

Executive summary

For millennia, humanity has thrived on Earth's natural resources, but during the last century growth and consumption has accelerated to such an extent, that our current model for human development has been brought into question.

Global population growth and rapid urbanisation are increasing our demand on environmental assets and we have been reluctant to account for the cost of pollution, natural resource loss and social degradation.

Rising numbers of people are becoming vulnerable to stresses and shocks associated with climate change, resource scarcities, ecosystem degradation, limited investment and the disruption of key resource flows. These shocks damage economic growth potential and the ability to reduce social and environmental degradation in both developed and developing regions.

There is a closing window of opportunity for many regions to act before they become locked into unsustainable and unsuitable development pathways.

This report introduces the work of The Ecological Sequestration Trust and its partners in developing solutions to these pressures. The Trust believes that by using integrated systems thinking and collaborative intelligence transformational change is truly within the reach of communities, businesses and governments globally.

This report introduces **resilience.io**. A computer-based platform, it is an analysis and decision-support tool, that allows users to accurately model resource flows, for example, energy, food and water, so that regions can manage both their economy and critical supporting ecosystems. It is a tool that allows regions globally to assess their current development path and map out a more sustainable and resilient trajectory. It is intended for use for planning, investment and policy-making, to embed resilience within regions in the long-term, as opposed to short term incident response management.

The **resilience.io** platform is currently being developed in a staged programme with an expert team covering fields as diverse as computer modelling, biophysical resources, values-based economics, earth systems, geospatial analytics and computer visualisation.

An early prototype will be demonstrated in Accra, Ghana as a part of the Department for International Development Future Cities Africa programme run by the Cities Alliance. Further demonstrator regions are also being established in Europe, China and Mongolia.



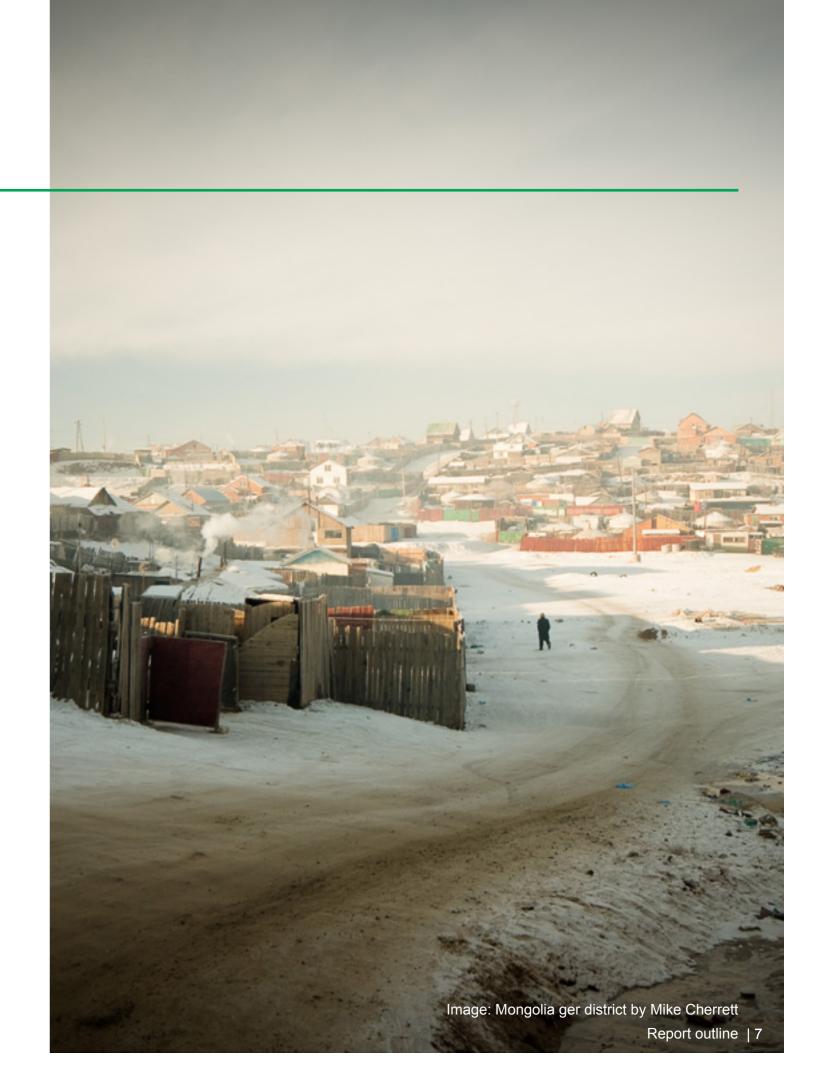
Report outline

This report is aimed at any individual or organisation with a role in achieving a more resilient, low-carbon development pathway for city-regions. It will appeal to those with an interest in the development of the **resilience.io** platform, as well as a wide range of professionals such as chief resilience officers, urban planners, policy makers from global to local, impact investors, practitioners and academics. It draws on 4 years of intensive research and design by The Trust and their partners to reach this understanding.

It is arranged in the following sections:

- 1 Background from challenges to opportunities (page 8) sets out the global and city scale challenges that threaten our capacity to sustain flourishing livelihoods and economies with the opportunities and initiatives that are quickly emerging to face these challenges.
- 2 Vision resilience decision support tools (page 10) presents The Trust's vision, that whole systems thinking and collaborative intelligence create the conditions to achieve the transformational change that is needed. It also outlines the research, and technology landscape that today make the **resilience.io** platform possible and proposes a set of principles for a resilience decision support tool.
- 3 resilience.io what are the core components of the platform? (page 16) describes in more detail the technical components that have been designed to work together to form **resilience.io** and to give real and trusted resilience insights to users in city-regions.
- 4 resilience.io what will it be used to do? (page 26) this section goes on to present how the platform under development is to be used to inform investment, planning and policy decision-making and foster collaboration, to contribute to transformational change.
- 5 resilience.io how is it being built and implemented? (page 30) outlines the current state of development together with plans to build and demonstrate **resilience.io** in city regions globally, including development and implementation partners and its role within the Department for Internation Developments Future Cities Africa program.

