Distributed Systems:

A design model for sustainable and resilient infrastructure

Business Intelligence and Policy Instruments

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The Victorian Eco-Innovation Lab (VEIL) seeks to identify and promote emerging technical and social innovations that could form part of future sustainable systems. VEIL creates conditions to explore emerging ideas and stimulate new ones, using a 25 year horizon to generate ideas for new trajectories for sustainable development.

VEIL was established through Our Environment Our Future – Victorian Sustainability Statement in 2006 and is funded through the Victorian Government Sustainability Fund. The project is a partnership between the University of Melbourne, Monash University, Royal Melbourne Institute of Technology, and Swinburne University. VEIL is managed by the research group of the same name in the Faculty of Architecture Building and Planning at the University of Melbourne.

The McCaughey Centre aims to build knowledge about the social, economic and environmental foundations of community wellbeing and mental health. A defining feature of the Centre's research is a commitment to improving social and health equity and reducing health inequalities. The Centre undertakes research, policy development, teaching, workforce development and knowledge translation.

The McCaughey Centre was established in 2006 with the support of the Victorian Health Promotion Foundation (VicHealth) and the Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne.

Workshops involving policy officers from across the Victorian Government were held in early 2007 to identify priority areas for eco-innovation in Victoria. A key theme arising from these workshops was concern about the sustainability and security of energy, water and food systems in Victoria given the challenges and responses to climate change. In a series of subsequent workshops and design research projects, the concept of distributed systems has been critical for the modelling of new sustainable systems and the visualisation of aspects of sustainable Melbourne in the year 2032. This briefing paper forms part of a communication process about current global research and practical projects on distributed systems, leading up to an international conference to be held in Melbourne in 2011. See www.regenerationconference.org for more information. An electronic copy of this paper and details of work done at VEIL can be found at www.ecoinnovationlab.com.

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A design model for sustainable and resilient infrastructure

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Executive Summary:

How do we prepare now for a future of unprecedented resource scarcity and environmental change? Unless we take radical steps to increase the resilience and sustainability of critical infrastructure, access to vital life systems and services is at risk. This paper highlights the dynamic forces increasing the vulnerability of current infrastructure and services and presents the case for distributed systems as an alternative design model. We suggest this model exists in the natural environment and in production and consumption systems that have already begun adapting to conditions of increased uncertainty, resource scarcity and a 'low-carbon' future. A distributed approach to system design offers many benefits over traditional infrastructure models. Research and case studies strongly suggest such an approach can:

1. **Increase the physical resilience of infrastructure**
2. **Foster social and institutional flexibility and innovation**
3. **Reduce the environmental footprint of production and consumption**

A strong and renewed interest in distributed systems is being fuelled by access to sophisticated technologies – particularly information and communications technology. This is allowing people to invent and adopt new ways to produce, interact and consume, that are increasingly localised and networked. This change in system design is developing rapidly in multiple sectors.

Over the next few decades the way people obtain their food, water and energy will undergo a major (r)evolution. One pathway sees people no longer relying on industrial production units hundreds or thousands of kilometres, or even continents, away. Instead they will source a greater proportion of essential resources, goods and services from within their 'neighbourhood'. Energy (principally electricity) is already showing signs of this transformation in most developed economies, with innovative arrangements of gas, solar, wind and biomass generators positioned throughout every region, backed up by new storage systems and some remaining large-scale centralised power stations. Developments in the water and food sectors seem to be following the same path.

This evolution sees a significant switch in people's role within the economy and in their identity as citizens; moving from one of passive consumption to a more active engagement in production and exchange of economic and social capital. In this future, people will no longer depend on contractual arrangements between corporatised utilities and government to ensure quality and security of services. Everyone will identify in one way or another as a 'prosumer' – being involved (either individually or through community arrangements) in the production as well as the consumption of part of the resources, goods and services on which they depend.

Introduction:

Time for systems change

"This is a discussion paper about the design of infrastructure – a critical leverage point for climate change adaptation and mitigation…"

The 2009 Climate Change Convention in Copenhagen highlighted the difficulty of generating meaningful international consensus on tackling global warming. There was no widespread denial of the issue or the need to take significant and urgent action, just a range of competing national interests and disagreement and obfuscation over where responsibility for the past and future lies. We are left with a growing problem of dire consequences and a seemingly impossible road to international action. This vacuum of inspiration and leadership should prompt us to seek other paths to the same end. International agreement is clearly vital but this does not mean we need to wait for an outcome before acting. Clearly, others are not.

