ISBN 978-0-9934156-4-7 | URBAN INNOVATION | No. 1 | APRIL 2024

# Civic Partners in Net Zero

Innovative approaches to universities working with their places to achieve net zero targets

Key Cities Innovation Network

Key Cities is a diverse cross-party network of 27 cities and towns across England and Wales that represents urban UK. With a combined population of more than six million contributing in excess of £150 billion to the economy, it includes some of the fastest-growing local economies in the country. Key Cities champions its places to unlock devolution, deliver prosperity and protect the environment.

www.keycities.uk

The Key Cities Innovation Network was formed in 2022 to foster scalable innovation and new approaches to the challenges and opportunities of urban UK today. The Network currently has 13 member universities:

University of Bath
University of Bradford
Coventry University
University of East Anglia
Lancaster University
University of Lincoln
University of Plymouth
University of Salford
University of South Wales
University of Southampton
Staffordshire University
University of Sunderland
Wrexham University

www.keycitiesinnovation.org
secretariat@keycitiesinnovation.org

Urban Innovation No. 1, April 2024
ISBN 978-0-9934156-4-7 (online)

**Civic Partners in Net Zero**

Edited by Professor Maria Hinfelaar and Kasper de Graaf

Review panel: Dr Paul Hildreth, Professor Maria Hinfelaar, Professor Ian White

Thanks to Jane Bowyer, Malcolm Garrett, Clare Kristensen

Published by Document for the Key Cities Innovation Network. Copyright © 2024 Key Cities Innovation Network.

Unless otherwise stated, the articles in this publication are made available under the terms of the Creative Commons Attribution 4.0 licence, https://creativecommons.org/licenses/by/4.0/.

Designed and produced by Images&Co, working in partnership with ING Media.

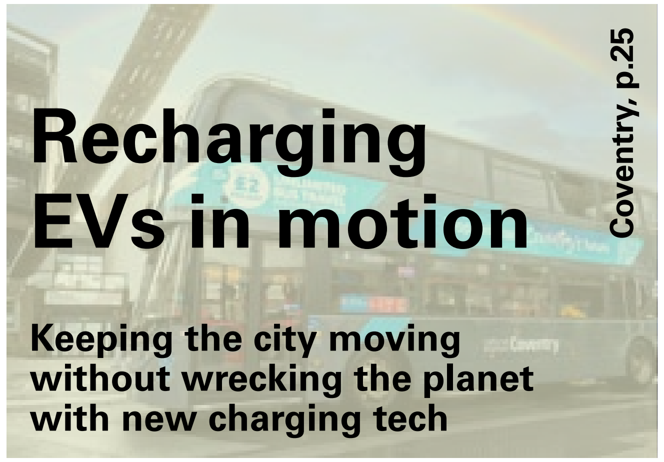
www.images.co.uk
www.ing-media.com

Cover picture: Educators and climate scientists developing the Morecambe Bay Curriculum (see p.47)

# Civic Partners in Net Zero

## Innovative approaches to universities working with their places to achieve net zero targets

Key Cities Innovation Network


Recharging EVs in motion
Keeping the city moving without wrecking the planet with new charging tech
Coventry, p.25


Culture change in schools
Educators and scientists embed environment in the national curriculum
Morecambe Bay, p.47


Local planning policy
How connecting policy and science is driving down carbon in construction
Bath, p.65


Play spaces and new homes
Working with citizens and industry to drive down carbon
Wrexham, p.85


The promise of biotech
How what we leave and waste in our cities can hold the key to sustainability
South Wales, p.97


The theatre of climate
Triggering an emotional response to science by engaging audiences
Southampton, p.129



## CONTENTS

John Merry and Ian White

Key Cities was established eleven years ago, and it is two years since we created the Key Cities Innovation Network to stimulate innovation through a strategic partnership between our places and universities across the country. The innovations presented here are evidence of the fertile partnerships that exist between universities and their places. Bringing them together in this volume shows our intent to leverage the power of civic partnership across our wider network.

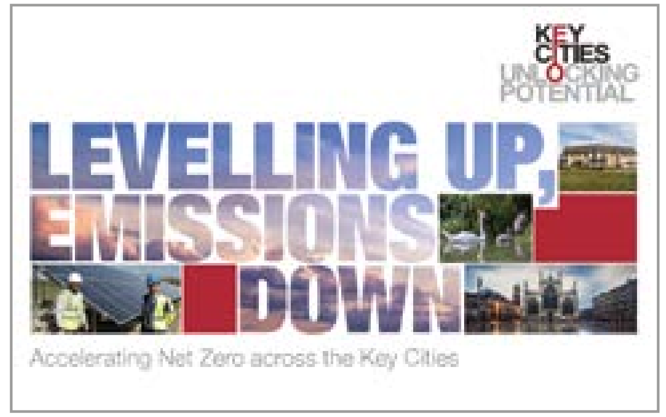
"The importance of universities to the regions desolated by the decline of traditional industries […] should be clear," the former Kings College London president Ed Byrne and home and education secretary Charles Clarke said in their 2020 book, The University Challenge[1]. Add to that decline the impacts of globalisation and multiple economic shocks over the last decade, and it is plain to see that attempts at 'levelling up', while delivering important benefits in many places, are failing to stem the underlying trend of growing inequality.

Economic protection and trade barriers, Byrne and Clarke maintain, will not rekindle the competitive advantages once offered by traditional industries. Future resilient competitive advantage for our regions and places will most likely come instead from "the creativity and innovation in new industries that universities are best placed to offer, properly stimulating and properly stimulated."

The Key Cities Innovation Network expands this stimulus beyond favoured concentrations to support equitable regional development nationwide. Over the last two years, our universities have contributed to Key Cities reports on culture[2] and skills[3], initiated cross-network collaboration on enterprise, and we are currently collaborating on a joint policy review on coastal communities led by the Leader of Plymouth City Council, Cllr Tudor Evans, and the Centre for Coastal Communities at the University of Plymouth.

> "Local partnership is ever more important when the national net zero trajectory is contentious."

Building on the Key Cities report 'Levelling up, emissions down'[4] published last year,




our focus in this volume is on partnership to achieve local net zero targets – something that is becoming ever more important when the national trajectory is clouded by contention. The ideas presented here are important and exciting. They hold the promise of significant impact locally and nationally, but it is important to remember that they are steps on a journey, starting points on which we can build both as a network and in partnership with government, communities and stakeholders.

The government's growing interest in Place over the last decade is welcome, as is the commitment to work with regions and places, with the implied promise of creating opportunity and equitable development in the many places and communities where productivity remains stubbornly low with growing inequality and deprivation. We look forward to working with government to deliver on that promise.

The measure is what this renewed interest delivers in terms of productive engagement, including what happens next with the compelling innovations presented here.

---

Cllr John Merry CBE is Deputy City Mayor of Salford and Chair of Key Cities.

Professor Ian White is the Vice-Chancellor of the University of Bath and Steering Group Chair of the Key Cities Innovation Network.

1 Byrne, E., Clarke, C. (2020). The University Challenge. London: Pearson.

2 Key Cities (February 2023). Culture and Place in Britain. Available at: https://keycities.uk/2023/02/06/culture-and-place-in-britain/.

3 Key Cities (October 2023). Skills for cities, skills for life. Available at: https://keycities.uk/2023/10/17/skills-for-cities-skills-for-life/.

4 Metro Dynamics and Opergy (May 2023). Levelling up, emissions down. Salford: Key Cities. Available at: https://keycities.uk/2023/05/09/levelling-up-emissions-down-full-report/.

Maria Hinfelaar and Kasper de Graaf

Welcome to this, the first in what we hope will be an annual compendium of innovations from the Key Cities Innovation Network.

It has been truly inspiring to work with colleagues from the network and learn so much about how universities work with their places, sharing the journey to net zero which we are all aiming for. This work built on exciting developments seen previously, such as the Key Cities Net Zero Data Dashboard[1] developed by Metro Dynamics and Opergy, which tracks progress across the network and benchmarks this against national averages. This is important, in the context of net zero targets which may vary across UK nations and even across individual local authorities. After all, climate change does not respect borders – so we must work together and be civic partners in net zero.

Introducing this compendium of place-based innovations, we offer perspectives and insights from key actors and stakeholders in this space: the Chairs of Key Cities and the Key Cities Innovation Network, the Leader of Gloucester City Council and Key Cities portfolio lead on climate, the Executive Director of Place and Levelling Up of Innovate UK, and the Chief Scientific Advisor to Southampton City Council.

The case studies which follow were initially presented at the Key Cities Innovation Network's annual symposium, which was hosted by Wrexham University in November 2023. Contributors were then invited to flesh them out for peer review, documenting how each university is supporting its place or region on the journey to net zero. The result is a powerful and rich set of evidence-based case studies describing innovative practices coming from original ideas.

> "Our opportunity is to develop ideas that can scale to all places large and small."

**Scalable innovation**

One of the defining opportunities for the Key Cities Innovation Network is scalable innovation: developing and applying ideas that can scale not only to large cities but to urban areas – and their associated rural and coastal places – of all types, demographies and sizes large and small, as represented by the diversity of the Key Cities. Thus, while recognising that each study in this compendium represents a specific locality with its own characteristics and actors, there is real scope for replicating ideas and practices elsewhere, thereby adding value to collective efforts to reduce carbon emissions at national or indeed global level.

**Themes**

The case studies fall naturally into two themes: technology-based innovation underpinning policy development on the one hand, and engagement with local communities on climate science on the other.

*Theme 1: Technology-based innovation and policy development*

This theme revolves around harnessing novel technologies to effect changes in outcomes from everyday activities such as transport, waste processing and residential development planning. Three of the case studies fall into that category.

It is widely known that electric vehicles offer cleaner transport solutions, with the potential to reduce pollutants and improve quality of life in urban areas. But is this technology transferable to large vehicles such as fleets of buses or trucks? What infrastructure would be needed to revolutionise electric vehicles by enabling 'on-the-go' recharging? What if it were possible to do this on dedicated stretches of road in specific locations within our cities or as part of the motorway network, thus achieving a step change in sustainable and clean modes of transport?

A case study prepared by Coventry University, working with a consortium of experts including Coventry City Council and private sector companies, sets out how this technology is being trialled locally in order to determine feasibility. Their Dynacov project aims to create an ecosystem for secure, automated wireless charging in dynamic fashion. If successfully rolled out, it could transform transportation and sustainability, subject to technical installation, grid connections and cost considerations.

Another barrier to overcome is the lack of high-level government support and dedicated funding. The opportunity is there: it is anticipated that a proportion of the HGV fleet will be electrified by 2040, so there has to be the political will locally and nationally to facilitate this through appropriate charging infrastructure.

Similar to transport, construction is a sector which is particularly challenging when it comes to decarbonisation, and hugely significant, as the built environment accounts for 25% of the UK's greenhouse gas emissions.

In a move which goes well beyond national building regulations, Bath & North East Somerset Council now requires all new buildings to achieve net zero operational energy, and major developments to meet an embodied carbon target. The University of Bath has worked with the Council to evaluate the impact of the policies on building designs and how they are being received by the industry. The new policies set a very high bar – for instance, for fuel-efficient heating systems in new-build residential developments, or the imperative for non-residential new-build developments to put in

1 https://keycities.uk/data/data-net-zero-2023/

place renewable energy generation in order to achieve net zero.

The study found that a significant proportion of planning applications was non-compliant with these challenging targets, partially due to emerging technologies which were not always deemed viable, and partially due to a lack of knowledge as the new policies represented such a radical departure from 'business as usual'. The study recommends bringing in a wider diversity of expertise and developing guidance, which would accelerate the required emission reduction across local authorities in the UK.

Another piece of the jigsaw in striving for net zero is the creation of a circular economy. The University of South Wales is collaborating with the Welsh government to research the positive impacts of new policies on municipal food waste management. It is a Welsh government objective to encourage food waste disposal through separate collections which can then be recycled for other purposes such as the production of fertilisers, using techniques of anaerobic digestion. The University also supported the Welsh government with the provision of relevant information to local authorities across Wales and the setup of anaerobic digestion processing plants.

Technologies for harnessing and converting the outputs from anaerobic digestion towards other purposes such as renewable energy are also interesting. Further work in this area can refine these pioneering biotechnologies and support their full-scale deployment and commercialisation.

*Theme 2: Working with communities*

The second theme is about raising awareness, influencing and changing behaviours. Central to this theme, clearly, is winning over people of all socio-economic backgrounds and age profiles.

Starting with the premise that scientists universally face considerable difficulties in communicating effectively with the public, Southampton University looked for more imaginative ways to talk about climate science research and teamed up with a local theatre company. The immediacy of climate change impacts can be overwhelming and people may feel powerless, unaware of what they can do collectively through individual actions. Intergenerational influence, particularly the young leading the old, can help to instill more confidence.

Stories in the Dust created fun group activities with children in the 5-12 age range, culminating in a show that combined theatre and science, with the children contributing their ideas and solutions. They were then able to transmit that enthusiasm not only in front of the theatre audience but also to their parents or carers at home. Demonstrating the impacts of climate change seen through the eyes of children in a creative performance setting appeared far more effective than more traditional ways of communicating science-related topics to the general public. There is the potential for similar partnerships between scientists and artists in other communities across the UK, replicating the approaches developed in Southampton and adding to the evidence base.

Another example of encouraging young people to become champions of change in the face of climate challenges is the Morecambe Bay Curriculum, developed by Lancaster University and supported by Lancaster and Morecambe College. The programme supports local educators with a passion for strengthening the focus on climate change and sustainability, which they found lacking in the national curriculum. Remarkably, the governance structure and project reach spans across all sectors of education from early years through primary, secondary, further education and universities, with specific projects mapped against core subject areas for each level of learning. Schoolchildren, teachers and academics work side by side.

Adopting the principle of participatory action research, bringing together real-life experiences to shape new knowledge, the projects were chosen for their relevance to Morecambe Bay as a place. This meant that there was a focus not only on protecting the natural environment and ecosystem, but also consideration of employability prospects, health and wellbeing and pride in the community. Co-designing the curriculum in this way ensures that there is ownership and shared learning across all the parties, where meaningful collaborations can bring about real and positive change. The Morecambe Bay Curriculum model could be adapted and transferred to other places.

Wrexham University's overarching civic mission strategy has inspired two projects which straddle across our themes of technological innovation and community engagement. The Ecological Citizen case study describes how communities can be mobilised to confront the climate crisis through accessible technology and small-scale interventions, for instance redesigning outdoor children's play areas with recycled or nature-based materials instead of hard plastics and metal. Individuals are urged to reflect on decisions made in their daily lives and the consequential impact on the environment.

A second case study documents a partnership between Wrexham University and ClwydAlyn Housing Association in North Wales to create large housing estates of the future powered by renewable energy. This project seeks to reconcile the twin, possibly conflicting, national commitments to an extensive house-building programme and to achieving net zero by 2050. The aim is therefore to create a model that housing developers are willing to build, home-owners are eager to buy and urban planners are happy to support. This requires a multi-disciplinary approach combining architectural design, renewable energy engineering solutions and storage modelling.

The two case studies from Wrexham University demonstrate different aspects of empowering communities and organisations as we work towards large-scale decarbonisation.

### Our civic role

The six papers in this compendium offer a compelling and fascinating insight into the groundbreaking work being done across our Key Cities. Universities have a critical role to play in brokering partnerships with their local authorities, community organisations and local people to create a more environmentally sustainable society. We have chosen to present the six case studies across both themes in random order, giving equal weight to technologically-focused examples underpinned by quantitative data and to community-based work documented through rich narrative.

In the final chapter, we offer a conclusion and some recommendations which we hope will be taken on board by national and local policymakers.

---

Professor Maria Hinfelaar is the Vice-Chancellor of Wrexham University.

Kasper de Graaf is the Programme Director of the Key Cities Innovation Network.

## THE REVIEW PANEL

The six studies published in this compendium were peer-reviewed by a panel comprising:

### Dr Paul Hildreth

Formerly of the Bartlett School of Planning at University College London, Dr Hildreth is an international advisor on cities, regions and local economies, contributing to national policy work and in local economic development, governance and place-shaping.

### Professor Maria Hinfelaar

Professor Hinfelaar is the Vice-Chancellor of Wrexham University. A member of the North Wales Economic Ambition Board and the Mersey Dee Alliance Board, her research specialism is in educational leadership and regional economic development.

### Professor Ian White

Professor White is the Vice-Chancellor of the University of Bath. An engineer with substantial research in optoelectronics, Professor White was previously the Van Eck Professor of Engineering at the University of Cambridge, where he also served as the Master of Jesus College from 2011 to 2019.

## THE AGENCY OF EVERYONE

Richard Cook

We've all heard about climate change and the greenhouse effect, but what exactly are they? What do they mean for our everyday lives? What can we in Key Cities, with our partners in the Innovation Network, do about climate change?

Perhaps more importantly, what can we do about it together?

The science is now well understood. Energy from the sun, falling as light, warms up the earth. Some of this energy is radiated back into space as heat, but some gets trapped in the earth's atmosphere. Some gases – such as carbon dioxide ($CO_2$) – are very efficient at trapping this heat. Carbon dioxide levels had remained relatively steady for at least the last 100,000 years. However, since the industrial revolution, with the burning of fossil fuels such as oil, coal and gas, the level of carbon dioxide in the atmosphere has now almost doubled – and is currently increasing at an alarming rate. As the level of carbon dioxide in the atmosphere increases, more heat is trapped, and the warming of the earth leads to climate change.

So what are the implications of climate change for us? The scientific consensus is that the most likely outcomes around the globe over the next century will be:

- Winters up to 30% wetter
- Flooding up to five times more frequent
- Droughts as often as once every three years
- Worsening summer air pollution
- More storms and gales, causing damage to property
- Loss of wildlife habitats and species
- Social unrest through increased migration
- Higher average temperatures creating increased need for cooling in offices and homes along with a higher probability of extreme temperatures
- Drier summers, putting a greater strain on water resources and wildlife, and on farmers to diversify crops
- Rising sea levels, leading to more coastal erosion
- Increasing frequency of weather events causing heat stress to the elderly and infirm

Opportunities to mitigate against these impacts are being created by developments in technology and the physical sciences, looking for ways of improving outcomes in areas such as transport, economy, biodiversity, adaptation, planning, building retrofit, food and farming, and renewable energy. Our universities are strong leaders in research and development, responsible for creating such improvements, which we will need to utilise for maximum beneficial effect.

But however clever our technological solutions are in mitigating against climate change, the fact remains that all of us have to adopt those technologies when they are available.

And that requires behaviour change.

Unless we, the individual citizens, are ready to make changes in our daily lives, we will fail to deal with the issue. We all need to:

- drive less
- switch to zero tailpipe emission vehicles
- take fewer overseas holidays
- generate less waste of all varieties
- eat less meat
- stop concreting and astro-turfing our gardens
- use renewable energy
- change the way we heat our homes and reduce our energy consumption

Behaviour change is one of the most crucial considerations. Unless we collectively make those changes, we will fail. It is estimated that seventy per cent of all climate change emissions are caused by the activities of individuals, so it is at that level that changes need to be made. So while science and technology create opportunities, persuading people to change their behaviour is more of a social science intervention – and in that regard, the educational function of universities is a crucial part of that journey.

Currently we, as politicians and policymakers, are failing in this task.

In its 2021 "Achieving Net Zero Emissions" report, the Public Accounts Committee concluded that politicians have "not ... engaged with the public on the ... individual behaviour changes that achieving net zero will require".

And this shows.

A YouGov / Times survey in July 2023 found that just 42% of those interviewed support the phasing out of gas boilers by 2035 and 55% think that policies to reduce carbon emissions should only be introduced if they do not result in additional costs for ordinary people, in the context when our national political institutions appear to be signalling a retreat from some of the most important tools we have for driving behaviour change, including structural and regulatory change and reasoned persuasion.

So we need to look at the changes that are necessary and assess whether people can be persuaded and facilitated to make those changes, or whether central or local government need to mandate them.

The evidence – and, indeed, the scale of the climate crisis we face – suggest we need both.

If we take a look at the Kuss and Nicholas 2022 review of 800 peer-reviewed studies into the most effective mechanisms for reducing cars in cities, we find that the top three – congestion charging, parking controls, and low traffic neighbourhoods – are all what we call 'demand side' measures, demonstrating just how important policy is in driving behavioural change.

But the research also emphasises the importance of improving the public transport user experience, travel planning, and car sharing, so 'supply side' measures that help to persuade people and make it easier for them to reduce their emissions also have an important role to play.

> "The answer to the question 'what is the solution?' is increasingly 'all of the above'."

As the climate crisis escalates, the answer to the question 'what is the solution?' is increasingly 'all of the above'.

That is why the six district local authorities within the Gloucestershire County Council area have come together with the County Council and other bodies such as the police and the NHS to form Climate Leadership Gloucestershire.

But we can't do this alone. At present this group does not include representatives of academic institutions, but I am keen to see this lack is resolved in the near future as Gloucestershire has three universities and they too will play a part in delivering net zero.

Most if not all the authorities within Key Cities have declared a climate emergency, which involves a target of reaching net zero in respect of their own emissions by 2030. This is a short timeframe and will be difficult to achieve. Although government has a timeframe to 2050 to make the country net zero, Gloucester City has a tougher target of 2045 to bring the entire district to net zero and I have an aim to help all Key Cities to reach the same target.

This will require adequate funding, technological innovation, full partnership cooperation – but above all, behaviour change.

That is why I am looking to the Innovation Network for help, both in creating innovative solutions through science and technology drawing on the expertise within our universities, and coordinating the means by which we can persuade people to change their behaviour and so change the trajectory of the climate crisis.

---

Cllr Richard Cook is the Leader of Gloucester City Council and the Conservative Deputy Chair and Climate Portfolio Lead of Key Cities.

Dean Cook

## A perfect storm

In 2009, Sir John Beddington, the then Chief Scientific Adviser to the UK Government, forecast a 'perfect storm' of food shortages, scarce water, and insufficient energy resources as the world needed to mitigate and adapt to climate change.

He spoke of a possible crisis by 2030 whereby "a whole series of events come together":

- The world's population will rise by 33%, from 6bn to 8bn,
- Demand for food will increase by 50%,
- Demand for water will increase by 30%,
- Demand for energy will increase by 50%.

However, Beddington was optimistic that scientists could come up with solutions to the problems. He said: "We need investment in science and technology, and all the other ways of treating very seriously these major problems. 2030 is not very far away."

With the climate emergency nearing dangerous tipping points, governments have been compelled to act.

As outlined in the UK's Roadmap to Net Zero, the UK government aims to reduce all direct emissions from public sector buildings by 50% and 75% by 2032 and 2037 respectively, against a 2017 baseline. All UK emissions are to reach net zero by 2050. There are also ambitious targets within each of the four nations. Scotland aims to reach net zero from all emissions by 2045, Wales has an ambition to reach net zero emissions in its public sector by 2030, and Northern Ireland aims to reduce its government emissions by 30% by 2030 (from a 2016/17 baseline year). These targets demonstrate the UK-wide commitment to reaching net zero goals.

The UK government is also investing in R&D at record levels as it strives to consolidate the UK's position as a science superpower and to leverage increased private-sector investment into R&D. The government's Innovation Strategy[1] has set out a vision for the UK to be a global hub for innovation by 2035. This strategy outlines the key technologies that will drive forward the UK economy and a mission-based approach for addressing societal challenges.

In November 2021, Innovate UK published its Plan for Action[2] outlining our approach to delivering the government's Innovation Strategy. With the UK low-carbon and renewable energy economy worth £46.7 billion in 2018 and employing 224,800 people, we committed to support UK businesses to develop, demonstrate, and scale technological solutions capable of being deployed domestically and across the world.

1 https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it
2 https://www.ukri.org/publications/innovate-uk-action-plan-for-business-innovation-2021-to-2025/



Our Strategic Delivery Plan 2022 to 2025[3] outlines how we will deliver this through the development and commercialisation of new ideas, supported by an outstanding innovation ecosystem that is agile, inclusive, and easy to navigate. This includes helping to maximise local strengths that can enhance UK capabilities and increase the regional and national impact of innovation clusters.

In short, we have now prioritised our organisation around three strategic axes, of:

- how we evolve our support to domains (sectors, missions and challenges),
- how we develop our products and services to best meet the needs of innovators across the UK
- how we consider Place in everything we do.

> "The global challenges are complex, but the solutions are often local."

## The power of Place

If we are to fully unlock our world-leading science and technology, a step change is required, driven by a fresh approach which is open, inclusive and collaborative. Although the global challenges facing us are complex, the ideas and solutions are often local. Through effective collaboration across cities, towns and regions across the UK, we can drive a more inclusive approach to innovation to help unlock these opportunities.

The Key Cities group is one of several place-focused mission groups we will work with to engage with the broadest range of actors and networks across all our great cities, towns and rural communities. We have committed to work with local partners to build greater coherence between national economic plans, local growth strategies and the government's overall innovation strategy.

Moving the UK towards net zero and tackling the climate emergency is just one example of where we can work with local leadership and harness the collective talent across all the nations and regions of the UK. In taking a place-based approach to tackling these grand challenges, it is vital that we encourage the support and participation of the University sector – ensuring a total ecosystem approach bringing together the research base, civic authorities and industry and engaging innovation clusters across the UK. Investing in innovation clusters also brings tremendous benefits to local economies and is one of the ways that we are supporting the UK government's levelling up agenda.

3 https://www.ukri.org/publications/innovate-uk-strategic-delivery-plan/innovate-uk-strategic-delivery-plan-2022-to-2025/

**Innovation clusters**

So what makes a good innovation cluster?

Strong innovation clusters are cited as positively influencing regional economic performance. At the heart of this is how they foster dense knowledge flows and spill-overs from universities to businesses, from businesses to businesses, and in turn feed back strongly to inform the underpinning science. They are widely acknowledged to have a major role in strengthening entrepreneurship and to boost new enterprise formation, as well as enhancing start-up survival, productivity and employment. Innovation clusters are highly complex ecosystems, over and above just a science base or industry supply-chain.

There is a clear role for government and civic authorities to help stimulate the environments vital for cluster success – for business, for innovation and institutional. The key role for government is to enable, whether in the form of providing direct access to finance where there is market failure, or in less direct ways such as the creation of enabling policy frameworks or strategic action plans. Civic authorities in particular have a very important role, providing local leadership. The university sector has much to contribute here also. In my mind, strong leadership is crucial to success.

However, innovation is risky and if we want to encourage entrepreneurial spirit, we need to think about how we de-risk and make that more attractive for those involved. According to Bloomberg, eight out of ten entrepreneurs who start new businesses fail in the first 18 months. Whilst that statistic may sound alarming, the importance of start-ups to the economy is enormous, since the reward of bringing a new idea or technology to market can revolutionise supply chains, improve productivity and create new industries.

We therefore need to be "creating safe places for people to carry out risky enterprise". Ultimately this is about the people. For a locality to grow its tech industries and supply chains, it needs to attract the best talent. Innovative places have the potential to become magnets for talent and investment and it's vital that we continue to push forward and invest in our homegrown talent, as well as attracting skills and technologies from around the world.

This is the reason we introduced our new £80m Innovate UK Launchpad programme[4]. Each locally-focused launchpad looks to grow a cluster of innovative SMEs, helping de-risk the innovation journey and offering tailored funding and support for businesses to innovate, collaborate and contribute to a supportive ecosystem. Eleven launchpads have so far been announced, covering Scotland, Northern Ireland, South West Wales, Mid/North Wales, West Yorkshire, North East England, Tees Valley, Liverpool City Region, Coventry and Warwickshire, South West England, and Eastern England. Two of these launchpads have a specific net zero focus, with several others contributing to developing underpinning technologies.

4 https://iuk.ktn-uk.org/programme/launchpads/

To support more mature and developed ecosystems, we are also leading delivery of the £100m Innovation Accelerator programme[5]. Announced in the government's levelling up white paper, the programme is a pilot for doing things differently through stronger co-creation with places to bring our national reach, our scale, our connections, our relationships with industry – to help those places shape the best programmes, but driven locally. Working closely with the leadership of the three pilot areas of Greater Manchester, the West Midlands City Region and Glasgow City Region, this really is an opportunity to do things differently. All three accelerators are investing to meet the needs of their local economies, and across the 26 projects there is significant activity that supports the transition to net zero.

**Leveraging local strengths to deliver national impact**

Through our Plan for Action, we committed to strengthening the national ecosystem and to support levelling up by fully embracing the diversity of strengths that we have in places across the whole of the UK. We have delivered on our intent to exploit opportunities that utilise the innovation specialities of regions outside of the Greater South East for demonstration activities, development of innovation hubs and the deployment of new strategic infrastructure.

5 https://www.ukri.org/what-we-do/browse-our-areas-of-investment-and-support/innovation-accelerator-programme/

For example, the Net Zero Living programme[6] aims to help local authorities unlock the sizeable markets for transforming their places to net zero. It brings together over fifty places from across the UK in a cohort that innovates and learns together on their journey to delivering great net zero outcomes for residents. The group is made up of local authorities from right across the UK and at various stages of development of their net zero plans. This cohort includes Key Cities members Portsmouth, Blackpool, Exeter, Southampton and Plymouth. The cohort is supported with technical training in key areas like financing, resident engagement, planning and regulatory issues to build capability and momentum. Some places are also funded to undertake innovative demonstration of what can be done to address those areas. These include leading cities like Bristol, aiming to show how a new financing structure can effectively blend public and private finance, but also places like Rossendale in Lancashire, which will be developing solutions for Net Zero Terraced Streets through a new holistic delivery model approach, or the development of

6 https://iuk.ktn-uk.org/programme/net-zero-living/

rural energy hubs as a delivery vehicle for the islands of Orkney and Shetland.

### Local action plans

Finally we have committed to build greater coherence between national economic plans, local industrial strategies and the government's innovation strategy by more localised support with colleagues in the government's Cities and Local Growth Unit, the Department for Business and Trade, British Business Bank, local business chambers, Intellectual Property Office and other business groups. We are working to integrate our UK-wide offers into the local gateways for business provided by growth hubs and the agencies of Scotland, Wales and Northern Ireland, and to connect their offers to our national gateway, the Innovation Hub[7]. We are building local-to-national-to-international networks by harnessing the resources and connections of our locally-based Innovate UK Business Connect and Business Growth teams and our Catapults.

The Local Action Plans we have developed with our partners are the formal commitment to how we will work strategically with Places to unlock their innovation potential and to grow their local economies. We have published Action Plans with the West Midlands, West Yorkshire, Liverpool City Region, Glasgow City Region, New Anglia, Wales, West of England and signed MOUs with Greater Manchester, Scottish Enterprise and Welsh government – with more to come. Only through stronger partnership and collaboration will we scale and grow place-based innovation this parliament and into the next.

---

Dean Cook is the Executive Director of Place and Levelling Up at Innovate UK.

7 https://ukinnovationhub.ukri.org/



AbuBakr S. Bahaj

Local authorities and their City Councils are responsible for the planning and the delivery of significant public services, yet they overwhelmingly appear to rely on modest internal scientific capacity in their decision-making processes. In many cases, there seems to be reluctance or lack of awareness of potentially useful scientific research and evidence that could enhance such decisions with positive consequences in terms of financial savings, critical in an era of economic austerity.

> "Well-informed scientific evidence should be encouraged at all levels of decision-making."

In essence, well-informed scientific evidence should be encouraged at all levels of decision making, but the lack of strong and embedded links between local authorities and the science base – universities, research institutions and so on, seem to undermine this. Strengthening such links will undoubtedly result in better decision-making and the development of appropriately relevant policies to address the challenges faced by cities, towns and their citizens.

In contrast, the national government has appropriately devised structures to gain insights from scientific advice. Replicating this at the local authority level will result in well-informed decisions to enhance services, provide growth, and address societal challenges in our towns and cities. Robust and fully scrutinised scientific advice could be facilitated around climate change, social care, cyber-security, poverty alleviation, economic growth and preparedness against threats such as floods, heatwaves, and pandemics.

These issues were central to my accepting appointment in 2012 as Chief Scientific Advisor (CSA) to the City of Southampton, the first in the UK as far as I am aware. I was approached for the role, firstly, because of my expertise as Professor of Sustainable Energy and Head of the Energy and Climate Change Division and Sustainable Energy Research Group at the University of Southampton[1], and secondly, because I have continuously and vigorously promoted – to the Council and others – various ideas to reconfigure the City as a place where people can live, thrive and benefit from city characteristics, enhanced services and infrastructure.

The role was devised to discharge a number of responsibilities by agreement between the City and the CSA:

1. Providing expert advice on scientific issues relevant to the City Council. This covers a wide range of topics within the expertise of the CSA or by

1 www.energy.soton.ac.uk

bringing in other expertise when and where required.
2. Serving as a liaison between the scientific community, policymakers, and the public. This includes engaging with stakeholders to build consensus around policy decisions as well as communicating scientific concepts in accessible language through various modes of engagement.
3. Supplying scientific insights and analyses to assist policymakers in making evidence-based decisions as well as assessing the potential impact of different policy options. This can encompass reviewing existing evidence and perhaps conducting further research.
4. Providing advice on relevant opportunities (nationally and internationally), on new and emergent scientific trends, as well as identifying emerging risks and effective strategies to address them.

These broad areas, which were subject to regular review, were devised to lead to more informed and effective policies and strategies by ensuring that scientific evidence is integrated into the City's decision-making processes.

These guidelines have generated a lot of interactions with the City with its elected councillors, and officers. I have unrestricted access to the Leader of the Council and attend Council and committee meetings to provide advice on relevant topics that arise from time to time. I have also created opportunities for joint workshops attended by both senior elected councillors and officers to discuss and provide solutions to pressing as well as future needs of the City.

### The green city charter

As an example, when the City declared a climate emergency and asked city organisations to sign its green city charter[2], I suggested and developed the green city tracker (GCC)[3] for the city, which has been used to support charter signatories. The GCC also acted as a conduit to engage with city institutions and linking up to address common challenges.

The relationship has developed over the years, and has continued with Council Leaders from both political parties. This has helped both sides to better understand each other's points of view, whilst ensuring decisions are supported by evidence. The advice given to the authority by the CSA encompasses matters related to city growth, environment, and energy as well as detailed advice across multiple sectors such as planning, housing, green spaces, transportation as well as transitioning the City to a low carbon pathway. This engagement has resulted in various joint projects, including university students' projects as well as projects jointly undertaken with externally secured funding.

### Evolving cities and towns

The City is very supportive of our research and activities, and entrusted me and my team to organise the Key Cities 'City and the Environment' event[4] in Southampton in February 2019, attended by around 70 participants. In addition, the City has been very supportive of our annual conference on Evolving Cities and Towns[5], the most recent of which was held in September 2023. Interactions such as these resulted in development of the Southampton Climate Commission[6], and the rejuvenation of the Southampton Energy Partnership, with more currently in the planning stage. I play a leading role in the Southampton Renaissance Board, which was established in December 2022 with a remit to steer the future growth of the City, address its net zero requirements, development of strategic skills, sustainable/place-shaping development and investment.

It cannot be denied that the recent periods of austerity have been difficult due to diminishing resources and the high churn of Council staff. Nevertheless, the relationship has grown from strength to strength and there is now a significant belief within the Council that such relationships are extremely important in its decision-making processes. Furthermore, I have over the years advocated for closer relations between the Council and the University, and in 2023, the University and the regional local authorities signed a Civic University Agreement to secure mutually beneficial outcomes for the University, the City and the regional local authorities.

### Building connections at all levels

The effectiveness of my role as CSA to the City of Southampton is reinforced by fostering national and international connections. Nationally, I have advised other UK councils to appoint CSAs, which in my view is important for both the local authorities and the science base and will allow better informed decision-making. Working with the previous CSA at the UK Department for Levelling Up, Housing and Communities, a new network has been developed to act as a local authorities advisory group. Whilst this has been useful in connecting key individuals, to make it more impactful will require further support and funding.

Internationally, as co-chair of the Foreign, Commonwealth and Development Office Research Advisory Group I contribute to UK science advice through the Chairs of Science Advisory Council, which is presided over by by the government's Chief Scientific Advisor.

2 https://www.southampton.gov.uk/our-green-city/green-city-charter/
3 https://energy.soton.ac.uk/gcc/
4 https://energy.soton.ac.uk/key-cities-meeting-city-and-the-environment/
5 https://evolvingcities.org/
6 https://southamptonclimatecommission.org/

The Evolving Cities and Towns Conference series which I established has led to international collaboration with cities in Asia, the Middle East and Africa, culminating in a special session on cities and towns during COP28 in Dubai last December.

---

Professor AbuBakr Bahaj is Professor of Sustainable Energy at the University of Southampton and Chief Scientific Advisor to the City of Southampton.

# Dynacov: recharging Electric Vehicles while in motion

A collaboration between Coventry University and Coventry City Council

Pioneering Dynamic Wireless Power Transfer for sustainable and efficient scale-up of Electric Vehicle charging

Kevin Vincent, Huw Davies, Olivier Haas (*Coventry University*), Shamala Gadgil (*Coventry City Council*)

#### Abstract

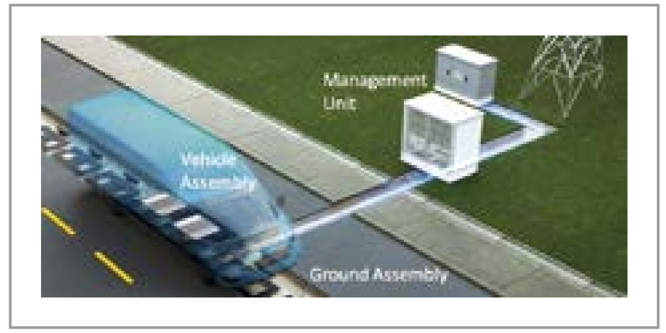
Dynamic Wireless Power Transfer (DWPT) revolutionises Electric Vehicles EVs by enabling on-the-go recharging through electromagnetic induction between a primary coil beneath the road and a secondary coil in the vehicle. Addressing EV limitations like range and recharging time, DWPT could drive EV adoption, especially among high-mileage vehicles, crucial for carbon emission reduction. The Dynacov project, led by Coventry City Council and funded by Western Power Distribution, aimed to develop DWPT and create an ecosystem for secure, automated wireless charging based on ISO 15118 standards . Targeting buses, heavy goods transport, and strategic road networks, this initiative involves Coventry University and Cenex in Systems Modelling activities to assess deployment areas and electrical grid impacts. Kenilworth Road in Coventry was chosen for DWPT feasibility assessment due to its varied traffic conditions and feasibility for infrastructure installation. Surveys confirmed viability and grid capacity to handle peak power demands. The initial project, constrained by the grid's capability at 150kW, aimed to simultaneously charge two vehicles. This technology could transform transportation and sustainability, but the next steps involve accurately estimating project costs for technology procurement, installation, grid connection, and project management. DWPT, showcased in Dynacov, holds the potential to reshape EV charging dynamics.

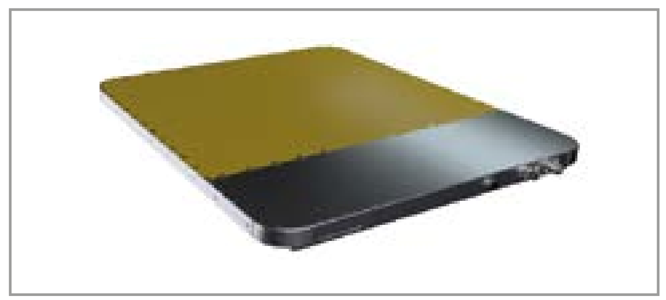
---

#### Introduction

The Dynamic Charging of Vehicles (Dynacov) project aimed to tackle the challenges set out in the third problem statement in WPD (Western Power Distribution, now the National Grid)'s Innovation Forward Plan 2019, which talks about the need for Distribution Network Operators (DNO) to better understand solutions which support the decarbonisation of Transport  through electric vehicles being able to pick up power from the road as they travel – thereby helping extend the range of heavier vehicles without them having to stop and charge.

For this feasibility project a consortium of expert organisations came together, led by Coventry City Council (CCC) (as local authority for integration and management), including WPD (the sponsor), Coventry University (for systems, modelling and simulation), Cenex (www.cenex.co.uk) (to model impact assessment). The DWPT developed by Israeli company ElectReon, was selected after a review of appropriate alternative technology suppliers. Dynacov builds on the technology prototyped by ElectReon in their home market and develops new knowledge in terms of systems modelling and impact with respect UK authority's and power supplier's requirements.



As outlined in this problem statement, whilst electrification of small passenger vehicles is becoming more established, battery technology is not yet sufficient to meet the economic and technical requirements of larger and heavier urban and freight vehicles (e.g. buses, delivery vehicles). The Dynamic Charging of Vehicles (Dynacov) project using DWPT technology was considered to be a potential innovation to address this. However, the impact on the electrical distribution network (especially considering power quality and harmonics) would be significant and needed to be understood.

The concept of DWPT is illustrated and described  in Figs. 1-4.

*Left from top:*

*Figure 1. DWPT system illustration showing the three physical components.*

*Figure 2. Coil segment of the ground assembly.*

*Figure 3. Above ground (left) and below ground (right) management unit.*

*Figure 4. Example of vehicle assembly.*

*Ground assembly (GA)*

Figure 2 shows an illustration of a coil segment. These copper coil segments make up the GA which is installed underneath the road surface. The GA emits the electromagnetic fields toward the Vehicle Assembly when the vehicle authorises a charge. The GA is controlled by the management unit (MU).

*Management unit (MU)*

Management units (MUs, Fig. 3), positioned roadside above or below ground as needed, support up to 60 coil segments forming a 100m road section.

*Vehicle Assembly*

Vehicle receivers (VRs, Fig. 4), installed under the vehicle's chassis, transmit power to the battery. VRs are modular, include a control unit, and can charge any battery type up to 800 volts. There are three VR categories: one for heavy-duty vehicles with high-power consumption and a 25kW charging rate, one for commercial vehicles also with a 25kW capacity, and one for private vehicles with adaptable power transfer providing 7, 11, or 22kW.

*Software*

A cloud-based charging management system is used to manage the connected charging infrastructure in real-time, providing a customised graphical user interface (GUI) for fleet operators. ElectReon's software enables energy metering at the Vehicle Control Unit, allowing multiple vehicles to charge simultaneously from various underground coil segments. Each vehicle can be associated with a different account for separate billing.

## Methodology

A comprehensive literature review was carried out by project partner Cenex to cover state of the art of wireless inductive (static and dynamic) charging systems and competing technologies such as catenary systems.

Use case development was carried out to evaluate scenarios for type of vehicle (heavy goods vehicles (HGV), passenger service vehicles (PSV), taxis, private cars); available infrastructure; type and location of service (if PSV), road topology (divided carriageway, lights junctions, Strategic Road Network etc).

Based on this topology assessment, combined with use case scenarios, a method was developed to determine the optimum location for the feasibility study.

A systems model was then constructed that could model and simulate traffic flow, speeds, assumptions of percentage of vehicles equipped with receivers. This simulation allows data to be built up in support of the demand on the power network, useful recharging capability received and accordingly fed into a business case assessment where costs and returns on investment could be estimated according to the various scenarios evaluated.

This assessment was concluded by considering the potential for deployment at scale, including potential implementation (physical feasibility and demonstrator costs) as well as an assessment of the supply chain required to support the development, supply and implementation of DWPT technology.

## Case study

After an extensive analysis of potential use cases, scenarios, topology and infrastructure requirements using the process outlined in Table 1, the location for the feasibility study was selected as an arterial route (Kenilworth Road) leading to the centre of Coventry. Table 1 highlights the evaluation criteria.  This process could be adapted and used to identify sites for scaling DWPT to other cities and regions.

