Searching for inefficiencies in the food–energy–water nexus

The future facing humanity is one of climate change, dramatic population growth, and rapid urbanisation. This has thrust a spotlight on sustainable food production, energy generation, and water provision. The three are not separate priorities, but intricately intertwined, and reducing waste in the food–energy–water (FEW) nexus is a high priority for Earth's sustainability. One project with an international reach centred around urban living labs (ULL) hopes to make a major contribution by developing and testing applicable methods for identifying inefficiencies in a city-region's FEW nexus with focus on waste reduction, recovery or reuse.

In the history of human civilisation, two epochs stand out as of such dramatic social, technological, cultural, and economic advancement as to be termed 'revolutions' – one agricultural and the other industrial. The first was a set of developments – geographically independent of each other – starting about 12,000 years ago that marked humanity's transition from hunter-gathers to a more agrarian lifestyle. Humans began farming and domesticating livestock. This coincided with a predisposition towards establishing settlements and static communities. Significantly, humans were directly involved in producing their own food, drawing on the natural resources of energy and water. Other service sectors that arose remained largely small-scale, relying on hand production.

This relationship remained largely in place until the early 18th century when developments in mechanisation gave birth to the first industrial revolution. The shift from hand- to machine production coincided with unprecedented population growth and the rapid urbanisation of those areas. This drew people away from more direct involvement in producing their own food and set in place the foundations for today's globalised food supply chain.


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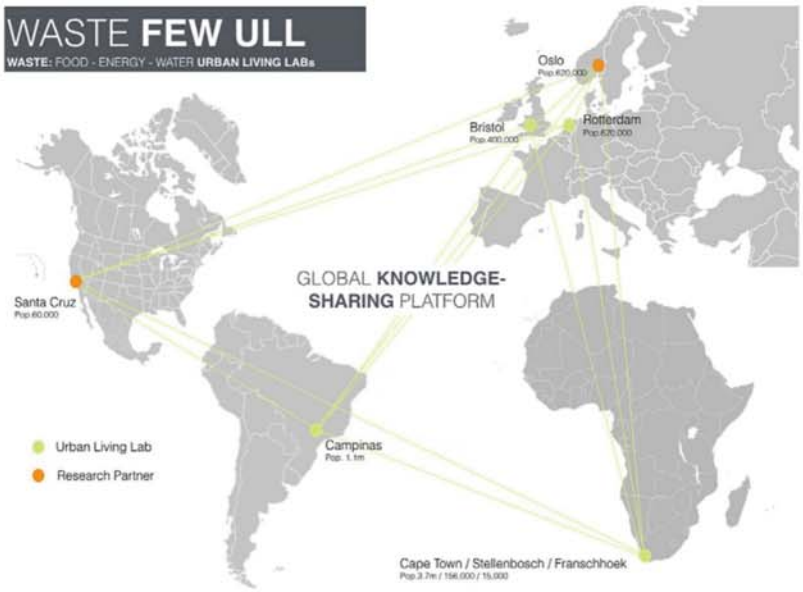
One of the consequences of population growth and our consumptive economy is increased strain on the food supply chains that stretch around the world. Associated anthropogenic climate change also directly impacts two of the fundamental components of food production: energy and water. Today, increased urbanisation and economic growth demand diversified food production – it is no longer directly farm-to-table. Instead, with technologies as enablers, it now follows a convoluted path of processing, packaging, and distribution around the world, adding further layers of energy and water use (Crippa et al, 2001). For example, it's not uncommon for products to have originated in one country, sent to different parts of the world for processing, only to arrive back in the same country for sale. As a result, the demands on energy and water and related impacts on the environment from food production are unsustainable.

To better manage our resources we need to examine the three components upon which we rely so much – food, energy, and water – not so much as separate domains for research but as directly interlinked: a nexus. Effective integration of FEW as a nexus also changes practice and performance, and how supply and demand is met.



The Waste FW ULL project's four case studies: Bristol, UK; Franschoek, South Africa; Rotterdam, in the Netherlands; and São Paulo, in Brazil. Norway and the US contribute to the project in all ULLs by providing economic modelling, and communicating and disseminating the outcomes of the projects.

THE FOOD–ENERGY–WATER NEXUS

The concept of a food–energy–water (FEW) nexus is relatively new and so far has not been widely implemented – it is simultaneously referred to as a 'water–food–energy nexus' or 'water–energy–food nexus' or 'water–energy–food security nexus'. Until relatively recently, research, development, and interventions in food production, energy generation, and water provision have been sectoral in approach. The idea that the three are interlinked has therefore demanded a paradigm shift in the international development agenda. It has also highlighted the increased complexities in addressing sustainability challenges across all three.