This report is an invitation to engage with The Trust on the vision, the platform and how these fit with your particular expertise or interest. A key principle of our work is that we are setting out to facilitate transformational change and are open to working with and empowering leaders in all disciplines to come together to make this happen.



1. Background - From challenges to opportunities

Humans are transforming the earth at an unprecedented pace. We dominate key global cycles of minerals and water and have become the single biggest influencer of most natural cycles (Sen and Peucker-Ehrenbrink, 2012). The environment is so significantly influenced by humans that geologists globally are considering whether to rename our age as the

"Anthropocene".

Global greenhouse gas (GHG) emissions, for example, have continued to rise, despite the concerted attention of the international community. In its 2013 assessment, the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) re-examined the impact of emissions scenarios based on the latest science. They found if GHG emissions do not level off until the latter part of the century, a temperature increase of 4°C above pre-industrial levels by 2100 is anticipated. Already we are witnessing the impacts of climate change such as extreme weather events, large scale food productivity changes with human displacements and health impacts as a result. GHG Emissions are also the main cause of ocean acidification and if continued. threaten the loss of ocean ecosystems and seafood (Roberts, 2013).

The world's population is growing by 80 million people annually. As a result the area of available land per capita on the planet to support life is shrinking. Over the last 100 years the average amount of land available to provide for food, energy, water, materials and to dispose of wastes has fallen from 8 ha per person to 2 ha per person. As a consequence of human land appropriation and a lack of environmental management, the ecosystem capacity of the planet to support life is reduced. A factor 4-5 reduction and reversal of pollution and ecosystems degradation and improvement in renewable resource productivity is required by 2050 to address the situation.

Progress in economic and social development during the past century has been achieved through the exploitation of the planet's finite resources and the destruction of its ecology. Whilst there is growing awareness of the earth's biophysical limits, we continue to make decisions within our economies and businesses with little regard to any natural planetary boundaries. In essence, we need a 'deeper economics' at the heart of decision making. We need a system that values the finite resources we consume, that takes account of our production and consumption impacts on ecology, demonstrates the value of regeneration of ecosystems, and defines social development beyond growth in Gross Domestic Product.

Within this picture of the challenges we face, the urban environment deserves special attention, both for developing and developed economies. Though cities come in many configurations with various densities and are frequently heralded as efficient economic structures, the reality is they have ecological footprints that vastly exceed their geographical area and bio-capacity. Today, over half of the global population lives in cities. Urban centres account for 70-80% of global energy consumption, produce 75% of the world's carbon emissions, consume 75% of the world's natural resources, and yet make up just 2% of the landmass. Further, the UN predicts 70-80% of the world's population will be city-dwellers by 2050.

Today, financial investments are being made that will determine our lifestyles for many decades to come, during which time we will be increasingly affected by global environmental and economic change. This gives us a closing window of opportunity to act before many regions will become locked into unsustainable

Rockefeller resilience definition: "The capacity of individuals, communities and systems to survive, adapt and grow in the face of stress and shocks and even transform when conditions require it."

and unsuitable development pathways.

Competition for space and resources and avoiding the worst impacts of climate change presents a huge challenge for society, but it is one that can be met with a coordinated. collaborative response and an integrated view of our cities and global systems.

The need for tools that can inform investment decisions follow from investors needs. Many international financial institutions (IFIs), including the World Bank, European Investment Bank and Asian Development Bank, to name but three, are seeking more attractive projects in city regions to invest in. Attractive in that projects demonstrate longer term stability and lower risk, or resilience. In working in cities, IFIs are seeking to achieve more inclusive urban growth. Key elements for urban investment and development have been identified as citizen engagement, breaking down silos, and increasing local capacity (FCC report, 2014).

A large share of investors embrace this approach, indeed pension funds are constantly seeking new local investment projects and the market growth in green, sustainable and innovation funds is strong. JP Morgan reported in its 2014 Spotlight on the Market that its respondent group of 125 investors committed \$10.6bn in 2013 and intend to invest 19% more in 2014, and citing a "shortage of high quality investment opportunities with track record" as the most limiting characteristics of the market today. The insurance industry too has \$9bn available for climate adaptation projects, in which they would contribute 40% of total cost, and they believe that 60% of disaster losses could be mitigated through adaptation (JP Morgan, 2014). Grosvenor, the UK based property company developed their own resilient cities

assessment and consider metrics as diverse as community, infrastructure, governance and planning systems (Grosvenor, 2014).

Beyond long-term economic interest there are. recognised needs for resilience for social and environmental reasons: For example: "

- The proposed set of Sustainable Development Goals (SDG's) that will come into being in 2015 focuses on overcoming poverty and inequality, and pays particular attention to resilient infrastructure, human settlements and cities (UN-DESA, 2014).
- The Royal Society explore the growing risks of extreme weather and advocate resilience as an integrated response to the destruction that can impact communities (RSA, 2014).
- The engineering firm Atkins together with the UK's Department for International Development advocate a need to futureproof cities to achieve more inclusive urban growth, particularly in the most rapidly urbanising countries (Atkins, DfiD, UCL, 2012).
- Indeed the Rockefeller Foundation, through the 100 resilient cities programme see resilience as making cities better for everyone, for the short and long term (Rockefeller, 2014).

For The Trust, our approach is to develop the tools that will provide insights to enable communities to plan ahead to achieve greater resilience. This means insights for planning, investment and policy making on a local level that support actions to mitigate and adapt to the impacts of climate change, decisions to cope with economic, social and ecological pressures on global supply chains of food, fuel and goods, and policies to recognise and overcome exposure to vulnerabilities.

2. Vision - resilience decision support tools

The Trust's vision

The Ecological Sequestration Trust is a UK Charity formed in 2011, to speed up and scale up transformative urban development towards a resilient, low carbon, resource efficient way of living. We have brought together world-leading modellers and sector experts to design and create **resilience.io**, a decision support tool. This platform aims to bring together the public, private, community and knowledge sectors to enable them to make wiser, collaborative decisions on policies that lead to improved resilience and attract increasing private sector investments.