**Table 1. Evaluation criteria for potential sites.**

| Site criteria | Rationale for inclusion | Essential / desirable |
|---|---|---|
| Part of the Connected Autonomous Vehicles (CAV) Testbed, a 300km network of roads across Birmingham, Coventry and Solihull, which is enabled for the testing of CAV technology. | ○ To enable different technologies to be tested simultaneously<br>○ To ensure ease of access for organisations based outside Coventry | Essential |
| Part of a National Express bus route | ○ To enable the use of a National Express bus in real-world testing | Essential |
| Unlikely to generate objections from local residents (i.e. not in the immediate proximity of homes, schools etc) | ○ To minimise the risk of objections causing delays to the project, or preventing it from occurring entirely | Essential |
| No other significant works already planned | ○ To avoid testing being disrupted by other works | Essential |
| Likely to be physically suitable for the installation (e.g. carriageway of sufficient width) | ○ Essential to ensure successful installation | Essential |
| Attracts a good mix of different vehicle types | ○ DWPT technology primarily aimed at larger vehicles | Desirable |
| Attracts a high volume of traffic overall | ○ Maximises chances of other organisations making use of the technology during the trial period<br>○ Ensures 'real world' nature of test | Desirable |
| Provides opportunities to easily test the technology in both free-flowing and stop-start conditions. | ○ Ensures different levels of performance at different vehicle speeds can be properly understood | Desirable |

*Kenilworth Road site*

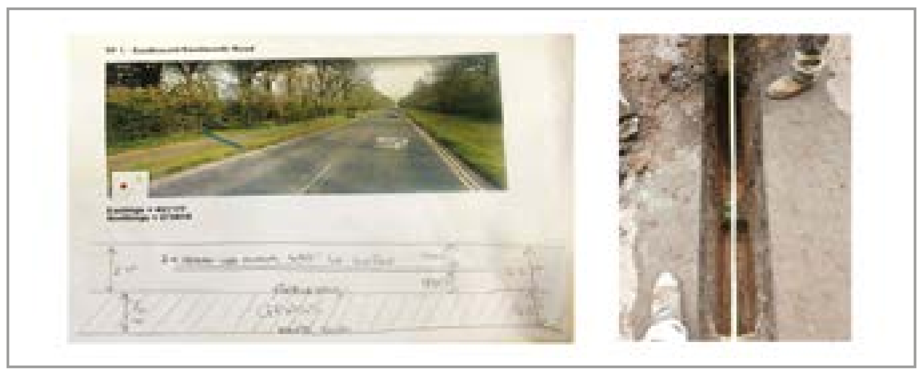
Based on discussions with ElectReon, it is understood that a stretch of road at least 100 metres in length is required for cost effective power transfer.

For this reason, and to minimise costs of a demonstrator, it is proposed to deploy two stretches (one Eastbound and one Westbound), each of 100 metres, along Kenilworth Road. These would be located around the intersections with the A45, as shown in Figure 5.

*Figure 5. Location of proposed installation.*

In order to properly establish the feasibility of installing DWPT technology, CCC carried out further investigations, the results of which are summarised below.

A topological survey on the case study route was conducted on 28 August 2021 by UK Land & Underground Surveys Ltd, which provided a report. The survey did not identify any issues with above-ground features that would negatively impact the installation of DPWT infrastructure. The results of the topological survey were shared with ElectReon to support discussions around the DPWT installation for the case study.



*Systems security*

Electricity networks, including EV charging infrastructure, are critical and must be secured against tampering and cyber-attacks. We envisage an ecosystem of multiple market participants, including the Road Charging Operator (RCO), Original Equipment Manufacturer (OEM), and Mobility Service Provider (MSP). The RCO operates the charging infrastructure, the MSP manages the end



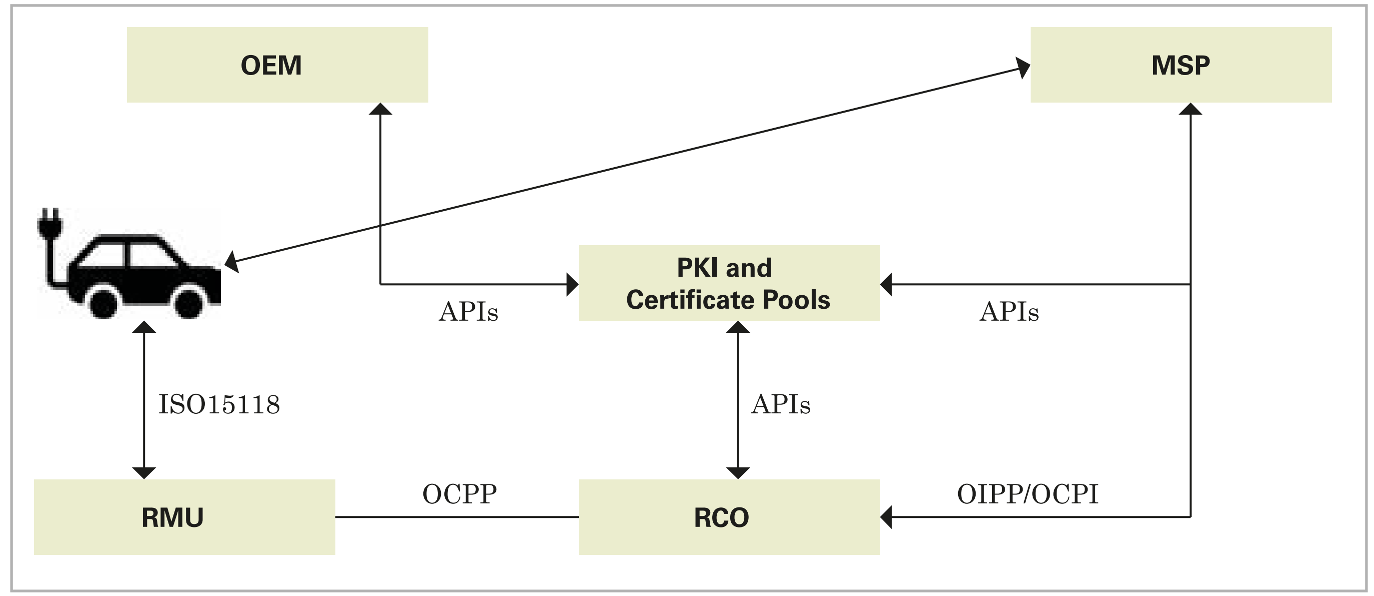


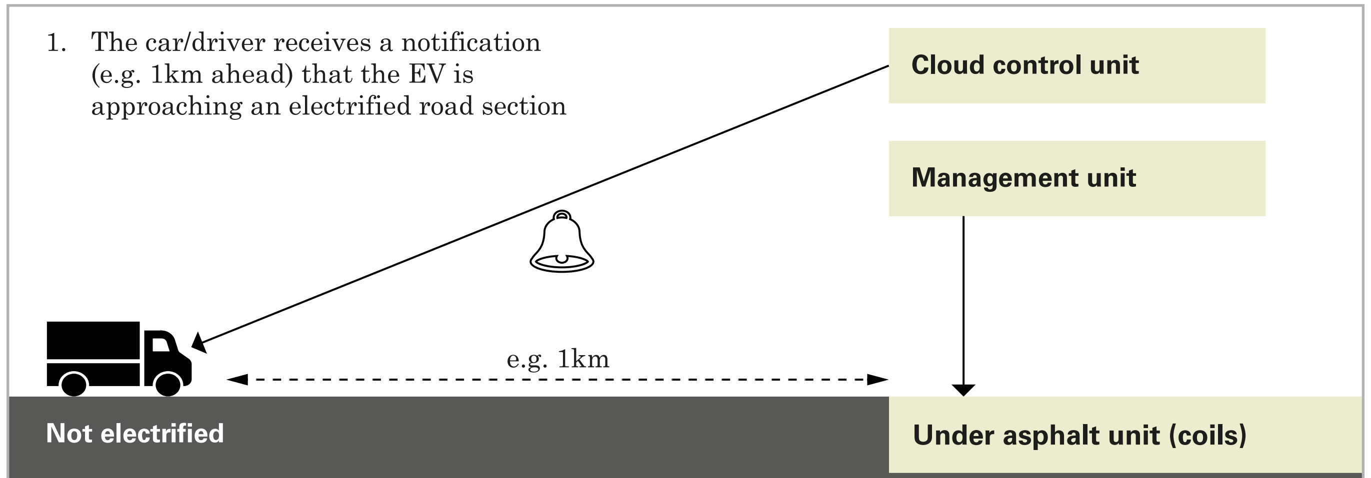

*Figure 6. The actors involved in the introduced concept indicating the communication protocols.*

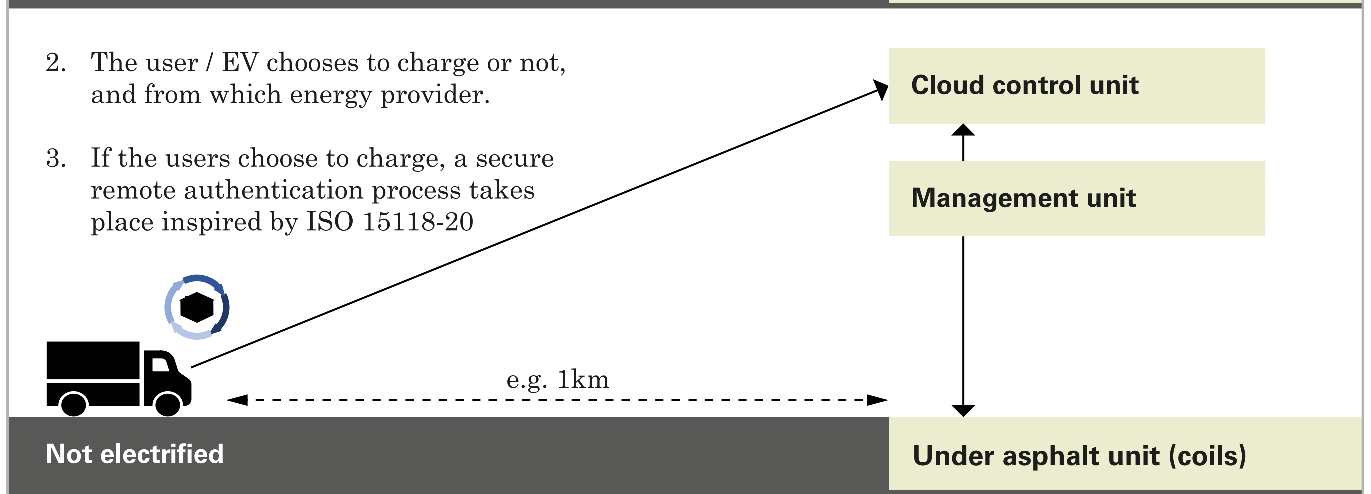
user's charging service contract, and the OEM manufactures the vehicle. To enable automated and secure authentication and authorisation for DWPT, each actor must meet certain requirements, mainly concerning minimum hardware and software specifications. A key element is the adapted version of the ISO 15118 communication stack, which provides secure and seamless access to the charging infrastructure and standardises a secure, bidirectional data flow between the EV and the charging system.

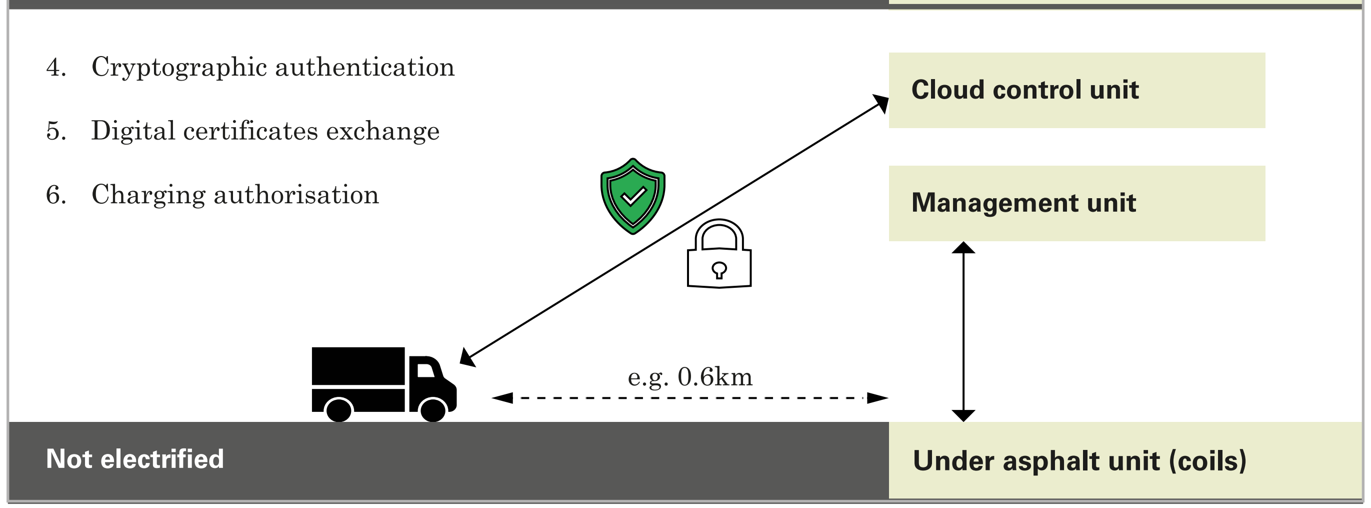
This level of security is achieved using cryptographic encryption techniques and digital certificates (Figure 6). The second element, the Public Key Infrastructure (PKI) system, regulates and manages the process of handling digital certificates between the actors involved. The communication between the vehicle and the road unit in the current version of ElectReon's DWPT solution is not secured in terms of the integrity of the signal, though the authenticity of the source is assured.

## Authentication process

The actions a car or user of a car will follow to get authenticated and authorised to use a certain electrified section of a road is shown in the next diagrams, Figures 7, 8 and 9 overleaf.




*Left from top:*

*Figure 7. Illustration of an electric vehicle approaching an electrified road section, along with the software and hardware components involved in the authorisation process.*

*Figure 8. The vehicle has received a notification from the cloud unit and is in the process of deciding whether to charge or not.*

*Figure 9. The EV decided to charge and completed the secure authorisation process before reaching the electrified road.*

---

EV charging on electrified roads involves message exchanges between the vehicle, road, and other entities like the road operator's backend, a Certificate Authority, and occasionally, the OEM backend. The process, though variable, remains consistent. OEMs can use digital contracts and certificates for automation and fleet options, making certificate management more efficient (Figure 10).

*Modelling*

Coventry University, with the support of project partner Cenex and Coventry City Council, was tasked to:

- Undertake modelling of traffic flows and vehicle usage patterns to identify the extent of dynamic wireless charging required.
- Identify the tools/services to be used by DNOs to assess the network impact when there is a connection request for this system from a vehicle charging service provider.

The study modeled power demand based on vehicle flows, assessing the electrical impact and business case of the proposed connection. It identified six factors for DWPT success: vehicle, infrastructure, journey, economic, user, and traffic. Traffic was simulated at the A45-A429 intersection, with energy usage and gain calculated based on vehicle speed.

A MATLAB® model was developed to analyse

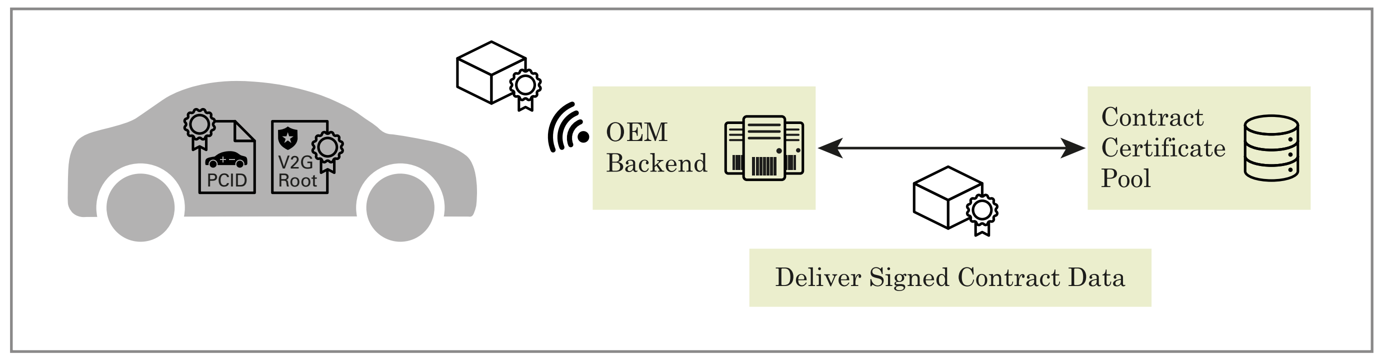
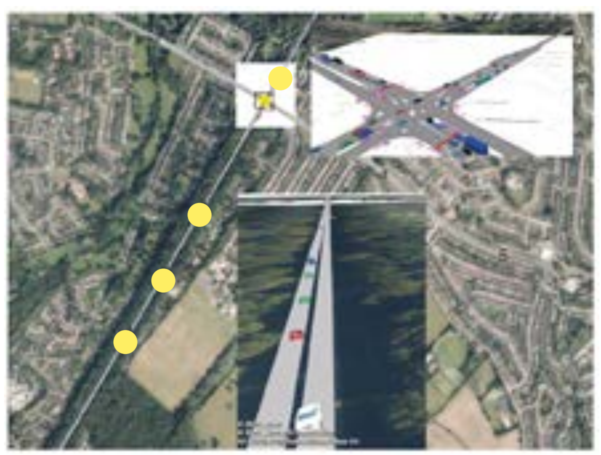



*Figure 10. Possible ways for the OEMs to communicate with their vehicle fleets.*

traffic flow and the impact of vehicle speed and lane occupancy. It used data like vehicle speed, time headway, and minimum distance headway to calculate lane and DWPT sections occupancy. Energy consumption data for various vehicles were sourced from multiple studies to estimate energy usage at different speeds. The model also focused on energy for range extension calculations to help in understanding the time vehicles spent on each DWPT section and the energy they could potentially receive if they requested wireless charging (Figure 11).

*DWPT-equipped and Electric Vehicle market penetration*

Vehicles need a receiver to request charging from the DWPT. The model allows for 0-100% of vehicles to be electric and equipped with DWPT receivers. The model assumes 100% of PSVs, 15% of cars, 3% of LGVs, and 1% of HGVs will be electric, continuing existing sales trends.



Measurement points for DWPT sections.

*Figure 11. Vissim model of the signalised intersection between the A429 and the A45.*

*Vehicle category*

Depending on category, vehicles can be equipped with one, two or three receivers. Hence, a vehicle with three receivers can receive energy at three times the rate of a vehicle with a single receiver. Cars, light goods vehicles (LGV), PSVs and HGVs are assumed to be equipped with 1, 2, 3 and 5 receivers respectively. The space occupied by each vehicle type on the DWPT section considers the length of the vehicle as well as the distance headway.

The recommended time gap for emergency stopping varies between 1 to 2 seconds, whereas a Cooperative Adaptive Cruise Control field study recorded that 55% of drivers following the lead vehicle adopted at least 0.55 seconds headway (Dey et al., 2016). The time headways for modelling are therefore 0.55, 1 and 2s.

*Battery voltage*

As the rectifier has a current limit, a lower voltage battery may place a cap on the rate of energy transfer achieved by a single receiver. For example, for passenger cars the receiver is derated to values less than 25kW due to limitation of battery voltage. The model allows for the ability to charge to be dependent on the energy transfer, which is a function of the State of Charge (SoC) and battery voltage. Resulting simulations therefore assumed that if the SoC at the end of the DWPT is less than 80%, cars, LGV, PSV and HGV are assumed to be able to charge at 25, 50, 75 and 125kW respectively.

*Instantaneous energy consumption*

Instantaneous energy consumptions are the most significant model parameters. Consumption is challenging to determine, due to discrepancy between data from manufacturers, specialised websites, measurements (in the case of the Enviro400EV electric buses in Coventry) and scientific publications. A look-up table was therefore developed based upon manufacturers' data to give the relevant consumption parameters based on minimum and maximum range.

Energy consumption in vehicles is influenced by the drive cycle, opportunity for energy regeneration through braking, ambient temperature, and ancillary loads such as heating, ventilation and air conditioning (HVAC). Total energy includes energy loss from motoring and energy gained via regenerative braking. As an example, Coventry buses use about 1.02 kWh/km but if ancillary load energy use is considered, energy consumption for buses in Coventry doubles to 2.02 kWh/km (Figure 12).

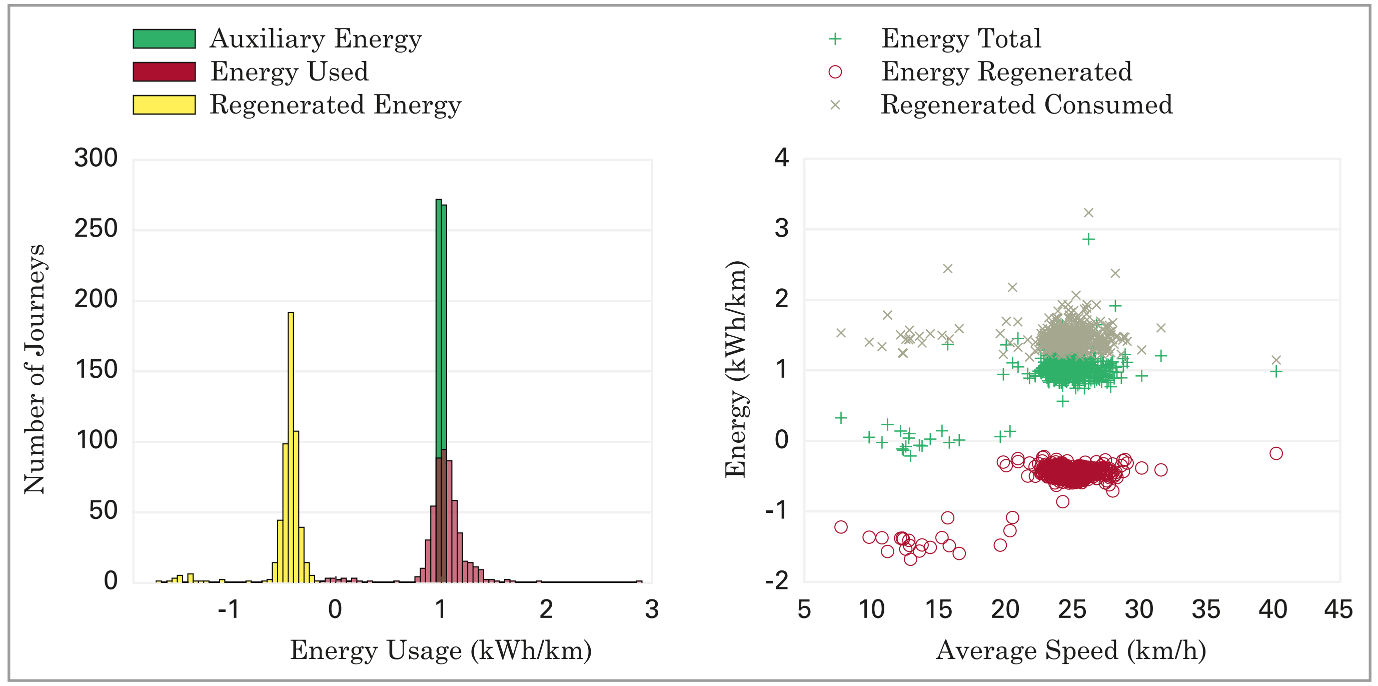



*Figure 12. Electric bus data (2021) used to justify, together with Hill (2020), the average PSV energy consumption.*

*Receiver rating*

At present the receiver rating is fixed at an upper value of 25kW, but in future, a different rectifier rating would potentially allow for a higher energy transfer rate. The simulation model allows the user to specify any receiver rating values; however, a value of 25kW is currently specified. In the model, cars, LGV, PSV and HGV are assumed to be equipped with 1, 2, 3 and 5 receivers respectively.

*State of Charge modelling*

Energy transfer from the DWPT system is limited by onboard energy storage, typically set at around 80% SoC due to battery chemistry considerations. The receiver can transfer energy directly to the traction motor. The simulation model allows charging if the battery SoC at the end of the DWPT section is less than 80% and used a truncated set of representative values from actual measurement of Coventry's electric buses from March to May 2021.

PSVs have predictable SoCs due to fixed routes and daily recharging whereas cars, LGVs and HGVs are expected to have higher variability in SoC.

*Traffic data*

Traffic data from various sources was used to analyse vehicle flows on Kenilworth Road and the A45. The data, including vehicle counts and speeds, was aggregated hourly to

*Figure 13. Location of the speed measurements indicated with a blue circle. The A429 is Kenilworth Road and the A45 is the Kenpass-Fletchamstead Highway.*

simulate speed ranges on the A429 towards Coventry and estimate the number of vehicles likely to pass over the DWPT sections (Figures 13 and 14).

The model was developed to calculate energy expenditure over the DWPT based on vehicle speed or average energy consumption from available data. The model sums up contributions from each vehicle type to calculate overall energy transfer per hour.

*Network impact*

The deployment of a DWPT system on the electricity network considers the following



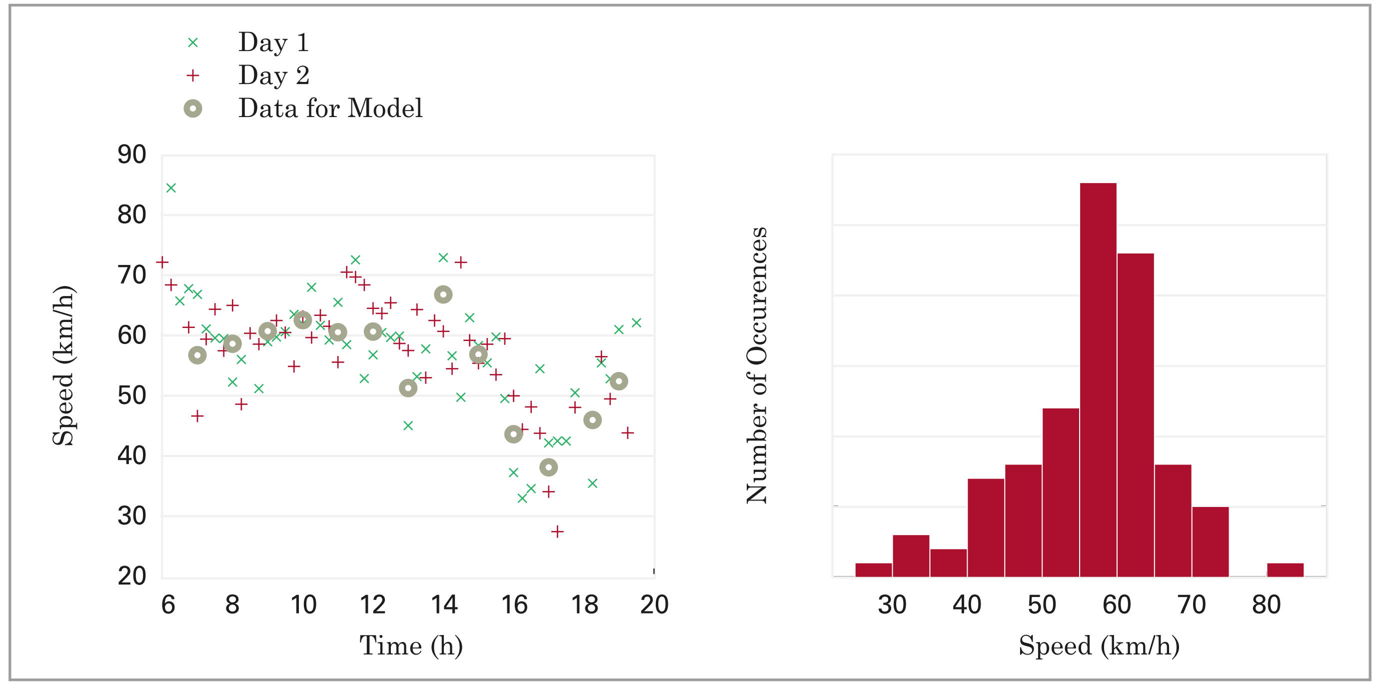



*Figure 14. Average speed measured every 15 min over 3 Mondays on the Kenilworth Road northbound towards Coventry (Vehicle Speed – Kenilworth Road, 2021).*

aspects:

- Network connection architecture: the architecture of the DWPT system's network connections, number of connection points, maximum import capacity and connection voltage,
- Power demand: how the real-time demand on the network is related to the vehicle power demand from the DWPT system,
- Power quality: the electromagnetic compliance (EMC) of the DWPT system,
- Earthing: how earthing should be provided for the DWPT system.

*Network connection architecture*

The ElectReon system could theoretically deliver 1.5MW at full efficiency, but in reality, it's lower as not all coils operate simultaneously. The maximum theoretical load isn't optimal, hence the power delivered by each DWPT segment is limited at the management unit, which is configurable based on use case. The system can connect to various grid connections and typically uses a 400V connection but prefers higher voltages for large-scale deployments to enhance grid-side energy efficiency. Before deploying DWPT, ElectReon collaborates with the Distribution Network Operator (DNO) to adapt to specific local conditions. The ratings used in previous deployments are as shown in Table 2.

**Table 2. ElectReon DWPT deployments Management Unit ratings.**

| | Use case | Connection | Power rating |
|---|---|---|---|
| Tel Aviv (Israel) | Bus | 125A at 400V | 87kW |
| Gotland (Sweden) | Bus and truck | 250A at 400V | 173kW |
| Coventry, Dynacov phase II demonstrator proposal | TBC | 231A at 400V | 160kVA assuming 100% efficiency |

*Network connection*

Each management unit therefore requires its own three-phase low voltage (LV) electricity network connection (Fig. 15). The illustration shows the connection of the management unit to an existing distribution substation also used to supply other loads. Note, for the figure shown, that in the UK the DNO will own the substation.

Options for connection may include single or multiple management units to dedicated substations or existing LV networks.

When DWPT is to be deployed on both sides of the carriageway, the possibility of connecting all MUs to the same network connection will depend on the availability of ducting to pass cables underneath the road, or the intent of the deployment to bore or dig across the road, given the disruption this may cause.

*Load management*

ElectReon's system can manage load between individual coils and sections to optimise the network connection based on use case. This is crucial for larger systems to minimise costs. Strategic planning when applying for a new connection can allow for future upgrades as more vehicles become compatible with the system.

*Power profiles and power density network impact*

Requested power isn't transferred 100% of the time due to the vehicle's movement and the spacing between transmitter coils. The vehicle's speed and the number of receiver coils also affect the power transfer. Spacing between transmitter coils can be adjusted to avoid obstacles in the road if required. The effect of less and more spacing between transmitter coils and speed and movement variables are considered to evaluate mean power requirements and load demand.

A single vehicle using a DWPT system will create a high frequency square wave of power demand on the network. The receiver is rated at 25kW, whilst the mean power transferred (shape, frequency and amplitude of the square wave) is different and dependent on the vehicle speed, alignment and transmitter coil length and spacing.

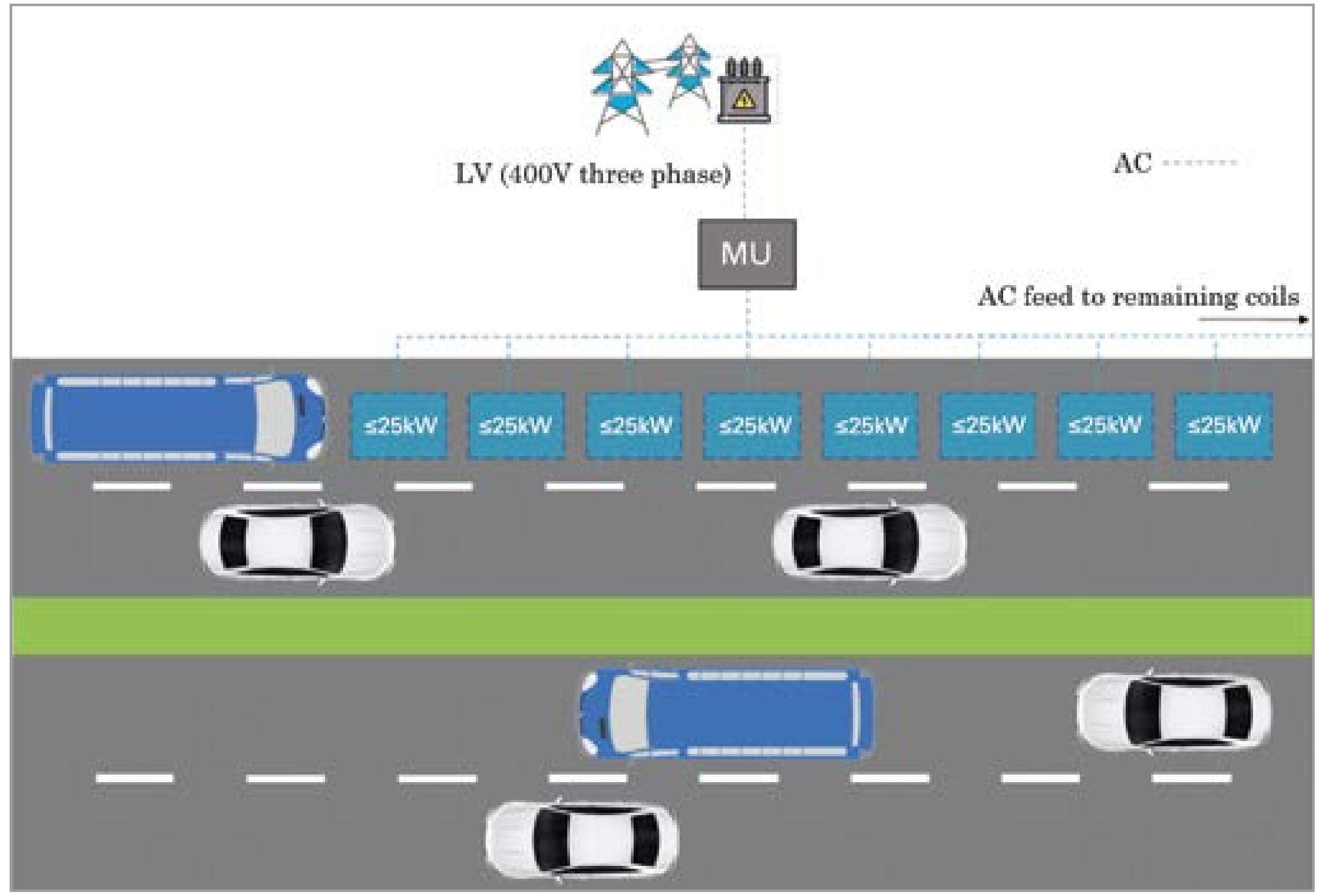



*Figure 15. Electreon system architecture for a single management unit (MU) network interface, direct to dedicated substation.*

In a deployment, it may be possible that multiple vehicles are using a DWPT system simultaneously, and the real-time power demand on the system will be a combination of the square waves of each vehicle. Note that due to varying real-time vehicle spacing the square waves of different vehicles are unlikely to collate perfectly, as the individual vehicles pass over coils at different times.

On larger vehicles with multiple receiver coils, ideally the size and spacing of the receivers would be designed to match that of the transmitter coils. This ensures that the demand from each coil-pair combines to create a single waveform of an amplitude that is simply a factor of the number of coil-pairs.

For multiple vehicles using a single segment, the maximum power will be limited by the rating of the management unit. In a scenario where the MU rating is exceeded, ElectReon has confirmed that power is managed between in-use coils with the ability to control power demand adaptively between the coils. The power density of system from previous trials has been stated as achieving up to 80%.

*Business case*

The question of whether to roll out chargepoints or EVs first is crucial with DWPT due to high capital costs. Simultaneous rollouts are essential. The model considers the entire infrastructure ecosystem, vehicle retrofits/integration, and savings from avoiding conductive charging and larger batteries.

*Costs*

DWPT has known capital costs for civil works, installation, and hardware. Network connection costs vary by location, and operational costs depend on local conditions. Understanding cost recoupment is key to assessing DWPT benefits.

*Uptake scenarios*

A shared public DWPT network could supplement private charging stations. Given the high capital costs and potential impact on all road users, strategic support via government policy and funding is necessary. A top-down approach was used to model DWPT uptake, making the assessment transparent and results easy to consider. For economic viability, DWPT should be installed on the most trafficked roads - the motorways

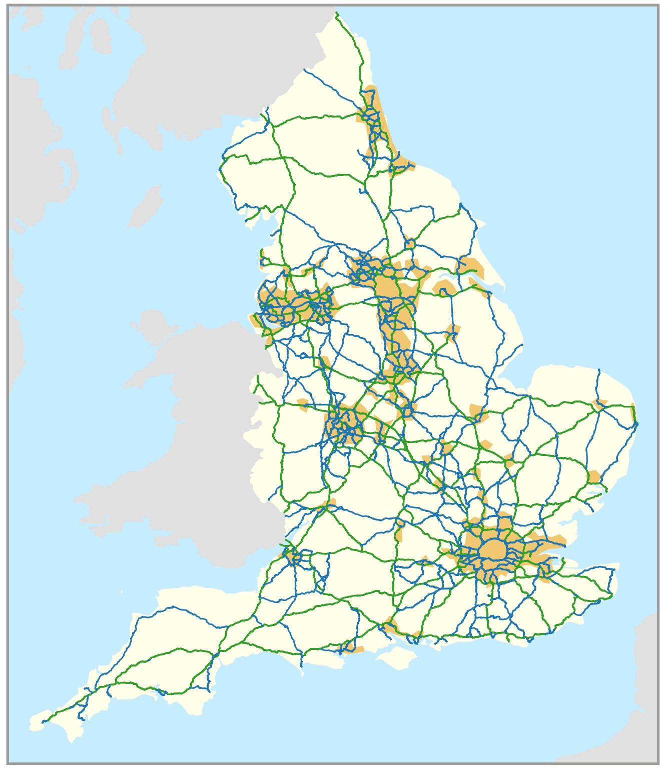


*Figure 16. Major Roads in England.*

and A-roads which account for one-third of all motor vehicle miles and two-thirds for HGVs.

In Great Britain there are:

1. 2,300 miles of motorway (99% trunk, 1% principal)[1]
2. 29,500 miles of A-road (18% trunk, 82% principal)[2]

1 Trunk roads are maintained by National Highways whereas principal roads are maintained by a local Highway Authority.
2 Road Lengths in Great Britain: 2020 - GOV.UK (https://www.gov.uk/government/statistics/road-lengths-in-great-britain-2020).

Figure 16 shows the geographic layout of the SRN controlled by National Highways and other major roads demonstrating clustering around major cities and conurbations controlled by local authorities. It serves to showcase the opportunity for scaling DWPT across the nation.

Based on a high-level assessment of the political and market situation and emerging trends, while there may be incentives to introduce an electrification enabler such as DWPT, other potential solutions (such as hydrogen, better batteries and ultra-rapid chargepoints) will compete for attention and funding and this is the key risk to the future of DWPT.

*Modelling*

An Excel-based model was developed to quantify and assess the business case of a range of DWPT rollout scenarios nationally. The key output metric of the model is the £/kWh of energy delivered by the charging system over its expected lifetime. This metric allows comparisons between DWPT and other technologies, e.g. conductive charging.

Scenarios were created to assess different use cases of DWPT within the model (Table 3). Note that Scenario 2 represents DWPT being installed on urban A-roads, but only on the approach to within 50m of traffic lights (assumed to be 5.5% of road length). This results in lower average speeds for vehicles over the DWPT strips, and relatively more energy being delivered.

The model for DWPT assumes an even distribution of traffic and similar mileage for all vehicles of a given type, which is a limitation as it doesn't consider geospatial data. This generalisation may cause errors in determining the number of vehicles best suited for DWPT and their mileage coverage. The actual business case for DWPT will vary by location due to these assumptions. However, a homogenised national view is sufficient for initial feasibility assessments. The model serves as a starting point for comparing

**Table 3. Scenario definitions.**

| | **Scenario 1** | **Scenario 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** | **Scenario 6** |
|---|---|---|---|---|---|---|
| Road Network in scope | Urban A-roads | Urban A-roads (Traffic Lights) | Urban A-roads | Trunk Roads | Trunk Roads | Motorways |
| Percentage of Road Network with DWPT | 90% | 5.5% | 50% | 90% | 90% | 50% |
| Vehicles in scope | Bus & Coach | Bus & Coach | All Vehicles | HGVs | All Vehicles | HGVs |
| Percentage of Vehicles Equipped with DWPT | 70% | 70% | 50% | 50% | 50% | 50% |

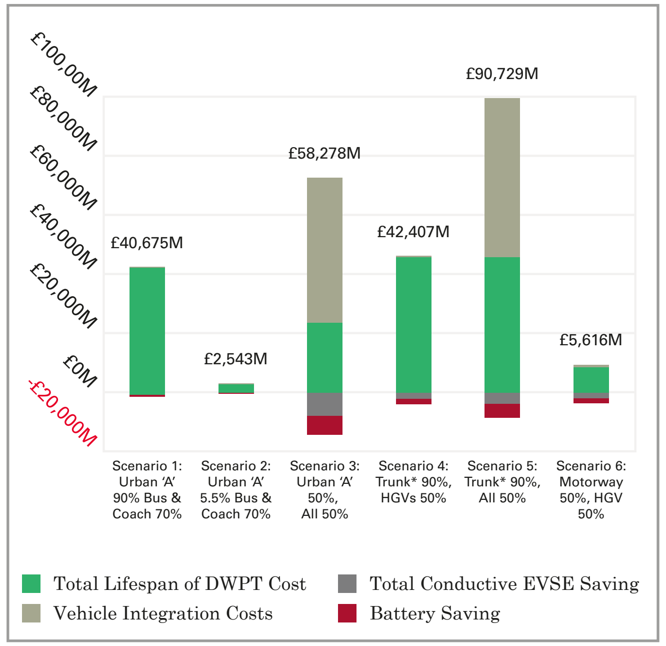



*Figure 17. Modelling results costs summary. (*Trunk roads form part of the Strategic Road Network and are maintained by National Highways.)*

DWPT with other charging solutions and identifying promising scenarios.

*Results*

Fig. 17 illustrates the significant variation in lifespan DWPT and vehicle integration costs across different scenarios. The majority of the DWPT cost over a decade is attributed to capital infrastructure, projected to decrease with technological advances and economies of scale. Savings from reduced conductive charger capacity and battery costs are depicted below the axis. In the 'all vehicle' scenario, integration cost surges due to an increased number of vehicles.

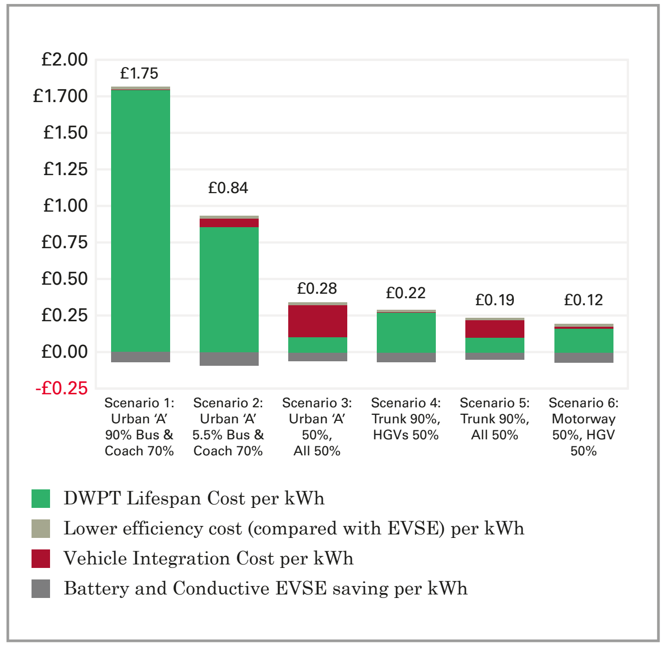



*Figure 18. Modelling results marginal costs per kWh.*

Fig. 18 presents costs for each scenario on a marginal kWh basis, spreading total cost across all energy delivered to vehicles over the infrastructure's lifespan. Scenario 6 offers the best value at around 12p/kWh due to high energy demand from the HGV fleet over a short road network. The most expensive is scenario 1, with a cost around fourteen times higher due to a long road network with low vehicle mileage. Scenarios 3 and 5 have the lowest DWPT lifespan cost due to high infrastructure utilisation. Vehicle integration cost is cheapest in scenarios 1 and 4, which maximise energy charged per vehicle.