Clean freshwater – the water we drink, bathe in, and irrigate our farm fields with – is in short supply, and many of the water systems that keep ecosystems thriving and feed a growing human population have become stressed. Energy, if renewable and correctly managed, can be inexhaustible in its supply. However, fossil fuel production – be it of coal, oil, or gas – is still a dominant global energy source, and it is highly water-intensive.

Specifically, the largest fraction of water use is for production of food. According to the Organisation for Economic Co-operation and Development (OECD), agriculture irrigation alone accounts for 70% of water use worldwide. Agriculture also remains a significant source of water pollution – agricultural fertiliser run-off, pesticide use, and livestock effluents all contribute to the pollution of waterways and groundwater.

So how do we feed a dramatically increasing global population in the face of climate change when the FEW resources are under considerable strain? The immediate response would be: let's find ways to produce more food; but that comes with the concomitant increase in energy and water use, a solution which is not sustainable. There is another approach: focus on efficiencies across the FEW nexus – one example among many (access to land, reducing pollution, sustainable local food production, etc,) is by finding ways to waste less. The waste-reduction approach is more sustainable.

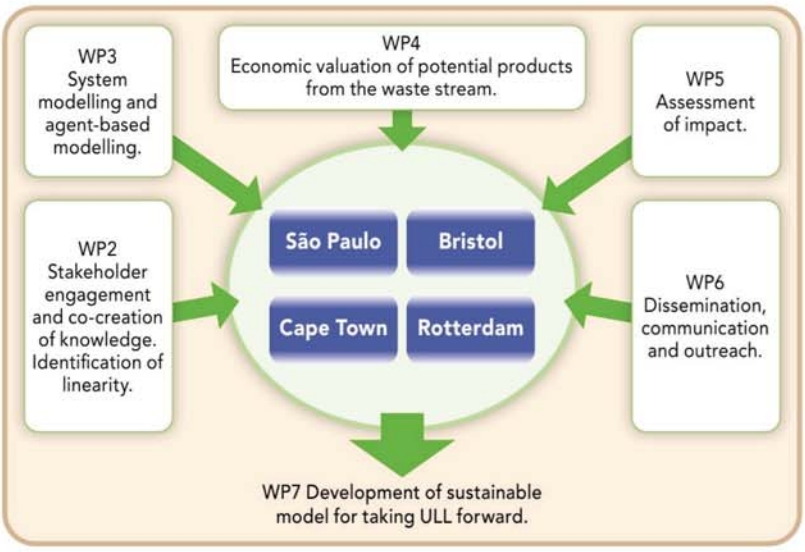
One of the consequences of climate change is increased strain on the food supply chains that stretch around the world.

The transition to sustainability is a new milestone of civilisation and an urgent collective transition goal for maintaining a sustainable global coupled human–natural system.

WASTE NOT, WANT NOT

In terms of food production, energy generation, and water provision and use, current economies are primarily *linear:* natural resources are processed and consumed, and throughout this process there is significant waste. A commonly used maxim is 'take, make, waste'. If minimising – ultimately, eliminating – waste is a priority, then an economy should be more *circular.* Here, the focus is on sharing, reusing, repairing, refurbishing, remanufacturing, and recycling to create a closed-loop system. This minimises the use of resource inputs and the creation of waste.

If you were to do a Google Scholar search into 'circular economy', you'd find a growing collection of research supporting real initiatives to encourage a move towards, at least, some configurations of circularity within individual sectors. A similar search into the FEW nexus (or any of its alternative framings) would produce a far smaller, largely theoretical, body of work. And while both fields of research may share terms and motivation, there is very little research investigating their overlap: applying the components of a circular system in an integrated food, energy, and water system.



The WASTE FEW ULL project: WP1 Project management and coordination.

According to the United Nations, 55% of the world's population now lives in cities, a figure projected to increase to 68% in less than 30 years, and the urban standard of living is increasing with associated increases in consumption.The Earth's finite resources will not be able to cater to the food production, energy generation, and water provision required to support for such expansion – environmentally, socially or, ultimately, economically – without substantial structural and systemic shifts.

Given that food, energy, and water are interconnected, that most of the world's people live in cities, and that controlling waste is a crucial component to issues of efficiency and sustainability, it makes sense that research is done to develop and test internationally applicable methods of identifying inefficiencies in a city-region's FEW nexus. This is the aim of the Waste FEW ULL project.