Collaboration

Collaboration – We see a clear need for a new type of Non-Governmental Organisation (NGO) with deep multi-disciplinary skills, to act as a neutral, trusted catalyst to foster new forms of collaboration between the public and private sectors, and champion new and effective means of involving communities. This collaborative decision-making process will lead to shared knowledge, mutually beneficial partnerships and enhanced capacity for achieving shared goals which are inclusive. At The Trust we call this Collaborative Intelligence.

Citizens are often un-empowered and placed outside the critical processes shaping and driving change. Our aim is to ensure that the information and insight we help regions to develop will draw on input from across cultures and communities and is made available to as wide a section of society as possible through innovative, accessible visually rich information. Our development program aims to establish collaboratories in demonstrator city-regions to help to achieve this - further details in section 5.

Integrated Systems

Integrated systems – To address the challenges of climate-change and resource pressures a systems approach is needed that provides an integrated viewpoint. This is what China calls an ecological civilisation. A systems approach provides insights into the interconnectivity and relationships between places, people and the environment including systems such as transport, housing, energy, water, waste, food and human health and the associated chemical and physical changes that are functioning within a city-region over time.

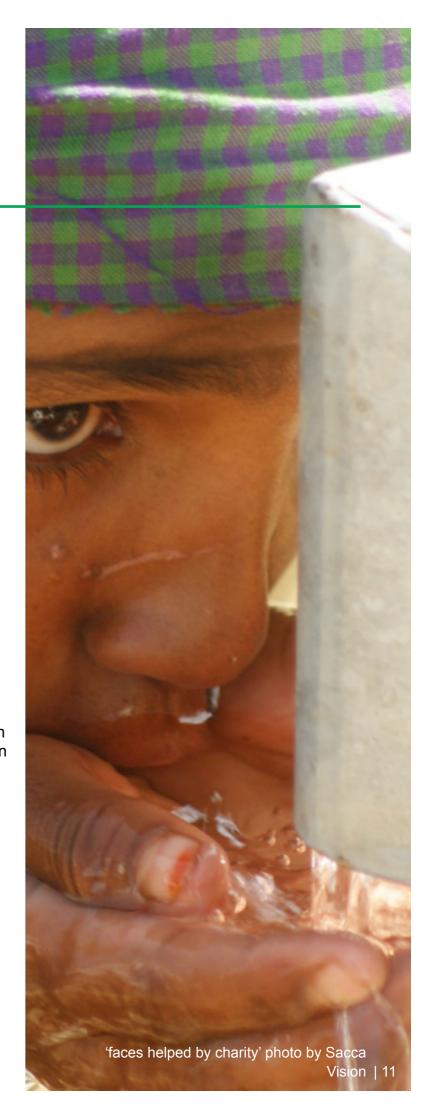
The eco-city and smart city movement is undergoing significant growth. Much focus is on providing the city with smart Information and Communication Technology (ICT) systems and a lower-carbon built environment. This is not sufficient. For a city to achieve resilience, it is necessary first to understand where it stands today in meeting its water, food, energy and other resource needs within an economic context. This requires an understanding of the extent to which a city relies on its regional hinterland to meet its needs and the extent to which resources are drawn in from a wider geography. Future scenarios can be tested against this baseline to build an understanding of the potential impacts across city systems.

Transformational change

Transformational change - There is an urgency for action to address our common planetary scale challenges. Incremental development in individual fields of expertise and sectors will not deliver the step changes required. The necessary radical shifts in consumption patterns can only come from systems innovation and active collaboration across multiple disciplines.

Whilst technology improvements will continue to be attractive, our approach is to build an understanding of how human systems and ecosystems interact and are affected by urban developments. We believe great progress can be made to achieving transformative change by using a systems approach informed by global best practice and experience.

Our aim is to demonstrate how this can be achieved at scale by 2025. Our approach is to demonstrate **resilience.io** in city-regions globally in order to show that effective collaboration based on insights from systems thinking can accelerate change towards more resilient, inclusive, low-carbon developments.



"This data is processed by the systems model and visualized to give an improved understanding of the human, economic and ecological systems within a region and how these are interlinked."

resilience.io

To meet this vision our plan is to develop and demonstrate the world's first open-source, integrated human-ecology-economics systems platform to enable low carbon, inclusive, resource efficient planning, policy-making, investment and procurement for city-regions globally.

resilience.io is designed as a computer-based platform that provides an integrated systems view of a city-region. It will be an analysis and decision-support tool for collaboration and resilience decision-making.

The **resilience.io** platform combines computer models of resource flows, human and business activities and infrastructure systems. The platform contains a growing library of processor models of typical human, industrial and ecological systems from across the world, the relevant ones of which are downloaded into the model using satellite imagery to create a tailored integrated processor model for a city-region.

It is designed to connect to many data sources, including from earth observation satellites, government and private sector records, local sensor networks, smart phones, tablets and local survey data. This data is processed by the systems model and visualized to give an improved understanding of the human, economic and ecological systems within a region and how these are interlinked.

Installing a local version of the model allows communities to manage both their economy and its critical supporting ecosystems on the basis of integrated systems insights. It allows city-regions globally to assess their current development path, taking account of the risks of climate change and resource scarcity and map out a more sustainable and resilient pathway. It is a tool for testing possible scenarios and driving towards a holistic set of social, environment and economic goals such as the post 2015 SDG's.

resilience.io is designed and created to support regional investment and performance based procurement in resilient growth of sustainable city-region systems with the governance and metrics that planners, designers and investors need. Utilities, services and transport infrastructure, construction, water and energy supply, clean technology, climate adaptation, agriculture and forestry, health and education are all part of this and together are vital components of resilient urban growth. The platform will enable public and private investment to be combined in the appropriate ratios to drive climate adaptation and mitigation within resilient inclusive development.

The platform also models the potential impacts of global resource supply chains and climate processes on the local level economic, social and environmental systems.