These costs can be compared with the costs of facilitating the electrification of vehicles through conductive chargepoints. The Cenex internal chargepoint deployment investment model calculates 11p/kWh for ultra-rapids.



A sensitivity analysis was carried out in which various parameters were altered to assess the impact on the per-kWh cost of DWPT. The parameters were assessed independently; each row in Table 4 represents a specific and independent change from the baseline.

This sensitivity analysis shows that the cost-benefit analysis (CBA) is highly sensitive to scale; if the number of equipped vehicles is lower and the percentage of road network equipped is lower, then the cost per kWh is higher. This would suggest that in the initial years of deployment, where the number of equipped vehicles and amount of road network equipped with DWPT will be lower, the costs could be significantly higher than the theoretical CBA in the baseline presented above.

*Business case by stakeholder*

DWPT rollout could lead to network connection cost savings by evenly distributing demand, reducing depot connection capacity needs. DWPT allows vehicles to travel further without plugging in, meet depot charging needs with smaller connections and transport greater payloads due to reduced battery size and weight. However, fleet operators must bear capital costs for vehicle integration and higher charging costs. DWPT

**Table 4: Scenario results from sensitivity analysis. DWPT coverage: roads and vehicle mileage.**

| DWPT (inc. cost offset) per kWh delivered | Urban A 90% Bus & Coach 70% | Urban A 5% Bus & Coach 70% | Urban A 50% All 50% | Trunk Roads 90% HGVs 50% | Trunk Road 90% All vehicles 50% | Motorway 50% HGV 50% |
|---|---|---|---|---|---|---|
| Baseline | £1.75 | £0.84 | £0.28 | £0.22 | £0.19 | £0.12 |
| Lifespan increased from 10 to 15 years | £1.22 | £0.59 | £0.19 | £0.16 | £0.13 | £0.09 |
| Power per receiver increased from 30 to 35kW | £1.49 | £0.71 | £0.23 | £0.18 | £0.16 | £0.10 |
| Half road coverage | (Urban A 45%) £1.76 | All vehicles 50% £0.93 | (Urban A 25%) £ 0.50 | (Trunk 45%) £ 0.23 | (Trunk 45%) £ 0.31 | (Motorway 25%) £ 0.14 |
| Half DWPT equipped vehicle | (35% Bus & Coach) £3.54 | (35% Bus & Coach) £1.68 | (25% all) £ 0.38 | (25% HGVs) £0.50 | (25% all) £ 0.29 | (25% HGV) £ 0.29 |
| Half road coverage and DWPT equipped vehicle | £3.55 | £1.76 | £0.60 | £0.50 | £0.41 | £0.30 |

systems can work with a range of vehicles, unlike catenary systems. If National Highways upgrades its networks with DWPT, tolls could be introduced to recoup lost petrol and diesel tax revenues.

## Conclusions

While ISO15118 has been considered, for a successful DWPT rollout it may be necessary to develop further standards. These standards will ensure user and public safety, facilitate technical interoperability between different manufacturers' systems, and help avoid pitfalls encountered during early development of conventional EV charging infrastructure. All DWPT hardware should comply with relevant guidelines and standards such as for EMC. DWPT systems should employ proactive and reactive protection mechanisms for safe operation under various conditions.

Business case modelling assessed several scenarios. A DWPT rollout for HGVs on motorways represents the lowest marginal cost per kWh, close to ultra-rapid conductive chargers. However, in half of the tested scenarios, DWPT's marginal cost was at least three times more expensive than conductive charging. The model accounts for shared DWPT resource reducing the need for private conductive charging and smaller batteries, though it has limitations.

The project at Kenilworth Road aims to understand the impacts of the DWPT system on the electricity network. The proposed £1.5m demonstrator could provide insights into system harmonics and power quality. However, the site may not be ideal for testing scenarios involving Heavy Goods Vehicles (HGVs) on motorways, which are of significant interest. Further comparisons of DWPT with other low-carbon technologies for heavy vehicles, such as conductive charging and hydrogen, are needed. The authors also hypothesise that DWPT could reduce the need for costly electricity network reinforcements required for high-power depot charging, as it distributes energy demand more evenly over time and space than conductive charging. Peak power demand for buses on Kenilworth Road is estimated not to exceed 75kW.

Network demand depends on six factors: vehicle compatibility, DWPT infrastructure, charging necessity, price, traffic conditions, and driving behaviour. These determine the feasibility of a charge event, its initiation, and the energy transfer rate. More research is needed to understand demand frequency distribution. However, the system's high diversity suggests that the required connection capacity will be much lower than the maximum theoretical demand due to the low probability of this demand and the equal energy distribution across in-use coils.

The rollout of DWPT lacks high-level government support and dedicated funding. Current targets for phasing out non-zero emission HGVs by 2040 don't specify a technology or infrastructure for decarbonisation. Geospatial analysis of vehicle traffic flows and energy infrastructure capacity is crucial for optimising any available funding. A holistic, systems-based approach is needed nationally, while regionally, key selection criteria have identified a site in Coventry. It's likely a proportion of the HGV fleet will be electrified by 2040, increasing electricity demand. DWPT can smooth demand peaks and lower network impacts, but its benefits haven't been quantified from a Distribution Network Operator's perspective. Further work is needed to improve technological maturity, clarify harmonic and power quality impacts, and understand marginal costs.

This paper has been developed and summarised from the deliverables and reports published by the Dynacov consortium, including:

- Dynacov Work Package 2 Literature Review, Cenex
- Dynacov Work Package 3 Report, Huw Davies, Olivier Hass (Coventry University), Samuel Abbott (Cenex)
- Dynacov Work Package 4 Report Deployment Analysis, Elaine Meskhi, Greg Payne, Chris Rimmer (Cenex), Shamala Evans-Gadgil, David Pipe (Coventry City Council), Kevin Vincent, Huw Davies (Coventry University), Mahmoud Draz (Hubject)

Copies available on request.

## References

Average car dimensions, 2021, https://www.nimblefins.co.uk/cheap-car-insurance/average-car-dimensions. Copyright © 2021. Copyright © 2021 NimbleFins

Dey, Kakan & Yan, Li & Wang, Xujie & Wang, Yue & Shen, Haiying & Chowdhury, Mashrur & Yu, Lei & Qiu, Chenxi & Soundararaj, Vivekgautham.Dey K. C. et al., 20162016, A Review of Communication, Driver Characteristics, and Controls Aspects of Cooperative Adaptive Cruise Control (CACC), in IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 2, pp. 491-509, Feb. 2016, doi: 10.1109/TITS.2015.2483063.

Electric bus data, 2021, electric bus - CV - 210301-210431 - EV LEBS - sent 190521.xlsx, Coventry City Council.

Electric vehicle database v4.2, 2021, Renault Zoe, Hyundai IONIQ 5 Long Range AWD and Tesla Model 3 Standard Range Plus, Peugeot e Traveller, https://ev-database.uk

EVSpecifications, 2021., Specifications, news and comparisons, https://www.evspecifications.com/, last accessed 22 November 2021

Hill, N., Amaral, S. Morgan-Price, S. Nokes, T., Bates, J. (Ricardo Energy & Environment), Helms, H., Fehrenbach, H., Biemann, K., Abdalla, N., Jöhrens, J. (ifeu), Cotton, E., German, L., Harris, A., Ziem-Milojevic, S., Haye, S., Sim, C., and Bauen, A. (E4tech), Hill N., 2021., Determining the environmental impacts of conventional and alternatively fuelled vehicles through LCA, Final Report for the European Commission, DG Climate Action, ED11344, Issue Number 3, Date

13/07/2020, https://ec.europa.eu/clima/system/files/2020-09/2020_study_main_report_en.pdf,

Individual car dimensions, 2021, https://www.automobiledimension.com/, Copyright © 2012-2021.

RENAULT DZE, 2021, https://www.renault-trucks.com/en/newsroom/press-releases/renault-trucks-unveils-its-second-generation-electric-trucks-complete-ze.,

Telsa Semi, 2021 https://www.tesla.com/en_GB/semi.

Vehicle count A429, 2021, 11 vehicle types, for years 2002, 2011, 2016, Department for Transport, dft_rawcount_local_authority_id_152.xlsx.

Vehicle count and turning counts A45-A429 intersection, 2021, TfWM_TCN1308_TC_2014.csv, Transport For West Midlands.

Vehicle Licensing Statistics, 2021, 2021 Quarter 2 (Apr - Jun) 2021, 29 September 2021, . Department for Transport, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1021032/vehicle-licensing-statistics-april-to-june-2021.pdf.

Vehicle Speed – Kenilworth Road, 2021., Dyna-CovDynacov_TM_Data.xlsx, Transport For West Midlands.

Volvo FH Electric, 2021., https://www.volvotrucks.com/en-en/trucks/trucks/volvo-fh/volvo-fh-electric.html.



# The Morecambe Bay Curriculum: bringing about culture change through education

Lancaster University

The curriculum development project was funded by Lancaster University.

The Eden Bear books were facilitated by the University of Cumbria with funding from Lancashire County Council.

## THE MORECAMBE BAY CURRICULUM: BRINGING ABOUT CULTURE CHANGE THROUGH EDUCATION

Bethan Garrett, Carys Nelkon


### Abstract

Inspired by news of the Eden Project Morecambe, a collective of educators launched the Morecambe Bay Curriculum (MBC) to explore how themes of environment, sustainability and place could be weaved into everyday teaching across all phases of education. The MBC is an educator-led movement, supported by Lancaster University and Lancaster and Morecambe College, which seeks to improve the educational outcomes of local people. As a collective, we aim to support the move towards net zero by empowering teachers to develop innovative approaches to education which explore local environmental challenges. By encouraging young people to develop the environmental behaviours needed to become future change-makers, teachers are developing a culture in the area where sustainable and pro-ecological practices are the norm.

This paper reports on the groundwork for the MBC and how this has led to an innovative curriculum design project. Collectively teachers and Lancaster University academics are designing content to support local educators, drawing on themes of place and sustainability. Whilst this work is still in its early stages, we share our reflections on the importance of prioritising community voices and communal ownership of the initiative, showing how this contributes towards cultural change.


### Introduction

Morecambe Bay is a beautiful and ecologically important place. But it has an image problem. This part of the coast represents the largest intertidal area in the UK and is one of the most biodiverse places in the country (Pollastri et al., 2023), meaning it can play a vital role in addressing the effects of climate change. However, the average person may never hear about the region's ecological significance; they are more likely to know of Morecambe's reputation as a 'lagging' seaside town, characterised by low employment, health, education and housing prospects (Agarwal et al., 2023; Ashmore, 2023).

Perhaps in contrast to popular opinion, Morecambe is a hopeful and community-minded place. Morecambe Bay Curriculum educators across the Bay believe a better future can be achieved through the power of education. Eden Project Morecambe has allowed the community to reimagine itself, recognising the need to care for the environment and strive towards net zero. Local investment offers the chance for a new dawn of prosperity both economically and ecologically and has prompted community action, as people better understand their role in protecting the region's rich biodiversity and the need for collective behaviour change.

The MBC's roots are found in a culture of participatory discussion which has grown across the Bay. The 'Love Morecambe Bay' initiative (2020), for example, brought people together "to dream and reimagine a future that is more full of love for people and the planet". The community conversations they initiated were extensive, engaging over 4,000 local people, training them to become facilitators, and hosting festivals and events in partnership with charities and health organisations.

The MBC adopted a similar process of conversations and dialogic discussions, valuing the views of those connected with education from across the region. Educators from Early Years to Further Education, together with academics and those working in third sector roles, were inspired by the hope presented by Eden and were motivated to meet regularly to find their place within this growing movement. They have been sharing innovative work from their own settings and connecting with others, using their discussions to produce a shared vision of education across the region. Teachers gathered in online working groups to hear about expeditions, the rewilding of school grounds, ethical gardening and addressing food poverty, and more.

Teachers are thinking more deeply about how we retain local talent in the area, how we prepare young people for green jobs, and how we can sustainably invest in the education of our communities. The MBC team

*Figure 1: MBC Educators gathering in July 2023 to share best practice and hear inspirational talks*

from Lancaster University has been critical in transforming talk into action and providing leadership and structure to diverse groups of educators. We have now progressed from a movement where enthusiastic individuals shared their own projects, to a structured and more accessible membership offer and a coordinated curriculum design project, which will be detailed in this paper. This process has been driven by the founding educators themselves, who have taken key decisions as the MBC has evolved and developed.

Eden encourages action by helping people see the beauty in our world and providing the knowledge and understanding needed to protect it. This links strongly with the educational approach of the MBC, valuing not only expert subject knowledge, but also the development of values, morals and skills associated with climate change. Curricula designed around these principles can stimulate individuals to become stewards of the environment, by developing awareness of problems and empowering them to act; with support this can lead them to espouse pro-ecological behaviours and values that can then impact back on the environment itself (Prince, 2017; Cordero, Centeno and Tood, 2020).

If we are to find a way out of the current crisis, we will need committed and flexible thinkers. This paper reflects on how positive relationships have been built with the community and how this has enabled the embedding of sustainability research directly into the National Curriculum. This work will continue to deliver a positive impact on teaching and learning that encourages and develops future change-makers.

## Methodology

The early stages of the MBC hosted a series of collaborative working groups, where teachers came together to share and shape their focus on environmental education. This local action reflected wider national concerns over the lack of emphasis on climate change and sustainability in the current English National Curriculum and OFSTED inspection frameworks (Harvey 2020; Teach the Future, 2022; Howard-Jones and Dillon, 2022). Lancaster University now facilitates these groups, providing administrative support for community conversations between teachers from all phases of education across Lancashire and Cumbria. There have been over 150 meetings focused on driving the curriculum forward, as well as extensive community-situated project work, examples of which are detailed in the case study below.

What is striking has been the long-standing engagement from teachers who continue to give up their valuable time every month. This ensures the MBC remains an educator-led movement, in which the work is determined and driven by those in the field who understand what the community requires (Bidandi, Ambe and Mukong, 2021). Figure 2 shows the structure of this and how the university and the college provided leadership to an initially organic and grass-roots process.

Given the focus on prioritising the perspectives of educators within the community, the MBC can be positioned as participatory action research (PAR), with these early stages being the 'participatory action inquiry' phase. This is the space where initial ideas and principles develop from a ground-up focus on "what works" (Chevalier and Buckles, 2019). Defined as a cooperative approach which aims to improve and empower (Savin-Baden and Wimpenny, 2007), this iterative process of knowledge generation brings together real-life experiences and perspectives to 'understand and shape the world' (Chevalier and Buckles, 2019:21). Whilst the structure shown in Figure 2 demonstrates how the university and college retained a guiding hand in governance and coordination, a key principle is that the generation of "legitimate knowledge" is not exclusive to the academy; rather the local knowledge of all members should be valued equally highly (Savin-Baden and Wimpenny, 2007). All members are empowered to contribute "on an equal footing", with both academics and teachers being part of a process of positive change (Jacobi et al., 2022). We recognise and value that, as practitioners, the educators bring their pedagogical skills as well as their knowledge of their local communities and as such they shaped the scope of the MBC.

Work within these groups initially led to the development of locally-focused projects, as enthusiastic individuals sought to explore what might be possible within their contexts. Whilst examples of inspiring local projects are detailed within the case study

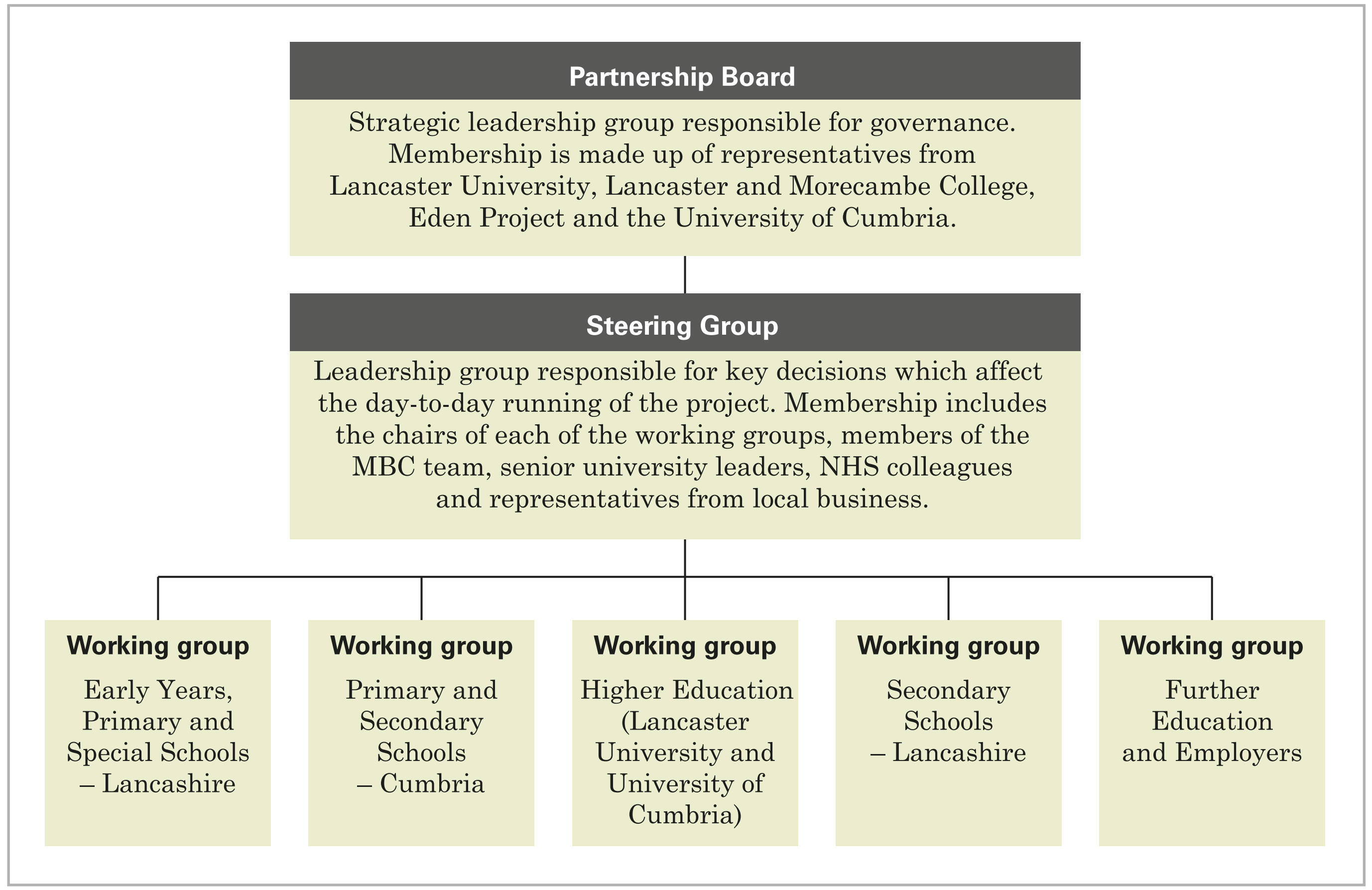



*Figure 2: The leadership and governance structure of the Morecambe Bay Curriculum*

below, it soon became necessary to extend the initiative so that it remains sustainable and reaches more teachers across the Bay. In order to inform the growth of the project, whilst maintaining its community-directed inception, an impact model was collectively developed and agreed (Fig. 3). At its heart we target the work of educators, supporting them in embedding place and environment into practice, but with an eye on the other key impacts the community has identified as important: employability prospects, health and wellbeing, and pride in the community.

The first step in bringing together the community to enact this vision was to provide an online platform which teachers could access by joining a free, formalised membership scheme. Educators can receive benefits such as shared resources, discussions and invitations to events and CPD. We have designed a baseline evaluation of schools' current approaches towards place and environmental education, allowing the MBC to track the impact of their involvement longitudinally.

Teachers have been clear that to continue this work, they need, firstly, better environmental knowledge, and secondly, the confidence to use it in the classroom. Our community of educators have therefore prioritised the development of high-quality, accessible curriculum resources, which demonstrate how educators can weave environmental and place-based knowledge into their teaching. This extends the reach of the MBC and

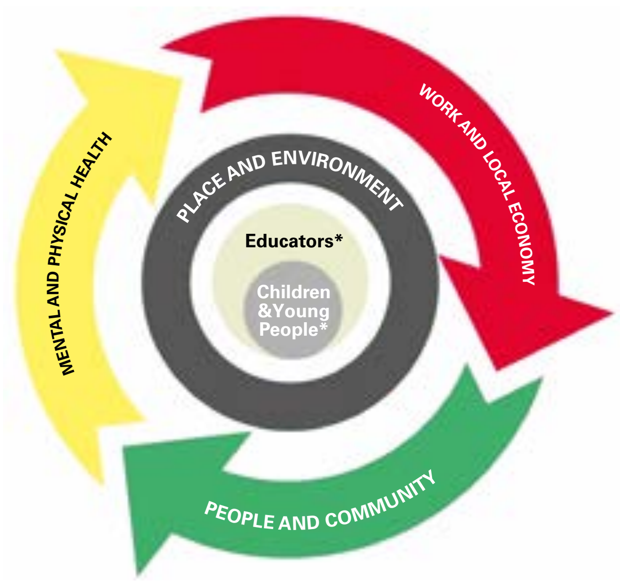



*Figure 3. Impact model for the Morecambe Bay Curriculum.*

addresses the challenge that teachers face in developing their practice in relation to sustainability and place. As noted previously, environmental issues are not explicitly covered in the current National Curriculum requirements and the recent DfE strategy has received some criticism for not going far enough (Howard-Jones and Dillon, 2022). The teaching of environmental sustainability requires expert multidisciplinary knowledge in which many teachers may not feel sufficiently confident (Oversby, 2015), with the result that some avoid addressing the topic completely (Wise, 2010). Given the potential for education to influence decision-making behaviours and reduce individuals' carbon footprints (Cordero, Centeno and Todd, 2020), it is important to ensure educators have expert support that enables them to draw on cutting-edge environmental and place-based research.

Our approach to curriculum design brings together academics from Lancaster University and local educators in an innovative co-design project. Twenty educators have partnered with seventeen academics whose work focuses on local, place-based and environmental issues within diverse disciplinary areas. Attempting to cover the entirety of the National Curriculum in one project was untenable, so our steering group selected the subject areas they saw as a priority. This includes science, the arts and humanities across Early Years, Primary and Secondary education, followed by more vocational routes into construction, agriculture, water management and tourism in Further Education. A full list is provided in the case study below. Ostensibly, the teacher will bring expert knowledge of what is required in the curriculum to design pedagogically motivating activities which are suitable for their local context, whilst the academics will bring cutting-edge research and subject-specific knowledge. However, this divide is not quite as discrete as might appear, as teachers also have specific subject knowledge and expertise, whilst many academics bring teaching skills, experience of working with young people and in-depth understanding of the region. As such, the partnerships can develop across the three domains (subject knowledge, pedagogical and contextual) in a mutually collaborative manner.

### Case Study

This case study details the work upon which the MBC has been built, as well as providing information about the current initiative of embedding sustainability into the curriculum. The initial projects helped to secure engagement from educators and encouraged them to continue to be involved in the project over a longer term, with many of the teachers from the projects phase now involved in curriculum design.

### Project 1: Eden Bear

One of the most prominent and ongoing projects is the work undertaken by Early Years educators, which uses 'Eden Bear' as a stimulus to explore young children's perceptions of place. Early Years classes utilise the bear as a resource to support local storytelling and children were encouraged to discuss their own understandings of place by taking photos of themselves with the bear in places important to them. Books were produced by the University of Cumbria, with financial backing from Lancashire County Council, which showed Eden Bear in various locations. Communities could thus see which places were valued by their own pupils and could also gain a sense of environmental similarities and differences across the Bay. This projective technique of children engaging with the bear as a 'third party' has proven effective in encouraging dialogue, supporting early language acquisition skills and in developing children's identity and sense of self (Warin, 2010).

Professor Jo Warin evaluated this project, highlighting the positive impact on oral storytelling and pupils' language development. By focusing on local stories, children and educators were encouraged to develop a greater sense of pride in where they live, linking to one of the core aims of the MBC. The evaluation also recognised how Early Years educators benefited from being 'pioneer members' of the MBC and how this encouraged them to collaborate further across the boundaries between their settings, cementing both their involvement in the initiative and their own localised community of practice.

*Figure 4: Early Years Pupils showing Eden Bear their local area, Ryelands Primary and Nursery School*

**Project 2: Little Researchers**

In 2023, children from local schools developed research skills by working alongside undergraduates from Lancaster University. Academics and practitioners supported students to engage children in environmental research by investigating real-life problems. This demonstrated to pupils in schools the important role which research in universities can play in addressing the climate crisis and gave students the opportunity to facilitate children's research, enhancing their employability. Children were asked to devise and research a question related to the broad themes of water, land, air, economy or community and the students, who had been trained in outdoor education practices, supported them through the process. The project culminated with the pupils presenting their findings in the university library to an audience which included researchers and academics.

Dr Nataša Lacković led on the project and noted how it increased children's awareness of local environmental issues and introduced them to the principles behind research and enquiry. By giving children ownership of the research question, the investigative processes and the presentation of their findings, the learning experience stimulated their creative and analytical thinking within a locally relevant context. As one teacher commented, the fact that it was research-led was the most valuable aspect because "there are few opportunities to work in this way in the primary curriculum setting". Having the opportunity to feel a sense of autonomy and ownership over their work is crucial for pupils' motivation (Ushioda, 2011) and the work children produced demonstrated how it had impacted their thinking and actions. Teachers also valued that the project encouraged all children to 'have a voice' and improved their oracy skills. A teacher-and-pupil toolkit was developed, which explains and exemplifies how to use this enquiry-based approach in practice. Schools across the Bay will therefore be able to replicate the pupil-led research process with their own questions and share their unique findings through the MBC's online membership platform.

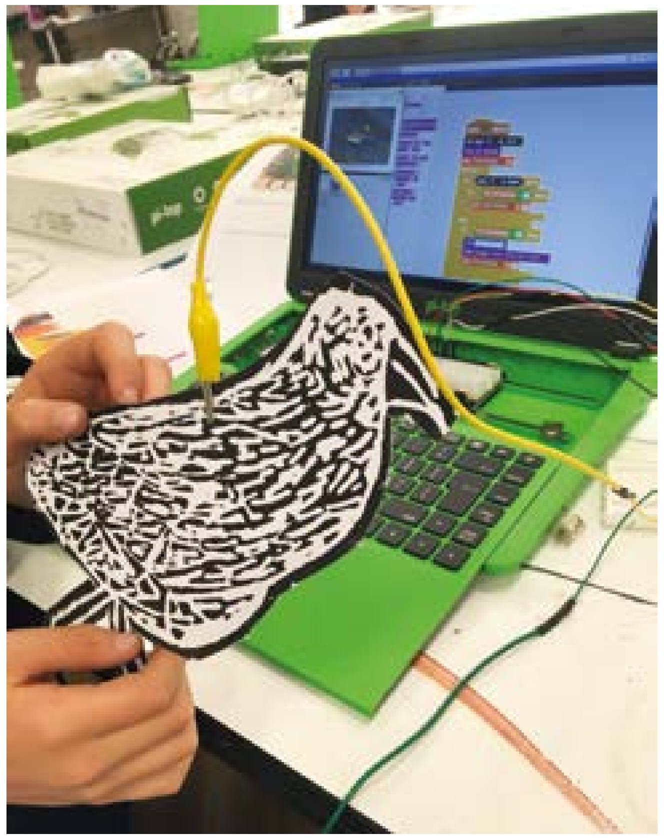
**Project 3: Who's Calling?**

Dr Liz Edwards combined her technological expertise in a project which explored digi-

*Figure 5: Pupils from St Paul's C of E Junior School, Barrow presenting their research at Lancaster University*

tal technologies and environmental change. Her work included opportunities for local school children to experience the natural environment first-hand and become attuned to the rhythms of the seasons and wildlife. By using innovative approaches, such as digital logbooks, the children would record and capture their observations and bird songs, in order to program and produce interactive displays that mapped their school's local environment. Edwards' technological expertise and knowledge of the natural world has empowered teachers to deliver two curriculum areas (computing and the environment) in which practitioners frequently lack confidence (Wise, 2010). The use of technology in enabling children to collect data on and assess the biodiversity in their school grounds has proved particularly innovative (Edwards et al., 2023) and aligns with other initiatives currently being undertaken as part of the National Education Nature Parks scheme (2023). By understanding the natural contexts of their school grounds, Edwards' methods could support schools in rewilding their localities as part of the drive to achieve net zero.

*Figure 6: Pupils using technology to connect audio files of birdsong to their artwork*



**Curriculum Design Project**

Bringing teachers and academics together to embed cutting-edge research into the National Curriculum framework is the MBC's biggest project to date. Collectively this group is developing curriculum resources that will be made available to all educational settings in Morecambe Bay. This work, which covers Early Years through to Further Education, is ongoing, taking place during the academic year 2023-2024, and is funded through the university's Widening Participation Access Group. The MBC has brought together 20 teachers and 17 academics to develop resources that support practitioners in weaving sustainability and place into their everyday practice. The project will enable all educators to access these high-quality curriculum resources, which they can adapt and apply in their own contexts, with the outputs comprising a resource booklet, CPD sessions and accompanying online guidance and exemplars.

The curriculum resources will follow the principles of Head, Heart and Hands. This framework can take schools beyond 'teaching to the test' and deliver the integrated and innovative curriculum which is required to address complex environmental issues (Robinson and Seleznyov, 2023). The philosophy is that as well as subject knowledge (Head), which is highly prized in today's education policy, the curriculum should also focus on developing the pupils' moral values and love for the environment (Heart) and their skills to solve complex problems in collaborative and multi-disciplinary ways (Hands). Environmental and place-based education recognises that problems may be ill-structured, complex and have multiple solutions, reflective of the climate crisis (Ardoin, Bowers and Galliard, 2020). Equally, pupils will only feel the drive to make changes to their behaviour and actions if they develop a positive emotional link to where they live and have the chance to experience being in the natural environment (Chawla, 2015; Adams, Lewis and Haughton, 2024). As such, the three aims ensure that pupils receive an education which leaves them informed about their locality, with a strong sense of identity linked to place and with the knowledge and skills required to solve complex problems.

Although Head, Heart, Hands represents the underpinning philosophy, we are not dictating the exact nature of what is designed. The project is driven by teachers and academics, and they will retain autonomy over what is produced. The MBC team's role involves coordinating their efforts to produce a coherent set of resources, as well as providing exemplars upon which they can draw. These could take the form of unit overviews, best practice lessons, drop-down days or project-based learning connected to specific locations around Morecambe Bay. Curriculum design is currently a key part of subject leadership across schools and educators themselves will be in the best position to judge what would be helpful to them. Our approach enables them to be creative and innovative but with an explicit focus on the National Curriculum to fulfil requirements for accountability.

The Steering Group selected the subject areas which are shown in full in Table 1 overleaf, together with examples of the university-based research which academics will contribute. This collaboration illustrates the role of Lancaster University as a civic university and the list demonstrates the vast range of expertise on which we were able to draw. Whilst in time we would hope to expand the subject areas, the following were deemed the priority spaces in which the MBC could contribute and enhance current teaching practice.

From the teachers' perspective, the collaboration with academics allows them access to cutting-edge research and knowledge from the university, enhancing their practice and giving them the confidence to engage with challenging environmental issues. There is often a disconnect between schools, their communities and universities (Cook and Nation, 2016), but by sharing the research of academics, it becomes clear that there are many elements which could prove relevant to educators in the area. The process of teachers and academics working together can serve to engender trust between the community and the university (Mayan et al., 2019), as they collaborate towards common social goals. From the teachers' applications, it is clear that whilst they may not be aware of all the work that goes on in the university, involvement in this project will make this visible. As one practitioner commented, the most exciting part of the project was

**Table 1: List of curriculum subjects and academic expertise**

| Age Phase | Subjects | Academic research fields | Additional expert input |
|---|---|---|---|
| Early Years | ○ Understanding the world<br>○ Expressive arts and design | ○ Children's psychological development, curiosity and creativity<br>○ How science and art interact around environmental issues | ○ How to adapt for SEND<br>○ Careers links and case studies |
| Primary Key Stage 1-2 | ○ History<br>○ Geography<br>○ Science<br>○ Art | ○ Cultural history of landscapes in Britain<br>○ Coastal hydrodynamics and changes in sediment and landscape<br>○ Environmental justice and risk-taking<br>○ Art through mobilities exploring the movement of people and things | ○ How to adapt for SEND<br>○ Careers links and case studies |
| Secondary Key Stage 3 | ○ History<br>○ Geography<br>○ Science<br>○ Design technology<br>○ PSHCE | ○ Historical analysis of cities using a past-futures approach<br>○ Human geography and sustainable food futures<br>○ Plant biology including the relationship between plant health and their immediate environment<br>○ Digital transformation in education and engineering<br>○ Environmental politics, marine policies and the blue economy | ○ How to adapt for SEND<br>○ Careers links and case studies |
| Further Education | ○ Agriculture and land management<br>○ Water management<br>○ Construction<br>○ Leisure and tourism | ○ Drought management, food production and water use within agriculture.<br>○ Water management in times of crisis<br>○ Built environments within a teaching and learning context<br>○ Machine learning and design in architecture<br>○ Sustainable tourism | ○ How to adapt for SEND<br>○ Careers links and case studies<br>○ Industry input from JBA trust, an organisation that aims to improve resilience to risk in the water environment |



"working with a partner who is approaching the same subject from a totally different perspective. A great way to produce a collaborative piece of work".

There are also benefits for the academics, who can share their work with an audience beyond the academy and see it applied in practice. One academic commented at the launch event, that their motivation for engaging in the project was to make their work useful and provide a context in which it could have a genuine impact on the local community. Lancaster University's engagement policy (2023) identifies the need to "shape the wider skills agenda in the region" and the MBC is one way in which this can be achieved. The genuine partnerships which the project enables inspire teachers and academics to work towards a clear, common goal, which they decide and shape together.

The co-design process has been facilitated by Dr David Pérez from ImaginationLancaster, a design school at Lancaster University which conducts applied research into people, places and their interactions. His expertise in bringing together diverse groups and ensuring that productive and mutually beneficial relationships develop has been extremely valuable. With his guidance, the MBC team have designed tools to guide the participants through thinking broadly about place and sustainability before narrowing this down to a focused idea for a curriculum resource. One participant commented:

"I enjoyed the way that the facilitators provided a balance of structure and freedom. There was always time and capacity to have important relationship-building conversations, yet you gave us just the right amount of structure and expectation to make those interactions meaningful. All the more impressive given how diverse we were." *—Lecturer, Lancaster University.*

*Figure 7: Academics and teachers meeting for the first time to discuss how best to work together, January 2023*

Two of the five days which teachers and academics commit are structured in this way, with the remaining three being flexible for each pair to decide on their approach. Building in flexibility and providing financial buyout for the five full days for each contributor was vital in ensuring that the project was manageable for colleagues who work in demanding roles. It also allows participants to determine how they can best work with each other. Figure 8 demonstrates a timeline of the process we are following, which could be

| December | January | February | March | April | May | June | July |
|---|---|---|---|---|---|---|---|
| Steering group decide on the subject areas and identify academics with relevant interests and research. Teachers are recruited. | Launch event with expert input where academics and teachers meet and decide on their approach. | *Ongoing paired work* | | | Input from Special Educational Needs experts and careers services. | Final quality assurance checks and printing of booklets. | Celebration and CPD event open to all members of the community |
| | | | Facilitated day where pairs share work completed so far and can peer-review each others' contributions. | Deadline for work to be submitted. | | | |
| | Between January and May, academics and teachers commit a further three days to work together on their resources – they retain control of the format and timing of these. | | | | | | |

*Figure 8: A timeline of the Curriculum Design process.*

applied in other contexts.

Following the production of the curriculum materials, a booklet of resources will be collated and widely shared. This will be reviewed by curriculum experts as well as specialist colleagues who will add additional content to show how resources can be adapted for learners with Special Educational Needs and Disabilities. Additionally, colleagues from Lancaster University's Management School careers team and Lancashire Careers Hub will input employability case studies, linking these educational experiences to the green jobs of the future. This serves to address a core aim of the MBC, which is to enhance the life chances and employment prospects of young people within the Bay, showing how these careers can benefit the environment, their future aspirations and their community.

## Conclusion

The work detailed in this paper represents the initial stages of the MBC and shows how a series of grass-roots projects has evolved into a programme of innovative curriculum design. The most significant aspect has been bringing together teachers and academics to collaborate in a supportive environment where they have the autonomy to achieve meaningful change. By listening to the voices of teachers and valuing the expertise they bring, we have secured long-term community involvement, which will extend to a broader range of schools over the next few years. Processes are now in place to assess the impact on both teachers and academics who have participated, and subsequently to track the impact on pupils.

It is important to note that the project would not exist without the extensive time spent in community groups supporting grass-roots projects. The time taken to build relationships with and listen to members of the community means the work is built on a strong foundation of trust; this is vital to acknowledge if the approach were to be transferred to other contexts. As Savan (2004: 381) notes, "long-term collaborations foster the trust and shared values critical to successful work involving partners based in widely differing institutional settings". Although this can be difficult within the contexts of time and university structures, the enthusiasm and participation of the teachers from across the Bay would not have been as successful without investment in the time and space for community conversations (Wood, 2017). By facilitating genuine partnerships and passing control to teachers, we attempt to subvert some of the hierarchies which can negatively impact on university-community relationships (Cook and Nation, 2016).

Research involving collaborations between universities and communities can be driven by a variety of reasons, many of which may be instrumental and focused on economic and reputational gains (Hains et al., 2021; Wood, 2017; Jagannathan et al., 2011). However, for the MBC, this is a project driven by our community of local educators. It emerged from the will of teachers and academics in the region and seeks to address more diverse aims such as strengthening democratic values and solving critical societal issues (Kooli, Jamrah and Al-Abri, 2019: 219). By building on the strong desire of educators to incorporate environmental and place-based learning into their daily work, we have created a community of practice in which we unite teachers and academics from across Lancashire and Cumbria. Although our approach is localised, the processes which have been described can be adapted and transferred. We suggest four core principles which would support the implementation of this work in other contexts:

1. Start with community conversations in order to understand the desires, motivations and expertise local practitioners bring and discuss these explicitly, recognising and resolving contradictions.

2. Ensure decisions remain within the hands of community members to engender trust and to ensure they feel valued.
3. Provide support, time and structure for meaningful collaborations but allow participants autonomy within the work they produce.
4. Think big – together we can achieve positive change even in the face of the climate crisis!

We recognise that the MBC is an ambitious undertaking, which could not have happened without the support and dedication of every one of our members. In a world which faces the most complex of 'wicked problems' in the climate crisis, we cannot lose sight of the need to care for the people and the place in which we live. However, we also need cutting-edge knowledge to raise awareness of solutions and children need to be informed of these opportunities throughout their time in nursery, school and college. Through education, we can embed positive actions and values that trigger the commitment needed to tackle the planetary emergency across the region and the work of the MBC makes a significant contribution to this. This case study has shown the power of genuine collaborations and the passion which our teachers and academics have to make a difference to the futures of young people in the area. Next time you hear mention of Morecambe, we hope that visions of a forgotten seaside town are pushed to the back of your mind and instead you think of the MBC Educators and their pioneering drive to create a better world.

### Acknowledgements

The curriculum development project was funded by Lancaster University. The Eden Bear books were facilitated by the University of Cumbria with funding from Lancashire County Council.

### Selected Projects

'Eden Bear' Project: https://www.lancaster.ac.uk/morecambe-bay-curriculum/news-and-case-studies/eden-bear-book-launch-event

'Little Researchers' Project: Little Researchers – a Morecambe Bay Curriculum project – Lancaster University

'Who's Calling?' Project: https://wp.lancs.ac.uk/thelostsounds/

### References

Adams, D., Lewis, R. & Haughton, C. (2024) Being and feeling of place. In: Rawlings-Smith, E. & Pike, S. Eds. (2024) Encountering Ideas of Place in Education: Scholarship and Practice in Education. Abingdon: Routledge.

Agarwal, S., Rahman, S. Page, S.J. & Jakes, S. (2023) Economic performance amongst English seaside towns. Current issues in Tourism. https://doi.org/10.1080/13683500.2023.2234070

Ardoin, N. M., Bowers, A. W. & Galliard, E. (2020). Environmental outcomes for education: A systematic review. Biological Conservation 241. https://doi.org/10.1016/j.biocon.2019.108224

Ashmore, R. (2023) Inside neglected UK seaside town with demolished pier so poor almost no one can pay their bills. Express. https://www.express.co.uk/news/uk/1781139/Morecambe-Lancashire-bills-seaside-cost-of-living

Bidandi, F., Ambe, A. N., & Mukong, C. H. (2021). Insights and Current Debates on Community Engagement in Higher Education Institutions: Perspectives on the University of the Western Cape. SAGE Open, 11(2). https://doi.org/10.1177/21582440211011467

Chevalier, J.M., & Buckles, D.J. (2019). Participatory Action Research: Theory and Methods for Engaged Inquiry (2nd ed.). Abingdon: Routledge.

Cook, J.R. & Nation, M. (2016). Community engagement: Universities' roles in building communities and strengthening democracy, Community Development, 47:5, 718-731

Cordero, E.C., Centeno, D. & Todd, A. (2020). The role of carbon change education on individual lifetime carbon emissions. PLOS One https://doi.org/10.1371/journal.pone.0206266

Edwards, E., Vidler, J.E., Underwood, L., Rubegni, E. & Finney, J. (2023) Supporting fieldwork for primary education with computing: micro-bit, clip-bit and games controllers. IDC '23: Proceedings of the 22nd Annual ACM Interaction Design and Children Conference. June 2023. 553–557 https://doi.org/10.1145/3585088.3593897

Hains, K.D., Rios, M., Hains, B.J., Koundinya, V.,

Abrams, C. & Standard, V. (2021). An exploration of community development higher education in the United States: A programmatic study. Community Development, 52(4): 425-239. DOI: 10.1080/15575330.2021.1874457

Harvey, F. (2020). The national curriculum barely mentions the climate crisis. Children deserve better. [Online] Available from: The national curriculum barely mentions the climate crisis. Children deserve better | Fiona Harvey | The Guardian

Howard-Jones, P. and Dillon, J. (2022). Climate Change education: A "world leading strategy" would benefit from being research-informed. University of Bristol. [Online]. Available from: Climate Change education: A "world-leading strategy" would benefit from being research-informed | PolicyBristol | University of Bristol

Jacobi, J et al. (2022) Transdisciplinary co-creation increases the utilisation of knowledge from sustainable development research. Environmental Science and Policy. 129: 107-115.

Jagannathan, R., Camasso, M.J., Mend, S.G., Varela, J. & Shah, A. (2011) University-community partnering using a mutual-interests approach. Community Development. 42(1): 410-423.

Kooli, C., Jamrah, A. & Al-Abri, N. (2019). Learning from Quality Audit in Higher Education Institutions: A Tool for Community Engagement Enhancement. FIIB Business Review 8(3) 218-228

Lancaster University. (2023) Strategic plan: Engagement. [Online]. Available from: https://www.lancaster.ac.uk/strategic-planning-and-governance/strategic-plan/engagement/

Love Morecambe Bay. (2020) The Story So Far. [Online]. Available from: https://lovemorecambebay.co.uk/?THE_STORY_SO_FAR

Mayan, M. Pauchulo, A. L., Gillespie, D., Misita, D. & Mejia, T. (2019): The promise of collective impact partnerships. Community Development Journal. 55(3): 515-532.