Innovative approaches to resource scarcity and environmental change are emerging across the globe and offer valuable insights into how we can act now to mitigate and adapt to climate change. These strategies are usually not born from national-level planning and directives but stem from communities, businesses and local governments seeking-out ways to act that make sense in their immediate context. In most cases, this involves re-thinking systems of provision of food, energy, water and transport services. It is leading to systems of production and consumption that are structurally very different from those we have been used to. There are parallels between these local solutions and approaches that strategic planners, risk managers and sustainability experts argue will offer long-term adaptation and mitigation outcomes.

This is a discussion paper about why the design of socially critical infrastructure is an important leverage point for climate adaptation and mitigation, why new system designs are needed and what form they might take. We argue that traditional food, water, energy and transport systems face a growing challenge from the convergence of climate change, oil scarcity and the continued degradation of ecosystems. Infrastructure design is fundamentally linked to the emergence of critical global problems and why societies are increasingly at risk.

"Infrastructure design is fundamentally linked to the emergence of critical global problems and why societies are increasingly at risk."

Members of the insurance industry, urban planners and system engineers have suggested the design of critical infrastructure must change to reflect a more uncertain future[1 2 3]. Such calls for 'system change' should not come as a surprise. Decisions that perpetuate traditional infrastructure models not only fuel global environmental problems, they lock-in our reliance on systems that are increasingly 'brittle'. Events like Hurricane Katrina and extreme heat events, floods and water shortages in Australia, have already demonstrated how transport, water and energy systems, as we know them, can be vulnerable to 'unusual' weather phenomenon (and particularly to compounding stress factors). Such events are likely to become more frequent and probably more extreme, so the vulnerability of our infrastructure and the design of more resilient systems will assume greater and greater importance.

People in the environmental field and environmentally innovative businesses have warned for decades that a sustainable future cannot be achieved through gradual improvements in existing production and consumption infrastructure. They have argued that long term solutions to climate change, resource depletion and environmental degradation require a

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1 Brauner, C. (2002) .
2 Potsdam Institute for Climate Impact Research, (2007)
3 Adams R (2009)

structural change to the way resources, goods and services are provided and to everyday lifestyles[4].

From different perspectives the search for technical, institutional and socio-ecological systems that are resilient and sustainable, is drawing on and experimenting with a distributed systems model. This approach addresses infrastructure design from a network perspective - revaluing diversity, redundancy and local resources. It suggests a design model for critical infrastructure with less emphasis on large, linear, 'centralised' systems, in favour of smaller, 'distributed' systems and networks of exchange. We argue this alternative can improve resilience and reduce environmental footprint.

Inevitably, part of the case for distributed systems involves pointing out the risks to current infrastructure and showing why dominant design and management approaches can contribute to social vulnerability. We are *not* arguing for abolishing large centralised systems; centralised and distributed systems can (and do) co-exist; they should supplement each other if cleverly designed. We do advocate real systemic (paradigm) change in the way we plan and develop sustainable infrastructure and economic activity in the coming decades. This will pose significant challenges to conventional 'command-and-control' principles that have shaped system designs to-date.

Aims and approach:

This paper presents 'ideas in progress', as we attempt to synthesise an understanding of the challenges facing existing systems and draw on current knowledge to understand how we create more resilient systems of production and consumption. We draw on examples, research and analysis from experts in the fields of risk, resilience, sustainability and infrastructure planning, that point in a common direction and suggest a new 'field of thinking'. We want your feedback and input about the ideas and assumptions in this paper and any examples that expand (or challenge) what we argue.

This discussion paper aims to:

- **Outline why established systems of production and consumption are structurally vulnerable to climate change impacts and resource scarcity (particularly oil).**
- **Describe and explore the 'distributed systems' model in contrast to traditional infrastructure design.**
- **Explore why distributed systems of production and consumption may prove more resilient and help society be more adaptive to climate variability and resource scarcity.**
- **Identify how and why distributed systems already play a significant role in society**
- **Suggest key areas where distributed systems can be advanced and further researched.**

4 For example see: Ryan C (2008) or WBCSD (2002).

Part One: The case for systems change

Mounting evidence indicates environmental change and resource scarcity will radically re-shape society over the next few decades. Socially critical infrastructure, systems of production, distribution and consumption are greatly exposed. Global warming, environmental degradation and oil scarcity will profoundly affect the provision of food, water, transport and energy - influencing the quantity and security of resource supplies, and destabilising operating conditions (in diverse and surprising ways). While it poses significant risks, change is unavoidable. If we are prepared and willing to re-think the structure and design of our current systems of provision we can shape this transformation to our long-term advantage.