Platform principles

resilience.io is being developed based on a set of core principles

- Open source free at the point of use. Any costs associated with the platform are anticipated to be covered by a revolving fund which will be repaid through a levy on the capital flow into invested projects that use the platform for design and procurement. All the described elements will be available to city-regions on a free of charge basis with just a nominal charge for system support. There may need to be layers of data confidentiality within the platform system.
- Web based pervasive and universally accessible, the model will be cloud based to enable download and access anywhere globally.
- ••• Intuitive and user friendly the platform will fail, if it is not easily accessible by a range of stakeholders including communities. It is imperative that scenario testing be intuitive, informative and take a proportionate amount of time so as not to present a barrier to use. The aim is that the platform speeds up, adds greater value to and reduces the cost of all stakeholder programmes in a region.
- Collaborative the platform should work with existing and developing regional decision making, planning, governance, procurement and investment processes and enable these to move seamlessly onto a new more resilient path. The concept of a "collaboratory" has emerged for implementation.
- **Regionalised** there may need to be nationally hosted versions available in countries such as China, linked to their national data systems and cultures.
- Visual all user outputs will be provided in a highly visual manner and within a cockpit/ dashboard setting. Supporting data will be immediately accessible on a click-through drill-down basis.

More details of the platforms design and functions are covered in following sections but first a quick outline of the innovations which make this approach possible, and a short review of what other city models exist.

Vision | 12

"This represents a new approach that will provide quantitative and qualitative evidence for improvements at all points in a city"

Technical innovations combine

One of many innovations proposed is the increasing use of computer-assisted modelling, simulation, monitoring, and assessment methods, which can be adopted to guide the supervision and measurement of the overall performance of city development efforts. This represents a new approach that will provide quantitative and qualitative evidence for improvements at all points in a city with scientific monitoring, recording and verification processes. Advanced computing power now offers the ability to model the integrated systems of a city and to better understand their • Integrating at least three domains from a interactions. This supports a collaborative scenario testing environment for city-regions.

Further combination of recent technological advances make this platform viable. Advanced computer processing and agent based systems modelling, the pervasiveness of mobile technologies and affordable earthbased sensoring, affordable, higher resolution and frequency space-based earth observation, cutting edge visualisation and user access through 4G networks all now make an integrated systems model for a city-region achievable. These technologies also provide accessibility to a diverse range of users across city-regions globally.

City systems models analysis

A thorough review of existing models was conducted for The Trust by Imperial College and IIER in 2013. The focus was on identifying models which provided the ability for integrated planning across multiple domains, matching

today's challenges for city planners in a world where additional dimensions, ranging from climate change mitigation to resource use efficiency are added into a picture which was until recently dominated by land use, traffic and utility services planning.

The reviewed models were identified on the basis of including:

- Spatial representation at a minimum of city
- detailed list of city systems
- Be operational in at least one city globally

The resulting seventeen identified existing models commonly deal well with simulation of city transport, household and business dynamics, and land use change. A limited number are able to yield insights in the optimization of building heat and electricity use, in comparing carbon emission impacts of planning scenarios, atmospheric outflows and their spatial decision effects, and the economic effects of climate events.

The review did not find any existing city models, which incorporate the following:

- Material conversions in human, industrial and ecological processes
- Detailed business to business transport movements
- Human well-being estimations arising from socio-economic and environmental change
- Urban ecosystem flows and their state
- Agricultural and ecosystem dynamics of the wider peri-urban area

Substantial limitations were found in the treatment of the city's economy as these are modelled based on assumed growth scenarios driving employment and business dynamics, as opposed to a resource-driven economic view or endogenous R&D modelling.

The conclusion is that The Trust's agentbased integrated resource flow and technology network model under development is to become the first comprehensive city regional model in the world that includes resources, economics and environmental linkages.



3. resilience.io - what are the core components of the platform?

A number of components make up the **resilience.io** platform and support the critical functions described in section 4.

Integrated computer models

This open-source urban-rural model provides a quantitative analysis of the system interactions between the economic (values and market), ecological and societal aspects of the region's resource flows and their connection to national and global resources. The objective is to simulate a functioning society as a set of human, ecological and business activities within the chosen city-region boundaries. While the model's spatial scale is a city and its hinterland, it is also an open system with mass and energy flows from and to the outside world. This gives insights into cross border resource use giving a true picture of global impacts of consumption activities within the city-region.

The model platform is built on an architecture of agent-based, socio-economic simulation, with an integrated resource flow and technology network model, that includes an integrated view of land use, agent activity, resource flows, and infrastructure networks.

Land use and function: A geospatial representation of the city-region, including surface and underground features, is used to characterise the spatially dependent properties of the system. This includes land use (urban residential, agriculture, forestry, etc); the identification of building types such as hospitals and power stations; soil quality; water bodies under and over the ground; topography; vegetation type and cover, and so

on. This representation provides the baseline for visualisation for user interaction and systems analysis, and also allows for spatial representation of datasets. For example, vegetation type and flood prevention capability.

Agent activities: These relate to human systems of people and businesses located spatially, to provide for simulated decisions, which drive physical systems that process resource inputs into outputs. All human agents are consumers of goods and services, most will be participating in the labour market, and some will be owners of infrastructure. Agent properties include well-being, health, skill, age and productivity. The agents carry out modelled activities throughout time and space and as a result enable a simulation of the resultant resource requirements.

Resource flows: the model uses the agent activities and land use to calculate the flows of renewable and non-renewable natural resource stocks and flows across the region (e.g. sun, wind, biomass, food, natural gas, biogas, carbon, nitrogen, phosphorous, water in different qualities), wastes (e.g. sewage, CO₂) and energy flows (e.g. power, heating, cooling) from agent activities. They are characterized by local availability, local demand, availability to import from a hinterland and beyond, and cost. Ecosystem modelling is based on natural cycles including sunlight, rainfall, nutrient cycles and other natural processes, and soils, and likewise ecological processes are modelled to integrate ecological health measures.