National Education Nature Parks (2023). How the nature park works. [Online] Available from: https://www.educationnaturepark.org.uk/nature-park

Office for National Statistics. (2021) Exploring local income deprivation: A detailed picture of disparities within English local authorities to a neighbourhood level. [Online] https://www.ons.gov.uk/visualisations/dvc1371/#/E07000121

Oversby, J. (2015) Teachers' learning about climate change. Procedia – Social and Behavioural Sciences. 167: 23-27.

Pollastri, S., Earl, J., Edwards, L. and Ilic, S. (2023) Morecambe Bay Timescapes: Drawing together coastal futures that will, may or could. TRACEY. [Online] Available from: https://eprints.lancs.ac.uk/id/eprint/191675/3/Pollastri_serena_Timescapes_TRACEY_AAM_1_.pdf

Prince, H. E. (2017). Outdoor education and sustainability. Journal of Adventure Education and Outdoor Learning. 17(2) 161-171. Available from: https://www.tandfonline.com/doi/pdf/10.1080/14729679.2016.1244645

Robinson, L. & Seleznyov, S. (2023) An Education of the Head Heart and Hands. Impact 18. [Online} Available from: https://my.chartered.college/impact_article/an-education-of-the-head-heart-and-hand/

Savan, B. (2004) Community-university partnerships: Linking research and action for sustainable community development. Community Development Journal 39(4): 372-384.

Savin-Basen, M. & Wimpenny, K. (2007) Exploring and implementing participatory action research. Journal of Geography in Higher Education. 31(2). https://doi.org/10.1080/03098260601065136

Teach the Future. (2022). Curriculum for a Changing Climate: Subjects. [Online]. Available from: Curriculum for a Changing Climate: Subjects (teachthefuture.uk)

Ushioda, E. (2011) Why autonomy? Insights from motivation theory and research. Innovation in language teaching and learning. 5(2) https://doi.org/10.1080/17501229.2011.577536

Warin, J. (2010) Stories of self: Tracking children's identity and wellbeing through the school years. Stoke on Trent: Trentham Books.

Wise, S.B. 2010. Climate change in the classroom: Patterns, motivations, and barriers to instruction among Colorado science teachers. Journal of Geoscience Education , 58 (5):297–309.

Wood, L. (2017) Community development in Higher Education: How do academics ensure their community-based research makes a difference? Community Development Journal. 52(4): 685-701.

---

Dr Bethan Garrett is Lecturer in Morecambe Bay Curriculum and Carys Nelkon Partnership Development Manager, both at Lancaster University.



# Net-zero-carbon construction: connecting policy and science

A collaboration between Bath & North East Somerset Council and the University of Bath

Will Hawkins, Joris Šimaitis, Andy Shea, Ellie Marsh, Stephen Allen, Peter Phelps, Katrina Kelly *(University of Bath)*; Alice Barnes, Richard Daone, Charlotte Smallwood *(Bath & North East Somerset Council)*; Alex Bell *(Chapter 2 Architects)*; Dr Elli Nikolaidou *(South West Net Zero Hub)*; Alex McCann *(Bioregional)*

**Abstract**

In January 2023, Bath & North East Somerset Council (B&NES) implemented the first local planning policies in the UK requiring, first, that all new building developments achieve net zero operational energy, and second, that major developments meet an embodied carbon target. Both go far beyond the existing national building regulations, but they are representative of a growing number of similar policies from local authorities.

This paper describes a collaboration between B&NES and the University of Bath which explored the first months of the new policies' implementation, to identify the impacts on building designs, the reception by practitioners, and opportunities for policy development and refinement. Thirty-eight eligible planning applications were analysed, the majority for minor residential buildings eligible only for the operational energy policy. Despite a non-compliance rate of over 50% – primarily caused by a lack of policy awareness – many applications for buildings theoretically achieving net zero operational energy were received, representing efficiencies far beyond current standards. However, scrutiny and monitoring will be required for these ambitions to be met in practice. A corresponding questionnaire was completed by 65% of applicants. Although the responses were largely negative, with particular concerns over cost and viability, there was broad support for the policies' aims and an expectation of long-term emissions savings.

A long-term study is now needed to track the evolving industry response, quantify the real emission savings through construction and occupation, and further engage with stakeholders to support the policies' implementation, development, and wider impact.

---

## 1 Introduction

### 1.1 Emissions and regulation in the built environment

The built environment represents one of the most significant global decarbonisation challenges, and currently accounts for 25% (UK Green Building Council, 2021) of the UK's greenhouse gas emissions through both the heating, cooling and powering of buildings (operational emissions) and their construction, maintenance and demolition (embodied emissions). Although climate awareness and action is accelerating in the sector, emission reduction is yet to materialise; operational emissions from buildings have dropped only 13% in the UK since 1990 (Ritchie, et al., 2020), largely due to electricity decarbonisation, whilst embodied emissions from construction have actually increased over the past two decades (Giesekam, 2022). A national housing shortage is driving accelerated construction of new homes, with 3.4 million expected over the next 25 years (Office for National Statistics, 2020). The technology and skills to create efficient net zero buildings exists in the UK, but these must rapidly become mainstream if climate targets are to be met.

Currently, national policy governing the emissions of new building construction is limited to Part L of the Building Regulations (HM Government, 2023), which has included operational emission targets since 2006. Embodied emissions are not currently routinely measured or regulated, but the amount of industry guidance, product emission data, and consensus around a calculation methodology is increasing (RICS, 2023). This has led to a campaign for a Part Z (2024) amendment to the Building Regulations which would mandate the reporting and capping of a building's whole life emissions (operational and embodied), with strong support from industry. However, the government chose not to support the associated parliamentary bill (UK Parliament, 2022), choosing instead to commission further research.

Meanwhile, local authorities have already begun implementing ambitious carbon reduction policies through the planning process, hoping to align with their own net zero targets which are often set well before 2050. As a result, they have become the frontier of UK sustainable construction legislation.

### 1.2 B&NES' pioneering planning policies

In January 2023, a number of new planning policies came into force in Bath & North East Somerset Council as part of the Local Plan Partial Update, as detailed in the Sustainable Construction Checklist (B&NES, 2023). There are three key policies relating to the construction of new buildings:

*Policy SCR6 - New build residential developments*

Policy SCR6 requires a space heating demand of less than 30 kWh/(m$^2$a), defined as the required active heat input over an average year to maintain a 20°C internal temperature. Connection to a low-carbon district heating network, where available, is required. The total energy use, which includes both regulated and unregulated energy consumption, must be less than 40 kWh/(m$^2$a). This must be matched or exceeded by onsite renewable energy generation, except for major developments (10 or more dwellings) where this is demonstrably infeasible, where the remaining deficit can be offset using the council's Carbon Offset Fund. Compliance with policy SCR6 is assessed via an Energy Summary Tool, a spreadsheet through which applicants submit building energy data generated using either the Standard Assessment Procedure (SAP) or the Passive House Planning Package (PHPP) methodologies. The tool addresses established differences between SAP and PHPP methodologies in their input, output and calculation methods (Moutzouri, 2011; Koch, 2015; PassREg, 2015), primarily through modifications to the SAP output. Although PHPP is preferred due to its proven reliability for energy efficient dwellings (Schnieders & Hermelink, 2006), its use was not mandated due to the additional training requirements compared to SAP – which is well established in the UK as the mechanism for Part L compliance – and software licence fees.

*Policy SCR7 – Major non-residential new build developments*

For major non-residential buildings, defined as those with 1,000 $m^2$ or more commercial floor space, policy SCR7 requires a 100% regulated operational emissions reduction relative to the Part L Target Emission Rate. This means energy use must be minimised through efficient building fabric and services, and exceeded by maximising opportunities for renewable energy generation. As with policy SCR6, any residual emissions which cannot feasibly be removed can be offset.

*Policy SCR8 – Embodied carbon*

Large-scale new build developments of more than 50 houses (residential) or 5,000 $m^2$ (non-residential) must submit an embodied carbon assessment, achieving less than 900 $kgCO_2e/m^2$ for substructure, superstructure and finishes including cradle-to-completion emissions (modules A1-A5 of BS EN 19578 (BSI, 2011)). This must be verified by a third party, and is submitted through completion of a table with accompanying description.

To the authors' knowledge, these were the first UK planning policies to require net zero overall energy use for all new buildings, and to set a limit to embodied carbon for larger developments. However, other councils around the country have since, or plan to, adopt policies which similarly require net zero operational energy for new buildings whilst having some differences in energy targets and approaches to embodied carbon (Simaitis, et al., 2023). Table 1 compares B&NES' policy with National guidelines, both the existing Part L and proposed Future Homes Standard, showing that net zero energy and embodied carbon restrictions are currently not planned at a national level. This highlights both the recency and significance of these local policies, as well as growing complexity and regional discrepancies across new building performance standards. In this rapidly evolving policy landscape, it is vital that the impacts and effectiveness of pioneering policies are properly assessed.

### 1.3 Project formation and aims

The University of Bath and B&NES have undertaken collaborative research under

**Table 1. Comparison of energy use and embodied carbon approaches against national policies.**

| **Policy** | **Implementation** | **Space Heating Demand** kWh/($m^2$a) | **Total Energy Use** kWh/($m^2$a) | **Renewable Energy Generation** | **Embodied Carbon Assessment** |
|---|---|---|---|---|---|
| B&NES (B&NES, 2023) | Adopted January 2023 | <30 | <40 Residential developments | Generation must meet 100% of total energy use | < 900$kgCO_2e/m^2$ Large residential and non-residential |
| Part L (HM Government, 2023) | Updated 2022 | < 50-82 estimated | < 63-106 estimated | Uptake encouraged to meet carbon reduction targets but not necessary | None |
| Future Homes Standard (Ministry of Housing, Communities & Local Government, 2019) | Adoption planned 2025 | < 15-20 Proposed | < 35 Proposed | PV is expected to cover equivalent to 30-40% of ground floor area | Has been called for in consultations |

the banner 'Our Shared Future' since 2019, covering research, student opportunities and consultation. Many different projects have taken place, exploring retrofit and carbon reduction, transport and travel logistics, green infrastructure, food security, and the rejuvenation of the high street (Hale, 2022). In January 2020, the University and B&NES, alongside Bath Spa University and the Royal United Hospitals Bath, announced a planned civic agreement. This has been in development since, with the establishment of the Future Ambitions Board through which collaborative projects and goal setting can be carried out. The agreement is set to be signed in 2024.

In October 2022, a collaboration was initiated between researchers from the university's Department of Architecture and Civil Engineering, who have a long record of research in the measurement and reduction of emissions in the built environment, and Sustainability and Planning Officers at B&NES, who were preparing for the imminent adoption of their new sustainable construction planning policies. The partnership was facilitated by the University's Climate Action Framework project, which was launched in 2020 to deliver a whole-institution response to the challenge of climate change. This newly-formed team developed a project proposal which aimed to:

- Understand industry adoption of the policies and their influence on building design.
- Determine practitioners' receptions and gather feedback.
- Inform future development of effective net-zero construction policies in B&NES, the UK, and elsewhere.

This paper discusses the activities and outcomes of this partnership, including an analysis of incoming planning submissions and a corresponding applicant questionnaire, before reflecting on the findings, implications and scope for wider development. More generally, the lessons learnt for other university and local authority partnerships are also detailed.

## 2 Methodology

### 2.1 Project organisation and collaboration

The project ran from January to July 2023, coinciding with the launch of the planning policies, and was funded by the university's Policy Support Fund (PSF) at a cost of £20k (University of Bath, 2022). The PSF was awarded to the university from Research England and aims to link university research with policy partners, and was vital in funding university staff, facilities, and a part-time research assistant. The final project team was enhanced by the addition of Chapter 2 Architects, a local practice with substantial experience on a range of building projects, and the South West Net Zero Hub, who are funded by the Department for Energy Security and Net Zero and provide support to local communities on decarbonisation in the built environment.

The collaboration was coordinated by the academic team, and featured regular online meetings, three half-day in-person workshops, and a central Microsoft Teams page for discussions, updates, meeting minutes, file sharing and document collaboration. The hybrid system of short, regular remote meetings with longer in-person workshops fostered effective engagement, knowledge-sharing, and research progress. The project culminated in the publication of a report through the university (Simaitis, et al., 2023).

### 2.2 Analysis of planning applications

Any planning applications which were validated by B&NES planning officers from the date of policy adoption (19 January 2023) to the end of the study period (1 July 2023), and were subject to one or more of the policies SCR6, SCR7 or SCR8, were collated and passed to the project team. Submitted building performance data was then extracted from the energy summary tool where available, alongside key details on the building type and application status. This enabled the compliance with relevant policies to be determined. In addition, the building energy performance data was compared and analysed in order to determine trends in the data, augmented by PHPP modelling to replicate results and investigate feasibility. This process was informed by workshops with the full project team. During the study period, a small number of applications were initially rejected and resubmitted, enabling a before and after comparison.

Due to the small number of major non-residential and large-scale project applications submitted throughout the project, these applications were assessed on an individual basis.

### 2.3 Applicant questionnaire

A questionnaire was developed by the project team, informed by early analysis of the application data, as well as B&NES' own experience of the policy development and implementation. Finalised and approved by April 2023, a link to complete the questionnaire was sent via email by B&NES planning officers to any applicants whose were subject to any of the new policies, either on receipt of the application, or retrospectively for those submitted previously.

The questionnaire featured 18 questions covering the applicant's professional background, experience in energy assessment and sustainability, experience of the policies and submission process, and opinions on its implementation, issues and potential effectiveness in reducing emissions. These ranged from multiple choice, ranking, and open questions. The full questionnaire has been published by Simaitis, et al. (2023).

## 3 Results and discussion

### 3.1 Analysis of planning applications

During the six-month study period, 38 full initial planning applications (excluding those that were outline applications, or resubmissions) were submitted, of which 35 were for minor residential developments subject to policy SCR6, making this the main focus of the study. There were also two major residential development applications (subject to policies SCR6 and SCR8) and one major non-residential application (SCR7 and SCR8).

A complete set of numerical results can be accessed through the University of Bath data repository (Hawkins, et al., 2023).

#### 3.1.1 Policy SCR6: Applications, building performance and compliance

Of the 37 applications subject to policy SCR6, 17 were compliant, with correct documentation and meeting policy requirements, whilst 20 were non-compliant (Figure 1). Non-compliance was predominantly due to incorrect document submission, indicating an unawareness of the new policies, and that many applicants take a reactive approach to changing requirements. Of the

14 applications with correct documentation, who used the Energy Summary Tool, only four missed the performance targets (three failed the renewable energy targets, one the space heating requirements, and one both). Applications of this nature would lead to discussions with planning officers to establish whether compliance could be feasibly achieved, or whether energy savings and generation had been maximised and any remaining difference offset. This would still result in significant carbon savings relative to current building standards.

Of the 22 applications which submitted performance results, 18 (82%) used SAP and only four (18%) used PHPP, indicating better familiarity with this method as expected. Six submissions, although compliant in terms of stated performance, gave incomplete information, making their feasibility difficult to scrutinise.

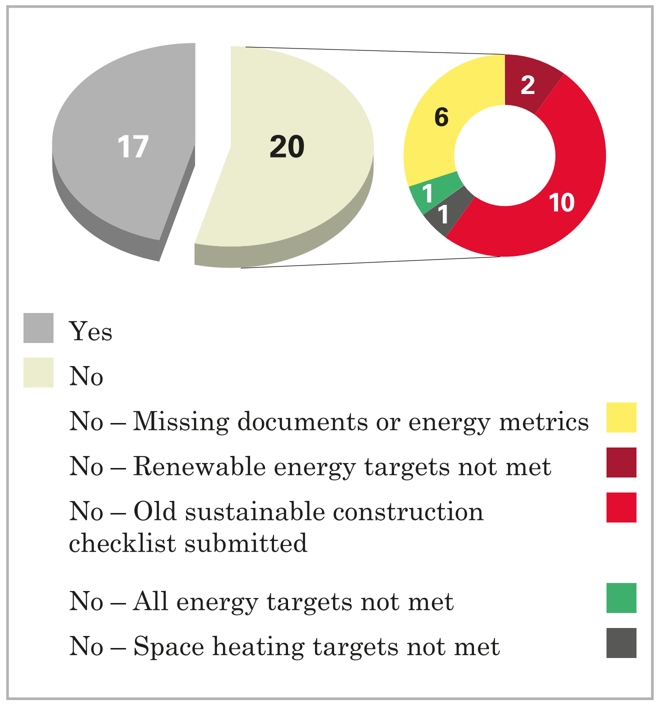



*Figure 1. Compliance rates of applications, and primary reasons for non-compliance with policy SCR6.*

Figure 2 plots the space heating, total energy use and renewable generation for each building in the submissions with available data. Six buildings failed due to a shortfall in renewable energy generation, with only one over the total energy limit and one missing the space heating target. In all cases, solar photovoltaics (PV) were the preferred renewable energy source, and it is possible that some buildings had insufficient roof space to match total energy demand. This issue was also highlighted in supplementary PHPP modelling.

All applications used grid electricity for all heating requirements and all except one development included air and/or ground source heat pumps. This indicates that natural gas or electrical resistance heating systems are either not compatible or economical for net zero energy buildings, which is consistent with previous studies (Kapsalaki, et al., 2012).

Figure 3 compares the different ventilation systems proposed, where given, showing that most applications chose a balanced mechanical system (where equal quantities of air is supplied and exhausted), with heat recovery used to further reduce energy input requirements.

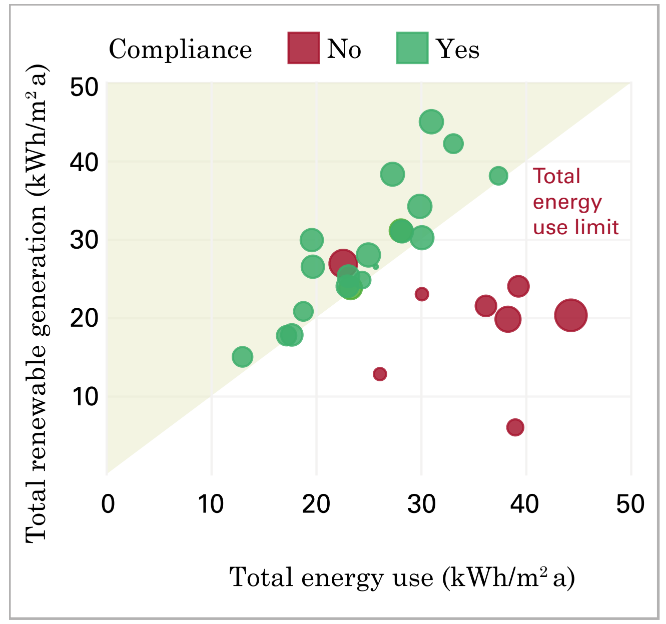



*Figure 2. Total renewable energy generation and total energy use from applications with correct document submissions. The size of circles represents space heating values, and their centres must be within the cream shaded area for compliance.*

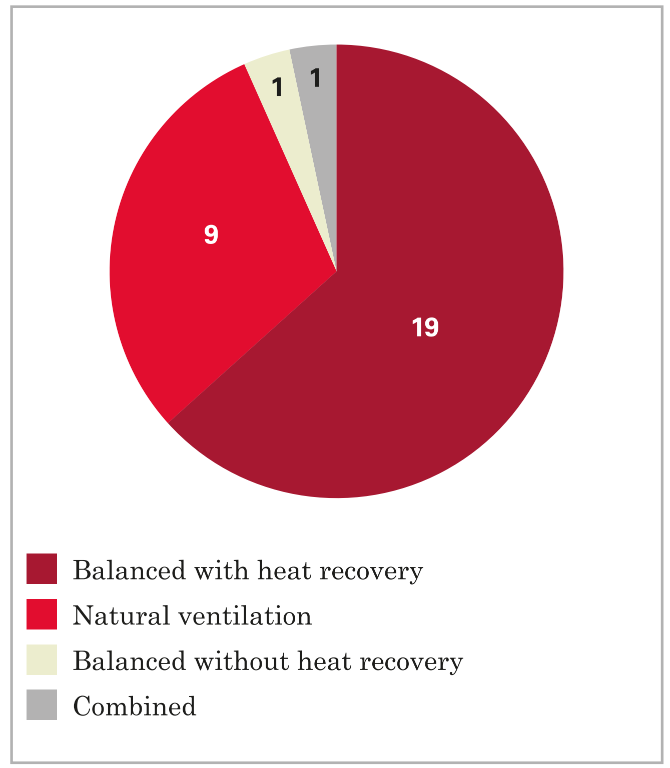



*Figure 3. Types of ventilation systems for proposed developments (where specified).*

During the period of study, three applications which were initially rejected were subsequently revised and resubmitted, revealing a wide variety of applicant approaches to the new policy. Table 2 compares the initial and revised submissions in each case.

Application #1 was initially incomplete, and their revised submission featured updated and compliant parameters. Application #2 initially failed to achieve compliance and did not use the energy summary tool. On revision, the correct approach was used, but the space heating performance remained more than twice the requirement, with the applicant going on to justify this in several ways, citing a desire for high vaulted ceilings and tension between solar gains for thermal performance and overheating risk, whilst also claiming a reduced overall energy consumption through using an air source heat pump. Application #3 changed very little of the building design, and resubmitted a revised final performance value which did not correspond to the SAP model, potentially indicating an attempt to bypass the requirements at planning stage.

**Table 2. Revised application case studies: parameters and outcomes for space heating.**

| | 1 | 2 | 3 |
|---|---|---|---|
| **Application #1** | | | |
| Air permeability, $m^3/(m^2hr)$ at 50 Pa | 3.00 | 5.00 | 2.50 |
| External wall U-value, $W/(m^2K)$ | 0.16 | 0.18 | 0.16 |
| Roof U-value, $W/(m^2K)$ | 0.12 | 0.11 | 0.10 |
| Ground floor U-value, $W/(m^2K)$ | 0.13 | 0.10 | 0.10 |
| Window U-value, $W/(m^2K)$ | 1.20 | 1.20 | 1.08 |
| Space heating, $kWh/(m^2a)$ | 30.00 | NP | 20.5 |
| **Application #2** | | | |
| Air permeability, $m^3/(m^2hr)$ at 50 Pa | 3.00 | 5.00 | 5.00 |
| External wall U-value, $W/(m^2K)$ | 0.16 | 0.16 | 0.16 |
| Roof U-value, $W(m^2K)$ | 0.12 | 0.10 | 0.10 |
| Ground floor U-value, $W/m^2K)$ | 0.13 | 0.11 | 0.11 |
| Window U-value, $W/(m^2K)$ | 1.20 | 1.20 | 1.20 |
| Space heating, $kWh/(m^2a)$ | 30.00 | 63.20 | 71.80 |
| **Application #3** | | | |
| Air permeability, $m^3/(m^2hr)$ at 50 Pa | 3.00 | 4.50 | 4.50 |
| External wall U-value, $W/(m^2K)$ | 0.16 | 0.16 | 0.18 |
| Roof U-value, $W(m^2K)$ | 0.12 | 0.11 | 0.11 |
| Ground floor U-value, $W/(m^2K)$ | 0.13 | 0.13 | 0.13 |
| Window U-value, $W/(m^2K)$ | 1.20 | 1.21 | 1.20 |
| Space heating, $kWh/(m^2a)$ | 30.00 | 38.40 | 15.10 |

*1. Target or recommended value*
*2. Initial submission*
*3. Revised submission*

### 3.1.2 Policies SCR7 and SCR8: Major and non-residential applications

One submitted major non-residential project, with a GIA of 1,290 $m^2$, should comply with policy SCR7 but not SCR8. The proposal included the partial demolition of an existing school teaching block and construction of 14 new classrooms. Conforming to the fabric-first approach, the application proposed an efficient building design with solar PVs to fully offset the operational energy usage, thus correctly interpreting and complying with policy SCR7.

Another mixed-use development proposed the demolition of an existing commercial industrial building, and the construction of two commercial units and 77 co-living studios with communal facilities, which must comply with policy SCR7 as well as SCR6. Originally proposed and rejected in 2022, the 2023 resubmission proposed an operational $CO_2$ reduction of 22%, despite the use of mechanical ventilation with heat recovery, heat pumps, and a roof-mounted PV system. This is far below the 100% required by SCR7, so the application proposed offsetting the remainder. Further resubmissions are still under consideration at the time of writing.

One major development application was received, a residential-led mixed-use development including more than 600 new homes on a brownfield site. This is likely to be the first UK development to be subject to both net-zero operational carbon requirements (SCR6) and an embodied carbon limit (SCR8). In terms of embodied carbon, the initial submission calculated an A1-A5 figure of 621 $kgCO_2/m^2$, well below the required value of 900 $kgCO_2/m^2$, although a lack of transparency prevented full scrutiny.

### 3.2 Questionnaire results and analysis

The questionnaire response rate was 65%, with 24 out of 37 applicants submitting partial (9) or full (15) responses. The respondents came from a variety of professional backgrounds (Figure 4), but were primarily architects (54%) or planning consultants (33%) who worked for organisations of fewer than 10 employees (83%) and had submitted over 10 planning applications (88%) and had over 10 years' experience in the construction industry (96%). Full questionnaire results are accessible through the University of Bath data repository (Hawkins, et al., 2023).

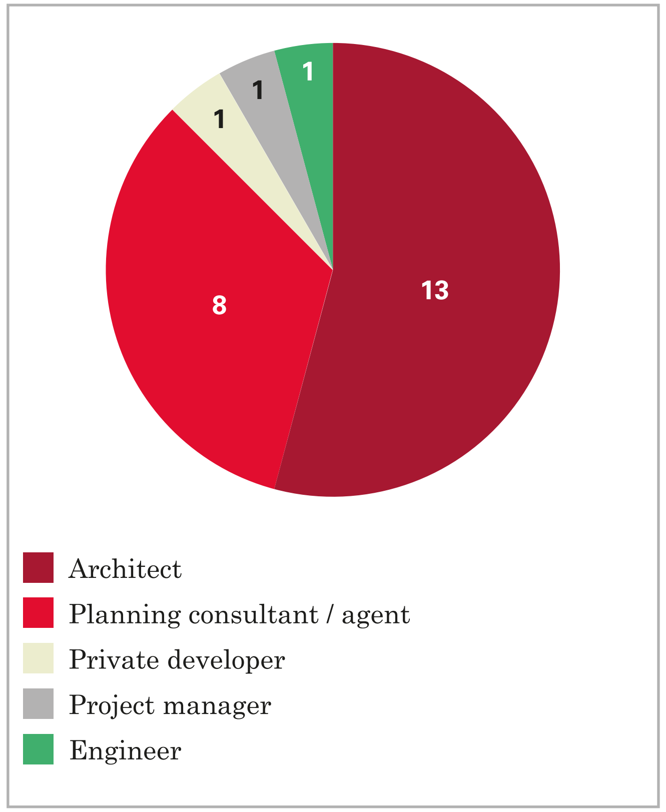



*Figure 4. Professional roles of questionnaire respondents.*

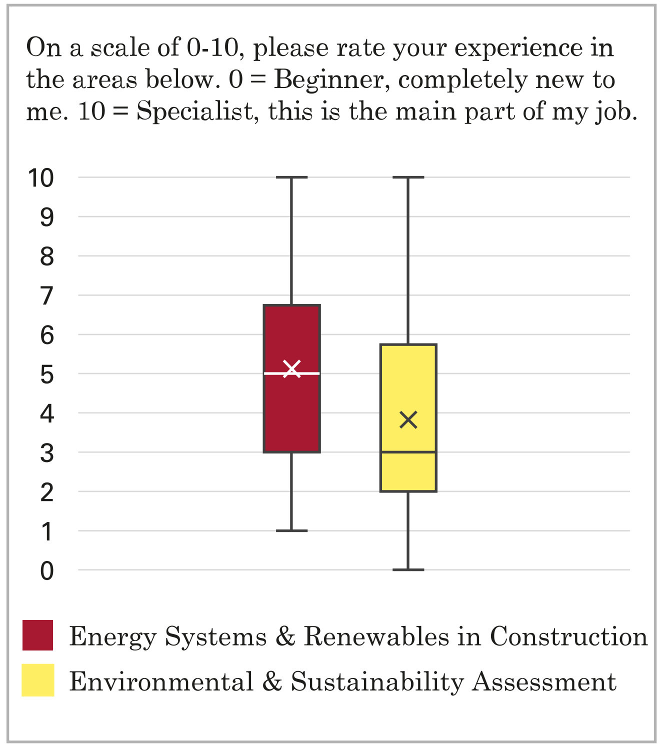
There was a wide range of perceived skill levels in relevant fields (Figure 5), although applicants generally scored their competency in "energy systems and renewables" higher than "environmental and sustainability assessment". The former aligns more closely with policy SCR6, which featured much more prominently in the applications than SCR7 and SCR8.

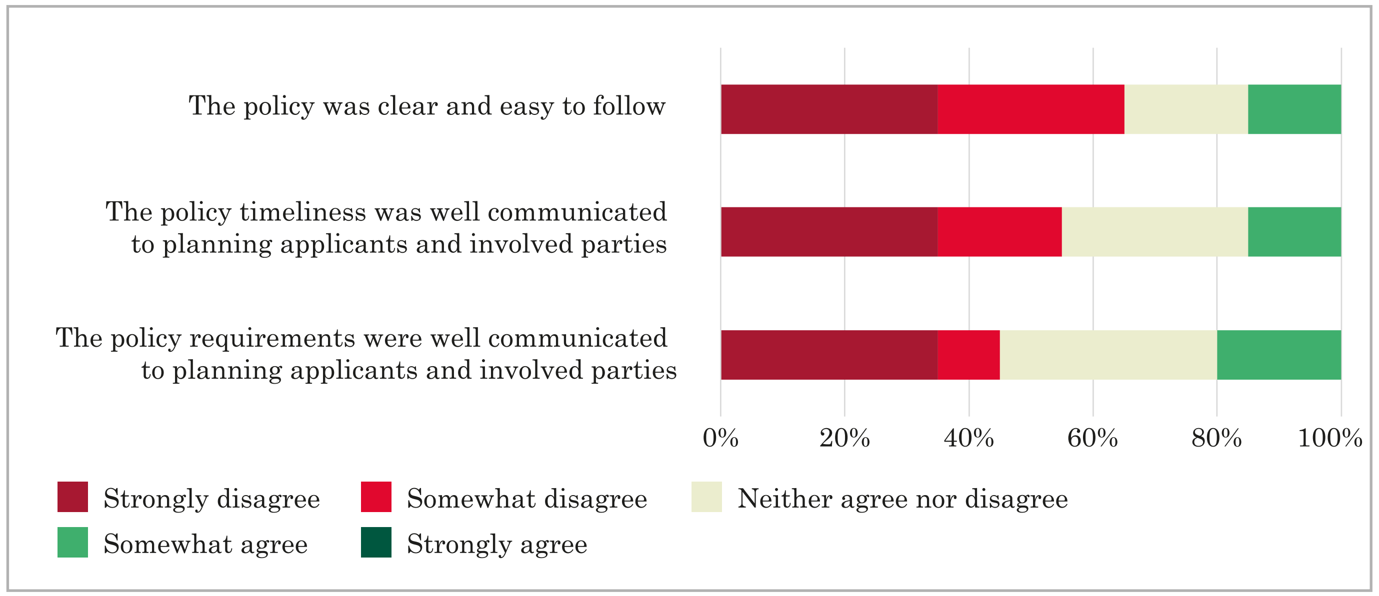
A clear majority (70%) of respondents became aware of the new policies through direct communication from B&NES. For some, this was during the policy consultation phase which began in 2020, whereas for several others, this was only after submitting an initially non-compliant application, indicating variable levels of engagement and a reactive approach from many applicants.

Figure 6 shows the respondents' perception of the new policy's clarity, timeliness and communication, again showing a wide range of opinion, albeit negative overall, particularly regarding clarity. In comments to this question, one respondent remarked that

*Right: Figure 5. Box plot showing perceived competency in fields relevant to sustainable building design. In this plot, the central line inside the box represents the median, the X symbol denotes the mean, and the box edges show the interquartile range. The whiskers extend to the maximum and minimum data points.*

*Below: Figure 6. Questionnaire responses relating to policy communication and clarity.*




the policy is "complicated", "replicates [the] building regs process" and is "unworkable – particularly in projects that don't have detailed construction drawings for planning stage, which they often do not have."

Respondents were asked about their priorities before the new policies, with over half indicating that reducing space heating demand and total energy use were already a 'high' or 'essential' priority (Figure 7), likely due to their inclusion in existing building regulations. Embodied carbon and carbon offsetting had the lowest priority, as well as the widest range between respondents.

Figure 8a shows applicants' perceived level of difficulty in meeting various aspects of the policies, which are generally seen as challenging with an average score of 6.6/10.0. On-site renewable energy was seen as the most difficult, and this is consistent with the analysis of unsuccessful applications (Figure 2). One respondent commented that the significant increase in the PV requirements is likely to have orientation, design, and cost implications.

Figure 8b details the perceived impacts on the design process of the same policy aspects, which averaged 5.6/10.0. The lowest scores were given to space heating, which is likely to be already considered by designers through building regulations, and to carbon offsetting, which only applies to major developments. While one respondent commented that there was "little overall impact as we

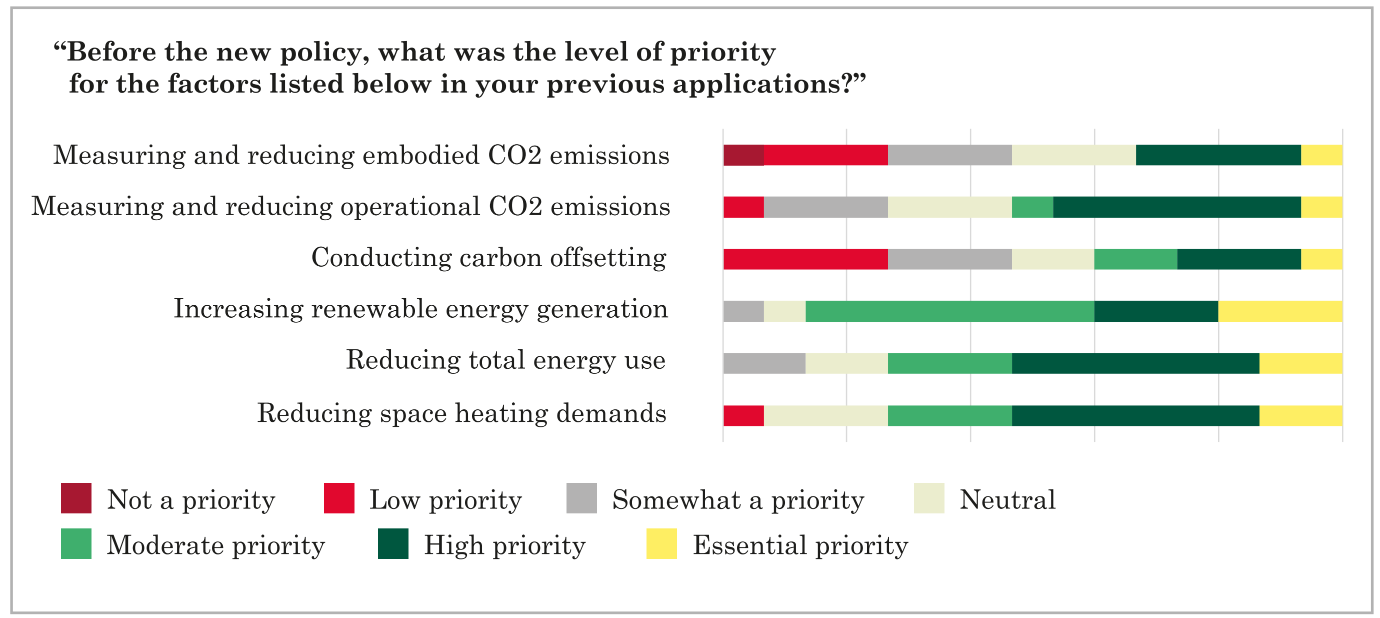



*Figure 7. Questionnaire results relating to design priorities prior to the new policies.*

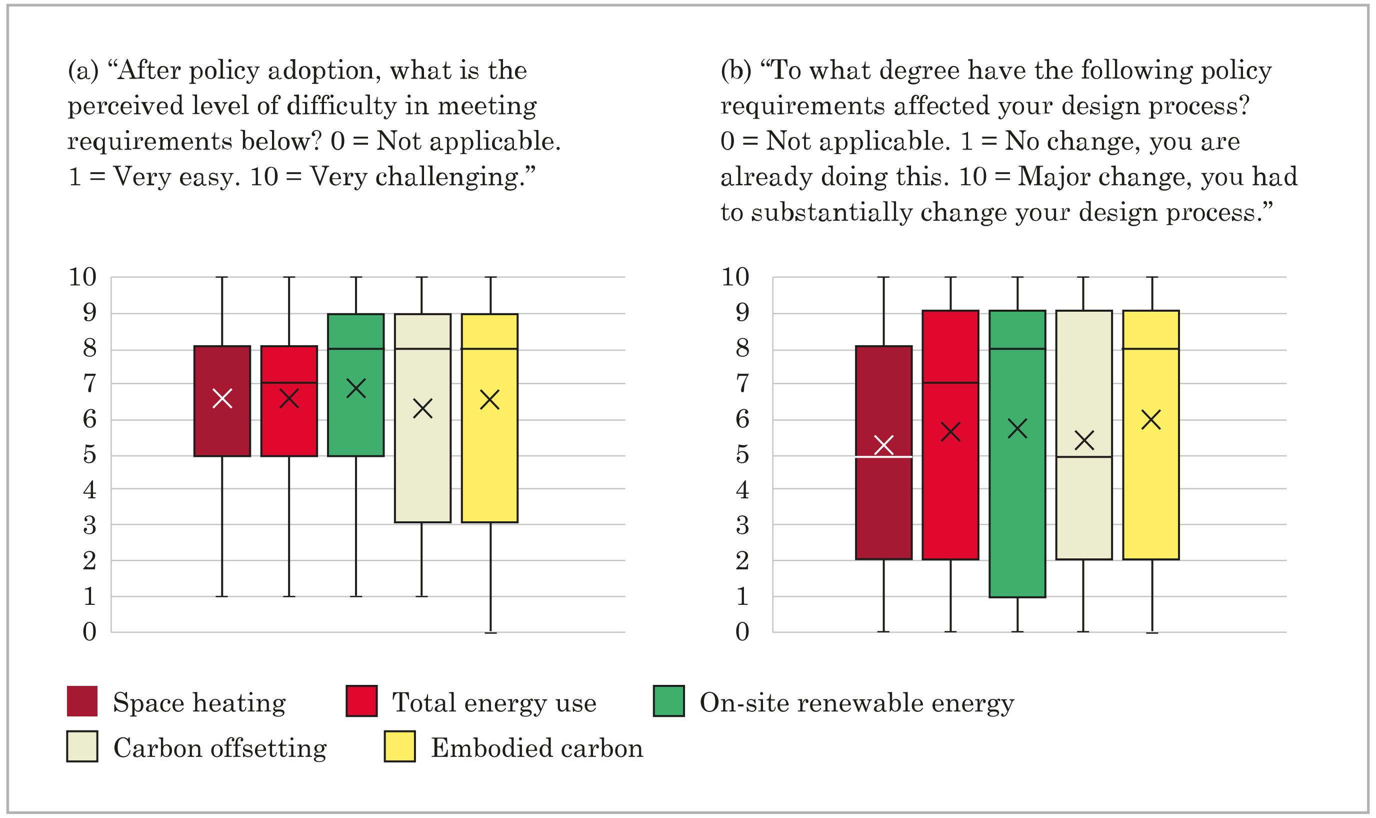



*Figure 8. Questionnaire results exploring a) perceived level of difficulty and b) impacts on design process across various policy aspects.and clarity.*

always try to design with sustainability in mind", others discussed the need to hire additional consultants, and considered the fabric performance targets to be "more or less impossible" or "unaffordable". This large diversity in attitudes was reflected in the wide range of results for this question.

Table 3 summarises responses to a series of questions on assessment methods and expertise. The results indicate an increased demand for Passivhaus certifications, training in PHPP and LCA assessment methods, and demand for external consultants, although this may reflect the bias towards small organisations among the respondents. The issue of cost was commented on regularly, typically referring to construction rather than design, with some concern for the viability of smaller projects.

A wide range of agreement was evident regarding the policy's anticipated impacts, summarised in Figure 9. Respondents gave a balance of positive and negative views on the expected impacts for both developers and the local community, yet there was agreement on the positive environmental impacts, particularly in reducing operational $CO_2$ emissions. There was a strong consensus that planning application costs may increase, yet respondents were positive overall about the broader long-term cost savings.

Finally, respondents were asked to give their overall view on the policy and application process, to provide any further comments and suggest ways to improve the ease of compliance and effectiveness in reducing emissions. Just under half of respondents had a negative overall view of the policy, with others either undecided or positive. Several comments showed concern regarding costs, particularly for smaller developments, which some respondents suggested may become unviable in areas with lower returns. One respondent proposed "proportional targets for both operational and embodied carbon, relative to the scale of the development". The high risk of air tightness performance levels not being met in construction was raised, leading to late-stage planning condition failures which may be costly to remedy. Specifically, it was noted that "Air Permeability at 3 [$m^3/(m^2hr)$ at 50

**Table 3. Questionnaire responses concerning respondents' expertise and assessment methods.**

| Question | Yes | No | Other | Comments |
|---|---|---|---|---|
| Did the project team already have the existing technical expertise to meet the new planning requirements? If not, how was this addressed e.g. training, hiring, external consultants? | 4 | 3 | 8 | Six respondents stated that external consultants were already being used for sustainability/energy assessments, whilst two indicated that new consultants are required |
| Before policy adoption, were alternative certifications such as Passivhaus considered? | 5 | 8 | 2 | Five respondents commented that cost was the principal reason not to implement voluntary schemes |
| Following policy adoption, have alternative certifications such as Passivhaus been considered? | 6 | 7 | 2 | Again, several respondents discussed cost as a key driver |
| Following policy adoption, have you considered new energy, environmental, and sustainability assessment tools? If so, please briefly summarise. | 3 | 6 | 6 | Four respondents expected this to be within the remit of external consultants, rather than themselves |

Pa] is currently a figure I see in less than 1% of all new builds I assess". Another respondent was concerned that the focus on operational carbon in policy SCR6 "risk[s] larger increases of embodied carbon that aren't being factored in".

The application process itself was seen negatively by around two-thirds of respondents, all of whom will have gone through an unfamiliar process for the first time. One frequent concern was the increased level of information required at planning application stage, and that "the rate fee expenditure for clients at risk before applications are determined is perhaps disproportionate for minor development". One suggestion was for a "staged process", while another respondent proposed using existing standards. One applicant also expressed doubt about the council's ability to rigorously check the models.

Despite evident concerns, there were several positive comments about the policy, which was described as "positive in principle" and "well intended", with one respondent saying that "we welcome policy that places more emphasis on environmental performance". This shows an understanding about the need to improve sustainability in construction, and an openness to changing practices to achieve this.

### 3.3 Discussion

This study highlights several technical aspects of the net zero energy policy which may be critical in determining its viability and effectiveness. Solar PV was the only renewable energy technology proposed in any application, but concerns were raised both in our analysis and the questionnaire about the potential difficulty in supplying adequate generation, particularly for unfavourable housing geometries or site aspects. This may require flexibility in the policies' application, albeit in a consistent manner. Improved air tightness is also key to minimising energy consumption. While demonstrably achievable, designing, constructing and verifying performance to these levels represents a significant shift from business-as-usual in UK housing, and risks jeopardising the policies' effectiveness if not achieved. Furthermore, as buildings become ever more reliant on an increasingly renewables-dominated electricity grid, energy storage (electrical or thermal) will become more important. This is one way in which a building-by-building approach is limited, and must be coordinated with local, regional and national energy strategies.