URBAN LIVING LABORATORIES

Waste FEW ULL is an international project comprised of teams from Brazil, UK, South Africa, the Netherlands, Norway, and the United States. It is funded via The Belmont Forum and JPI Europe, who convened a global partnership of funding organisations, international science councils, and regional consortia committed to advancing transdisciplinary science to understand, mitigate, and adapt to global environmental change (Keith & Headlam, 2017).

The project understands that attempts to address inefficiencies in a city-region's FEW nexus will fail if the inherent complexities are ignored. There are no simple plug-and-play solutions, and broad, ill-considered edicts by authorities are acknowledged as likely to fail. If a project is to succeed, it needs a research approach that respects and addresses these complexities.

At the heart of the project is learning connected with real-world stakeholders and activity – lifting experimentation away from the hypothetical model-building parameters of research and into real-life urban-based projects. A growing example of such projects are what's known as 'urban living laboratories', or ULLs. The idea is that ULLs bring researchers out of their academic 'bubbles' and into a range of real-world problem areas, working directly with stakeholders – companies, the public sector, and citizens – to co-create solutions.

ULLs operate locally where researchers and stakeholders design and run social, ecological, and technological experiments and generate feedback and social learning. This helps contribute to a more inclusive, sustainable, and strategic urban innovation and transformation agenda. In essence, the ULL approach is an intervention to leverage systematic urban change, focusing on pursuing common goals. For the Waste FEW ULL project, a key goal was to find solutions that could be scaled up and offered to other city regions to identify and address inefficiencies within their FEW nexus. In essence, the outcome is *global learning for local solutions*.

A ULL has three broad phases. The first is scoping the project – exploring all stakeholders' challenges and needs for their specific urban area and agreeing on the overall project. The second phase is experimentation – building a solution prototype and continually testing and improving it. Importantly, this is in a real-life setting, working collaboratively with diverse stakeholders. The third phase is evaluation and application – the viable upscaling and roll-out of the solution. In this project the ULLs are considered experimental spaces and innovation platforms where inefficiencies in the FEW nexus are addressed as a stepstone towards increased sustainability.

The Waste FW ULL project identified four urban areas worldwide as case studies, each with a different priority and scale: Bristol, UK; Franschhoek, just outside Cape Town in South Africa; Rotterdam in the Netherlands; and São Paulo in Brazil. Norway and the US contribute to the project in all ULLs by providing economic modelling, and communicating and disseminating the outcomes of the projects.

Food production is no longer directly farm-to-table. Instead, it follows a convoluted path of processing, packaging, and distribution, adding further layers of energy and water use.

The project team was aware that, collectively, the four case studies would face multiple constraints typically found – to varying degrees – in other urban areas: government and non-government

agencies, power structures, issues of land ownership, regulatory frameworks, data availability, perceived lack of commercial opportunities, socio-economic inequalities, physical and non-physical barriers, cultural resistance, and social indifference or inertia towards change. The priorities would need to be different at each ULL, but the same principles would guide their overall methodologies.

Firstly, they would each undertake a range of stakeholder engagement approaches (eg, development of existing working relations, project meetings, stakeholder recruitment and engagement, research workshops) to map and model their unique system of agents, the processes involved and the prospective data sources; and identify the inefficiencies, power dynamics, and variables that impact the project. Secondly, they would undertake a range of research activities depending on ULL context and local capacity/skills/expertise. Thirdly, and emergent from each ULL, they would develop impact plans that consider the stakeholders' interests, activities, and risks. Finally, they would form a replicable model or 'tool-box' and share their methodologies to foster knowledge exchange.

In essence, the overarching goal of the Waste FEW ULL project is for the four city-regions to demonstrate that it is possible to identify the most pressing inefficiencies in their FEW nexuses; to find the most viable ways to address those inefficiencies; and to show evidence they worked and had potential to be applied elsewhere.

Given the issues inherent in addressing complex, real-world problems (eg, alignment and coordination of timelines and goals; time-consuming coordination and management; the differences in culture and governance among ULLs), and the experience in the team in undertaking similar projects, it was anticipated that challenges would present themselves (LSE, 2011; Simon et al, 2018).

