **[S8]**.

5. Sources to corroborate the impact

S1 Testimonial letter from CEO, Seawater Greenhouse Ltd (PDF document)

S2 Wired UK article Mar 2018 (PDF document; http://www.wired.co.uk/article/charlie-paton-seawater-greenhouse-desalination-abu-dhabi-oman-australia-somaliland)

S3 S. Neales - This is the Future of Farming, The Australian, 13 August, 2016 (PDF document) Link to article - behind paywall)

S4 Ingenia Seawater Greenhouse article Sept 2019 (PDF document)
https://www.ingenia.org.uk/Ingenia/Articles/0dcfbb73-b634-487a-93ec-669c2f3ac2bc)

S5 FT article on Sundrop and Seawater Greenhouse Ltd 2017 (PDF document)
https://www.ft.com/content/e4a6ffd2-7e45-11e6-8e50-8ec15fb462f4)

S6 Somaliland First Harvest – Article in SomTribune, 2018 (PDF document)
https://www.somtribune.com/2018/01/30/seawater-greenhouse-reaps-first-somaliland-veg-crop-grown-just-sea-water/)

S7 Testimonial letter from CEO and Co-founder, Red Sea Farms Ltd (PDF document)

S8 Shell Springboard Award notice May 2018 (PDF document)
https://www.energyvoice.com/other-news/182718/shell-offers-350k-funding-pot-to-low-carbon-businesses/)