In terms of the policy implementation, this study highlighted a widespread lack of awareness through the first six months after adoption, although this can be expected to improve over time. More generally, there is a need for new skills and knowledge among many designers and developers, as well as within local authorities themselves to verify and scrutinise applications, and to provide constructive feedback. With considerable financial pressures, there are opportunities to streamline these processes through both conventional training and support materials, and potentially by harnessing advanced computation and machine learning. Increased costs were a commonly raised concern, in both the early pre-planning design stage and in construction. Notably, no respondents implied that additional costs might be offset by an increased value of the finished building from improved sustainability and efficiency.

The primary objective of the policies is emission reduction, and despite both clear evidence of enhanced ambition in building design and performance, and a perception that this will be achieved, this remains untested at this early stage. Impacts on real emissions will only emerge over a longer period as the buildings are designed in detail, constructed, and occupied.

### 4 Conclusions and recommendations

This paper has detailed a collaboration between researchers at the University of Bath, B&NES, and local stakeholders which investigated the impacts of pioneering sustainable building planning policies during the first months of their implementation. Through analysis of eligible planning applications and a questionnaire, which primarily covered small residential developments, several conclusions were made:

- Around half of eligible planning submissions were non-compliant, primarily due to a lack of policy awareness by practitioners working on small residential projects. Where a valid approach was taken, it appears that providing sufficient renewable generation is the most technically challenging requirement to meet.
- Compliant applications promise buildings with significantly improved efficiency compared to current regulations, although whether this is achieved in practice remains uncertain and potentially difficult to verify.
- Applicants noted that the policies represent a significant departure from business-as-usual and raised concerns about cost uplift and skills shortages. However, there was general agreement that policies will be effective in reducing emissions, as well as support for the policies' intentions, attitudes which might be harnessed to support smooth and effective implementation.

This short-term study represents the beginning not only of B&NES' policies, but also of greater ambition, monitoring and regulation in emissions reduction across the UK, with both local and national policies developing quickly. There are several opportunities for further projects, which might:

- Expand the study temporally, to determine how policy responses are evolving, and to determine whether the performance claims made at planning stage are realised through design development, construction and occupation, thus enabling the real emission reductions to be measured and tracked.

- Expand the study geographically to include other local authorities with similar policies, capturing a greater number and variety of proposed building developments, facilitating knowledge-sharing and enabling a comparison between differing approaches.
- Bring in a wider diversity of expertise, such as social scientists, innovation experts and policy researchers, to add to the technical nature of the current work and evaluate practitioners' responses in greater depth.
- Comprehensively review the current state of sustainability-driven local planning policies across the UK, of which many exist at various stages of development.
- Review the construction policy with respect to Local Area Energy Planning (LEAP), which will be significantly influenced by the energy characteristics of buildings (UK Parliament, 2022).
- Produce guidance tailored to specific stakeholders, with exemplary designs demonstrating routes to compliance, and ensure information is widely and clearly disseminated.
- Explore technology-led opportunities to enhance and streamline policy enforcement.

This project represents a successful local partnership between academics and policymakers, bringing numerous co-benefits for each. For researchers, working closely with local authorities represents a direct pathway to research impact, as well as a means of accessing original and unique datasets. For local authorities, it provides specific and world-leading expertise and the opportunity for deep analysis. As always, funding is key to unlocking this, but this project shows that small grants can be leveraged into meaningful outputs and lasting collaborations over short periods of time. In this case, pre-existing networks were key to the project's initiation and team formation, demonstrating the importance of maintaining links outside specific projects. More generally, the project reveals the potential for symbiosis between researchers and policymakers, where a university's expertise can support policy implementation, and data gathered through policy implementation can produce novel and impactful research.

## Acknowledgements

The authors would like to thank all project partners, including the University of Bath, B&NES, Chapter 2 Architects, the South West Net Zero Hub and Bioregional. Our sincere thanks also goes to all the questionnaire respondents for their valuable time and insight.

## References

Bath & North East Somerset Council, 2023. Planning Obligations Supplementary Planning Document. [Online] Available at: https://beta.bathnes.gov.uk/sites/default/files/2023-01/PlanningObligationsSPDJan2023%28accessible%29.pdf

Bath & North East Somerset Council, 2023. Sustainable Construction Checklist: Supplementary Planning Document. [Online] Available at: https://beta.bathnes.gov.uk/policy-and-documents-library/sustainable-construction-checklist

Bristol City Council, 2022. Bristol Local Plan Review: Draft Policies and Development Allocations. [Online] Available at: https://www.bristol.gov.uk/residents/planning-and-building-regulations/planning-policy-and-guidance/local-plan/local-plan-review[Accessed September 2023].

BSI, 2011. BS EN 15978:2011 Sustainability of construction works.. s.l.:British Standards Institution.

Central Lincolnshire Local Plan Team, 2023. Central Lincolnshire Local Plan. [Online] Available at: https://www.n-kesteven.gov.uk/central-lincolnshire [Accessed September 2023].

Cornwall Council, 2023. Climate Emergency Development Plan Document. [Online] Available at: https://www.cornwall.gov.uk/planning-and-building-control/planning-policy/adopted-plans/climate-emergency-development-plan-document/ [Accessed September 2023].

Giesekam, J., 2022. Written Evidence submitted to Building to net zero: costing carbon in construction. [Online] Available at: https://committees.parliament.uk/writtenevidence/36116/html/ [Accessed July 2023].

Greater Cambridge Shared Planning, n.d. Policy CC/NZ: Net zero carbon new buildings. [Online] Available at: https://consultations.greatercambridgeplanning.org/greater-cambridge-local-plan-first-proposals/explore-theme/climate-change/policy-ccnz-net-zero [Accessed September 2023].

Hawkins, W. et al., n.d. Dataset for "Pioneering Net Zero Carbon Construction Policy in Bath & North East Somerset. [Online] Available at: https://researchdata.bath.ac.uk/id/eprint/1318

HM Government, 2023. Conservation of fuel an dpower: Approved Document L. [Online] Available at: https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l [Accessed 2024].

HM Government, 2023. Approved Document L: Conservation of Fuel and Power. Volume 1: Dwellings.. [Online] Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133079/Approved_Document_L__Conservation_of_fuel_and_power__Volume_1_Dwellings__2021_edition_incorporating_2023_amendments.pdf

Koch, C., 2015. PassReg SAP-PHPP review Gap and feasibility analysis. [Online] Available at: https://passregsos.passiv.de/images/c/cc/PassREg_SAP-PHPP_Project_Report.pdf [Accessed 26 July 2023].

Ministry of Housing, Communities & Local Government, 2019. The Future Homes Standard: changes to Part L and Part F of the Building Regulations for new dwellings. [Online] Available at: https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings [Accessed September 2023].

Moutzouri, E., 2011. Comparison between PHPP and SAP & Elaboration of monitored data for two dwellings with different insulation levels. MSc Thesis: University of Strathclyde.

North Somerset Council, 2021. Creating Sustainable Buildings and Places in North Somerset: Guidance for energy efficiency, renewable energy use and the transition towards zero carbon development. [Online] Available at: https://n-somerset.gov.uk/my-services/planning-building-control/planning-policy/our-local-plan/local-plan-2039 [Accessed September 2023].

Office for National Statistics, 2020. Household projections for England: 2018-based. [Online] Available at: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/householdprojectionsforengland/2018based#change-in-number-of-households [Accessed July 2023].

Passivhaus Trust, n.d. Two approaches, one goal. [Online] Available at: https://www.passivhaustrust.org.uk/news/detail/?nId=906 [Accessed July 2023].

PassREg, n.d. Comparison of PHPP with SAP 2012 (UK). [Online] Available at: https://passregsos.passiv.de/wiki/Comparison_of_PHPP_with_SAP_2012_(UK).html [Accessed 26 July 2023].

RICS, 2023. Whole life carbon assessment for the built environment. [Online] Available at: https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/whole-life-carbon-assessment [Accessed January 2024].

Ritchie, H., Rosado, P. & Roser, M., 2020. Emissions by sector: where do greenhouse gases come from?. [Online] Available at: https://ourworldindata.org/emissions-by-sector [Accessed January 2024].

Schnieders, J. & Hermelink, A., 2006. CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building. Energy Policy, 34(2).

Simaitis, J. et al., 2023. Pioneering Net Zero Carbon Construction Policy in Bath & North East Somerset, s.l.: University of Bath.

UK Green Building Council, 2021. Net Zero Whole Life Carbon Roadmap: Technical Report. [Online] Available at: https://ukgbc.org/wp-content/uploads/2021/11/UKGBC-Whole-Life-Carbon-Roadmap-Technical-Report.pdf

UK Parliament, 2022. Carbon Emissions (Buildings) Bill. [Online] Available at: bills.parliament.uk/bills/3107



# Empowering communities to drive transition to net zero carbon

Wrexham University

David Sprake, Alec Shepley, Daniel Knox, Tracy Simpson, Karen Heald, Shafiul Monir, Yuriy Vagapov and Cerys Alonso

**Abstract**

This paper explores two case studies conducted by Wrexham University emphasising its part in the journey towards a sustainable future, and its community and business engagement amid global environmental challenges. Using a mix of qualitative and quantitative methods, the study examines the university's initiatives, including decarbonisation research, industry collaboration, climate change education, and a strategic Low Carbon Transition and Delivery Plan. In the context of universities contributing to sustainable development, Wrexham University's civic engagement aligns with the shift towards community-centric approaches. Addressing challenges in adopting sustainable practices, the paper explores how the university navigates complexities in balancing economic, social, and environmental considerations. Two case studies, Ecological Citizens and Large Housing Estates of the Future, provide insights into practical implementation. The Ecological Citizens project, supported by the Engineering & Physical Sciences Research Council (EPSRC), focuses on fostering ecological citizenship through technology and community-centric approaches. The Large Housing Estates of the Future case study explores collaboration with local business to implement sustainable practices. The paper concludes by commending Wrexham University's success in translating research into action and collaborating with industry. It stresses the need for continuous evaluation and adaptation to sustain positive impacts. Wrexham University's experience serves as a case study for institutions aligning with global sustainability goals, showcasing the transformative power of collective engagement for a more sustainable future.

Keywords: low-carbon transition; community empowerment; industry collaboration; ecological citizenship; sustainable development

---

**Introduction**

In the face of escalating environmental challenges and the imperative for sustainable development, institutions of higher education are increasingly called upon to take a leadership role in fostering societal change (Sen et al., 2022). This paper explores two case studies demonstrating part of the transformative journey undertaken by Wrexham University, as it aligns its mission with the global necessity for a low-carbon future. In particular, the focus is on the university's commitment to empowering local communities through a comprehensive strategy for sustainable development. As the world grapples with the pressing need to achieve net-zero emissions to help mitigate climate change, Wrexham University is committed to innovation and civic engagement, exemplifying how academic institutions can serve as catalysts for positive environmental change while actively involving the communities they serve. This paper explores the multifaceted dimensions of Wrexham University's approach, encompassing not only technological advancements and infrastructural improvements but also the integration of a civic mission that seeks to inspire a sense of shared responsibility for achieving a sustainable and resilient future.

The imperative to address climate change and achieve a sustainable, low-carbon future has become a driving force for socially responsible institutions worldwide, compelling them to integrate environmentally conscious practices into their core missions (Kourgiozou et al., 2021). Wrexham University's commitment to this cause stands within a broader context shaped by the convergence of global environmental challenges and the recognition of academia's pivotal role in fostering change. The role of universities as agents of sustainable development has gained prominence in scholarly discourse. Scholars such as Filho et al. (2019) highlight the potential for higher education institutions to contribute not only through research and innovation but also by instilling sustainability values in students, faculty, and the broader community. Wrexham University's journey towards a low-carbon future can be understood within this framework, emphasising the interconnectedness of academic institutions and sustainable development.

A critical aspect of Wrexham University's approach lies in its commitment to civic engagement. Research by Chawla and Cushing (2007) underscores the importance of fostering a sense of environmental responsibility within communities through active participation. By involving local stakeholders, Wrexham University's initiative transcends traditional academic boundaries, aligning with the civic mission towards a shared goal of net-zero emissions. Acknowledging the challenges faced by academic institutions in adopting sustainable practices is crucial for understanding the nuances of Wrexham University's journey. Insights from scholars like Lozano et al. (2017) shed light on the complexities of balancing economic, social, and environmental considerations in institutional decision-making. Examining how Wrexham University navigates these challenges provides valuable insights for other institutions seeking to embark on similar paths.

Wrexham University's emphasis on community empowerment aligns with the growing recognition of community-centric approaches in sustainable development. Research by Reed et al. (2009) emphasises the importance of local engagement and participatory processes in achieving sustainability goals. Wrexham University's integration of community-focused initiatives reflects a holistic approach that extends beyond campus boundaries. Wrexham University's journey serves as a compelling case study within this broader context, providing insights into the practical implementation of strategies for low-carbon transition and civic mission towards achieving net-zero emissions, and we present two case studies in this paper to illustrate how we support our communities in their journey to net zero.

## Methodology

Within the broader context of Wrexham University's journey towards a low-carbon transition and civic mission for achieving net-zero emissions, two distinct case studies are chosen. Both have a strong local dimension and involve working in partnership: Ecological Citizens and Large Housing Estates of the Future. These case studies encapsulate specific initiatives that showcase the university's commitment to sustainability, community engagement, and innovative solutions. By examining these cases, we gain deeper insights into the practical implementation and impact of Wrexham University's strategies in fostering a low-carbon future.

## Case study 1: Ecological Citizens

The Ecological Citizen(s) (Ecological Citizens, 2023) project spans a four-year duration and is situated at the Royal College of Art in collaboration with the Stockholm Environment Institute at the University of York and Wrexham University. The primary objective is to cultivate and actively promote Ecological Citizenship through technologically apt interventions, with a focus on empowering individuals and communities to take positive climate action.

Phillips et al. (2023), suggest that humanity faces serious challenges in the coming decades: climate change, biodiversity loss, growing inequality, and more. We have a collection of rules and norms that reward some behaviours and punish others. In their current form, our systems seem to incentivise overconsumption, degrade communal bonds, and destroy natural wealth. By uniting a diverse team of experts in design, science, and technology, the initiative known as 'Ecological Citizens: Tools, Technologies, and Means to Enable Sustainable Citizens' is framed to confront the ecological and climate crisis. Leveraging the digital economy, the project aims to instigate sustainable change that transcends individual actions. Functioning as a research network, Ecological Citizens seeks to mobilise varied communities, utilising accessible technology and community-centric approaches such as:

- Citizen Science
- Activism
- Collective Learning
- Advocacy
- Design Strategies
- Manufacturing
- Environmental Science
- Engineering Practices

By fostering collaboration, the network aspires to address a spectrum of urgent issues, ranging from biomaterials and wildlife corridors to local manufacturing and repair. Drawing upon the expertise of diverse partners, including the Royal College of Art and collaborators from academia, business, and civil society, the network is poised to deliver impactful solutions for generations to come.

*Ecological Citizenship: Rethinking Play Spaces for Sustainable Communities*

In an era emphasising the importance of environmental sustainability, the concept of Ecological Citizenship has gained increasing relevance (Knox, 2023). The role of individuals as citizens in their communities extends beyond mere coexistence with nature; it entails active contributions to the well-being of the environment. The image presented depicts an old children's play area being replaced by a less eco-friendly structure along the banks of the river Dee part of our region, just outside Wrexham and forming the boundary between North-East Wales and West Cheshire in England. This illustration encapsulates the essence of Ecological Citizenship, urging individuals to reassess their responsibilities as stewards of the Earth.

In urging individuals to reflect on the decisions made in their daily lives and their consequential impact on the environment, the scenario prompts a critical examination.

*Figure 1. The replacement of the old play area (Knox, 2023).*

Specifically, the replacement of the former play area with a structure that is not only costly and maintenance-intensive but also less environmentally friendly raises pertinent questions. The inquiry extends to the broader consideration of whether the choices being made align with principles of sustainability and if they contribute to instilling values of resilience and responsible environmental stewardship in future generations. It encourages contemplation on the design aspects of areas like the one depicted in Figure 1.

Children's play areas serve as more than mere recreational spaces; they present valuable opportunities to instil ecological and sustainable values from an early age. Illustrating this concept, the play area adjacent to the river Dee, surrounded by flourishing wildlife, signifies a harmonious coexistence between human activity and nature. This riverbank locale and its surroundings hold the potential to function as an outdoor classroom, facilitating experiential learning for both children and citizens, forging a profound connection with the natural world.

However, the replacement of this idyllic scene with a sleek, metallic play area raises ecological concerns. The elevated environmental cost associated with producing and maintaining such structures, coupled with potential limitations in accessibility for children of diverse abilities, calls for critical assessment. Responsible Ecological Citizens recognise the need to comprehend how decisions regarding the redesign and repurposing of play areas impact both the community and the environment. Striking a balance between fun, engagement, and proactive change is essential, fostering a profound connection with nature and the environment.

Central to the promotion of Ecological Citizenship is the thoughtful design of products and spaces. Prioritising eco-friendly materials and considering the long-term environmental repercussions of structures and investments is imperative. Rather than opting for flashy alternatives, a more sustainable approach involves revitalising existing spaces. For instance, designing the play area with recycled or repurposed materials, incorporating educational elements about the local ecosystem, and emphasising sustainability can pique children's interest in preserving and extending the environment. Community gardens, allotments, wildflower meadows, and bug hotels exemplify ways to optimise such spaces.

Furthermore, ensuring the accessibility of play areas to children of all abilities contributes to an inclusive connection with nature. Choices, whether substantial or trivial, resonate with environmental consequences, impacting future generations. Striving for thoughtful, sustainable, and inclusive design in play spaces becomes imperative, envisioning them as opportunities to instigate resilience and cultivate active Ecological Citizenship.

### Case study 2: Large Housing Estates of the Future Powered by Renewable Energy

The Large Housing Estates of the Future case study delves into Wrexham University's collaboration with local authorities, developers, and residents to envision and implement sustainable practices within future and current large housing estates. This initiative seeks to integrate cutting-edge technologies, energy-efficient infrastructure, and community engagement strategies to transform traditional housing developments into eco-friendly, resilient, and socially inclusive spaces. By examining this case study, we gain insights into the complexities of large-scale urban development and the role of academia in driving sustainable solutions for housing, energy, and community well-being.



The UK faces a persistent housing shortage, prompting the government's commitment to an extensive house building initiative. Simultaneously, the nation strives for a 100% reduction in carbon dioxide emissions by 2050 (Boardman, 2007). This commitment involves eliminating primary fossil fuel usage in buildings, integrating zero carbon electric vehicle charging points, and adopting low carbon heating. However, a crucial challenge remains: how can future housing developments be constructed and operated with net zero carbon emissions? An energy model was created to simulate energy usage and energy production from various renewable sources, making use of 40 years' worth of hourly metalogical (Wind and Solar) data.

Original PhD research carried out was to identify an optimal solution utilising current technology with a case study to design a low-carbon viable, operational housing estates energy supply. The aim was to create a model that housing developers are willing to build, homeowners are eager to buy, and urban planners fully support. The energy model applied for a test housing estate (1,000 houses) analysis is shown in Figure 2.

This research stands out for its innovative approach, employing novel methods to achieve objectives. It combines multidisciplinary fields such as the built environment, renewable energy production, economics, social housing issues, EV charging requirements, and energy and storage modelling. These considerations are synthesised through a unique algorithm to obtain an optimum, desirable overall solution.

The findings reveal that, with an approximate 5-7 % increase in the average property price, the optimal solution provides homeowners with unlimited energy and complimentary electric car charging for life, at no

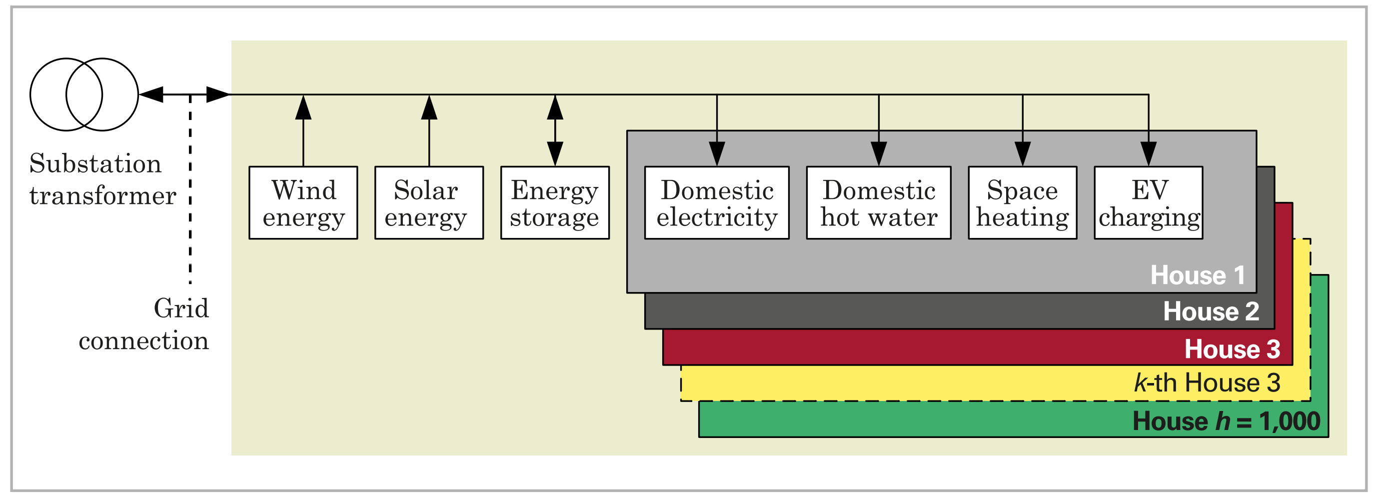



*Figure 2. Energy model architecture (Sprake, 2023).*

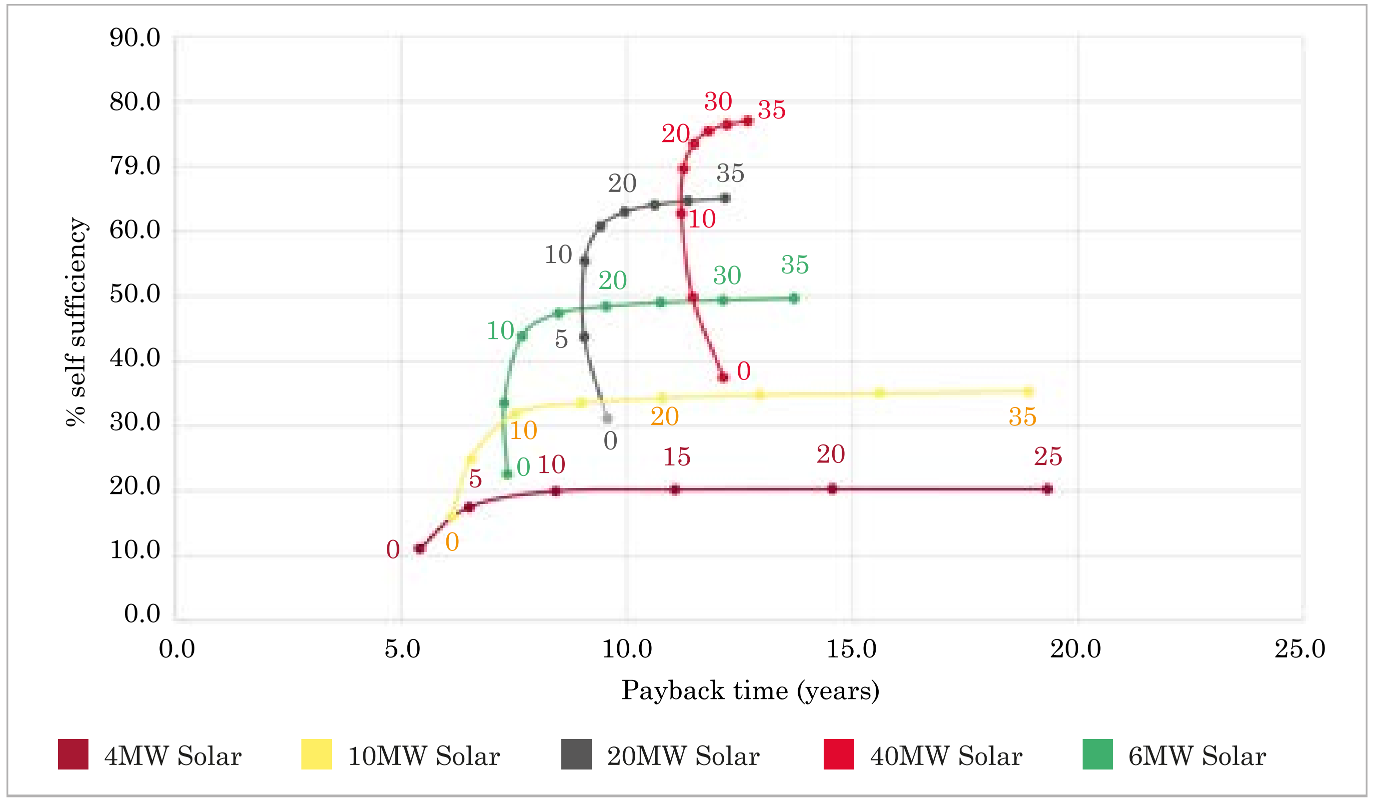



*Figure 3. Example analysis 1,000 houses result graph to show simple solar energy payback times vs system self-sufficiency from the national grid, at different levels of energy storage. Part L of UK building regulations insulation levels (Sprake, 2023).*

cost, paid for by excess energy sold back to the grid. Additionally, generated income by selling energy back to the grid covers the running and maintenance of the system, and additionally (with some systems) an income for each homeowner of the developer. An example of the analysis results is shown in Figure 3 above. Adopting a 'community' energy business structure enhances community creation, aligning with national grid goals to decarbonise and decentralise the national grid. The findings contribute valuable insights to the existing knowledge base, and the methodology and findings are being taught to engineering undergraduates on relevant programmes.

*Knowledge Transfer Partnership: ClwydAlyn Housing Association*

As part of a strategic collaboration aimed at advancing sustainable practices in large-scale housing developments, Wrexham University has entered a Knowledge Transfer Partnership (KTP) with ClwydAlyn Housing




*Figure 4. Devolvement of approximately 250 affordable homes in Acrefair (10 miles from Wrexham University) (Sheehan, 2013).*

Association. ClwydAlyn Housing Association is a registered social landlord managing over 6,200 homes in North and Mid-Wales. With around 750 staff, it provides housing management services. This partnership holds particular significance in the context of ClwydAlyn Housing Association's development to construct a 250-house estate near Wrexham (Figure 4). The foundation of this collaborative initiative lies in the research conducted under the project titled "Large Housing Estates of the Future: The Use of Smart Grids, Renewables, and Storage to Meet 2050 Carbon Reduction Targets."

The research, led by the author, addresses the pressing challenge of achieving carbon reduction targets within the housing sector. In response to the UK government's commitment to achieving a 100% reduction in carbon dioxide emissions by 2050, this initiative explores innovative approaches to design low-carbon and operationally sustainable energy supplies for housing estates. The integration of smart grids, variable renewable energy sources, and energy storage solutions stands at the forefront of this research, aligning with the broader national goals of transitioning to cleaner and more efficient energy systems.

Through the Knowledge Transfer Partnership, the research outcomes and insights gained from the Large Housing Estates of the Future project are directly applied to the real-world scenario of ClwydAlyn Housing Association's housing development, and the model and methodology can be used for any future housing estate construction or business. This collaborative effort aims to bridge the gap between academic knowledge and practical implementation, fostering a seamless transfer of expertise and innovations from the university to the housing association.

ClwydAlyn Housing Association's commitment to incorporating these research findings into the construction of the 250-house estate (Figure 4) reflects a proactive approach toward sustainable development. By embracing smart grids, renewable energy sources, and energy storage solutions, the housing association is positioned to contribute substantially to the reduction of carbon emissions in line with national targets.

This collaboration underscores the practical application of academic research in addressing real-world challenges, showcasing the potential for collaborative efforts between academia and industry to drive positive environmental change in the construction and operation of large housing estates.

## Conclusion

The two case studies are intended to demonstrate two very different aspects of the development scale, case study 2 (Large Housing Estates of the Future) being practical and actioned in the real world, and the other (Ecological Citizens) in its embryonic phase, where real-world developments and projects will likely emerge and be replicable as the project evolves. In conclusion, the research has revealed that Wrexham University has not only embraced its role as a knowledge hub but has actively translated research into tangible actions, collaborating with industry partners to develop and implement innovative solutions for a sustainable future. In examining the dual case studies, a common thread of commitment to environmental sustainability and responsible citizenship emerges. These case studies underscore the imperative for individuals, communities, and organisations to actively contribute to the wellbeing of the environment, aligning with the ethos of ecological citizenship. The emphasis on decarbonisation research underscores the institution's commitment to advancing the frontiers of knowledge while directly contributing to the global imperative for carbon reduction.

Within the first case study, Play Spaces for Sustainable Communities considers the critical evaluation of play spaces as more than just recreational areas, emphasising their role in instilling ecological values from an early age. The replacement of the play area next to the river Dee, with a less sustainable structure prompts questions about the choices made in designing public spaces. Thoughtful design, the use of eco-friendly materials, and inclusivity in play space design are recommended as essential elements in fostering active ecological citizenship. The case study urges a reflection on the broader implications of such decisions on future generations and the environment.

In parallel, the second case study highlights the collaborative efforts between academia and industry in the form of a Knowledge Transfer Partnership. The partnership between Wrexham University and ClwydAlyn Housing Association exemplifies the practical application of research insights to address real-world challenges in large-scale housing developments. By incorporating smart grid energy modelling, renewable energy sources, energy storage solutions, ClwydAlyn demonstrates a proactive commitment to sustainable development, aligning with national carbon reduction targets. This collaborative model showcases the potential for academia-industry partnerships to drive positive environmental change in housing construction and operation which can be replicated in other arenas.

In conclusion, these case studies collectively advocate for a paradigm shift towards ecological citizenship and sustainable practices. Whether in the redesign of play spaces or the construction of large housing estates, responsible decision-making, thoughtful design and the application of research outcomes are pivotal. By fostering a deep connection with the natural world, encouraging inclusivity, and bridging the gap between academic knowledge and practical implementation, these case studies provide valuable insights into creating resilient, sustainable communities. They serve as beacons guiding individuals, communities, and organisations towards a future where environmental stewardship is a shared responsibility, and sustainable practices are embedded in the fabric of our society.

## References


Boardman, B. (2007) Home truths: A low-carbon strategy to reduce UK housing emissions by 80% by 2050. Oxford: University of Oxford, Environmental Change Institute.

Chawla, L. and Cushing, D. F. (2007) Education for strategic environmental behaviour, Environmental Education Research, 13(4), pp. 437–452, https://doi.org/10.1080/13504620701581539

da Silva, L.A., de Aguiar Dutra, A.R., and de Andrade Guerra, J.B.S.O. (2023) Decarbonization in higher education institutions as a way to achieve a green campus: A literature review, Sustainability, 15(5), article number 4043. https://doi.org/10.3390/su15054043

Ecological Citizens Team. (2023). Ecological Citizens. Retrieved from https://ecologicalcitizens.co.uk/.

Filho, W. L. et al. (2019) The role of planning in implementing sustainable development in a higher education context, Journal of Cleaner Production, 235, pp. 678–687. https://doi.org/10.1016/j.jclepro.2019.06.322

Knox, D. (2023) Ecological citizenship: Rethinking play spaces for sustainable communities, Wrexham University's Blogs. https://wrexham.ac.uk/blog/posts/ecological-citizenship-rethinking-play-spaces-for-sustainable-communities/

Kourgiozou, V. et al. (2021) Scalable pathways to net zero carbon in the UK higher education sector: A systematic review of smart energy systems in university campuses, Renewable and Sustainable Energy Reviews, 147, article number 111234. https://doi.org/10.1016/j.rser.2021.111234

Lozano, R. et al. (2017) Connecting competences and pedagogical approaches for sustainable development in higher education: A literature review and framework proposal, Sustainability, 9(10), article number 1889. https://doi.org/10.3390/su9101889

Phillips, R., West, S., Shapley, A., Baurley, S., Simmons, T., Pickles, N., & Knox, D. (2023). Defining ecological citizenship; Case-studies, projects & perspectives; analysed through a design-led lens, positioning 'preferable future (s)'. Design for Adaptation Cumulus Conference Proceedings Detroit 2022.

Reed, M. S. et al. (2009) Who's in and why? A typology of stakeholder analysis methods for natural resource management, Journal of Environmental Management, 90(5), pp. 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Sen, G. et al. (2022) Achieving sustainability and carbon neutrality in higher education institutions: A review, Sustainability, 14(1), article number 222. https://doi.org/10.3390/su14010222

Sheehan, R. (2013) Proposal for 20+ new homes on former factory site in Acrefair awaits approval, North Wales, 2 November. https://north.wales/news/wrexham/proposal-for-20-new-homes-on-former-factory-site-in-acrefair-awaits-approval-46120.html

Sprake, D. (2023) Large housing estates of the future and the use of smart grids, renewables and storage to meet 2050 carbon reduction targets, PhD Thesis. Wrexham University.

Worsham, M. and Brecha, R.J. (2017) Carbon lock-in: an obstacle in higher education's decarbonization pathways. Journal of Environmental Studies and Sciences, 7, pp. 435–449. https://doi.org/10.1007/s13412-017-0431-z



# Biotechnologies as catalysts for driving net zero

University of South Wales

Sandra Esteves, Savvas Savvas, Rajkumar Gangappa, Ciaran Burns, Angela Oliveira, Adam Henley, Joanne Donnelly, Michael Darke, Viktoria Bendikova, Melanie Johnson, Sathiyanarayanan Ganesan, Tim Patterson (*Wales Centre of Excellence for Anaerobic Digestion, Sustainable Environment Research Centre, University of South Wales*), Sky Redhead and James Reed (*Faculty of Computing, Engineering and Science, University of South Wales*)

**Abstract**

R&D impact delivered by this work extends to policy development and to the benefits derived from delivering circularity, green growth and reducing carbon emissions by anaerobic digestion that (1) recovers a variety of organic wastes and low value biomass and (2) produces bioenergy and fertiliser. Other biotechnologies being developed can recover resources for the production of fuels ($CH_4$, $H_2$ and $NH_3$), chemicals e.g. volatile fatty acids, biopolymers e.g. polyhydroxyalkanoates and single-cell proteins that can be used for animal feed. Biotechnologies delivering solutions for Power to X, for energy storage and for the capture and use of carbon have also been a focus of our research. Monitoring and control methodologies for the biotechnologies have been developed, including the use of analytical technologies such as FT-NIR, GC-IMS and qPCR. Work continues on the valorisation of digestates as microbial and algae growth media, and the recovery of nutrients (NPK). Evaluations of the fate of polymers in the environment, their biochemical recycling and the production of biostimulants for soil and crop improvements, nitrogen fixing and emissions' reduction are all in progress. Technologies are currently across the TRL 3-6 range and require further R&D to progress them to commercialisation. Deploying industrial biotechnologies is essential to act as sustainable catalysts for change and for delivering net zero, circular economy and green growth. Biotechnologies can impact beneficially on the sustainability of cities and benefit their relationship and integration with surrounding rural areas.

## 1 Introduction

The primary role of the Wales Centre of Excellence for Anaerobic Digestion (the Centre) at the University of South Wales (USW) is to undertake collaborative and targeted research projects focused on (i) technical, economic and environmental optimisations of anaerobic digestion plants, (ii) development of new and novel biotechnologies and recovery processes supporting net zero and circular economy, and (iii) the provision of evidence to allow the development and implementation of ambitious policy measures, whether within an individual company, a local authority, or across devolved or central government.

The research work at USW has already driven policy changes and commercial deployment of innovative sustainable waste resource recovery technologies, as well as renewable gas for heat, transport and energy storage in the UK and internationally. For example, by 2021, research led to state-of-the-art anaerobic digestion (AD) infrastructure in seven food waste recovery hubs in Wales and carbon footprint savings of 660 kt $CO_2$e/year, leading to Wales having the third highest municipal recycling rates in the world. The UK deployed 683 AD plants supplying 4.1 TWh of electricity per year, enough to power 1.3 million homes with direct employment of around 10,000 people. UK-based AD industry has cut emissions by approximately 5.1 Mt $CO_2$e/yr, equivalent to 1% of total UK emissions. The research has also been instrumental in enabling EU policy and financial incentive changes that resulted in the delivery of 2.4 billion $m^3$/yr of biomethane for grid and transport use. In the UK and by 2021, the capital expenditure of the biomethane sector had been £1.5bn, with an associated revenue of £450 million per annum and the sector directly employed approximately 1,000 people. Monitoring and control methodologies developed at the university were used by numerous companies to drive sustainability and commercial efficiencies within AD plants. The research continues to support further increases in biomethane production, contributing to the ambitions of, for example, the REpowerEU (aiming for a tenfold increase in biomethane by 2030).

A significant increase in production and use of biomethane in the UK from food wastes, animal slurries, crop residues and algal biomass, and from gases such as $CO_2$ is feasible. But this is only one of the possible bioconversions. R&D has also been directed at developing biotechnologies for the conversion of wastes into fuels such as hydrogen, ammonia and alcohols, volatile fatty acids (VFAs), single cell protein (SCP), polymers, microbial inoculants and biostimulants and phenolic compounds. Biotechnologies could be placed at the heart of other industrial operations, e.g. renewable energy storage, the coupling of the electricity and gas networks and other commodity sectors, and the recycling of metals, nutrients and (bio)plastics. Research at USW across these areas stands at TRLs 3-6, and requires further R&D to reach commercial scale.

## 2 Driving AD deployment in Wales, the UK and the EU

Supporting the deployment of AD technology and future prospects for growth are briefly summarised for Wales, the UK and Europe.

### 2.1 AD legal and policy framework, deployment and future prospects for growth

Policy support for AD in Wales has to date been primarily driven by the need for waste management, with renewable energy production seen as an environmental and commercial added benefit. In support of meeting challenging recycling targets in Wales from 2008 onwards, the Welsh government (WG) recognised the role that AD could play in recycling municipal food waste. Publications such as Monson et al. (2007) and Patterson et al. (2008) supported these evaluations, concluding that AD was preferable to other recovery technologies, and that source segregation of food wastes was critical both to reducing digestate contamination and to improving the quality of dry recyclates.

WG followed with the development of specific policies that encouraged (and mandated) the recycling of waste streams including food waste, as well as discouraging the disposal of municipal food waste to landfill. By setting high recycling targets, providing powers to impose source segregation of recyclable materials (including food waste) and discouraging local authority landfill disposal, this created conditions that were more favourable for the development of alternative recycling technologies than had previously been the case. As legislation was formed, and AD was recognised as the most appropriate technology for treating municipal food waste, WG anticipated bottlenecks in its adoption, recognising that AD would be an unfamiliar technology to many organisations and individuals, and to the planning process at local authority level. WG enabled the provision of information by the USW team to local authorities, planning departments, statutory consultees and the public. WG also instigated other support including waste communication campaigns to raise public awareness; procurement support for AD plants treating municipal food wastes (to which we contributed); sustainable waste management grant funding for sustainable services; funding for separate collection of food wastes; and a blueprint for providing collections of weekly food waste and dry recyclables.

WG oversaw a municipal food waste treatment procurement programme delivering £50 million capital support through public/private partnerships to support local authorities in delivering treatment capacity, to meet EU landfill diversion and statutory national recycling targets. Research by our team concluded that biogas infrastructure options could be delivered on a regional scale via hubs according to Life Cycle Assessment (Patterson et al., 2011a). Where appropriate, local authorities were grouped to form seven-LA Hubs to provide economies of scale and commercially attractive propositions for private sector investment. The scheme delivered the initial 5 AD plants with a treatment capacity of 141k tonnes per year. Alongside this, Welsh Water centralised its AD operations into six AD facilities for recovery of sewage sludge (four plants incorporate thermal hydrolysis and are classed as advanced AD plants (AAD). The Five Fords AD plant, for example, injects biomethane into the gas network. Outside the water sector, there are currently 33 AD plants in Wales: 13 for municipal food and industrial wastes, and 20 being farm based, treating predominantly agricultural residues. Figures for 2023 indicate that there was a total installed electrical generation capacity of over 20 MWe treating over 450,000 t/yr of organic wastes. In Wales, there is still capacity for recovery of commercial/industrial/agricultural wastes.

### 2.2 Deployment of AD in the UK and future prospects for growth

Driven by landfill diversion and renewable energy generation, AD has seen a significant increase in deployment across the UK since 2009, for the recovery of municipal, industrial and agricultural organic wastes. Areas of support which had a positive effect in the uptake of the AD technology related to renewable energy incentives, establishing standard environmental permits and the development of the QP/PAS110. According to the Anaerobic Digestion and Bioresource Association (ADBA), there were a total of 723 AD plants in 2023, including the ones treating sewage sludge, with a generation capacity of 584 MWe and 103,174 $m^3$ of biomethane/hr from 133 biomethane facilities (see Table 1). According to Wales & West Utilities (WWU), in 2022 there were over 100 plants across the UK with capacity to produce enough biomethane to heat over 770,000 homes each year, saving around 1.2 million tonnes of carbon. A map of the biogas/biomethane plants in the UK can be found at https://www.google.com/maps/d/u/2/viewer?mid=1Cmjo3Jh0q70T-2p5IPFCW3xWPqT6ekUM&ll=55.942253942228874%2C6.421686505749507&z=4.

**Table 1. UK AD plants and energy-generating capacities (ADBA, 2023).**

| Type of plant* | No. of operational plants | Capacity of operational plants |
|---|---|---|
| **Excluding sewage plants** | | |
| Electricity/CHP | 427 | 497 MWe |
| Heat-only | 6 | 0.4 MWth |
| Biomethane | 120 | 91,175 $m^3$/hr |
| **Total** | **553** | **2,156 MW** |
| **Sewage sludge plants** | | |
| Sewage sludge CHP ** | 157 | 215 MWe |
| Biomethane sewage | 13 | 11,999 $m^3$/hr |
| **Total** | **170** | **659 MW** |
| **Total (all sectors)** | | |
| Electricity/CHP | 584 | 713 MWe |
| Heat-only | 6 | 0.4 MWth |
| Biomethane | 133 | 103,174 $m^3$/hr |
| **Total** | **723** | **2,814 MW** |

* Electricity / heat / biomethane
** Number of plants does not include CHPs on biomethane sites

ADBA established the potential for energy recovery by 2025 if wider available resources and $CO_2$ from biogas were utilised, and higher efficiencies supported by R&D achieved, i.e. up to 35% of domestic gas demand.