THE HIDDEN VALUE IN WASTE

The UK's ULL is in Bristol, a port city and one of the smallest of the UK's Core Cities, albeit the most populous in south-west England. It is a historic city – its wealth in the 17th and 18th centuries derived largely from colonial commodities, including slavery, tobacco, and sugar – and the home to two universities. Its economy is primarily driven now by aerospace, electronics, IT, and creative media. Bristol was European Green Capital in 2015 and was ranked top in Britain in the Forum for the Future 2008 Sustainable Cities Index.

The Bristol ULL team chose as their focus waste reduction and resource recovery in the city's waste processing plant based just outside the main city in Avonmouth, which processes all the sewage from the city, almost all of its residential food waste, and around half of its commercial food waste. The initial focus was on viable phosphorous recapture from sewage, though during the project the focus shifted to prioritising residential food waste (and associated plastic contamination), albeit with a continued interest in phosphorous recapture.

The partnership started with three centrally-active food, energy, and water agencies in the city: the Bristol Food Network, a community-interest company that connects organisations and community projects focused on transforming Bristol into a sustainable food city; the Centre for Sustainable Energy, a nationally-recognised charity that shares knowledge and practical experience, and undertakes research and policy analysis in sustainable energy; and Wessex Water/GENeco, which owns and operates the city's sewage infrastructure and a major waste processing plant. As the project developed, these three were joined by Bristol Waste, the council-owned company that manages the city's waste processing, and Resource Futures, a locally based, national non-profit consultancy focused on waste reduction. The ULL was co-led by two intermediary agencies: Daniel Black & Associates (db+a) and The Schumacher Institute – alongside the Consortium Lead, University of Coventry, which provided expertise in food, water, and resilience. They were supported by the universities of Bath

We need to examine the three components upon which we rely so much – food, energy, and water… as directly interlinked, as a point of connection: a nexus.

The Bristol ULL team focus on waste reduction and resource recovery in the city's wastewater treatment system, specifically, testing viable phosphorous recapture from sewage.

(environmental economics), Reading (planning and design thinking), UCSC in Santa Cruz (communications), and CICERO in Norway (macro-economics).

Food waste costs the UK economy billions of pounds each year and much of it is avoidable. The ULL team calculated that Bristol throws away £150 million of food waste each year. It's 33,000 tonnes of commercial food waste is contaminated by 1,000 tonnes of plastic. The ULL's valuations also showed: a) that it's far more beneficial to the environment if we reduce consumption in the first place, rather than focusing on recycling, but also, b) that existing macro-economic policy landscapes inherently incentivise more waste, rather than less (increasing consumption, increasing economic growth, increasing waste). Reducing and recapturing the nutrients from both food waste and phosphorous are essential if we are to address soil depletion, yet cities in the UK have relatively little power compared to the central government (eg, in terms of tax raising, investment opportunities) and with much of the controlling institutions, whether consciously or unconsciously, maintaining business as usual. Using valuation may be one way of disrupting unsustainable practices to shift on to a more sustainable trajectory.

Phosphorous is an ideal qualifier for a circular economy: It is an essential nutrient necessary for the growth and development of plants and animals upon which our food supply depends. It is the chief ingredient in phosphate fertiliser, the agricultural demand for which is increasing. However, reserves of rock phosphate – the primary source – are rapidly dwindling. At the same time, in food consumption, humans excrete unwanted phosphorous, which then enters wastewater systems; too much phosphorous carries serious ecological risks, especially if it makes its way into the waterways. If phosphorous can be economically extracted – with minimal energy usage – from wastewater, then not only does that reduce those risks, but it also provides a renewable source of this crucial nutrient for the food chain.

SCALING UP THE BRISTOL ULL

The Bristol model holds promise as an international method of identifying inefficiencies in a city-region's FEW nexus because it encourages stakeholders to see the, sometimes hidden, value of otherwise wasted resources in a system.

Here are several videos showing some of the activities going on in Bristol: wastefewull.weebly.com/bristol-ull.html#videos

LINKING INNOVATION PROJECTS

Like Bristol, Rotterdam in the Netherlands is a port city, but it is a highly active port – Europe's largest seaport, in fact – with all the associated benefits and challenges. It is also the country's second-largest city.