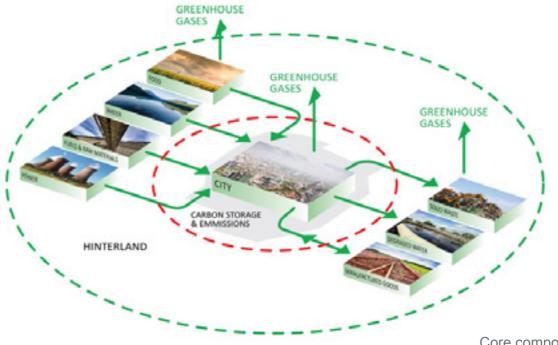
Service and infrastructure networks: the model platform is designed to enable local

utility and infrastructure owners to plug and play existing system networks to the model. These networks can include roads, railways and waterways, gas pipelines, power grids, water and communications networks. The resilience.io platform enables local networks to be modelled as part of an integrated regional system, so that owners can design changes in partnership with land-use development planning, and work together to improve resource efficiency. Additionally, this component is being developed to enable 'plug and play' connections to private sector building and infrastructure models.

Technologies/Infrastructure Processes:

The platform is being provided with a library of industrial, infrastructure, and ecological processes that can be downloaded to drive resource flow analysis. New technologies can be introduced to reflect the range of options considered locally. Technologies can come in different scales reflecting different degrees of centralization or decentralization.





Core components | 16

The layers described above are core building blocks of the **resilience.io** platform and combined, provide an integrated systems view of a city-region. Further components we believe are critical to the platforms success are introduced as follows:

- Cross-sector metabolism
- Global to local linkages
- User cockpits for intuitive sector specific access
- Data collection and data brokerage
- Expert support
- Transparent build for robust development

Cross-sector metabolism

All natural and human ecosystems can be perceived as material and energy conversion networks and processes based on the biophysical laws of our world. The accounting of these networks across human systems, ecological systems, and economic productive and consumptive systems, have until now been measured in an unintegrated fashion from each other. Within the model the agents (people, communities and companies) drive consumption and production decisions that result in resource flow networks and ultimately insights into the integrated nature of systems.

A core link within the **resilience.io** model is between resource conversions, as material and energy balances, and agent simulated human activities and decisions. All activities across sectors can be described as resource conversions with labour inputs in space and time. Within the model this will be done through categorisation into fourteen sectors (see opposite page).

Within a city region, significant features in the built environment are to be identified

spatially on a Geographic Information Systems platform, including their use and resource requirements and outputs, such as demography, labour, material and energy needs, embodied flows, and job and skill requirements. People and companies as agents in the model will be associated with the built environment on an approximate: basis, including households and employment location. In doing so, resource flows can be simulated based on the activities of people and company decisions resulting in goods and service supply and demand. These resource consumption activities include but are not limited to leisure, work, food, travel and sleep. Each activity profile will be linked to a resource consumption profile which will in turn allow for the simulation of resource consumption over space and time. This approach gives a finegrained resource based view of the economy and allows the impacts of different policy or investment decisions to be tested. Where historical data exists, the data analysis can go back in time as well as forward in order to give confidence in the platform's use.

Chemical manufacturing Water supply Biological processing onstru Mineral extraction Energy generation -ood processing animal Forestry Human resource consumption Recycling, disposal & manufacturing Core components | 19

"The functionality will provide users with access to global climate change impacts on the local city-region"

Global to local linkages

A key component of regional resilience planning comes from an appreciation of the relationship between local decisions and how global events and developments affect a region. The **resilience.io** platform is envisioned to provide for these linkages in three key areas:

- 1. Global supply chain resource flows flowing into (and out of) the city-region.
- 2. Global climate change impacts on weather and weather events.
- 3. Global Impacts stemming from events such as supply chain disruptions, weather events, and commodity price spikes.

These linkages generate a value-chain whereby global modelled developments reinforce and refine the insights of scenario planning in the city-region. The effects of long run changes in weather are to be addressed through using input scenarios from IPCC global climate models. Also an examination is to take place on how weather event impacts affecting economies can be operationalised using a catastrophic risk modelling framework. The functionality will provide users with access to global climate change impacts on the local city-region, and to assess risks and aid decision making for resilient growth and investment.





All Image credits: Geodan - Phoenix

User Cockpits

Perhaps the most critical element of the platform will be the creation of 'cockpit' user interfaces. The aim is to provide human access to the model via a friendly, intuitive interface. A very detailed view of all of the integrated systems could perhaps be too complex for most functions. To this end a set of sector specific cockpits will be developed providing a sector view into the overall cityregion model. It is envisioned that these cockpits will include the following: urban design, utility design, water, agriculture, forestry, mobility/transport, health, education, policy and governance, communities and culture, industry, jobs and skills, property and land. In this way an urban planner, or health professional for example will see the information that is key to their jobs

User Cockpits will combine visualization with intuitive user interfaces, to enable quick and effective access to the platform, and to carry out scenario testing. Resilient project scenarios can be iterated and feedback provided between different users to support collaboration. For example for purposes of planning; investment; risk management; design; construction management; or asset management. In addition a gaming version of the platform will be made available for rapid interactive use by all ages and skills.

Core components | 20 Core components | 21

Data, data collection and data brokerage

The value of the platform will ultimately rest on the quality and range of data available to it. Indeed the unique problem many users have told us they face, is access to multiple data sets of sufficient quality to create an integrated view of policy or project impacts.

The Trust, in conjunction with its partners will be developing a data collection strategy identifying the minimum data and data quality requirements for operating the platform successfully and this will form a part of installing the platform in a new city-region location. The systems model will need selected data to describe the overall resource system and therefore over time users will learn how to select the best representative data.

The Trust is ensuring that rapidly emerging globally recognized open data protocols and measurement systems are followed so that **resilience.io** will connect with city region initiatives that are gathering pace.

In addition The Trust's partners are developing a data brokerage system.

This data brokerage element is crucial to enable access to a wide variety of data sources, including space based Earth Observation and location data, national, regional and local open data sets, proprietary data sets, ground based sensors and crowd-sourced data. In order to achieve this level of data access, a defined cataloguing and data processing service will be required so that

models can access these data sets. Within the European context, for example, we will be able to incorporate open source standardised data formats through the world leading INSPIRE program. It will also be important to enable the set of models developed to communicate with many other existing or future models in a 'plug and play' fashion, a technology currently being scoped for this is the OpenMI mechanism. To this end, the data-brokering framework will set out a modeling interface definition. Finally, the data-brokering framework will support a standard interface between the models and the user. This will form the communications link between user cockpits and the resilience.io platform, as well as the resilience.io platform with existing and future models.

system Φ brokerag data resilience.io

4. User interfaces

Intuitive open source web based data interfacing to enable citizens to visualise the impacts of a proposal using portable devices through advanced visualisation.