**Table 2. AD feedstocks and energy potential by 2025, "high" potential scenario (ADBA, 2020).**

| Feedstock type | TWh usable energy* | Usable energy after R&D* |
|---|---|---|
| Household food waste | 4 | 5 |
| C&I food waste | 5 | 6 |
| Farm animal wastes and bedding | 8 | 9 |
| Crops | 12 | 17 |
| Sewage sludge | 5 | 5 |
| Other potential sources | 2 | |
| Nature conservation managed | | 0.4 |
| Straw | | 3 |
| Uncontaminated organic street sweeping (e.g. leaves) and park waste (e.g. grass cuttings, leaves).** | | 3 |
| Household garden waste (e.g. grass cuttings, leaves) | | 3 |
| Orchard waste (e.g. apple pomace) | | 1 |
| AD integrated into greenhouse horticulture with waste heat, $CO_2$ use | | 2 |
| Glycerol, dependent on biodiesel industry | | 0.5 |
| Fish processing waste, conventional sources | | 0.5 |
| Higher value food production integration, such as hydraponics, aquaponics and aquaculture (overlap with greenhouses) | | 2 |
| Microalgae (e.g. using nutrients from sewage sludge, digestate etc. and waste heat, $CO_2$ and water from AD plants. Also potential to use grid electricity. | | 4 |
| Macroalgae (seaweed etc.) | | 1 |
| Power to gas via hydrogen with AD | | 31.8 |
| **Total** | **35.4** | **95.3** |
| Domestic gas demand | 300 | 270 |
| **Percent of domestic gas demand** | **12%** | **35%** |

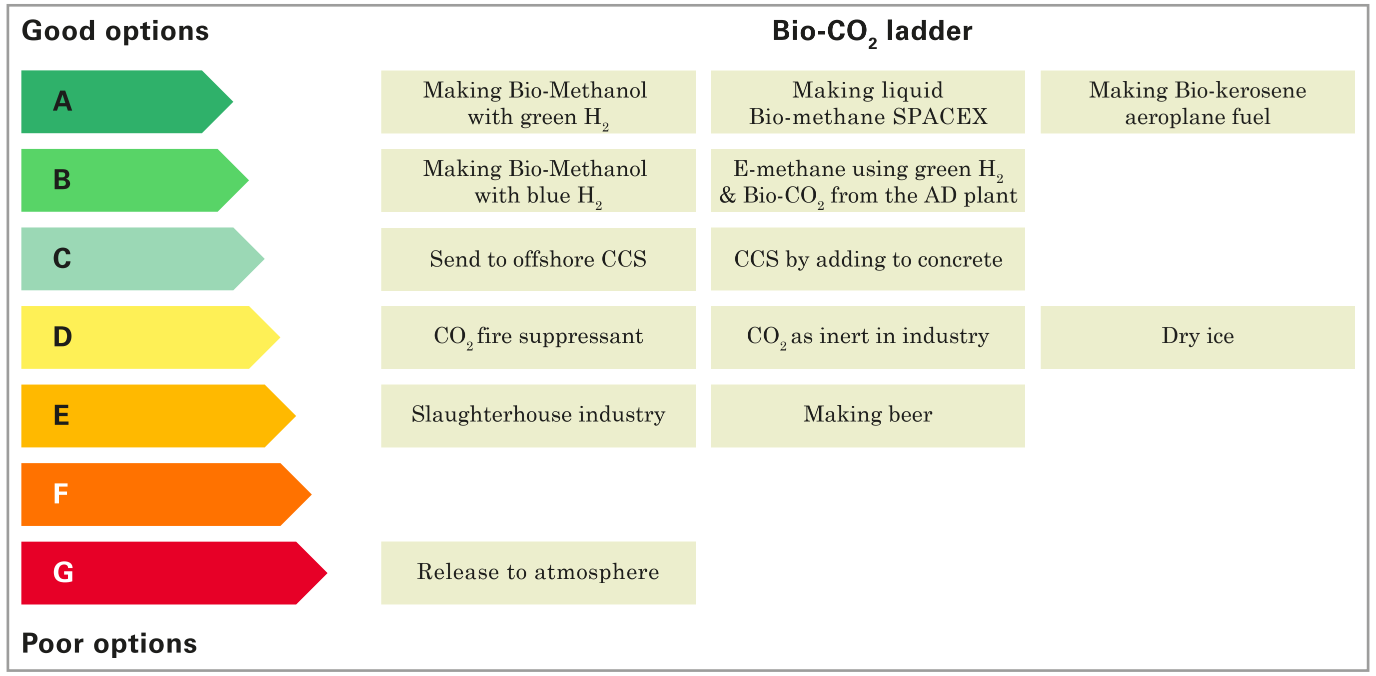
* After 10% parasitic ** Pre-treatment, dry AD

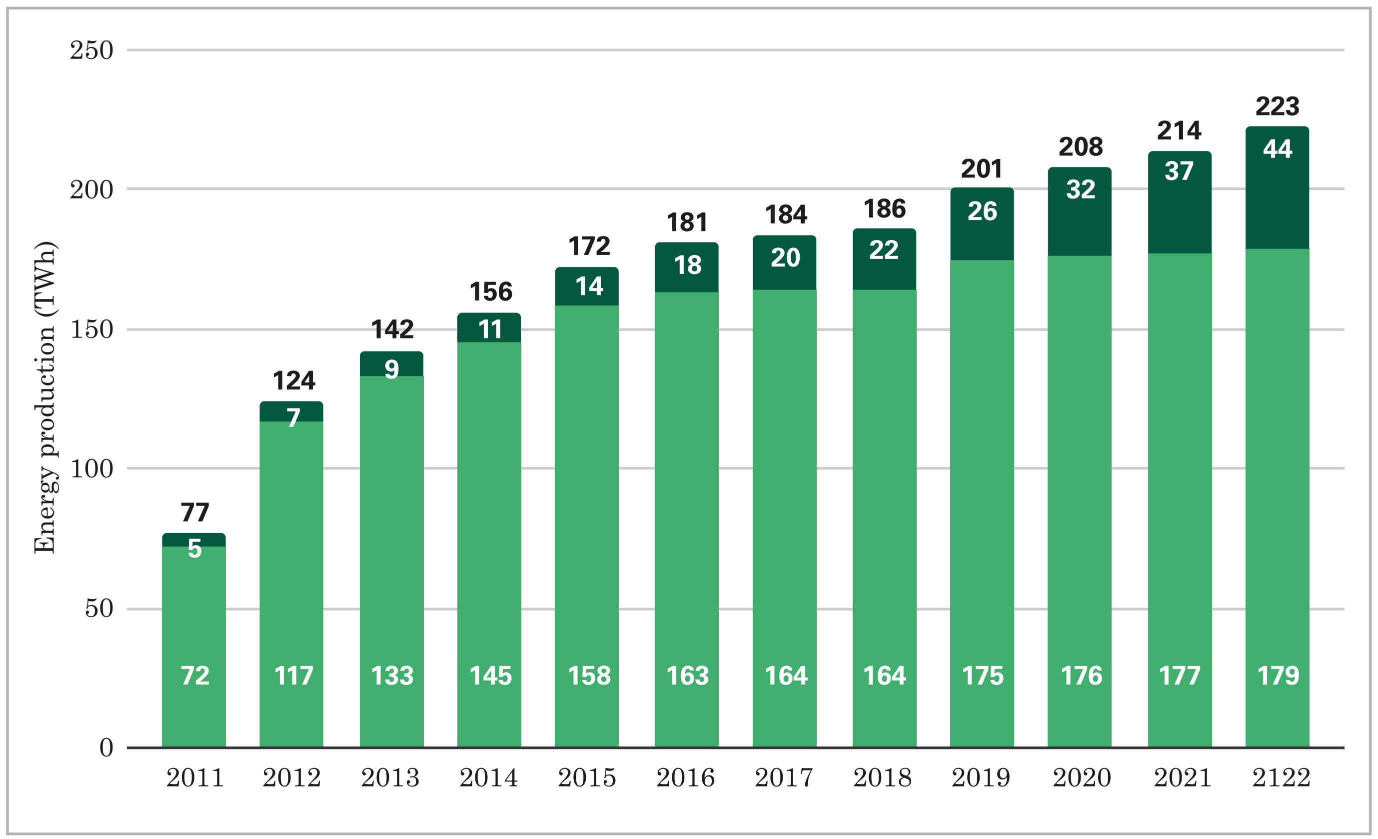
It is estimated that approximately 70-100 million tonnes of slurry are produced by UK agriculture every year, with the majority remaining untreated. The relatively widely distributed resource has traditionally meant that treating these materials has not been economically viable when energy alone is viewed as the driving factor. As such, deployment of AD in agriculture specifically for the treatment of residual material, is relatively low. The additional value from nutrient recycling, reduced environmental pollution and lower emissions are almost always overlooked and not factored into the overall case for deploying AD across the agricultural sector. The volumes of material are so large that the overall energy contribution would be significant, both regionally and nationally, and the approach would also deliver reduced agricultural pollution and partial decarbonisation of the agricultural sector. Collaboration between farms and innovative plant configuration, in conjunction with financial and technical support for farmers, is likely to be required before AD can successfully be deployed as a mainstream technology across the sector. Further work is also required to recognise and recover the value associated with digestates and some of the current work by the team featured later in this paper.

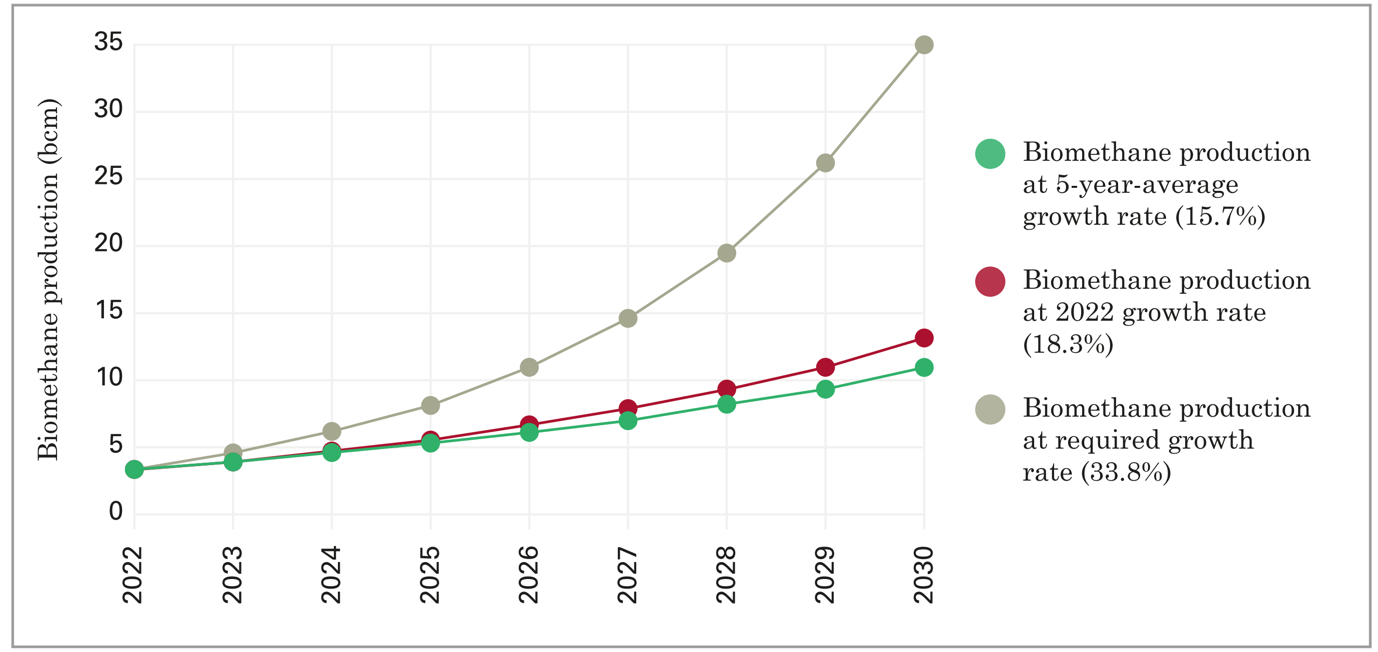
Biogas comprises typically around 40-50% biogenic-$CO_2$. This is generally emitted to the atmosphere at the point of end use, or during biogas upgrading. There are emerging opportunities to capture and utilise this $CO_2$ for conversion into other products, including fuels, chemicals, biopolymers or SCP. According to CNG Services, there are a number of uses for the bio-$CO_2$, some better than others as shown in CNG's Bio-$CO_2$ ladder (Fig. 1). The production of synthetic methane using recovered $CO_2$ already features in the energy strategy of several countries including Denmark and Finland, and in the strategies of individual energy providers including Nortegas (Spain), and Terega (France). It is desirable that sectors which may currently be considered separate, such as renewable energy production, $H_2$-production, waste management and carbon management, should become more integrated to deliver greater value and enhanced material and energy efficiencies.

### 2.3 AD Deployment in the EU and future prospects for growth

The EU has seen a significant growth in AD deployment, driven by landfill directive targets and renewable energy incentives. One of the evidence documents that was used for establishing incentives for biomethane linked to the EU Renewable Energy Directive (RED) was Patterson et al. (2011b). This work demonstrated the need to establish a support mechanism based on energy content, as opposed to mass or volume for biofuels, and gathered early data on upgrading and utilisation of biomethane as a fuel. The RED lead to more attractive financial sup-




*Top left: Figure 1. The Bio-$CO_2$ ladder according to CNG Services Ltd (March 2023): it is assumed that all the biomethane goes into the gas grid and is used as per the Biomethane Ladder.*

*Left: Figure 2. Shows the growth in biogas and biomethane production in Europe (2011-2022) (223 TWh ~ 21 billion $m^3$). (Source: EBA Statistical Report, 2023).*

*Above: Figure 3. Achieving the 35 bcm target for biomethane: current vs. required growth rate. (Source: EBA, 2023)*

port for biomethane across European Member States. Fig. 2 shows the growth in biogas/biomethane production in Europe from 2011 until 2022 achieving 19,491 biogas and 1,323 biomethane plants by the end of 2022.

In 2022, the European Commission launched its REPowerEU Plan, which aims to save energy, produce more clean energy and diversify energy supplies. As part of this plan, the Commission has recognised the contribution that AD can play in contributing sustainable gas supplies, and has set the ambitious goal of producing 35 billion $m^3$ (bcm) of biomethane per year by 2030 – 10% of the EU natural gas consumed (Fig. 3). This is a nearly tenfold increase from the current production of biomethane, and so is clearly going to require a substantial evolution of the AD sector. Biogases already provide Europe with 21 bcm of renewable gas, and EBA's first biomethane investment outlook shows that at least €18 billion has already been earmarked for investment in biomethane production in the years ahead. According to the EBA (2023), by 2050 the sector can deliver up to 167 bcm, meeting two thirds of future gas demand. The Centre's R&D continues to support further increases in biomethane production, contributing to the ambitions within both the UK and the EU. Further R&D support is therefore critical.

## 3 R&D delivered and in progress at the Centre

### 3.1 Monitoring tools developed to support AD and biorefining facilities

Anaerobic technologies are versatile processes able to convert municipal, industrial and agriculture wastes and low value biomass. The AD process is delivered by complex and dynamic systems where mechanical, microbiological and physico-chemical aspects are closely linked and ultimately influence the process performance (Esteves et al., 2012). Although inherently stable, these bioprocesses can reach instability by: a) organic/hydraulic overloads, b) toxic/inhibitory compounds, c) lack of essential nutrients/trace elements for microbes' maintenance/growth, d) sub-optimal temperatures. Appropriate monitoring of key parameters allow: a) loading flexibility; b) feedstocks' diversification; c) maximisation of conversion efficiencies and yield product quality; d) access to more demanding markets for products; e) reduction in plant/process downtime; f) reduction in plant size and operating costs; g)

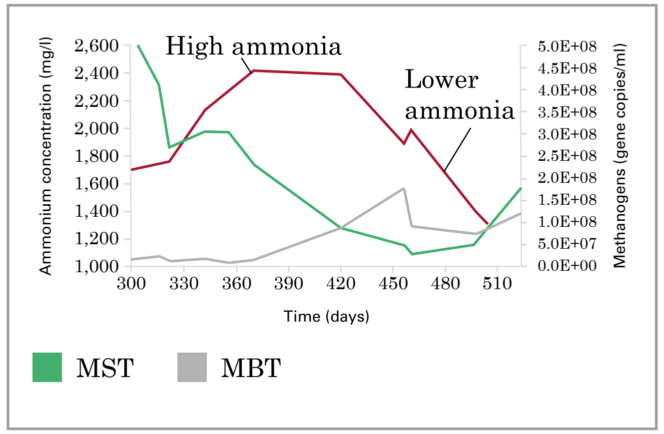



*Figure 4. The impact of ammonium concentration on MST microbial cultures which led to MBT cultures to increase until ammonium reduced (adapted from Williams et al., 2013).*

enhancement of environmental benefits and reduced impacts. R&D work has concentrated on developing three main areas of monitoring: 1) microbial profiles and synergies for selecting appropriate inocula and developing/maintaining robust microbial cultures; 2) improvement of VFAs monitoring methodology (Jobling-Purser et al., 2014); 3) developing multi-parameter analytical and modelling tools able to deliver in-line or at-line monitoring and to rapidly indicate the status of physical-chemical parameters of feedstocks, intermediates and products.

#### 3.1.1 Microbial profiling of anaerobic bioprocesses

The team developed a quantitative polymerase chain reaction (qPCR) methodology based on the 16S rRNA gene for profil-



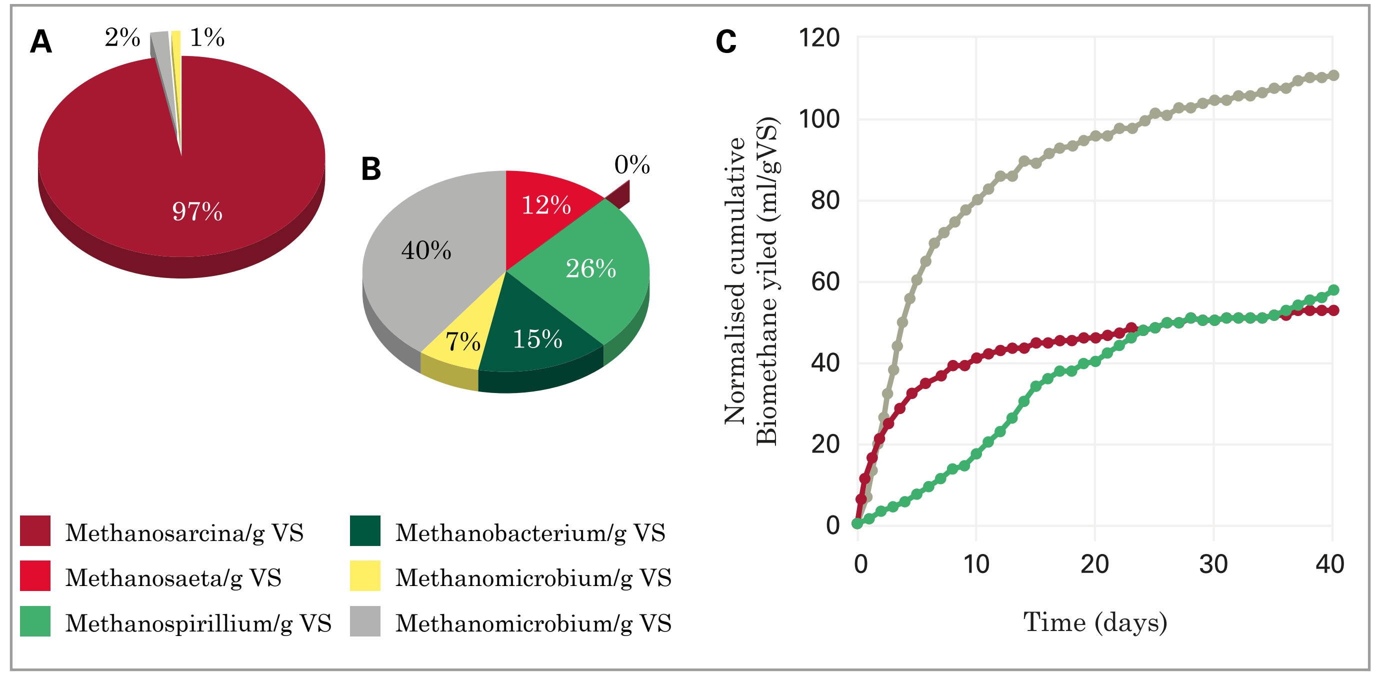



*Figure 5. Archaea distribution:* **A** *Sewage sludge digestate from AAD.* **B** *Conventional sewage sludge digestate.* **C** *Further digestions of the digestates. A (green line) and B (red line) and a mixture of A and B digestates providing improved biochemical characteristics for biodegradation and biogas production (adapted from Esteves et al., 2015).*

ing microbial cultures that has been used for identifying main groups of bacteria and methanogens that are converting acetic acid and hydrogen (family-levels for *Methanosaetaceae* (MST), *Methanosarcinales* (MSC) and order-levels of *Methanobacteriales* (MBT), *Methanomicrobiales* (MMB), and *Methanococcales* (MCC)) (Williams et al., 2013). This technique was able to quantify gene copies of important groups and the general profile of microbial cultures and their trends over long periods. More recently there has also been on-going work to develop a rapid qualitative methodology for a number of important species using loop-mediated isothermal amplification (LAMP). Research demonstrated that anaerobic processes are not black-box processes. Once a variety of parameters are monitored and microbial profiling has been established, informed management decisions to improve plant performance can be taken – for example, identifying that microbial communities are being depleted due to lack of essential minerals or high organic loads, or when ammonia is in excess (Fig. 4). Figure 4 demonstrates how ammonia inhibition shifts the dominant methanogens from MST to MBT in a food waste digester: $H_2$

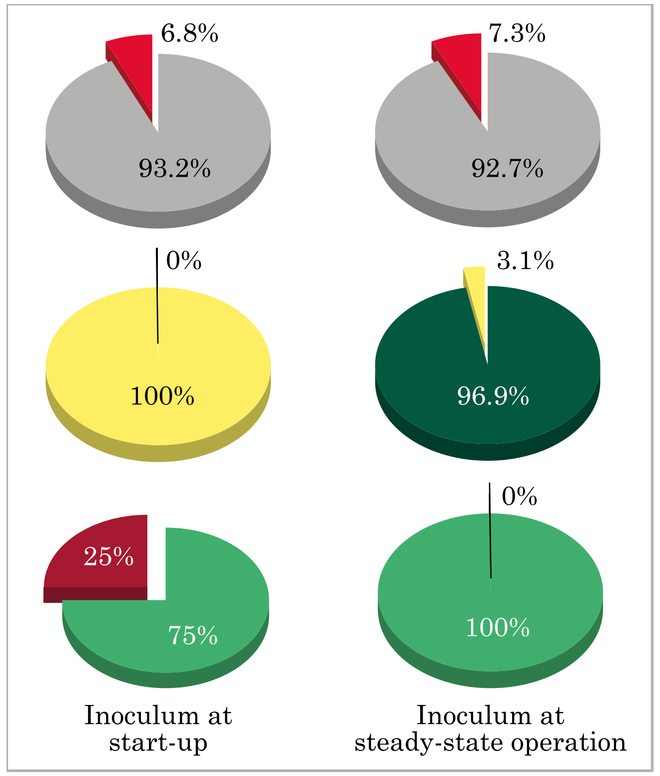
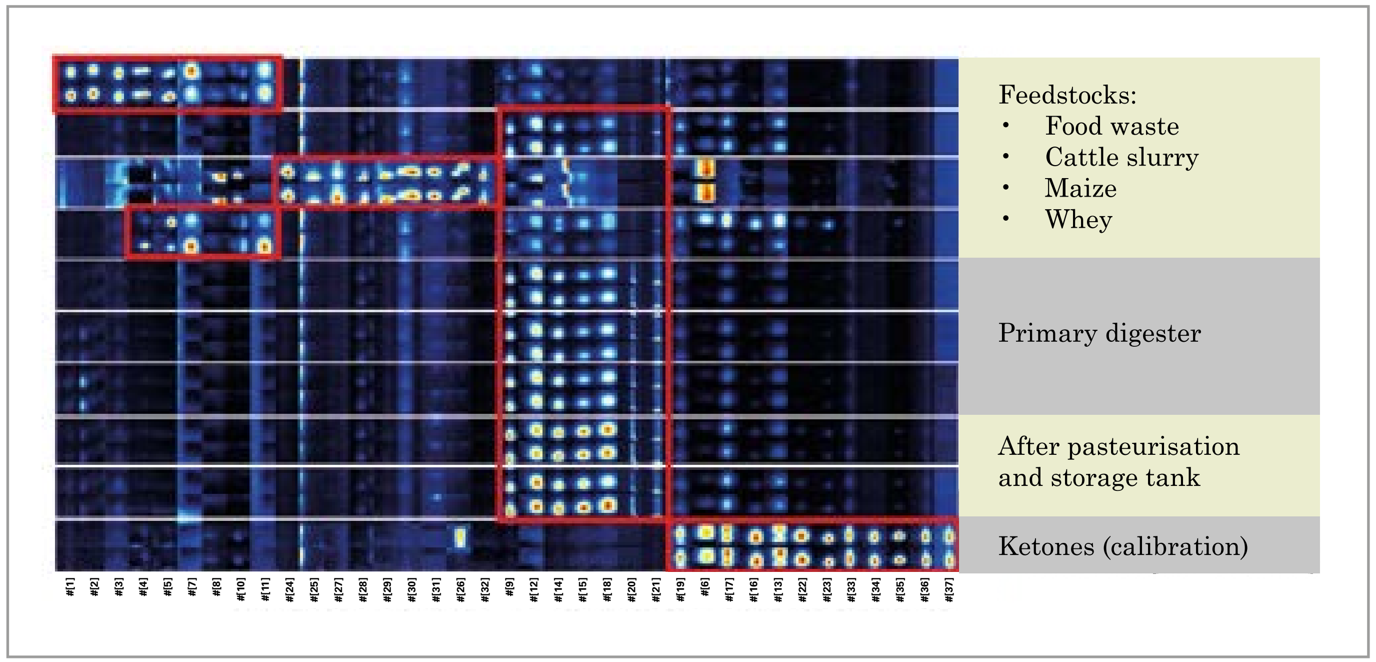



*Figure 6 (left). Microbial profile of the inoculum at start-up and at steady-state operation of an $H_2$ and $CO_2$ biomethanation process to deliver renewable power storage (adapted from Savvas et al., 2017).*

*Gene copy numbers for:*

- *bacteria*
- *methanogenic archaea*
- *acetoclastic methanogens*
- *hydrogenotrophic methanogens*
- *MBT*
- *MMB + MSC*

*Figure 7 (below). Chemical fingerprints relevant to an AD plant samples-and-ketones mixture used for calibration using the laboratory analytical viewer (LAV) software (Adapted from Oliveira et al., 2019).*





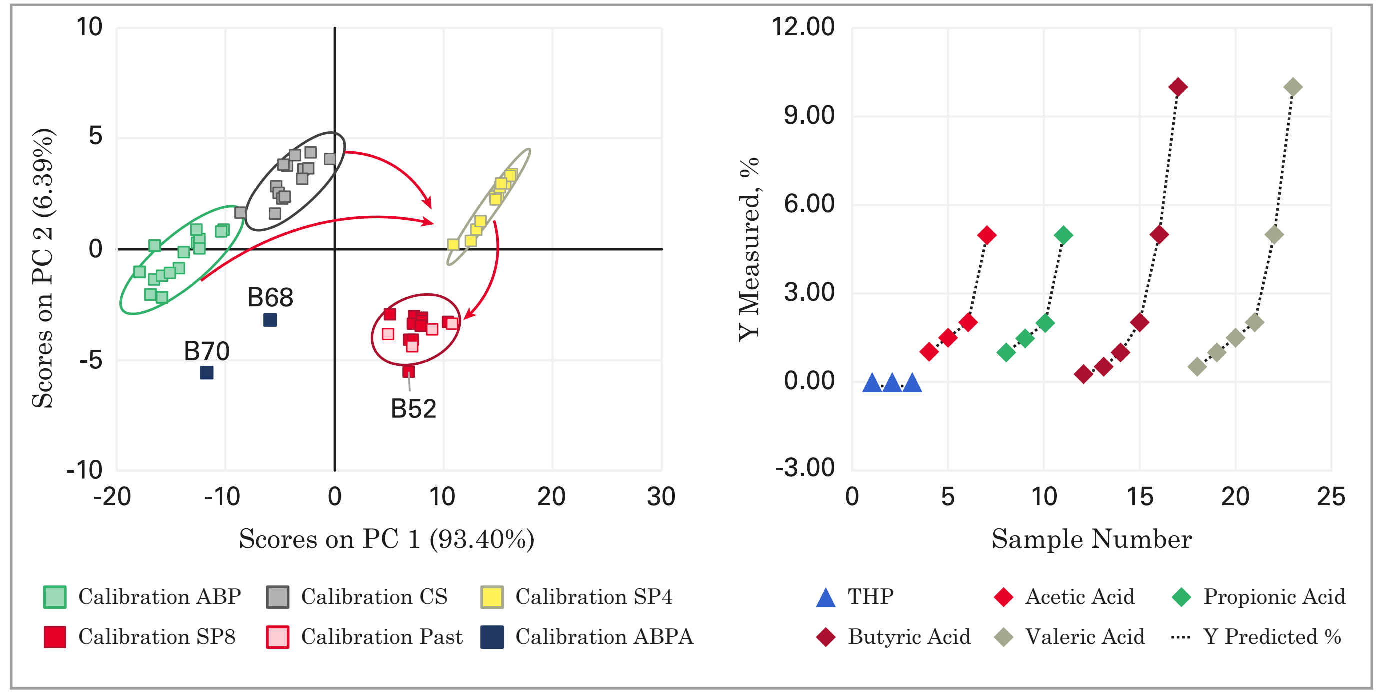




*Figure 8. A. Characteristics of a plug flow reactor's feedstocks (animal by-products (ABP) – food wastes), cattle slurry (CS), intermediates (fermentates SP4), digestate (SP8), and post pasteurisation (past). B. Speciated VFAs measured and predicted at various concentrations.*

pathway took over until ammonia decreased. Figure 5 shows digestate stability cannot be further reduced due to lack of microbial diversity in advanced AD. Figure 6 shows the enrichment and profile of communities in a biomethanation plant.

### 3.1.2 Multiparameter (real-time) monitoring for anaerobic processes

Gas Chromatography – Ion Mobility Spectrometry (GC-IMS) has been used as a multi-parameter monitoring tool for the optimisation of AD by improved performance and energy production, odour management, and improved environmental compliance and performance. Results have demonstrated that GC-IMS can be used to discriminate between feedstocks, intermediates and final products, represented by their different chemical signatures. These signatures can be used for fingerprinting, identification and quantification of volatile compounds (Fig. 7). A number of compounds have been identified and calibrated for e.g. terpenes, aromatics, ketones, alcohols, VFAs, esters, aldehydes, and N and S-compounds. Analysis can be performed typically in less than 10-20 minutes for a broad range of samples (gas, fluid, and solid matrices) and analysis can be done both off- and online. GC-IMS

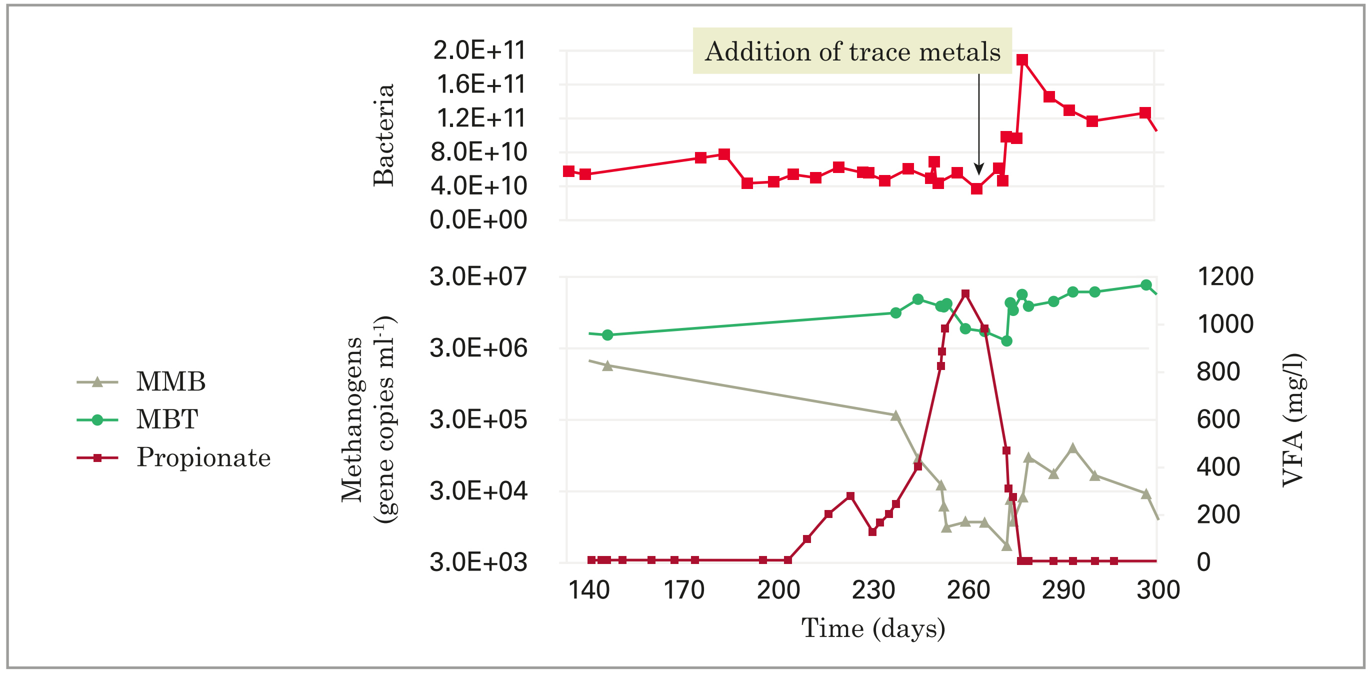



*Figure 9. The impact of addition of trace metals in a food waste digester (adapted from Williams et al., 2013).*

can analyse target/non-target compounds of relevance to AD and other biotechnologies. GC-IMS has also been found able to rapidly diagnose sources of pollutants within environmental matrices (e.g. water bodies and soils) when integrated with artificial intelligence-based pattern recognition tools.

The team has also developed strategies for operationalising Fourier transform near infrared spectroscopy (FT-NIRS)-based real-time monitoring for optimisation of AD processes (Reed et al., 2011, 2013; Darke, 2024). FT-NIRS models are able for example to establish organic loading, solids degradation, measurement of VFAs and the impact of associated treatments (Fig. 8).

GC-IMS and FT-NIR can complement monitoring parameters and analyse samples offline as well as online in real time. Both are suitable to be process analysers and for deployment in AD and other biotechnology-based plants operating on a variety of feedstocks, and are suited to multi-design facilities.

### 3.2 Examples of strategies that have been evaluated to optimise AD performance

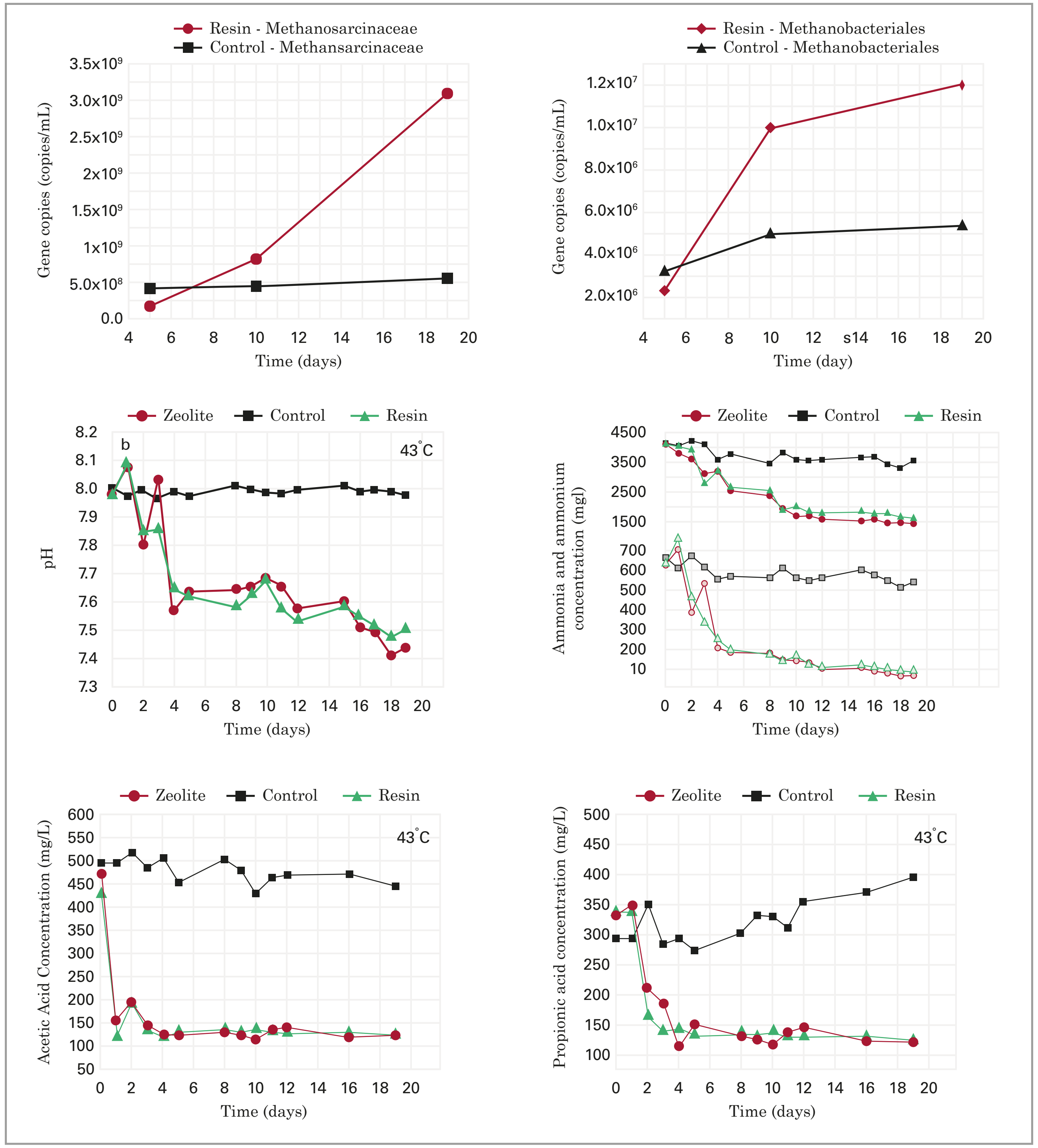
Enhanced monitoring and control strategies that have been developed and implemented have enabled:

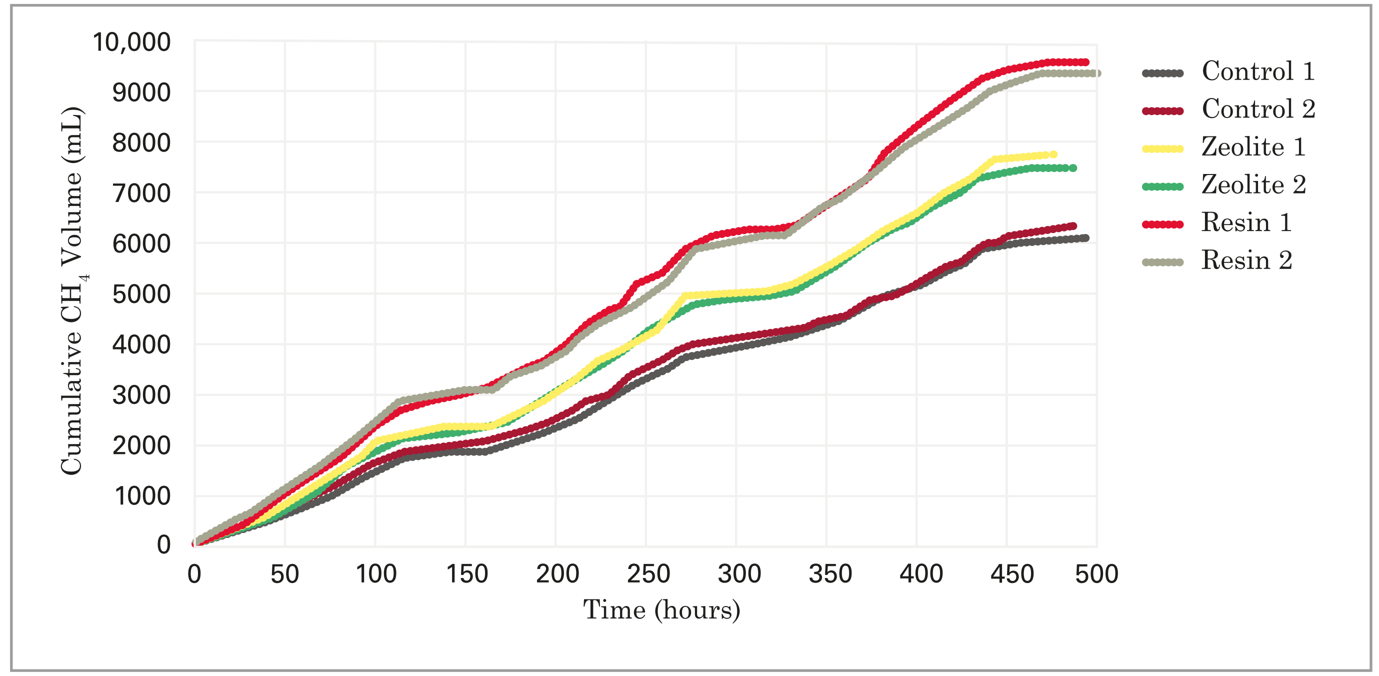
- Optimisation of trace element availability to ensure healthy microbial populations and process recovery (Fig. 9);
- Ammonia reduction strategies to yield up to 50% more biogas (acids reduction and populations increase) (Fig. 10);
- Pre-treatment of feedstocks (thermal, chemical (Devlin et al., 2011), biological, mechanical (ultrasound) (Fig. 11)) to improve process efficiency.

### 3.3 Valorisation of digestates and novel uses

In Europe, the most established use of digestates is soil conditioning and fertilisation. According to the EBA (2023), 73% of digestate was used directly as a biofertiliser on agricultural land, or was upgraded and also used on agricultural land as a biofertiliser (15%). Digestates can increase soil health and crop growth by delivering stable organic matter (regulating soil structure) as well as delivering valuable nutrients and enabling the replacement of fossil fuel fertilisers. EBA (2023) reported that in Europe, in 2022, 31 Mt of digestate (dry matter) were produced with a nutrient content of 1.7 Mt N, 0.3 Mt of P and 0.2 Mt of K, that can replace approximately 15, 11 and 6 % of synthetic fertiliser in terms of N, P and K respectively, and reduce GHG emissions of approximately 10 Mt of $CO_2$eq. EBA estimates that, with the expected growth of AD across Europe, by 2030 and 2050 digestate use will contribute to a reduction of 24 and 57 Mt of $CO_{2eq}$ GHG emissions respectively. By replacing synthetic fertilisers, this is predicted to equate to avoiding natural gas of 4 and 10 billion $m^3$ by 2030 and 2050 respectively.