DRIVERS OF CHANGE

Of the major global forces for change, environmental degradation is most understood. It already has a profound impact on primary production and the availability of natural resources[5]. Its impacts on food and water security are particularly widespread. Critical industries such as fishing and agriculture have already suffered major declines in some areas. Ecosystem services such as water purification and soil fertility are also widely degraded.

Extensive research indicates climate change will affect the supply and security of food, water and even energy supplies[6 7 8]. Higher temperatures, more extreme weather events and shifts in weather patterns will change where, how, and with what certainty, agricultural crops can be grown. The same factors (combined with greater evaporation, increased likelihood of algal blooms and wild fires) are already reducing the security of water supply. Energy supply will be affected via lower inflow to hydro-generation dams and greater frequency and intensity of storms disrupting sea-based oil and gas supplies from regions like the Australia's North West and the Gulf of Mexico. Higher temperatures may also increase energy loss during transmission and disrupt energy distribution. Electricity and gas lines are already vulnerable from fires and from melting permafrost.

Oil scarcity or 'peak oil' is the least recognised but perhaps most pressing force for change[9]. Diverse risks are posed by the decline in oil output and a permanent shift in oil market conditions from excess oil supply to excess demand[10]. This is about to occur in the next few years [see Fig. 1]. With demand rising and output falling, oil and gas prices are expected to become extemely volatle (probably increasing rapidly in price) – destabilising supply and triggering 'knock-on' effects. Most aspects of modern society are vulnerable. Oil and gas are vital to food production, storage and distribution, as well as to the pharmaceuticals, pesticide and fertiliser industries. Oil underpins global

USEFUL SOURCES:

The resilience Institute
http://www.stockholmresilience.org/
This organisation conducts research exploring the nature of change in complex natural and social systems. A number of valuable papers can be downloaded from here.

Victorian Climate Change Summit.
http://www.climatechange.vic.gov.au/summit/Resources.html This site contains a collection of documents outlining some of the main threats to Victoria from Climate change.

Industry Taskforce on Peak Oil and Energy Security (ITPOES).
http://peakoiltaskforce.net
This group is made up of British companies that aim to raise awareness and understading of oil scarcity. Reports from 2009 and 2010 can be downloaded here.

Fuel for Thought
http://www.csiro.au/files/files/plm4.pdf This links to a document produced by the CSIRO and a range of Australian business and industry groups. It explores oil scarcity scenarios and outlines why Australia is particularly vulnerable.

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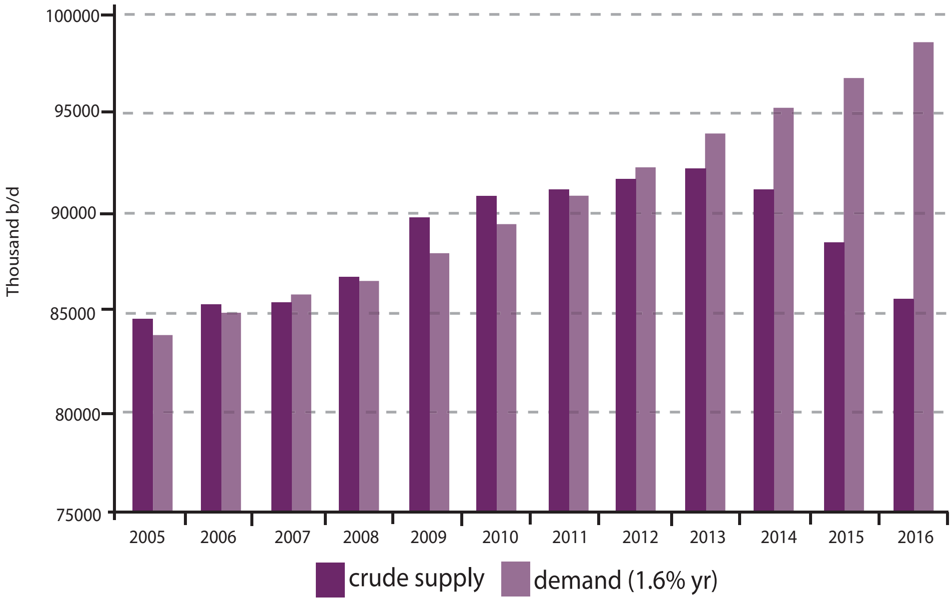
[5] See for example Millennium Ecosystem Assessment, (2005).
[6] Allen Consulting Group (2005).
[7] Auld H, MacIver D, Klaasen J (2006))
[8] See also: http://www.climatechange.vic.gov.au/summit/Resources.html
[9] The UK Industry Task Force on Peak Oil (ITPOES) considers oil scarcity the most immediate threat to global stability - of greater urgency than climate change. UK Industry Taskforce on Peak Oil & Energy Security (ITPOES) (2008) 'The Oil Crunch: Securing the UK's energy future.' The Peak Oil Group.
[10] See a discussion of Macquarie Investment Banks' recent report on peak oil. http://www.futurespros.com/news/commodities---futures-news/interview-when-will-we-hit-peak-oil%20-try-2009---macquarie-84926