3. Model services

The use of Open modelling interface will allow plug and play connection of existing and future models to **resilience.io** based on like for like parameters.

2. Data cataloguing and processing

Data standards, cataloguing and maintenance will be developed for all data types and formats to ensure efficient storage, quality and cross communication.

1. Data access

The collection of multiple data sets of sufficient quality is fundamental. Data collection requirements and subsequent data collection strategies will ensure relevant high quality inputs into the data cataloguing and processing phase.

Core components | 22

Expert support - Advisory board - members, models,.. expertise

The Trust has established an expert advisory board covering sectors: as diverse as forestry, human and ecological health, and the circular economy. The Trust will work: with these experts to ensure the latest thinking in these domains is embedded into the model: algorithms and user cockpits, to support accurate assessment of new resilient projects. The Trust will oversee a series of workshops and research with this group to: understand the interrelated issues and define particular parameters : and algorithms within the model. The first of these has already been completed to develop insights into the interrelationships between human and ecological health, and one will be held in February 2015 on finance and insurance.

Currently, identified domain experts are as follows and going forward, The Trust would like to engage with additional leading domain experts:

Expert advisors

Dr Bob Bishop - Earth simulation Prof Michael Braungart - Cradle to cradle design Dr Ruth Deakin - Systems learning and leadership Dr Fasla Kongjian Yu - Ecology and water systems Prof Herbert Girardet - Urbanism Andy Goldring - Permaculture systems Robin Haycock - Transport modeling Graham Hillier - Process technologies Prof Laura Lee - Architecture Dr Marcus Lindner - Forestry Robert Lisney OBE - Materials resource recovery John Liu - Ecological remediation Nick Mabey - Climate Politics Dr Kerry Mashford - Sustainable urban development William McDonough - Cradle to Cradle design Donald McNally - Bioreactors Alan Midgley - Project management systems David Miller - City leadership .. Jeffrey Newman - Community development Pankaj Patel - Bio energy Michael Pawlyn - Architect and biomimicry Sanjay Prakash - Architect Prof Kristin Vala Ragnarsdottir - Macro Health Dr Robin Stott - Physician and health Dr Geoff Smith - Space data applications Michael Velders - Urban agriculture



4. resilience.io - what will it be used to do?

"users should be able to easily generate and test new projects, policies and scenarios within the platform"

The previous section provided a description of the key building blocks of the **resilience.io** platform, and this section describes the key functions:

Collaboration and policy-making
Integrated planning
Investment and procurement
Economics and circular economy
Learning and research

Collaboration and policymaking

The Trust has already explored how a trusted collaborative environment would be created through workshops held in Surat, India, UlaanBaatar Mongolia, Tianjin in China and Dorset in United Kingdom. Also learning has been drawn from the events run by Culture Futures worldwide over a period of 10 years. The conclusions are as follows:

- It is important to engage communities through their cultural history and to bring this into the GIS platform to help communities to move forward.
- Communities generally prefer the platform to be set up within an independent governance structure, maybe a social enterprise that has representatives of stakeholders on a governance board and has local Universities supporting the data verification and technical aspects.
- Communities enjoy the process of bringing interests together through an independent broker and find it easier to find ways to move ideas forward.
- Energy can be created quickly through empowering existing community led development projects.

A critical success factor, is to achieve effective local collaboration that includes the most vulnerable, through a trusted, transparent representative governance structure. In this way

multiple stakeholders are able to use the platform to gain the collaborative intelligence needed to understand and support particular project portfolios and overall improvement in human well-being. The platform also needs to provide a 'collaborative access environment.' The exact nature of this may vary between city-regions depending on the levels of local governance and inclusiveness. However, it is envisaged that a collaborative 'serious computer gaming' environment will enable facilitated group access to engage on certain project scenarios. This will include being able to interrogate the voices and pictures of current and past cultures of the community. There will be a requirement for users from multiple locations to have access to particular projects or scenarios both simultaneously and over time to support collaborative project development. Groups of users should be able to easily generate and test new projects, policies and scenarios within the platform.

At the highest level the collaborative groups will look at indicators across the three domains, spatially and temporally distributed. Users will be able to go deeper into why relationships exist and how scenarios will affect the region depending on the KPIs of their interest. The platform is being developed in an open source manner to provide transparency of the research and to ensure value and robustness.

Standard policies or combinations of policies can be tested as scenarios such as those highlighted in Future Proofing Cities (Atkins, DfiD 2012), Resilience to Extreme Weather (RSA, 2014). Further, specific city indicators will enable comparing courses of actions across cities such as the newly amalgamated ISO:37120 set of indicators for city services and quality of life.



"the economy is modelled on physical interactions between participants and systems"

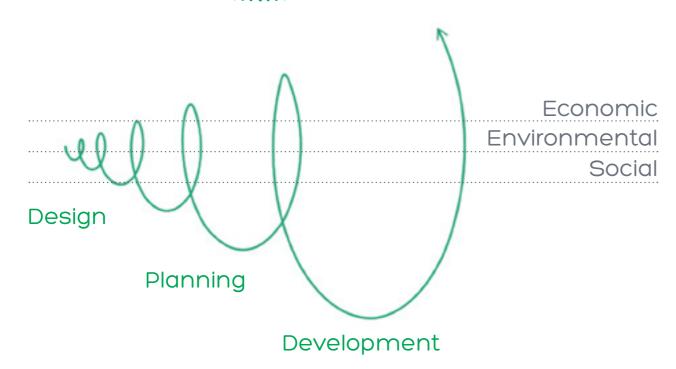
Integrated Planning

The structure described in the previous section provides a powerful planning tool that can lead to transformational change of cities. A direct link will also exist with the regional planning system to enable new projects to be easily assessed against local and strategic plans including measures such as jobs, visitors, ecological, social and economic impacts and climate mitigation as well as local planning and regulations.