Digestate separations and further processing can also facilitate novel opportunities for digestate use. Valorisation routes include the separated solids fraction and their processing via pyrolysis, gasification of hydrothermal carbonisation, which result in the production of char, hydrochar, biofuels and for insect cultivation. Further processing and the production of a liquid fraction can be used for example through membrane filtration including reverse osmosis, evaporation and ammonia stripping (Oliveira et al., 2013), the precipitation into struvite (Tao et al., 2017) and its use in hydroponics and for the production of microalgae (e.g. Stiles et al., 2018). Microalgae cultivation represents a promising strategy for obtaining products such as animal feed, bioplastics, bioenergy and biofertilisers, among others. Other uses for digestates in the future may include the production of soil/crop biostimulants, and the recovery of bioelectricity, for example through microbial fuel cells. The use of digestate nutrients and microbial stimulants to promote VFA production from sewage sludge has been evaluated by Kumi et al. (2016). This study indicated that the addition of recovered microbial nutrients, as nutrient source in the fermentation, resulted in VFAs 27% higher than the control. Passanha et al. (2013) investigated the use of micro-filtered digestate as nutrient media (NM) for a

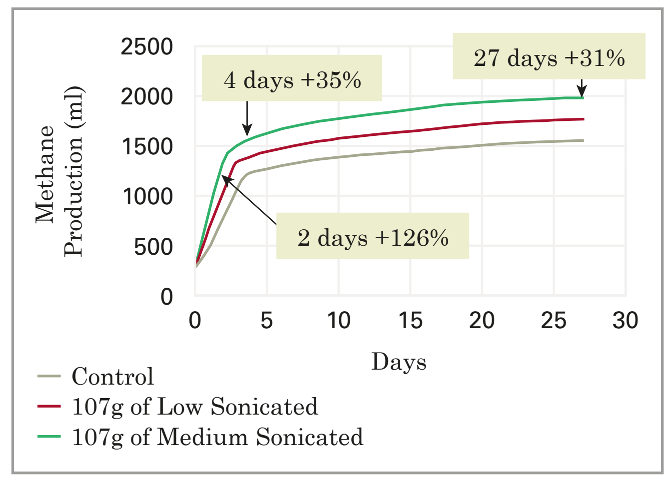


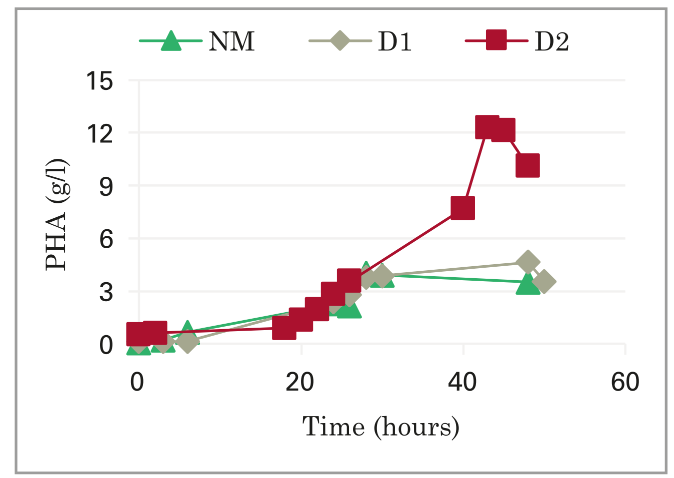




*Left and above: Figure 10. Impact of ammonia adsorbents when deployed at AAD plants operated at 43ºC on sewage sludge (adapted from Tao et al., 2016).*

*Below left: Figure 11. The improved performance provided by a sonication step within AAD of sewage sludge.*

*Below right: Figure 12. The positive impact of micro -filtered digestate on PHA production in comparison to nutrient media (adapted from Passanha et al., 2013).*



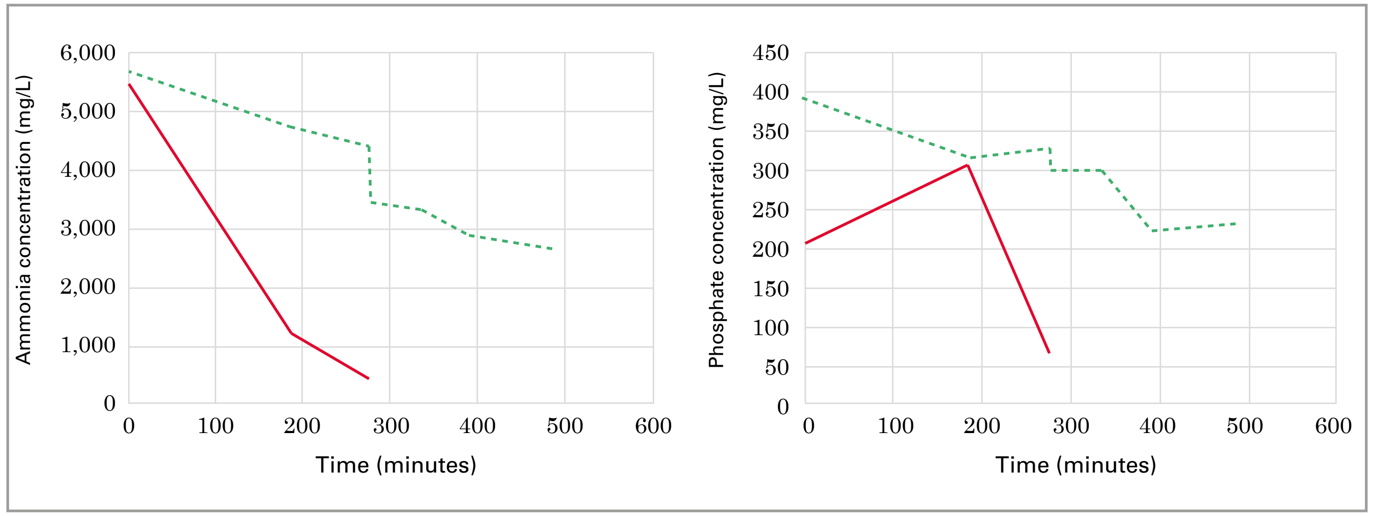



*Figure 13. Two strategies for ammonia and phosphate recovery from a digestate.*

pure culture biofermentation, which yielded SCP and in the case of a D2 yielded nearly 3x more polyhydroxyalkanoate (PHA) (a biodegradable and bioderived polymer) production, as compared to the conventional nutrient media (NM) (Fig. 12).

Fig. 13 shows two strategies for concurrent ammonia and phosphate recovery from a nutrient rich digestate from abattoir wastes. The results in red were achieved using a combination of a resin and an electrically driven membrane and illustrate higher and faster recovery of nutrients.

Work had already established that processing feedstocks such as animal slurries and sewage sludge via AD plants reduces pathogen load. Research has also found that antimicrobial resistance (AMR) genes in conventional anaerobic digesters operating on sewage sludge at mesophilic temperature significantly decreased after digestion, except in the case of ermF (Figure 14). Further understanding AMR-related mechanisms and how AD plants could further reduce resistance continue to be the aim of our work. Current work also includes investigations related to AMR in digestates when in storage and when used in soils. Other on-going investigations include emerging compounds in digestates and mechanisms for their reduction (e.g. per/polyfluorinated substances). In relation to emerging pollutants, it is imperative that feedstocks themselves carry reduced loads. Tighter policies and regulations affecting their use in manufacturing and in packaging will be critical if circularity is to be achieved.



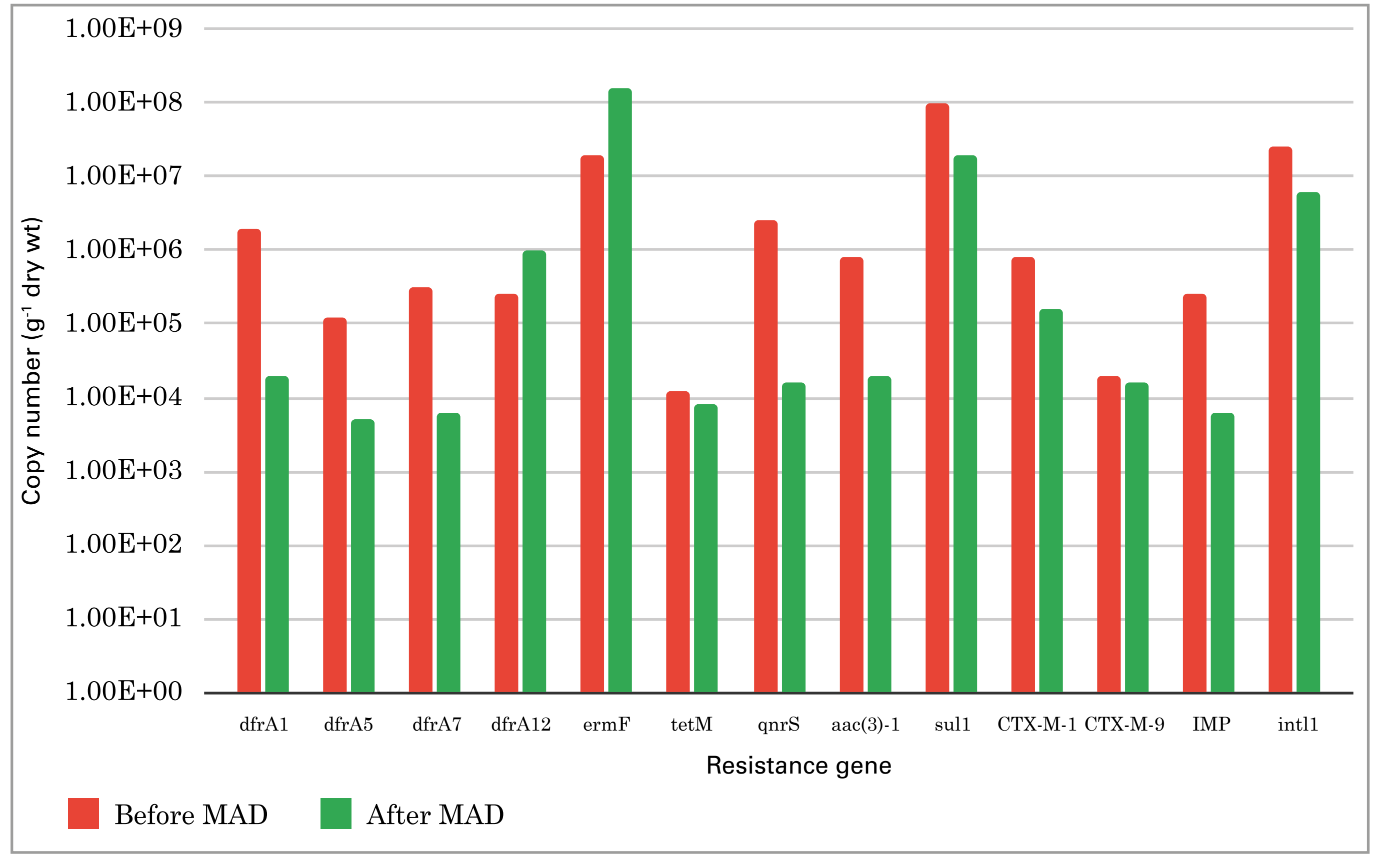



*Figure 14. Antimicrobial resistance genes in conventional anaerobic digesters operating on sewage sludge at mesophilic temperature (adapted from Redhead et al., 2020).*

### 3.4 Bioprocess configuration for methane and hydrogen production to match gas grid demand

AD plants have typically operated on a fairly constant output for biogas throughout the day and year to match electricity-grid-supply-based load requirements. If biomethane is to replace significant natural gas network supply, delivering to daily and seasonal needs will be required (Fig. 15).

One strategy is to ferment feedstocks into compounds such as organic acids, which can be segregated and stored in a concentrated liquid form rather than producing methane and requiring the transport and storage of biomethane as compressed gas. Whilst the segregation and concentration of organic acids (Fig. 16) can take place using membrane technology, the fibres recovered can be available for other types of recovery (such as lignin or phenolics) or production of biochar. Other benefits of this strategy relate to reducing the need for small-scale digestion

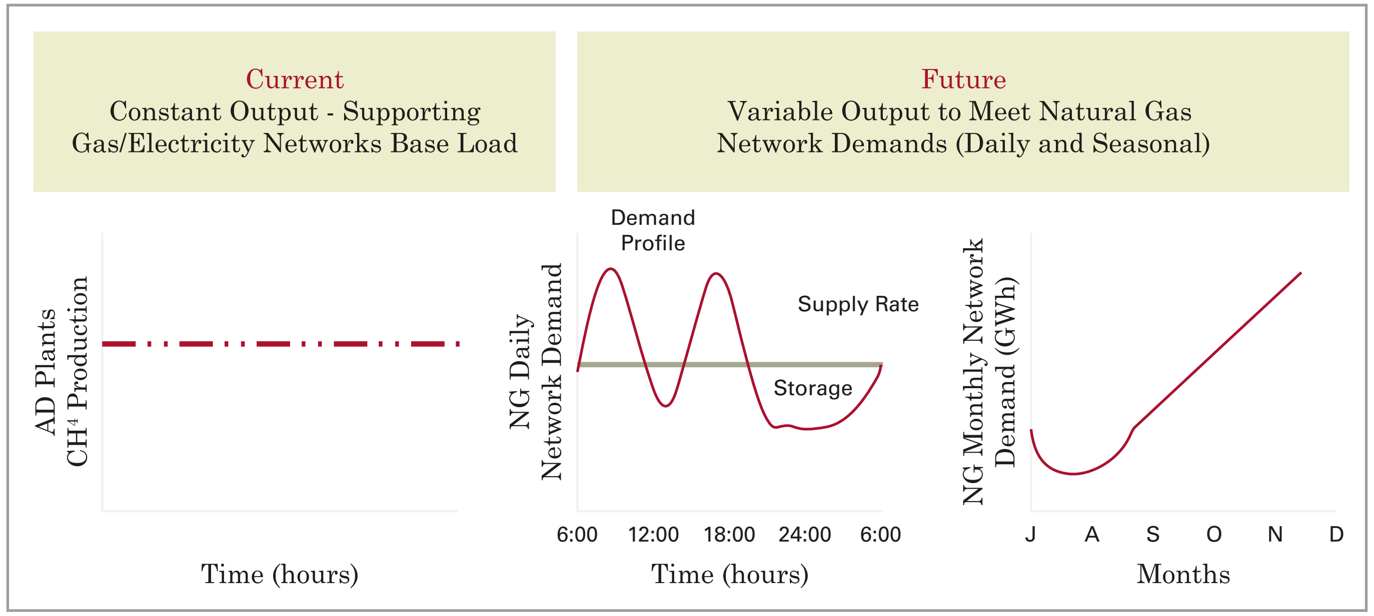



*Figure 15. Current and future operation of AD plants to match biomethane production with the gas grid demand.*

and gas processing infrastructure in distributed small and medium-size farms (VFAs can be transported to a centralised facility), reducing the risk of disease spreading when untreated slurries are mixed between numerous farms and co-recovery of nutrients (NPK). The centralised high-rate digester can be operated to match the demand for gas in the gas network. VFAs can be collected and stored in summer and utilised for production of biomethane in the winter season. This novel strategy decouples temporal availability of feedstock from gas demand, overcomes financial constraints that limit AD deployment in small farms, and is expected to deliver significant carbon savings with a reduction of methane losses. As simultaneous nutrient recovery is possible, diffuse nutrient pollution is also eliminated. Fig. 16 shows a schematic of novel biotechnologies-based circular economy concepts that are being developed to contribute to net zero ambitions, bridging resources and needs between rural and urban environments. The aim is to extract value from regionally-distributed farm animal slurries and intermittent renewable power sources by converting first to VFAs and then to other sustainable products, whilst also recovering nutrients and fibres. Energy products from VFAs as well as $H_2$ and $CO_2$ will include biomethane, e-methane, and biohydrogen, which will be produced and injected into the natural gas network when there is demand.

The UK beef and dairy slurry-based resource of nearly 70 million tonnes of collect-



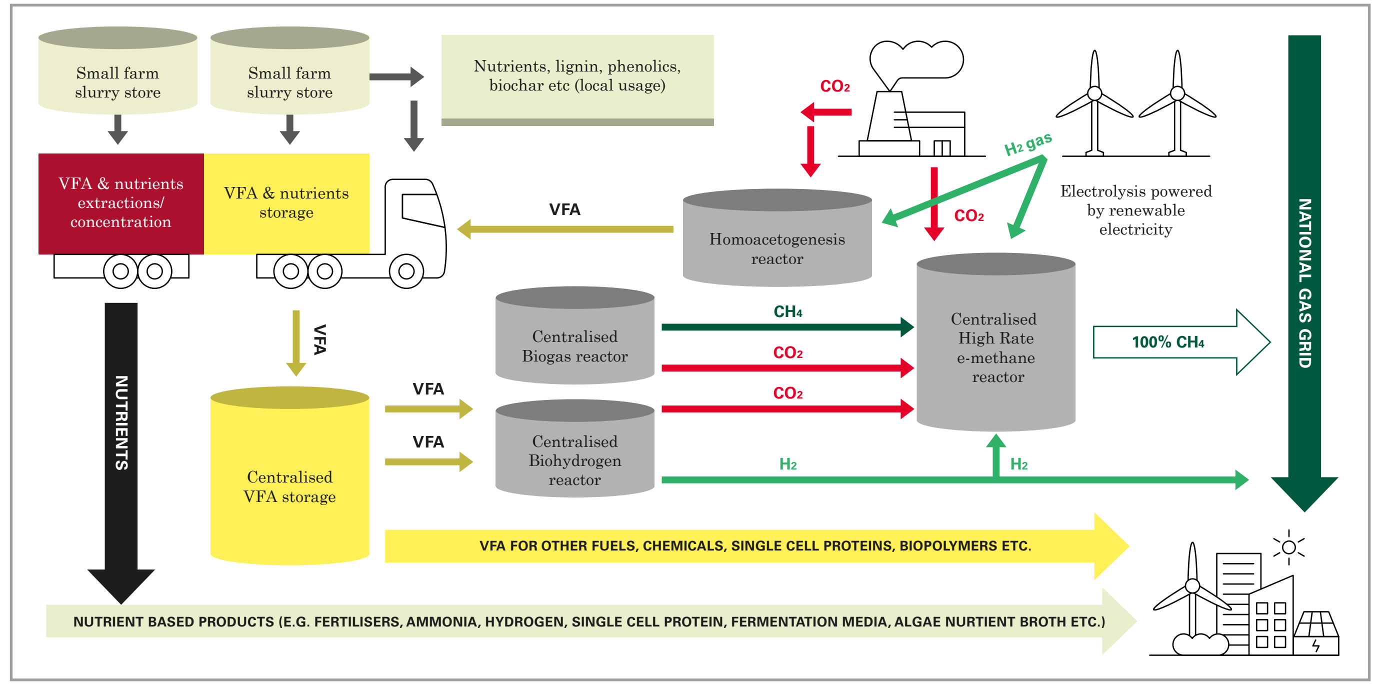



*Figure 16. Schematic of novel biotechnologies-based circular economy concepts to contribute to net zero ambitions, bridging resources between rural and urban environments (processes not to scale).*

ed excreta per annum (5.9 million tonnes VS/year) (Defra, 2008) could lead to a yearly production of 432,000 tonnes of VFAs, 2.11 TWh of biomethane, 274,000 tonnes of ammonium sulphate fertiliser. If the e-methane biotechnological process was also implemented to utilise the $CO_2$ from biogas alone, a total of 108 million m$^3$ of $CO_2$ could be recovered, leading to an additional 1.1 TWh of e-methane, and a total $CO_2$ saving of 961,000 (tonnes $CO_{2eq}$) would result from the biomethane, e-methane and fertiliser produced. When including savings from emissions avoided by treating the animal slurries, a total GHG emission savings of 57.2 million tonnes of $CO_2$eq is delivered.

Whilst dark fermentations from complex organic wastes have been achieved for the purpose of biohydrogen production, these lead however to a large energy content remaining in VFA form (e.g. Massanet-Nicolau et al., 2010; Premier et al., 2013). The biohydrogen production from VFAs within the team is at an earlier stage of development. This can be achieved through bioelectrochemical systems (e.g. Kyazze et al., 2010, Popov et al., 2015) or via photosynthetic microbes. Fig. 17 shows the production of $H_2$ and $CO_2$ by a pure culture strain of photosynthetic bacteria from VFAs and $N_2$. Whilst hydro-

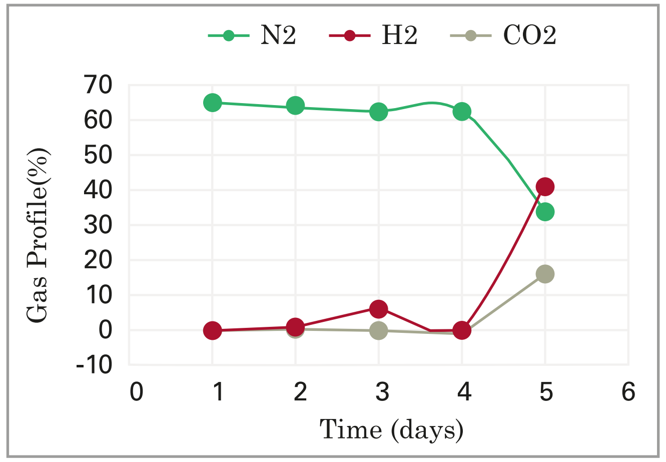



*Figure 17 – Biohydrogen production from VFAs and $N_2$.*

gen could be used for injecting into the gas network it can also be used in vehicle fuels (Patterson et al., 2013, 2014).

### 3.5 Biotechnologies for renewable power storage and $CO_2$ use delivered by mixed microbial cultures

R&D to develop synthetic-methane (or e-methane) production using renewable $H_2$ and $CO_2$ has progressed. The ex-situ mixed culture hydrogenotrophic methanogenesis technology brings multiple benefits including recycling $CO_2$, biogas upgrading, renewable energy storage, optimising value from renewable energy assets and the provision of a hydrogen-carrier that is transported easily and cost-effectively. The biological Power to Methane (bPtM) process provides a compelling solution for biogas upgrading, renewable electricity storage and carbon use.

To establish itself as a viable method, bPtM must deliver: high conversion efficiency and consistency; low parasitic energy and operational footprint; process scalability and integration, as well as delivering on financial terms. These have been the areas which the team has contributed towards, in particular efficient design (Fig. 18) (e.g. Savvas et al. 2017, Savvas et al., 2024), operational strategies (Savvas et al., 2024, Savvas et al., 2022, Savvas et al., 2018), microbial cultures enrichment and maintenance (Savvas et al., 2018, Savvas et al., 2016), integration of the technology with full scale $CO_2$ and energy infrastructure (Patterson et al., 2017) and financial modelling (Bendikova et al., 2023). The team has investigated and developed multiple reactor types, sources of microbial catalysts, start-up and operational strategies, for example during intermittent supply of gases, and now has a comprehensive understanding of the benefits and drawbacks of multiple process configurations. In particular, the team has been driving gas solubilisation and operating strategies as well as the ability to control microbial metabolisms and deliver stable-high-conversion operation over long periods. The team has developed a modular biofilm-based reactor platform that delivers very stable, high-quality gas output, recycles nutrients within the system, and has low reactor energy requirements. The team has also filed patents and registered trademarks in relation to these developments and has incorporated a spin-out company. A larger-scale



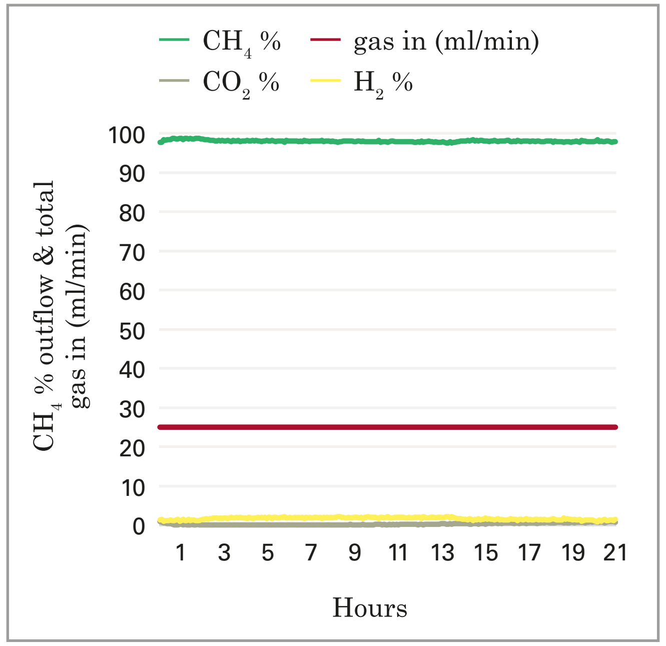
*Figure 18. Examples of bespoke reactor designs developed for laboratory and pilot operations, some allowing up to 10 bar pressure operation.*

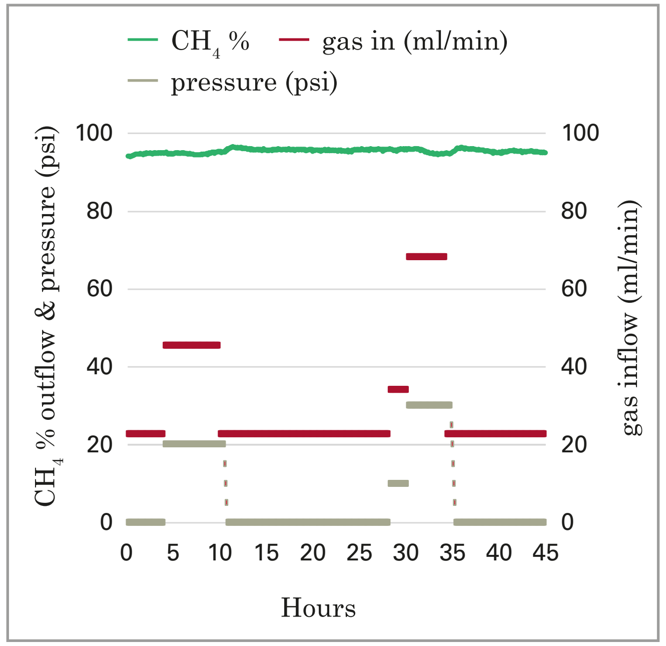
demonstration would deliver scaling-up, integration, long-term performance and optimisation, enabling further progress towards commercialisation of the technology and full-scale deployment.

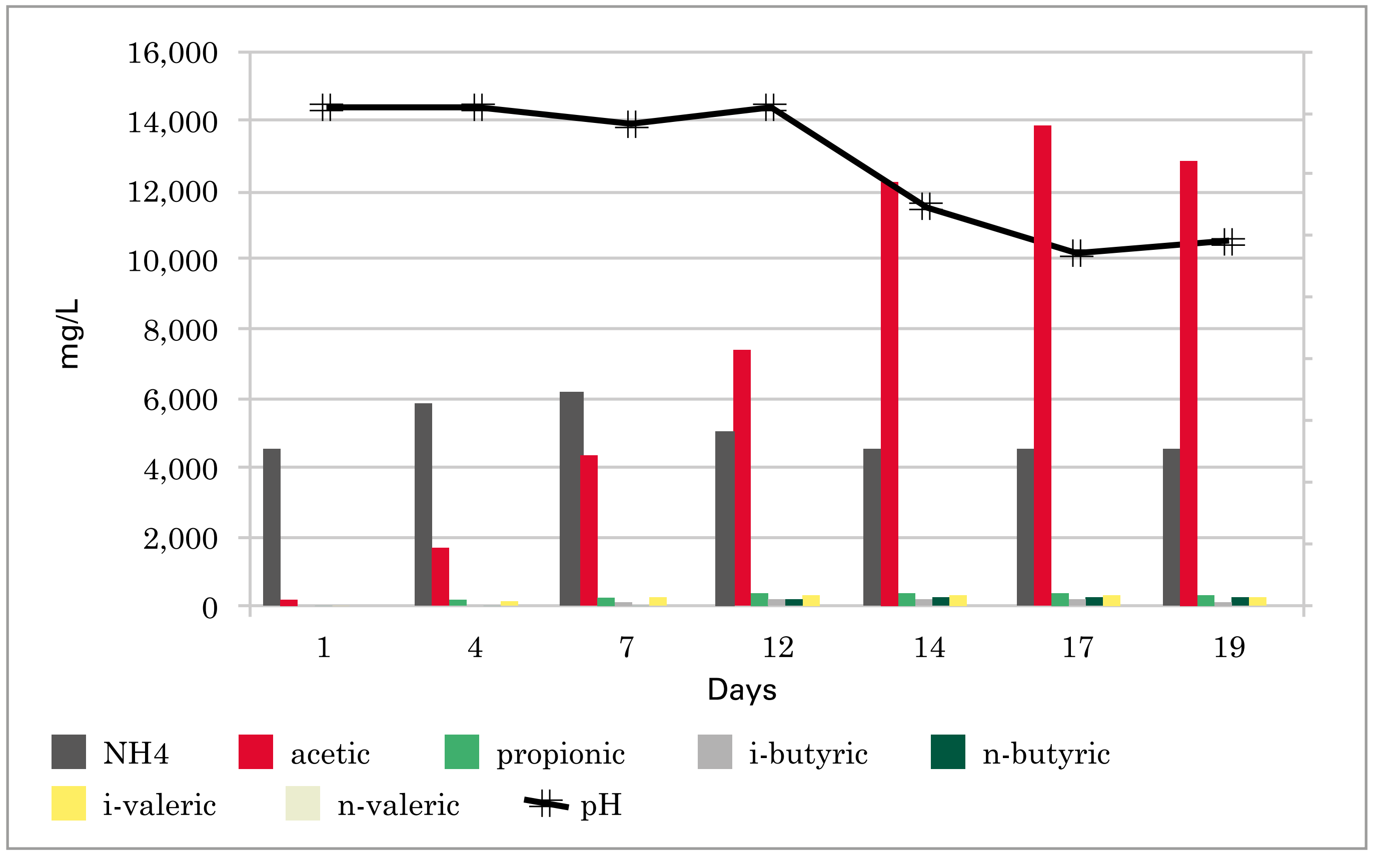
For example, long-term, high-conversion performance has been achieved. Fig. 19 indicates that a gas effluent of above 98% in $CH_4$ content can be achieved stably for long periods with $CO_2$ levels close to 0%. The importance of 'natural gas quality' means no further upgrades required, reducing capital/operating costs with gas quality able to meet gas pipeline standards. Fig. 20 demonstrates a novel strategy developed to achieve a stable conversion by adjusting the internal reactor pressure.

Other products can be produced from $H_2$ and $CO_2$, namely acetic acid (Fig. 21). In addition, this gaseous conversion platform is enabling other biotechnologies to be developed for $CO_2$ conversions to other fuels, chemicals, inoculants, biostimulants, biopolymers and SCP (for animal feed).

Microbial biomass or cell proteins are being increasingly investigated as a source of protein-rich animal feed (Jones et al., 2020). Hydrogenotrophic archaea are among the species that could be used for such purpose (Linder, 2019) due to their high protein and




*Clockwise from top left:*

*Figure 19. Full $CO_2$ conversion leading to a high-quality end product of >98% $CH_4$ (adapted from Savvas et al., 2024).*

*Figure 20. Stability of conversion to $CH_4$ regardless of the gas input rate enabled by pressure adjustments.*

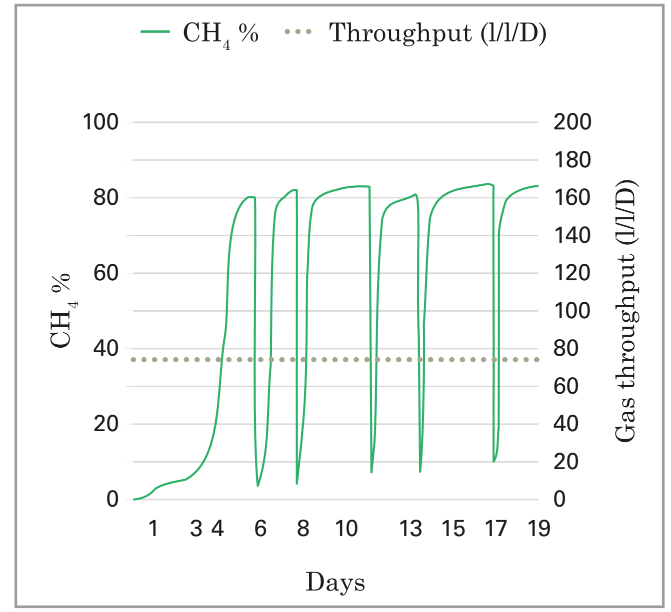
*Figure 21. Production of VFAs, mainly acetic acid from $H_2$ and $CO_2$ gaseous streams.*

*Right: Figure 22. Conversion of $H_2$ and $CO_2$ to $CH_4$ with co-recovery of SCP.*

carbohydrate content. Coupled to methane production, biomass production could potentially increase the overall value delivered by the bioprocess. Fig. 22 showcases an investigation into the continuous production of methane under periodic washout from where SCP can also be harvested. Microbial profiling indicated that hydrogenotrophic archaea had increased by 19,308% by the end of the experiment.

### 3.6 Novel bioprocesses for the production of PHAs and SCP and from single cultures

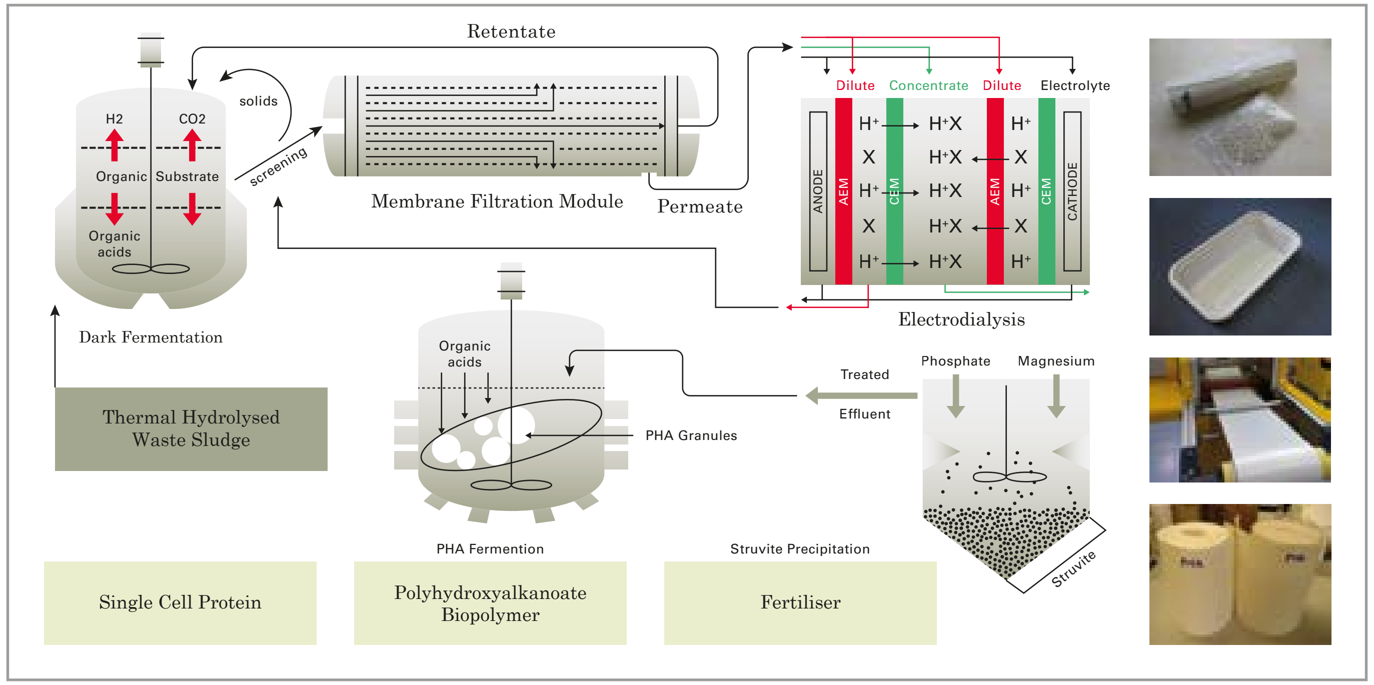
Microbial single-cell proteins and PHAs can be produced using VFAs directly as a consistent quality carbon-based intermediate and sourced from a multitude of feedstocks (e.g. food wastes, animal slurries industrial effluents, sewage sludge) (e.g. Passanha et al., 2013, Kedia et al. 2013, 2014, Tao et al., 2014). Fig. 23 shows a schematic of




the bioprocess development for valorisation of sewage sludge into SCP, PHA and a fertiliser. Fig. 23 also shows the processing of PHA into products (e.g. pellets, films, trays). The biopolymer processing was conducted at Bangor University's Biocomposite Centre.

Alternatively, $CO_2$ can also be used for the production of SCP and PHAs as the sole carbon source. Fig. 24 shows a laboratory setup at USW for the production of SCP and PHA from $CO_2$ as the only carbon source and without supply of $H_2$.

SCP has the ability to replace amino acids within animal feed supplies. PHAs already have wide applications and their uses continue to grow in numerous areas, e.g. packaging, waste bags, diapers, wipes, biofuel precursor, biocomposites, agriculture plastics, animal feed, skincare products, insu-




*Above: Figure 23. Bioprocess development for valorisation of sewage sludge into SCP, PHA and a fertiliser (left) (adapted from Tao et al., 2014). Processing PHA into products (e.g. pellets, films, trays) (right) (source: Biocomposite Centre).*

lation foams and a variety of biomedical applications. The unique properties that make them desirable materials for biomedical applications are their biodegradability, non-toxicity, biocompatibility, thermoplasticity, elastomer behaviour, simple tunability, and immunotolerance. PHAs have been found suitable for various medical applications: drug carriers, biocontrol agents, biodegradable implants, scaffold in tissue engineering (e.g. Goonoo et al., 2016, 2017), memory enhancers, and even anticancer agents.

Fig. 25 shows full degradation of a biopolymer film based on PHA in AD conditions within 15 days (A), which would enable food waste caddy-liners or pet waste plastic bags to be completely digested in conventional AD systems. However, when a variety of biopolymer formulations are developed, degradability can vary. For example, when a type of PHA is blended with another co-polymer, anaerobic degradability reduces. However, additives can improve degradability (B).

## Conclusions

Biotechnologies have and will continue to be able to deliver resource recovery and contribute to net zero, circular economy and green growth. These can deliver sustainable fuels, chemicals, polymers, feed using organic resources and inorganic gases within urban and rural settings, contribute to the sustainable treatment and recycling of organic wastes and carbon, and contribute to renewable energy storage. Microbial-based processes can be delivered at low parasitic energy, low temperature, low pressure and with minimal chemical usage, all contributing to reduced environmental impacts. Further R&D, scaling-up, integration and demonstration are essential to support full-scale deployment and commercialisation of new and improved biotechnologies.

*Figure 24. Production of SCP & PHAs using $CO_2$.*


## Acknowledgements

The authors acknowledge the funders and collaborators for the following projects: ERDF Wales Centre of Excellence for Anaerobic Digestion, IEE Biomethane Regions, ERDF/SMARTExpertise-SMART-CIRCLE, ERDF-Beacon+, ERDF/A4B AAPBS and SuPER$^{PHA}$, IUK-Renewable Synthetic Methane, BEIS-BioGrid, BBSRC-C1Net – PHA platform by anaerobic bacteria, Sêr Cym-

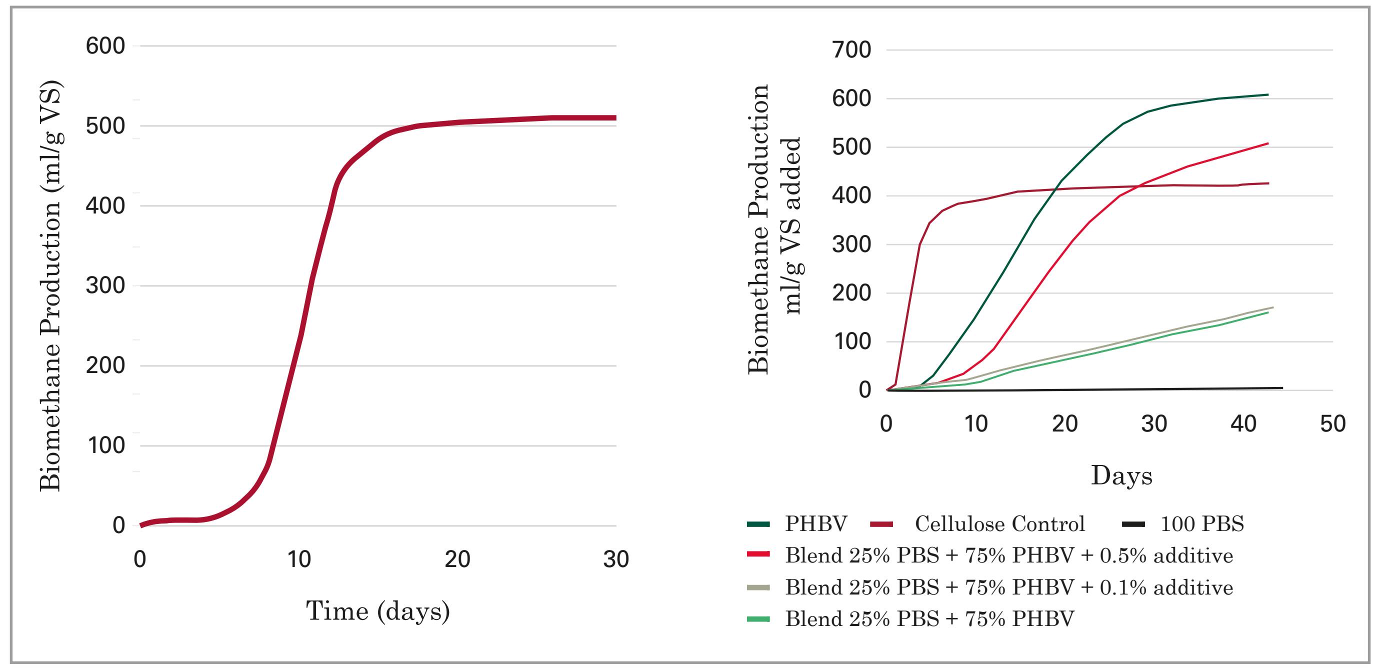




*Figure 25. (A) PHA based film with no residual polymer at the end of digestion, (B) AD of PHA based blends).*

ru-BioPOL4Life; OFGEM NIA – Flexible Methane Production, and C2-C4 Alkane Gas Production, ESF KESS (DCWW, WWU) Projects; EPSRC-$CO_2$BioPol Fellowship.

## References

Bendikova V., Patterson T., Savvas, S, Esteves, S. (2023). Economic and policy requirements for the deployment of Power to Methane (P2M) for grid-scale energy management. Energy Reports, 10: 4271-4285

Darke M (2024) Operationalisation of FT-NIRS based real-time monitoring for optimisation of anaerobic digestion. PhD Thesis. University of South Wales

Darke M., Donnelly J., Henley A., Savvas S., Kumi P., Oliveira A., Patterson T., Reed J., Chong Z., Wilson V., Matthews R., Vergara L. and Esteves S (2019) Ultrasound to Maximise Anaerobic Digestion of Thermally Hydrolysed Sewage Sludge. Poster Presentation IWA 16th AD World Congress, Delft, June 2019

Defra. (2008). The National Inventory and Map of Livestock Manure Loadings to Agricultural Land: MANURES-GIS. Department for Food, Environment and Rural Affairs

Devlin D.C., Esteves S.R.R., Dinsdale R M and Guwy A J. (2011) The Effect of Acid Pretreatment on the Anaerobic Digestion and Dewatering of Waste Activated Sludge. Bioresource Technology 102: 4076–4082

Esteves S, Oliveira I, Tao B, Williams J, Hegarty F, Devlin D, Anthony C, Anthony R, Faizal M, Donnelly J, Abu-Orf M and Reed J (2015) Findings and Recommendations Report From R&D Evaluations for Cardiff and Afan's Wastewater Treatment Works. Biomethane Regions Deliverable Report for Intelligent Energy Europe

Esteves S., Miltner M., Puchas K. (2012) Review and Guide for Monitoring Anaerobic Digestion and Biogas Plants for the Optimisation of Biogas and Biomethane Production. IEE Biomethane Regions Project Report.

Goonoo, N., Bhaw-luximon, A., Passanha, P., Esteves, S. R. & Jhurry, D. (2016) Third generation poly(hydroxyacid) composite scaffolds for tissue engineering: Third Generation PHA-Based Scaffolds for TE. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 105(6):1667-1684

Goonoo, N., Bhaw-luximon, A., Passanha, P., Esteves, S., Schönherr, H. and Jhurry, D. (2017) Biomineralization potential and cellular response of PHB and PHBV blends with natural anionic polysaccharides. Materials Science and Engineering: C. 76, p. 13-24

Jobling-Purser B., Thai S.M., Fritz T., Esteves S.R., Dinsdale R.M. and Guwy A.J. (2014) An improved titration model reducing over estimation of TVFAs in AD of energy crop, animal slurry and food waste. Water Res. 27: 162-170.