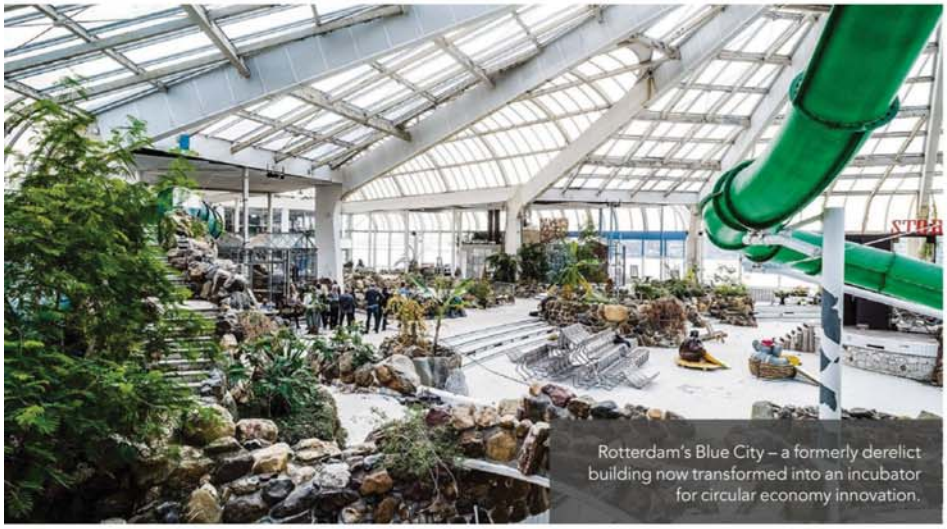
One of the biggest problems – if not the biggest – in transitioning from a linear to a circular economy is that solutions don't scale, at least not quickly enough. So, the Rotterdam Waste FEW ULL team chose to focus on how to accelerate circular models for city or region-wide waste uptake.

Based in Blue City – a formerly derelict building now transformed into an incubator for circular economy innovation – the Rotterdam team realised that, given the complexities of a circular economy and the FEW nexus, projects designed to address inefficiencies usually focus on a specific feature. Methodologically, this makes sense, but such a siloed approach also risks restricting overall uptake. So, the team decided on an impact approach: identifying and developing linkages between projects. The idea makes sense: it helps to have a coordinated, systemic effort if you want to address systemic inefficiencies.

There is another approach: focus on efficiencies across the food–energy–water nexus – find ways to waste less.

The approach has wings because there are other cities around the world like Rotterdam – highly developed, forward-thinking cities ahead of the curve in terms of their research and experimentation in circular economy projects. Finding ways to connect them to build momentum would help bring about necessary systemic change.

wastefewull.weebly.com/rotterdam-ull.html



Rotterdam's Blue City – a formerly derelict building now transformed into an incubator for circular economy innovation.

SELF-SUSTAINABILITY IN INFORMAL SETTLEMENTS

If urbanisation is more rapid in developing countries, then the work of the South African Waste FEW ULL team holds much promise. The team has chosen Franschhoek, a small, picturesque town about 75km outside of Cape Town. The area is braced with mountains and dotted with wine farms and historic buildings, but it is also home to Langrug ('Long back'), an informal settlement of about 7,000 people that is under-serviced in terms of electricity, water, and

sewage services. It is also a microcosm of South Africa's urban landscapes: nodes of development and relative wealth buttressed against ever-growing peri-urban informal settlements with little in the way of servicing infrastructure. As a result, water run-off from such settlements is usually severely contaminated.

To address this issue in Langrug, the South African team have established The Water Hub nearby. Its purpose is to test and develop nature-based solutions to treat the contaminated water run-off. Six large biofiltration cells, each filled with different natural media such as carbon sources, already treat approximately 5,000 litres of contaminated water per day and remove up to 75% of impurities. That results in water quality that meets irrigation standards.

The research aims to determine optimal retention time, volume, and flow in each cell. In line with the concept of a circular economy, this water is used to irrigate vegetables rather than discharging into streams, further polluting the catchment, and impacting on downstream health and ecological services. To complete the circle, energy to pump and transfer water from the river, through the filtration systems and irrigation, is powered by solar cells and stored in batteries.

One of the most significant barriers in the project is land ownership – an emotional, political, and ethical issue in South Africa. Land ownership is critical to identity and self-worth. Also, without the rights to the land they occupy, the residents of Langrug have no legal basis for demanding servicing from the local municipality. Instead, they rely on grassroots activism and the support of lobbying NGOs. The idea behind The Water Hub is to develop processes that such settlements could roll out to make themselves self-sustainable.

Langrug is one of the thousands of informal settlements that surround developed urban hubs worldwide. As climate change impacts undeveloped and developing nations more heavily, and their citizens flock to urban areas looking for solace and hope, those settlements will grow. Therefore, a model that could make them part of a city's more sustainable and efficient food-energy-water nexus is desperately needed.