Integrated urban master-planning, acknowledges the interdependence of urban systems and communities as well as the effects of global issues, such as climate

change resilience and economic uncertainty, on the future of our city regions. Masterplanning needs to be built on insight into the way places influence well-being, work and lifestyle, as well as technical understanding of interconnected systems such as transport, energy, water, waste and information. Most important of all there will be a direct link to regional economic benefit.

resilience.io will enable city planners to move away from spatial plans with discrete and unconnected elements to establish truly integrated plans. This tool will also enable planners to plan effectively for urban growth.



Integrated design Integrated Planning Accelerated development

Investment and procurement

The outputs from the platform will facilitate investment and performance based procurement which will increase value for money in city regions. Impact investors, or regional investment funds will look for clarity on business case, risk profile and impacts, and for alignment to financial regulation. The Trust is establishing regional investment funds with investors that are keen to explore more patient capital investment options alongside social impact bonds, climate adaptation funds and green investment products. An investment criteria framework that will inform the specific output needs will be established early in 2015.

Further, the platform will present values-based outputs for particular project proposals. In this way a city authority has the means to procure projects not simply on cost, time and quality but also on additional values such as air or water quality, educational standards or health. For example, the integrated systems view enables links to be made between infrastructure, human health and health care costs.

Economics and the circular economy development

Using the agent based information and associated resource flows, the entire integrated "economic system" is modelled with all relevant exchanges and processes, to the level of detail required to capture the majority of resource flows. In order to correctly represent the long-term viability of cycled systems, the economy is modelled on physical interactions between participants and systems - which are complemented with a monetary component. This enables strategies

and investments for a "circular economy" to be tested and evolved over time.

The entire "economy" is modelled on a non-monetary basis using a labour hour based value of exchange between agents. The model includes five different markets, a labour market, a skills and capabilities training market, a market for health services, a goods and services market, and an infrastructure market for ownership including asset value.

The entire ecosystem is modelled so that money exists as a facilitator of transactions. based on economic theories of supply and demand, such that at any stage all elements can be supplemented with a monetary component. Equally, credit is possible in the system, shifting accumulated resource/inputs/ processes capabilities from participants who have accumulated beyond their needs to those who might benefit more.

This approach enables a clear understanding of the impacts certain policy or investment measures may have on a cities metabolism.

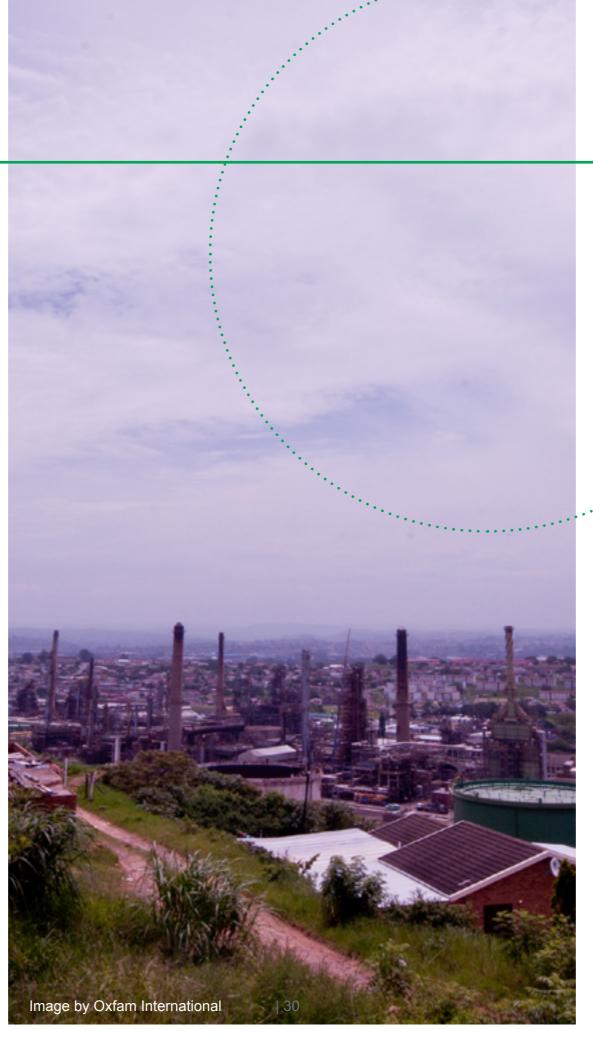
Learning and research

The Trust is planning to develop global learning and research networks derived from common platform use, to encourage education and research into resilient future development and develop research into the continued robust development of the **resilience.io** open source platform. This global teaching and research programmes will focus on sustainability, enterprise and innovation. As the use of the platform is scaled up across the world this platform will enable sharing of best practice and establishment of a community of users.

User Examples

Dr. C. is a university researcher working on agricultural engineering in a developing country megacity with a large agricultural supply hinterland. He is worried that as the city population grows in number and wealth, it will outstrip the hinterland's ability to support the cities resource requirements. He uses the model to simulate the demand that the growing city will create for key hinterland resources such as food and wood products and sinkrelated services, and assess how constraints in hinterland resource supplies might affect resource costs for local citizens and businesses. He can also assess as to how the introduction of new technologies and services, combined with regulations to avoid pollution and soil erosion from extensive farming will impact the ability to provide a stable long-term supply of relevant food staples to the city.

As outputs he gains metrics which quantify resource demands of the city over time under a range of population developments, including migratory scenarios. He can contrast the anticipated range in resource demands with the estimated quantities that can be supplied from the hinterland in the future, versus quantities that need to be imported to meet demands. This metrics provided give insights in the ability of the population and business to afford these imports, and the extent of erosion of local livelihoods, due to reduced purchasing power and business activities associated with increases in resource costs.



Ms. B. works at the metropolitan environmental health unit, and is examining a feasible solution to reduce the landfill health hazard by tackling the waste problem directly. She finds that scrap tires are one of the biggest chemical hazards in case of fires yet also are reasonably easy to recycle.