Jones, S.W., Karpol, A., Friedman, S., Maru, B.T., Tracy, B.P. (2020) Recent advances in single cell protein use as a feed ingredient in aquaculture, Curr. Opin. Biotech 61: 189–197

Kedia G., Passanha P., Dinsdale R. M., Guwy A.J., Lee M. and Esteves S.R. (2013) Addressing the Challenge of Optimum Polyhydroxyalkanoate Harvesting: Monitoring Real Time Process Kinetics and Biopolymer Accumulation Using Dielectric Spectroscopy. Bioresource Technology 134: 143–150

Kedia, G., Passanha, P., Dinsdale, R. M., Guwy, A. J. & Esteves, S. R. (2014) Evaluation of feeding regimes to enhance PHA production using acetic and butyric acids by a pure culture of *Cupriavidus necator*. Biotechnology and Bioprocess Engineering. 19(6): 989-995

Kyazze G., Popov A., Dinsdale R., Esteves S., Hawkes F., Premier G., Guwy A. (2010). Influence of catholyte pH and temperature on hydrogen production from acetate using a two chamber concentric tubular microbial electrolysis cell. International Journal of Hydrogen Energy, 35 (15) 7716-7722.

Kumi, P. J., Henley, A., Shana, A., Wilson, V. and Esteves, S. R. (2016) Volatile fatty acids platform from thermally hydrolysed secondary sewage sludge enhanced through recovered micronutrients from digested sludge. Water Research. 100, p. 267-276

Linder, T. (2019) 'Making the case for edible microorganisms as an integral part of a more sustainable & resilient food production system.' Food Sec. 11: 265-278

Massanet-Nicolau J., Guwy A., Dinsdale R., Premier G. and Esteves S. (2010) Production of Hydrogen from Sewage Biosolids in a Continuously Fed Bioreactor: Effect of Hydraulic Retention Time and Sparging. International Journal of Hydrogen Energy. 35 (2) 468-478.

Monson K.D., Esteves S.R., Guwy A.J. and Dinsdale R.M. (2007) AD of Biodegradable Municipal Wastes – A Review, University of Glamorgan ISBN 978-1-84054-156-5

Oliveira A, Chong ZS, Patterson T, Reed J, Kumi PJ, Esteves S (2019) Development of a Novel Multi-Parameter Monitoring Tool for Odour Management and Environmental Compliance of Anaerobic Digestion Technology. ODOURS 19 - International Conference on Odours 16th - 17th May 2019, University of Aveiro, Portugal

Oliveira, I., Hegarty, F., Reed, J., Victoria W., V. and Esteves, S.R. (2013) Ammonia stripping methodologies for pre and post digested thermally hydrolysed waste activated sludge: Preliminary investigations. 18th European Biosolids & Organic Resources Conference & Exhibition, 19th November 2013, Manchester

Oliveira, I., Reed, J. P., Abu-Orf, M., Wilson, V., Jones, D. and Esteves, S. R. (2016) The potential use of shear viscosity to monitor polymer conditioning of sewage sludge digestates. Water Research. 105, p. 320-330

Passanha P, Esteves S.R., Kedia G., Dinsdale R.M. and Guwy A.J. (2013) Increasing PHA Yields From *Cupriavidus necator* by using Filtered Digestate Liquors. Increasing polyhydroxyalkanoate (PHA) yields from *Cupriavidus necator* by using filtered digestate liquors. Bioresource Technology 147: 345–352

Passanha P., Kedia G., Dinsdale R.M., Guwy A.J., Esteves S.R. (2014). The use of NaCl addition for the improvement of PHA production by *C. necator*. Bioresource Tech. 163: 287-294

Patterson T, Savvas S, Chong Z., Law I, Dinsdale R and Esteves S (2017) Integration of Power to Methane in a waste water treatment plant – A feasibility study. Bioresource Technology 24(A): 1049-1057

Patterson T., Dinsdale R.M and Esteves S. (2008). A review of energy balances and emissions associated with biomass derived transport fuels relevant to the UK context. Energy & Fuels 22 (5) 3506-3512

Patterson T., Esteves S., Dinsdale R., Guwy A. (2011a). Life Cycle Assessment of Biogas Infrastructure Options on a Regional Scale. Bioresource Technology, 102, 7313 – 7323

Patterson T., Esteves S., Dinsdale R., Guwy A. (2011b). An evaluation of the policy and techno-economic factors affecting the potential for biogas upgrading for transport fuel use in the UK. Energy Policy, 39, 1806 – 1816

Patterson T., Esteves S.R., Dinsdale R, Guwy A, and Maddy J. (2013). Life Cycle Assessment of Biohydrogen and Biomethane Production and Utilisation as a Vehicle Fuel. Bioresource Technology 131: 235–245

Patterson, T., Esteves, S., Carr, S., Zhang, F., Reed. J., Maddy, J., Guwy, A. (2014) Life Cycle Assessment of the Electrolytic Production and Utilization of Low Carbon Hydrogen Vehicle Fuel. International Journal of Hydrogen Energy, 39, 7190-7201

Popov, A. L., Michie, I. S., Kim, J. R., Dinsdale, R. M., Guwy, A. J., Esteves, S. R. & Premier, G. C. (2015) Enrichment strategy for enhanced bioelectrochemical hydrogen production and the prevention of methanogenesis. International Journal of Hydrogen Energy. 41, 7, p. 4120-4131

Premier, G.C., Kim J.R., Massanet-Nicolau J., Kyazze G., Esteves S., Penumathsa B. KV, Rodríguez J., Maddy J., Dinsdale R.M., Guwy A.J. (2013) Integration of biohydrogen, biomethane and bioelectrochemical systems. Renewable Energy, 49: 188-192

Redhead S, Nieuwland J, Esteves S, Lee D-H, Kim D-W, Mathias J, Cha C-J, Toleman M, Dinsdale R, Guwy A, Hayhurst E. (2020) Fate of antibiotic resistant E. coli and antibiotic resistance genes during full scale conventional and advanced anaerobic digestion of sewage sludge. PLoS ONE 15(12): e0237283

Reed J P, Devlin D., Esteves S.R., Dinsdale R. and Guwy A. (2013) Integration of NIRS and PCA techniques for the process monitoring of a sewage sludge anaerobic digester. Bioresource Technology 133:398-404.

Reed J.P. Devlin D., Esteves S.R.R., Dinsdale R. and Guwy, AJ. (2011) Performance parameter prediction for sewage sludge digesters using reflectance FT-NIR spectroscopy. Water Research. 45 (8): 2463-2472.

Savvas S, Donnelly J, Patterson T, Chong Z and Esteves S (2018) Methanogenic capacity and robustness of hydrogenotrophic cultures based on closed nutrient recycling via microbial catabolism: Impact of temperature and microbial attachment. Bioresource technology 257: 164-171

Savvas S, Donnelly J, Patterson T, Chong ZS and Esteves S (2017) Biological methanation of $CO_2$ in a novel biofilm plug-flow reactor: A high rate and low parasitic energy process. Applied Energy, 202: 238-247

Savvas S, Gangappa R, Johnson M, Bellini R, Patterson T, Chong Z, and Esteves S (2022). Anaerobic fermentations – a prerequisite for an efficient sector coupling. 8th International Conference on Renewable Energy Gas Technology (REGATEC). Malmö, Sweden

Savvas S, Gangappa R, Ni X-N, Davies W, Barton W, Thomason M, Patterson T, Esteves S R. (2024) The Tubular Baffled Reactor and its Potential for the Biological Methanation of Carbon Dioxide. Renewable Energy Journal (Accepted)

Savvas, S., Donnelly, J., Patterson, T., Dinsdale, R., Esteves, S. (2016). Closed Nutrient Recycling via Microbial Catabolism in an Eco-Engineered Self Regenerating Mixed Anaerobic Microbiome for Hydrogenotrophic Methanogenesis. Bioresource Technology, 227: 93 – 101.

Stiles WAV., Styles D, Chapman SP, Esteves S, Bywater A, Melville L, Silkina A, Lupatsch I, Grünewald CF, Lovitt R, Chaloner T, Bull A, Morris C, Llewellyn CA (2018) Using microalgae in the circular economy to valorise anaerobic digestate: Challenges and opportunities. Bioresource Technology 267 (2018) 732–742

Tao, B., Donnelly, J., Oliveira, I., Anthony, R., Wilson, V. and Esteves, S. (2017) Enhancement of microbial density and methane production in advanced anaerobic digestion of secondary sewage sludge by continuous removal of ammonia. Bioresource Technology. 232: 380-388

Tao, B., Passanha, P., Kumi, P., Wilson, V., Jones, D. & Esteves, S. (2016) Recovery and concentration of thermally hydrolysed waste activated sludge derived volatile fatty acids and nutrients by microfiltration, electrodialysis and struvite precipitation for polyhydroxyalkanoates production. Chemical Engineering Journal. 295, p. 11-19

Williams J., Williams G., Dinsdale R., Guwy A. and Esteves S. (2013) Monitoring methanogenic population dynamics in a full-scale anaerobic digester to facilitate operational management. Bioresource Technology 140 (2013) 234–242.

# Stories in the Dust: the arts as a medium to communicate climate science

A collaboration between the University of Southampton and Stories in the Dust Theatre Company

Ian D. Williams, Anna Harriott, Iona Johnson

**Abstract**

Modern society urgently needs to address dangerous climate change. This is hugely challenging and requires active public engagement. Many political, environmental, social, technological, legal, and economic approaches have been trialled, but only slow progress has been achieved. Scientists universally face considerable difficulties in communicating research findings to the public in an effective manner. Historically, scientific communication has focused on public education and raising awareness. However, recent studies have highlighted that ideology, not knowledge, best predicts environment-related attitudes and behaviour and hence emotion-based approaches are being tested. This paper provides an overview of techniques used for scientific communication and makes the case that new, more impactful methods are necessary. We outline an interdisciplinary approach that combines science and theatre to generate a co-created show that applies intergenerational influence combined with emotional responses and personification to help promote pro-environmental attitudes and behaviours. Stories in the Dust (SITD) is a theatre show for ages 5-12 with themes of climate change, displacement, and hope. SITD was initially devised by two actors who tested the show concept, receiving positive feedback from community audiences. The next stage was a research & development period in partnership with a primary school and a university professor who acted as a scientific and educational consultant to engage participants & develop show/wraparound content. The show went on tour October to November 2023, with pictures, reviews, and resources available on a dedicated website. Reflections on the approach detail what worked well, what challenges were faced, how practice could be replicated elsewhere, how innovations may be sustained, and future aspirations and plans. The SITD team's plan is to provide entertaining and thought-provoking theatre shows that provide employment for the arts community as well as improving the way that scientists engage in scientific communication.

Keywords: climate change; interdisciplinary; scientific communication; theatre; intergenerational influence; behaviour change.

---

## 1 Introduction

Modern society faces many persistent problems, including the urgent development and realisation of technological and social approaches to addressing dangerous climate change. Accelerating effective large-scale carbon management requires active public engagement and motivation and this is hugely challenging. Many political, environmental, social, technological, legal, and economic (PESTLE) approaches have been trialled, but only slow progress has been achieved. This is partly because scientists commonly encounter substantial difficulties in communicating research findings to the public in an effective manner (Williams, 2023).

Scientific communication is the practice of communicating science-related topics – science, technology, engineering, and maths (STEM) – to non-experts. Traditional methods of public communication – consultation papers, community information (posters, leaflets, doorstepping, focus groups), public meetings, workshops and seminars, advisory panels, stalls at fairs / events, mass media campaigns, writing articles for newspapers, magazines, and online fora – tend to have narrow, predominantly short-term impacts. Even very high-profile campaigns – for example, the use of children's TV characters The Wombles to highlight the problem of littering – did not stop litter. Other terms are used interchangeably for similar activities, including outreach and public engagement, although they are slightly different.

Outreach activities are generally regarded as public lectures, workshops, and events to inspire public understanding of STEM topics. Outreach activities are frequently used to stimulate school children to take up STEM study in higher education. The goal of public engagement is to involve the public in participatory (i.e. two-way) scientific conversations, often about shared issues and problems, to benefit society.

Scientific communication is a vital tool when scientists need their findings to generate impact, defined as primary and secondary long-term effects produced by an intervention, directly or indirectly, intended or unintended. Research outputs on topics such as climate change need to inspire changes in public knowledge and behaviour to create impact.

There has been a historical tendency to assume that any divergence between scientific and public views is caused by incomplete/flawed public knowledge and so communication efforts have focused on public education and raising awareness. However, recent studies have highlighted that ideology, not knowledge, best predicts environment-related attitudes and behaviour (Nisbet et al., 2015). Thus, a few researchers have moved away from investigating cognitive bias towards understanding the effectiveness of emotion-based approaches (Cooper and Nisbet, 2016; Brock et al., 2022).

The problem is particularly important in environmental science due to the immediacy of the issues (Stamm, Clark and Eblacas, 2000; Moser, 2010; Post, 2016). Whilst the public are now generally highly aware of a range of environmental issues (Brock et al., 2023), they are unaware of the positive impacts they can generate by the collective consequences of individual actions (Hamilton, 2016; Knight, 2016; Borthakur and Govind, 2017). Awareness is significant, because, firstly, citizen support is essential for implementation of ambitious environmental policies and, secondly, populism and its rhetoric are currently burgeoning, which often pushes the public away from policies based on science-based evidence (Huber et al., 2020). To communicate scientific findings in a way that is more accessible and acceptable to the public, and to produce a positive impact, new methods must be explored. Universities have an important role in collaborating and engaging with their local stakeholders to facilitate the desired move towards a more sustainable society.

One rarely used method that has previously shown success is intergenerational influence (Maddox et al., 2011), where one generation has a positive influence on the behaviour of another. To develop curiosity and enhance the wider skills of undergraduate and postgraduate students, one of the authors (Williams) has, for over 30 years, facilitated them to reach out to primary/secondary schoolchildren. The purpose is to actively demonstrate how the thinking characteristics, skills and attributes of student scientists/engineers can be integrated and further developed to engage the next generation.

To illustrate, with (now defunct) environmental charity Wastewatch, Williams worked on the "Taking Home Action on Waste" (THAW) project, which was the first attempt to measure the intergenerational influence of an education programme on (recycling) behaviour at home (Maddox et al., 2011). Focusing on primary-age children, the project showed that the school-based education programme led to improved household participation in recycling as well as decreasing amounts of residual waste. The THAW study inspired American researchers to show that teaching in this way significantly increased parents' concern over the issue (Rosen, 2019). The method's influence is further demonstrated by work of the UK's Primary Engineer Programme[1]. University students routinely report that having to explain a concept to younger students helps them to better grasp it: the query of an outsider forces them to replace their false feeling of understanding with actual reasoning.

Another rarely utilised approach involves using music, theatre and art performances and exhibitions to reach the public; to raise awareness, educate and change attitudes through evoking emotional responses. There is a long history of art and theatre being used to communicate problems within society. Creative artists have an ability to convey issues in a highly emotional way, which can raise awareness, promote reflection, and encourage behavioural change.

Theatre is habitually politically charged with contemporary social issues. Theatre could hold considerable power in tackling climate change via storytelling but – maybe surprisingly - there is scarcely any history of green theatre, and certainly no noteworthy examples of climate change productions (Butler, 2009). However, in theory, theatre could help to shape public opinion by creating emotion and empathy in immersive and visual ways.

In contrast, music has long been used for the purposes of environmental activism and protest, with a timeline that stretches from Woody Guthrie's "This Land is Your Land" (1945) to Raye's "Environmental Anxiety" (2023). Music can cause measurable neurological responses in the brain linked with specific emotional responses, both positive and negative (Bharucha and Curtis, 2008; Goldstein, 2013; Sittler et al., 2019). These emotional responses demonstrate how deeply music can affect the public and how it may be able to capture their attention. If the public demonstrates a strong emotional reaction to a piece of music designed to evoke a response to clear evidence-based information about an environmental issue this may aid them to gain new knowledge or change their behaviour (Crowther et al., 2016; Wodak, 2018), or both. A musical approach has been used by Williams during his work as an educator and it has also been used by De Feo et al. (2019) as part of the Italian Greenopoli Method for waste management education.

Evaluating the potential of communicating environmental information and research through the arts is a newly emerging area. Few research projects have used the arts as a scientific communication method, and indeed the few research papers on this topic tend to be reflective, not systematic studies. Existing reflective papers meditate on the past experiences of scientists' involvement with creative projects and their perceived success, all concluding that the creative arts have the potential to raise awareness (Stolberg, 2006; Curtis, 2009; Curtis, Reid and Ballard, 2012). The role of empathy has been discussed in Curtis (2009), creative arts are recommended as a tool to create empathy towards ecological and environmental issues. Sommer and Klöckner (2019) is one of the few systematic papers on the potential of climate change inspired art as a tool to evoke emotion and finds art can inspire an immediate emotional response in audiences.

As well as providing context for the need to find new, more impactful means for scientific communication on environmental topics, this paper outlines who is involved in the interdisciplinary SITD project, why they are involved, reflections on how the SITD approach has evolved, what outputs have been achieved to date and future aspirations and plans.

## 2 Who is involved in Stories in the Dust?

Several participants with a wide and varied range of skills are necessary for co-creation of an interdisciplinary educational show

1 https://www.primaryengineer.com/

that combines science and theatre. To illustrate, we provide a brief overview of the background and skills of the core SITD team here, with the wider team listed in the Acknowledgements.

Anna Harriott is an Actor, Theatre Maker, Facilitator and Producer with extensive experience delivering professional shows, community projects and facilitating workshops in a variety of settings. She is a programmer for Pound Arts[2] in Wiltshire, runs Tall Tree Theatre and is co-creator of Stories in the Dust. Anna (and Iona) are Associates of Climate Museum UK. Anna led on producing, project management and budget management.

Iona Johnson is an Actor, Musician, Facilitator and Theatre Maker. She has worked on many projects[3] catering for specific and diverse audiences. Iona facilitates in schools nationwide for The Paper Birds, in children's hospices for Oily Cart and universities/theatres for Frozen Light. She is co-creator of Stories in the Dust. Iona led on accessibility, workshop content and Education Pack creation.

Ian Williams is Professor of Applied Environmental Science[4] at the University of Southampton. He is a qualified schoolteacher and an experienced university academic and research leader. He has published extensively on carbon/waste management, resource efficiency, behaviour change, pollution, and sustainability. Ian provided expert scientific input and education-related expertise and led on delivery of the SITD Education Pack. PhD student Toby Roberts provided artwork for the Education Pack.

The collaborating school was Longford Primary[5], near Salisbury. Specialist class teachers facilitated delivery of workshops, provided educational/pastoral care for the pupils and supported project evaluation.

## 3 How did Stories in the Dust evolve?

### 3.1 The artists

In 2022, Anna and Iona started to work on their debut show as a creative pair. They had worked in similar circles in the industry but had never collaborated on a project until a chance meeting backstage sparked the start of what was to become *Stories in the Dust*. They bonded over the belief that theatre for young people can be bold, honest and should address societal issues.

Anna and Iona believe that theatre is a tool for social change. It holds a mirror up to its audience, who are active participants, required to personally reflect on what they are experiencing. They are free to interpret the performance based on their own life experiences whilst being shown new perspectives. It is a deeply individual and participatory experience that allows people space to process societal problems and explore potential solutions. And so they began to create a show that would do just that.

Through a theatre devising process inspired by world news and the climate emergency, they developed a show that addressed climate anxiety in young people (see Appendix for their personal perspectives and reflections). They were given research and development (R&D) space at Salisbury Arts Centre and received seed funding for the initial version of SITD from MAST[6] through the Emergency Festival[7]. The show then pilot-toured to four areas of deprivation through Wiltshire Creative[8].

This led to Anna and Iona writing a successful bid for funding to Arts Council England, receiving funds for a three-week R&D project, in partnership with Pound Arts and Longford Primary School, with support from Wiltshire Creative. Via MAST, they reached out for an environmental scientist as a potential consultant to their new SITD project, to help embed the show in fact and create an accompanying education pack.

### 3.2 The scientist

Ian Williams has been an environmental scientist for 35 years (see Appendix). In 2019, he devised and started the TRACE (Transitioning to a Circular Economy) with artists project, a novel and ground-breaking collaboration between scientists, creative artists, and primary schoolchildren. The aim of TRACE was to trial and critically review the capability of intergenerational and creative projects to communicate to the public about e-waste to stimulate behaviour change towards circular economy principles.

As part of this trial, in March 2020, children from Otterbourne School in Hampshire, UK, put on musical performances and took part in art exhibitions, shown in a video[9], a website[10], a reflective blog[11] and a range of articles[12].

Together with the SÓN orchestra[13], led by Robin Browning[14], the team worked with schoolchildren to develop and produce original musical performances focusing on e-waste. Children were encouraged to think about the amount of electrical equipment they had in their homes and to consider what happens when it is discarded. The creative artists involved were guided by scientists to further their own understanding

2 https://poundarts.org.uk/
3 https://www.ionajohnson.co.uk/projects
4 https://www.southampton.ac.uk/people/5x28ky/professor-ian-williams

5 https://www.longford.wilts.sch.uk/

6 https://www.mayflowerstudios.org.uk/
7 https://www.mayflowerstudios.org.uk/what-s-on/emergency-festival-2022/
8 https://www.wiltshirecreative.co.uk/

9 https://www.youtube.com/watch?v=duDdWoq8B-ZE
10 https://ewaste.thesonproject.com/
11 https://generic.wordpress.soton.ac.uk/arts-at-unisouth/2020/05/18/susannah-pal-sotsef/
12 https://www.circularonline.co.uk/features/children-are-instrumental-to-addressing-e-waste/
13 https://www.sonorchestra.com/
14 https://www.robinbrowning.com/

about e-waste generation and solutions to this crisis. It cumulated in two musical performances with an associated art exhibition (by the artist Susannah Pal) that took place in March 2020 at the University of Southampton.

The TRACE project was highly successful in developing a new way to communicate to the public (Brock et al., 2022). All groups – creative artists, school children and the public – showed that they had become more aware of issues relating to e-waste and had had an emotional response to the project. All the artists and a majority of the public reported via an end-of-project survey that they intended to change their behaviour following the TRACE project:

- 99% of the audience reported a rise in awareness of e-waste issues,
- 70% indicated an intention to change e-waste disposal,
- and 65% indicated an intention to change reuse and repair behaviour.

The intergenerational influence (Maddox et al., 2011; Istead and Shapiro, 2014) – where one generation has a positive influence on the behaviour of another – clearly contributed to raising awareness. Households where children had frequently discussed the project or were speakers or soloists or caregivers, were more likely to report higher levels of awareness.

This fresh thinking to combine intergenerational influence and music/arts as a mechanism for communicating environmental research made the project a success. The critical analysis showed that anthropomorphism of e-waste and creating empathy was effective in creating emotional responses. There was compelling evidence that intergenerational influence between children and caregivers improved the caregivers' e-waste awareness. Caregivers whose children were highly engaged with the project were more likely to report higher levels of awareness and state an intention to change behaviour.

The TRACE project received an award at the 2021 MRW National Recycling Awards for Campaign of the Year. The independent, expert panel of judges at the awards praised the project for being "glorious and innovative, while targeting a very serious issue". They said: "It is so different – the idea of bringing different generations together and combining art and music was fascinating. It's a great example to encourage others to think outside their current way of doing things."

The project also contributed inspiration for the BBC to launch a new environmental initiative, *The Regenerators* (BBC, 2021), which aims to educate and inspire children, young people and families to take simple steps to build a greener future.

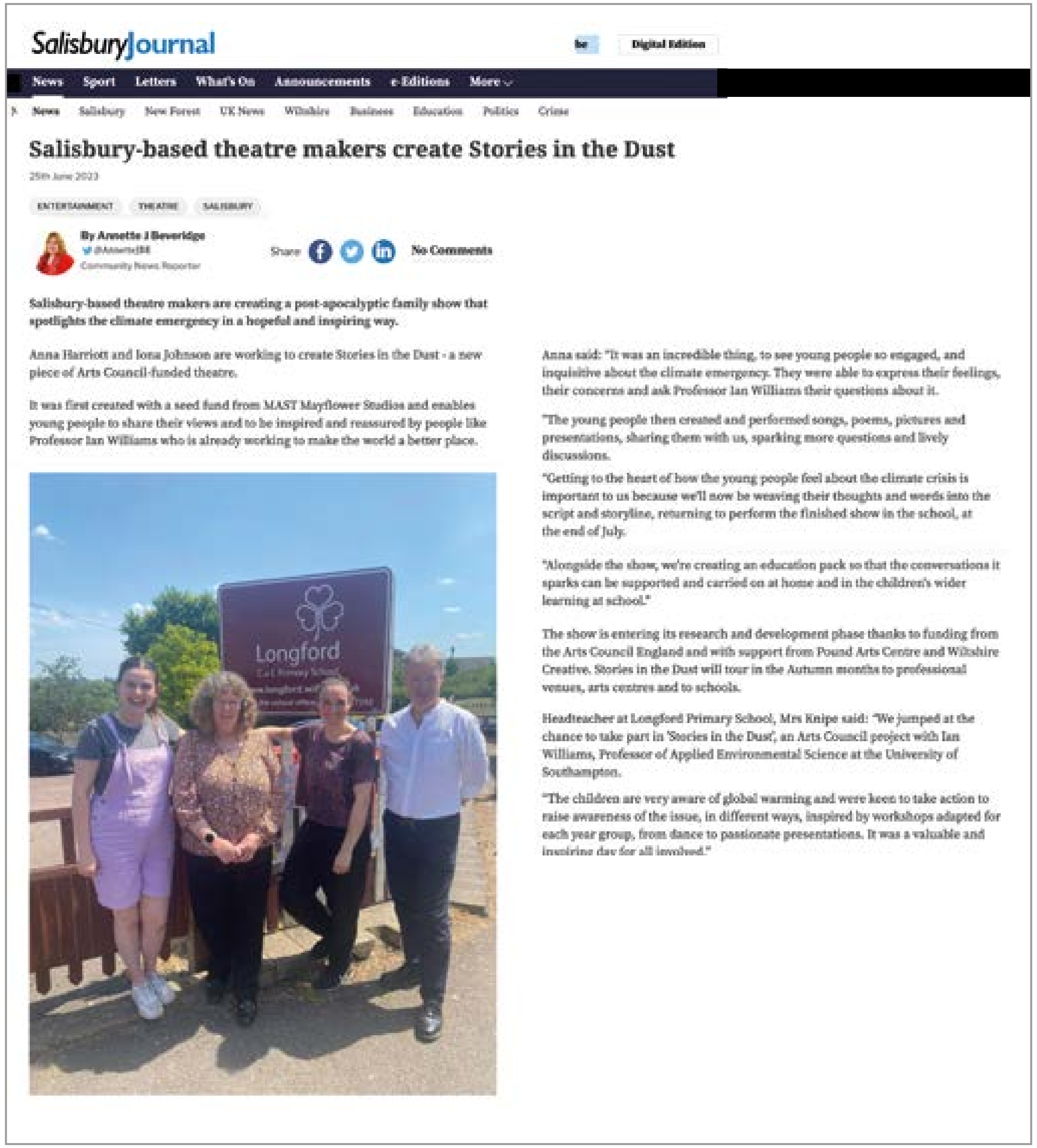
Encouraged by this success, Ian devised and secured funding in 2022 for environmental communication projects with an Artist in Residence[15] and a Musician in Residence[16]. These projects were also highly successful, and led to an invitation to participate in the Mayflower Studios (MAST) Climate Siren Poets[17] project and Emergency Festival[18] in October 2022.

## 4 The Stories in the Dust philosophy and approach

We know the power of theatre/music to engage, inform and give young people an opportunity to express their viewpoint/voice on topics. We decided to combine scientific material about climate change with the principles of edutainment to share information in an open, adaptable, and creative way to build understanding and stimulate curiosity in the next generation. The SITD project builds on the theories of edutainment, intergenerational influence, and personification. It requires an open-ended, interdisciplinary, multi-way exchange of ideas and concepts between the participants who work together over an extended period to co-create an educational show that allows the voices of young people to be heard.

Our method of engaging young people was to create flexible, diverse workshops that allowed participants to explore their thoughts and feelings in fun, active group activities, which then developed into more focused, individually creative responses. During our R&D period, we devised drama activities and games, related to the specific environmental topics identified and selected in our project preparation. At a day-long workshop at Longford School (see Figure 1), we both tested and broke out of these activities to include discussions with Ian as the science expert to inform the young people. We allowed their questions to inform the focus of the workshop, reinforcing the fun activities with research-based evidence and offering the opportunity for reassurance and positive discussions about what individuals can do to create a change. We asked the young people to creatively respond to the topics explored, giving them a platform to share their thoughts and feelings. We then set them tasks to complete, extending the learning beyond the workshop. They created artwork, poems, presentations and performances inspired by the workshop, with further independent research done in the classroom. We returned to the classrooms at the end of the day to be an audience for these, and then hosted an additional question-and-answer session with Ian. The young people's responses to the different elements of the workshop/day revealed to us their specific areas of interest and their understanding of the topics covered. The creativity and flexibility of the workshop allowed every child to respond, no matter their learning style,

15 https://cdt-sicities.soton.ac.uk/2022/05/11/my-plastic-world-susannah-pal/
16 https://www.robinbrowning.com/news/musician-in-residence-project/
17 https://www.capefarewell.com/sirens/
18 https://www.mayflowerstudios.org.uk/what-son/emergency-festival-2022/



SalisburyJournal

Digital Edition

News Sport Letters What's On Announcements e-Editions More

News Salisbury New Forest UK News Wiltshire Business Education Politics Crime

## Salisbury-based theatre makers create Stories in the Dust

25th June 2023

ENTERTAINMENT THEATRE SALISBURY

By Annette J Beveridge
Community News Reporter

Share No Comments

**Salisbury-based theatre makers are creating a post-apocalyptic family show that spotlights the climate emergency in a hopeful and inspiring way.**

Anna Harriott and Iona Johnson are working to create Stories in the Dust - a new piece of Arts Council-funded theatre.

It was first created with a seed fund from MAST Mayflower Studios and enables young people to share their views and to be inspired and reassured by people like Professor Ian Williams who is already working to make the world a better place.



Anna said: "It was an incredible thing, to see young people so engaged, and inquisitive about the climate emergency. They were able to express their feelings, their concerns and ask Professor Ian Williams their questions about it.

"The young people then created and performed songs, poems, pictures and presentations, sharing them with us, sparking more questions and lively discussions.

"Getting to the heart of how the young people feel about the climate crisis is important to us because we'll now be weaving their thoughts and words into the script and storyline, returning to perform the finished show in the school, at the end of July.

"Alongside the show, we're creating an education pack so that the conversations it sparks can be supported and carried on at home and in the children's wider learning at school."

The show is entering its research and development phase thanks to funding from the Arts Council England and with support from Pound Arts Centre and Wiltshire Creative. Stories in the Dust will tour in the Autumn months to professional venues, arts centres and to schools.

Headteacher at Longford Primary School, Mrs Knipe said: "We jumped at the chance to take part in 'Stories in the Dust', an Arts Council project with Ian Williams, Professor of Applied Environmental Science at the University of Southampton.

"The children are very aware of global warming and were keen to take action to raise awareness of the issue, in different ways, inspired by workshops adapted for each year group, from dance to passionate presentations. It was a valuable and inspiring day for all involved."

or individual access needs. From a simple drawing to a dance move, to a complex presentation, each child's contribution informed us.

To support replicability and scale-up of the SITD approach, an accompanying bespoke education pack has been created that is freely available from the website[19]. We believe the SITD approach is scalable for all types of area – rural and urban, big and small, coastal and inland – and can be applied generically.

After the R&D period, in Autumn 2023, SITD went on to tour to professional venues including *artsdepot, Half Moon, Greenwich Theatre, Everyman Cheltenham and The Plough.* It also toured to community venues, libraries, schools and through rural touring schemes.

The show received strong reviews and audience comments[20] and four stars from The Reviews Hub.[21] The SITD team are now reflecting on the first tour to provide evidence of the project's success/failure, inform and

*Left: Figure 1. Longford School workshop day. From The Salisbury Journal.*[22]

19 https://www.storiesinthedust.co.uk/resources
20 https://www.storiesinthedust.co.uk/reviews
21 https://www.thereviewshub.com/stories-in-the-dust-greenwich-theatre-london/
22 https://www.salisburyjournal.co.uk/news/23609160.salisbury-based-theatre-makers-create-stories-dust/?ref=rss&utm_source=dlvr.it&utm_medium=twitter

improve future activities, and inform the practices of others.

The show continues to gather momentum and the team are regularly approached by venues and schemes wanting to book the show. This has enabled them to build a tour for autumn 2024 and to develop new relationships with venues and promoters. Plough Arts Centre in North Devon (an Arts Council England-designated Priority Place) has pledged further, ongoing support.

"Having read that Stories in The Dust with Anna Harriott and Iona Johnson was to be a post-apocalyptic play for 5 years+ I was curious about how that would work, but it most certainly did work and in such a way that it gently mesmerised an audience of all ages at The Plough Arts Centre on 26 October 2023, who sat transfixed as this apparently simple yet deceivingly complex tale unfolded and immersed the audience in a different reality.

"It was a really beautiful show; delicate, poignant, lyrical, funny, brave and ultimately encouraging. It resonated with so many recent and current news stories, plus fears for the future of mankind and the planet, with little echoes of Golding's *Lord of the Flies* and Brecht's *Mother Courage* as the two women survive each moment, each argument, each small triumph and find the determination to cling to life and hope. The powerful songs, the playful interplay with the audience and the hidden surprises within the set and props added a joyful dynamic backdrop to this incisive piece of theatre, which must surely have a future life after the current tour is over. I can't wait for them to bring it back to our venue."

*—Richard Wolfenden-Brown, Director, The Plough Arts Centre*

**5 Findings and next steps**

Conveying the gravity and adverse impacts of climate change to the public effectively is a huge challenge. The SITD show has shown that combining theatre and science can generate a show – in this case a form of scientific communication – that applies intergenerational influence combined with emotional responses to theatre/music that can help to promote pro-environmental attitudes and behaviours. To support replicability, scale-up and sustainability, a bespoke education pack for primary-age children has been created.

Audience responses showed that demonstrating the effects of climate change seen through the eyes of children was effective in stimulating emotional responses. As previously seen in the TRACE project, intergenerational influence contributes to raising awareness in caregivers when emotions become heightened because of visual and aural stimulation by creative artists.

Anecdotal evidence from the SITD audiences and performers suggests that the children and audiences seem to have grasped the importance and likely future impacts of climate change. These responses were probably due to a combination of factors: i) the story-telling skill and stagecraft of the performers, ii) the public judged that the scientific evidence which underpinned the SITD story was trustworthy and authoritative, and iii) the emotional messages from performances worked well, i.e. hope exceeded fear. The SITD team know that these suppositions are tentative and require further research to provide firmer evidence. Nevertheless, the SITD approach is clearly promising and could therefore be applied in future to generate public support for pro-environmental policies that are based upon independently peer-reviewed, widely supported, and trusted scientific evidence. Scientists and researchers are encouraged to develop interdisciplinary partnerships with creative artists to test this theory and to potentially accelerate uptake of their research findings.

SITD will tour again in Autumn 2024 alongside an extensive accompanying workshop programme that serves to embed the project into communities, educate, inform and inspire. The team will create bespoke installations of local captured voices, hosted by venues, elevating young people's thoughts and feelings on the Climate Emergency, and developing relationships between venues, their communities, and the science world.

The project has ongoing support from its partners and will be touring through Cultrapedia in Lancashire (a levelling-up area), through Celebrating Age in Wiltshire, into Salisbury Hospital and many more venues, both professional and community, including multiple Arts Council England-designated Priority Areas. This work will also enable us to test our theory quantitatively, and to inform, educate and actively listen to our audiences, facilitating their individual creative responses to the themes of the show, as well as enabling future development/innovations (e.g. a show for secondary school children, shows on other sustainability-related topics) and further informing creative work. Indeed, in the next iteration of the SITD approach we will actively develop methods to secure more information on benefits and outcomes (for example, any resulting changes in behaviour).

It is worth highlighting that the project contributes to the University of Southampton's Sustainability Strategy, its Civic University agenda and its support for the arts. The SITD team's plan is to provide entertaining and thought-provoking theatre shows that provide employment for this professional artistic community as well as stimulating long-term strategic projects that will improve the way that scientists communicate, inspire, and inform the next generation about climate change and other environmental issues.

**Acknowledgements**

The TRACE project was funded by the University of Southampton's EPSRC Impact Acceleration Account 2017-2020. Stories in the Dust was originally seed-funded by MAST Mayflower Studios for their Emergency Festival and pilot-toured through Wiltshire Creative (2022). The show's 2023 R&D period was funded by Arts Council England National Lottery Project Grants, in partnership with Pound Arts and Longford Primary School.

The further Creative Team are: Russ Tunney, Director; Orpheus Alexander, Design: Set & Puppets; David Lewington, Sound Design & Arrangement; Rachel Bayton, Design: Costume; Mark Dymock, Design: Lighting; Toby Roberts, Education Pack Illustrator.

We are particularly grateful to, and acknowledge the vital contribution of, the staff and students from Longford Primary School, Salisbury, England.

**References**

BBC (2021). "BBC Bitesize launches The Regenerators ahead of COP26 climate change conference". Available at: https://www.bbc.com/mediacentre/2021/bbc-bitesize-the-regenerators (Last accessed: 2 January 2024).

Bharucha, J.J., Curtis, M. (2008). Affective spectra, synchronization, and motion: Aspects of the emotional response to music. Behavioral and Brain Sciences 31, 579–579.

Borthakur, A. and Govind, M. (2017). Emerging trends in consumers' E-waste disposal behaviour and awareness: A worldwide overview with special focus on India. Resources, Conservation and Recycling. 117, 102–113.

Brock, A.; Williams, I.D. and Kemp, S. (2023). "I'll take the easiest option please". Carbon reduction preferences of the public, Journal of Cleaner Production, 429, 2023, 139398.

Brock, Alice; Browning, Robin; Campanie, Anca; Pal, Susannah and Williams, Ian D. (2022). Developing public communication methods by combining science, creative arts and intergenerational influence: the Trace Project. Detritus, 21, 114 - 128.

Butler, R. (2009). Can theatre do anything about climate change? Available at: https://www.theguardian.com/stage/theatreblog/2009/may/22/climate-change-theatre (Last accessed: 2 January 2024).

Cooper K. E. and Nisbet E. C. (2016). Green narratives: How affective responses to media messages influence risk perceptions and policy preferences about environmental hazards. Science Communication, 38, 626-654.

Crowther, G.J., McFadden, T., Fleming, J.S., Davis, K. (2016). Leveraging the power of music to improve science education. International Journal of Science Education 38, 73–95.

Curtis, D. J. (2009). Creating inspiration: The role of the arts in creating empathy for ecological restoration. Ecological Management & Restoration, 10(3), 174–184.

Curtis, D. J., Reid, N. and Ballard, G. (2012). Communicating Ecology Through Art What Scientists Think. Ecology and Society, 17(2).

De Feo, G.; Ferrara, C.; Iannone, V. and Parente, P. (2019). Improving the efficacy of municipal solid waste collection with a communicative approach based on easily understandable indicators. Science of The Total Environment, 651(215), 2380-2390.

Goldstein, A. (2013). Thrills in response to music and other stimuli. Physiological Psychology 1980 8:1 8, 126–129.

Hamilton, L. C. (2016). Public Awareness of the Scientific Consensus on Climate. SAGE Open. 6(4), 215824401667629.

Huber, R.A.; Fesenfeld, L. & Bernauer, T. (2020). Political populism, responsiveness, and public support for climate mitigation. Climate Policy, 20(3), 373-386.

Istead, L. and Shapiro, B. (2014). Recognizing the child as knowledgeable other: Intergenerational learning research to consider child-to-adult influence on parent and family eco-knowledge. Journal of Research in Childhood Education. 28(1), 115–127.

Knight, K. W. (2016). Public awareness and perception of climate change: a quantitative cross-national study. Environmental Sociology. 2(1), 101–113.

Maddox, P., Doran, C., Williams, I.D., Kus, M., (2011). The role of intergenerational influence in waste education programmes: The THAW project. Waste Management. 31(12), 2590–2600.

Moser, S. C. (2010). Communicating climate change: History, challenges, process and future directions. Climate Change, 1(1), 31–53.

Nisbet E. C., Cooper K. E., Ellithorpe M. (2015). Ignorance or bias? Evaluating the ideological and informational drivers of communication gaps about climate change. Public Understanding of Science, 24, 285-301.

Post, S. (2016). Communicating science in public controversies: Strategic considerations of the German climate scientists. Public Understanding of Science. 25(1), 61–70.

Rosen, J. (2019). How teaching kids about climate change can influence their conservative parents. Los Angeles Times, 6 May 2019, available at: https://www.latimes.com/science/la-sci-climate-change-kids-parents-20190506-story.html (last accessed 3 May 2021).

Sittler, M.C., Cooper, A.J., Montag, C. (2019). Is empathy involved in our emotional response to music? The role of the PRL gene, empathy, and arousal in response to happy and sad music. Psychomusicology: Music, Mind, and Brain 29, 10–21.

Sommer, L. K. and Klöckner, C. A. (2019). Does Activist Art Have the Capacity to Raise Awareness in Audiences? A Study on Climate Change Art at the ArtCOP21 Event in Paris. Psychology of Aesthetics, Creativity, and the Arts. 15(1) 60-75.

Stamm, K. R., Clark, F. and Eblacas, P. R. (2000). Mass communication and public understanding of environmental problems: the case of global warming. Public Understanding of Science, 9, 219–237.

Stolberg, T. L. (2006). Communicating science through the language of dance: A journey of education and reflection. Leonardo, 39(5), 426–432.

Wodak, J. (2018). Shifting Baselines: Conveying Climate Change in Popular Music. Environmental Communication 12, 58–70.

Williams, Ian (2023) Combining art and science for effective public communication. Royal Society of Chemistry Environmental Chemistry Group – Bulletin, 24-27.

# Conclusion

All Key Cities have declared a climate emergency and are committed to ambitious timescales to achieve net zero. The UK Government has legislated to mandate that all UK emissions reach net zero by 2050. If those targets are to be met, then the actions of local authorities, local institutions and industries, local communities and individual citizens will be key.

**Understanding**

The innovations in this volume show that civic dividend in practice: universities delivering advances in science and technology, local authorities using their policies and powers to achieve better outcomes, industry and communities embedding sustainable practice, educators and creatives supporting culture change through better understanding.

**What next?**

The promising science around biotechnology and charging heavy goods and transport vehicles must surely lead to commercial application.

The efforts to inculcate scientific understanding in young people and the community through education and the arts should be widely adopted.

Co-designing sustainable solutions with industry and communities is an essential part of the journey to net zero, building partnerships and methodologies such as those described here.

Local policy, based on scientific evidence, can both inform the national legislative and regulatory framework and seek to mitigate where it is failing to support decarbonisation.

> “Co-designing sustainable solutions is an essential part of the journey.”

From this, can we distil some recommendations to further the practical impact of these efforts?

**Key Cities**

Last year, Key Cities called for the role of local government in achieving net zero to be clearly defined, for the government to invest in specialist staff, skills and capacity to support the green transition, and to invest in upgrading the National Grid to support renewable energy generation.

These are important factors in obtaining the best outcomes from civic partnerships and collaborations; we echo these calls.

**Data collaboration**

In addition we urge our member institutions and cities to continue collaborating on research-based innovation for the benefit of our places and communities – in this and other policy areas – with a particular focus on data and technologies to support equitable regional development.

**Government**

Achieving net zero and averting the climate emergency requires commitment at all levels, with the government providing a stable and realistic framework to stimulate long-term partnership and investment.

We call on government – national and devolved as appropriate – to ensure its focus on place extends to all parts of the country, with meaningful partnerships and funding mechanisms to support scalable and replicable place-based innovation, both within and across sectors and regions.

ISBN 978-0-9934156-4-7