Filling the engine room of a permaculture garden with duckweed: nature's way of adding amino acids, iron, vitamin A, and protein to the soil.

https://twitter.com/Kwenje88?/status/1109054293116678145

youtu.be/ibCnOfMmM08

DEVELOPING THE ATTITUDINAL FRAMEWORK

Brazil has a high level of urbanisation – 87% of its population live in cities, the most populous of which is São Paulo. It is, in fact, the world's fourth-largest city proper by population. It also sits in the wealthiest region of Brazil – the southeast – and therefore enjoys a relatively buoyant economy. Measured by GDP, it has the largest economy in the southern hemisphere.

São Paulo also sits within the Atlantic Forest, which runs along the country's south-eastern coastline. It is an integral part of the city-region's identity. Many of the more than a hundred dams scattered around the city sit within the forest area and are an essential part of the city's water infrastructure. Just over a tenth of the original forest remains today, its natural grandeur eaten away by an insatiable quest for more agricultural land, driven by the rapid expansion of São Paulo and the neighbouring metropolitan areas. Therefore, the city offers an ideal space to study the

At the heart of the project is connected learning – lifting experimentation away from the hypothetical model-building parameters of research and into real-life urban-based projects.

The Brazil team is investigating aquaponics as one of the five modes of food production. Left: Professor Maria Celia Portella holding an aquaponics solution. Right: members of the Brazil team during a visit to the aquaponics plant.

sustainability of an urban area rapidly squandering its natural environment.

The São Paulo (SP) in *Natura* Lab – the city's ULL – decided that preserving the Atlantic Forest would play a key role in finding a viable model for the transition to a sustainable food system. Others include using traditional knowledge to apply ecological concepts and principles to farming, finding ways to increase revenues from sustainable agriculture, and developing a network of reliable smallholder farmers by helping secure their land ownership.

If an urban area like São Paulo is to reimagine its FEW nexus, focusing on securing efficiencies, it needs the support of its citizens. So, the SP in *Natura* Lab is focusing on changing people's perceptions of transitioning to more sustainable food systems. The main goals of the ULL are: a) to model (using system dynamics method) the food production systems at the border of the Atlantic Rain Forest, and b) to foresight potential transition agents in terms of change towards more sustainable modes of production (from conventional to agroecological modes, or from conventional to integrated modes of production, such as aquaponics).

They are doing this in part by turning to real solutions embedded in the indigenous knowledge of the area. This is important if the city develops urban food production as a powerful tool to help preserve the Atlantic Forest.

The team has developed a transition decision-making tool based on 13 sustainability factors. The tool considers using three dimensions: firstly, the physical and material conditions of sustainable food solutions; secondly; the attributes of community, which is related to mindsets towards such solutions; and, thirdly, the rules to use – the effects that agreements, regulatory issues, and environmental laws can have in terms of production systems and personal benefits.

Research into the nexus is needed, but as a field of study, it is new. This is why the Waste FEW ULL project is so important.

This model has considerable value if applied elsewhere, because it will help develop the attitudinal framework needed for the necessary changes to address inefficiencies in a city's FEW nexus while contributing to the conservation of the natural ecosystems.

wastefewull.weebly.com/satildeo-paulo-ull.html
wastefewull.weebly.com/satildeo-paulo-ull.html#videos

HUMANITY'S HOPE IN RESEARCH

Climate change is a reality, and its impacts are evident. Feeding a growing, increasingly urbanised global population when the supply chains stretching around the world are straining and unsustainable will require a coordinated effort. Piecemeal interventions ignore the issue's complexities and the interconnectedness of food production, energy generation, and water provision. Research into the nexus is therefore needed, but there is much more research to be done. This is why the Waste FEW ULL project is so important.

The four case studies – Bristol, Rotterdam, Franschhoek, and São Paulo – are all live and ongoing; the lessons they are learning are continually feeding into the growing corps of research into the FEW nexus. The more they know, the finer they can tune their models, and the more we can understand about finding the hidden value in waste, connecting circular economy projects, empowering citizens of informal urban communities, and developing the attitudinal framework needed to move towards solutions that consider both the human and natural systems.

They may have different priorities they intend to share with other urban areas around the world, but their goal is the same: to find internationally applicable methods of identifying and addressing inefficiencies in a city-region's FEW nexus. If human civilisation hopes to survive this self-inflicted epoch of anthropogenic climate change, it may well need their acumen and insights.