She uses the model to simulate the resource flows associated with tires and their disposal in landfills for the next ten years, based on tire lifetime and the number of vehicles on the road. They run additional simulations with a policy choice which 'forces' the use of tire shredding machines phased during a period of ten years, combined with alternatives including i) the burning of shredded tires in local cement kilns and re-use of metals in local manufacturing, ii) the export of shredded rubber and metal scrap.

As outputs they gain metrics which identify the reduction in produced tire wastes and landfilling, and as a consequence potential reduction and uptake for other uses of firewood in case of incineration of shredded rubber in cement kilns. To gain insights into health effects of different interventions a graph with a range indication of the reduction in hazardous emissions for fire incidents is provided based on tire composition. Additional information is gained on the required investment and added economic activity and jobs in relation to the number of tire shredding units which would be needed, plus suggestions for the appropriate location of the units in the city such as relative to the placement of cement kilns. Also spatial visibility is provided on technology related GHG emissions related to the various types of scenario inputs, such as a changes in emissions of cement kilns.

5. resilience io ÷ how is it being built and implemented?

2016

2018



Specification
Data requirements
Model development
Demonstrate Accra

Pesilience.io build and connect

User cockpits
ICES/ OASIS
Data system

Earth Observation

The development of **resilience.io** is phased, from feasibility and conceptual frameworks to prototype, iterative adding of functionality and content, a released product and development of tailored local model versions. Taking an innovation development approach The Trust is working with Imperial College and Institute for Integrate Economic Research (IIER) to refine the concept and is now embarking on building an early prototype. It is expected that a 5 year programme will allow the complete construction, iterative testing, value demonstration in a number of locations, and

launch, of a first version of the platform. At this stage the platform can be 'downloaded' for any city region globally and the work to build a local version can commence by any interested party.

The early prototype development of the model as a proof of concept is part of the DfiD and Cities Alliance Future Cities Africa project (FCA). It is anticipated that Accra in Ghana will be the city where the **resilience.io** early prototype will first be demonstrated as part of this feasibility program.

The FCA project sets out to support at least 8 cities in Africa to become future proofed to climate, environment and natural resource challenges, so that they are **inclusive and resilient, and have growing economies**. It will help make cities work for the urban poor. It will conduct an in depth feasibility and scoping study and develop innovative tools to enable rapidly growing African cities to realise their potential as centres of growth and job creation; use research and evidence to develop targeted urban action plans; and will deliver new research to fill data and evidence gaps to maximise sustainable economic growth.

This prototype will demonstrate the ability to:

- Generate a comprehensive spatial understanding of the physical basis of resource production and consumption over time for all sectors of society and their interrelations.
- Link productive and consumptive system as driven by simulated people and companies as model agents with behavioural rules.
- Simulate a substantial portion of a region's resource flows between companies and citizens based on behavioural logic.
- Provide in-depth insights in how policy and technology decisions can positively affect resource flows, expressed in terms of social, economic, and environmental performance indicators.

The prototype will be at the level of prototype software, to enable the project team to demonstrate its overall functionality.

resilience.io demonstration

Prototype demonstrations
Data
Europe
Mongolia

Mongolia China Africa resilience.io scale up

<u>2019</u>

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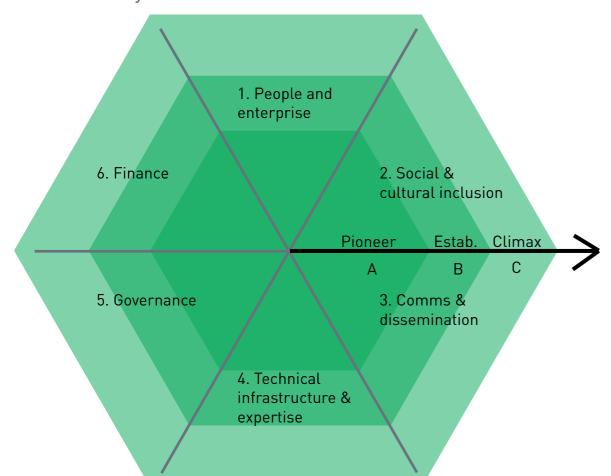
"Collaboratories - Collaborative Laboratories"

Building a local version of the model

In parallel to the prototype development activity described, a number of further 'demonstrators' are being established by The Trust in a small but diverse set of city regions including Ulan Bataar in Mongolia, Dorset in Europe and Tianjin in China. In these regions The Trust is investigating the establishment of Collaboratories - Collaborative Laboratories, where stakeholders from public, private, academic and community sectors can come together to explore the use of systems thinking to resolve real local challenges.

It is envisioned that after release of the model, a new city region will download the platform and begin to populate it with local data. In order for it to be successful a combination of elements would need to be in place including governance, social and cultural inclusion, people and enterprise, finance, local data collection capacity, and leadership. These elements are presented in the diagram below.

Collaboratory elements



To 'install' resilience.io in a new city-region a tailored version of the platform is to be built in the local region. Locally tailored mechanics and physical infrastructure knowledge is developed using up-to-date information from earth observation satellites, government and private sector records, socio-economic surveys, and data streams from local sensor networks, smart phones and tablets. The data of the cityregion and its hinterland is used to develop a simplified computer version of the economy, driven by in-built socio-economic mechanics, which lead to simulated decisions that drive resource productive and consumptive cycles. Running such a locally informed version of the model gives an improved understanding of the complex human, economic and ecological systems within a region and how these are interlinked. Through inclusion of import/ export supply and demand curves between the "Rest of the World" and the spatially defined boundaries of the city-region, mechanics of physical and economic flows can also be identified. It can thus be shown how resources on a regional level are connected with those at national and global level, to see how changes in the global economy and environment affect local economic, social and environmental systems.

The three types of local data collection required in a city-region include:

 Physical and built-environment related data (square km grid data) to a suitable level of approximation for model mechanics and the relevant decision scale. Within this relevant point sources are to be described.

- Socio-economic data to populate the model with people and companies as simulated decision agents, and as to include locally tailored behavioural mechanics.
- Identification where required of locally specific technology and process systems, rapidly built using a library of resource conversions which can be attributed to local infrastructure and technology. This is fundamental to improve data quality for local energy and material flows and related source emissions.

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Delivery partners







Imperial College London









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