transport, commerce and trade. Because cheap, secure access to oil has shaped urban design, people in car-based societies can be at high risk from oil scarcity; locked into low-density suburbs with little access to alternative mobility[11 12].

Figure 1: Oil supply and demand projections.

This figure shows the imminent shift in global oil supply conditions; from conditions of excess oil supply to excess demand.

Source: Peak Oil Consulting. Taken from ITPOES (2008)



USEFUL SOURCES:

Planetary boundaries
http://www.nature.com/news/specials/planetaryboundaries/index.html
This site explores the implications of sudden shifts in natural systems at a global scale.

Thresholds of Climate Change in Ecosystems.
http://downloads.climatescience.gov/sap/sap4-2/sap4-2-final-report-all.pdf
This report outlines why small changes in climate conditions can trigger sudden and unwanted change. It presents many examples and explores their implications.

Change will not be incremental

"*The human pressure on the Earth System has reached a scale where abrupt global environmental change can no longer be excluded. To continue to live and operate safely, humanity has to stay away from critical 'hard-wired' thresholds in Earth's environment…*" Johan Rockström, 2009. Director - Stockholm Resilience Centre[13].

The nature of change in complex systems adds a new layer of risk and uncertainty. Put simply, 'complex adaptive systems'[14] such as the climate, the economy and ecosystems, do not change gradually when highly stressed. They have a range or boundary of conditions within which change is relatively predictable. As human impacts push systems close to these thresholds of stability[15 16 17], they can behave unpredictably – with small changes having big and often surprising results. These affects are the kinds of 'high impact, low probability' events that planners, engineers, insurers find extremely hard to prepare for.

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[11] Dodson J, Sipe N (2008)
[12] Newman P, Beatley T, Boyer H (2009)
[13] Rockstrom J, Steffen W, *et al.* (2009)
[14] Economic, social, ecological and climatic systems are all complex and adaptive; they are comprised of many interacting elements that can each adjust to changes in their immediate environments but also affect the functioning of one another.
[15] Rockstrom J, Steffen W, *et al.* (2009)
[16] See also: http://www.nature.com/news/specials/planetaryboundaries/index.html
[17] US Geological Survey (2009).

Thresholds will play an important role defining how easily we can adapt to environmental change and resource scarcity. Pushing systems over critical 'tipping-points' has seen the sudden failure of vital fisheries[18], rapid shifts in ecosystem health and extreme weather events. Extensive research indicates global climate thresholds also exist[19 20]. Warming of just a few degrees has the potential to trigger the permanent loss of Arctic ice, the Greenland ice sheet (holding enough water to raise oceans by 7m) and the Amazon rainforest[21]. System volatility can pose a major risk at a local level. As analysis of recent disasters show, *"…above critical thresholds, small increases in weather and climate extremes have the potential to bring large increases in damage to existing infrastructure*"[22]. Table 1 shows how variations in local and regional weather conditions consistent with climate change predictions for Australia can have disproportionate results.

TABLE 1: THE LOCAL IMPLICATIONS OF CLIMATE VOLATILITY

Weather related change	**Outcome**
1C increase in mean summer temperatures	17-28% increase in bushfire risk
1.3C increase in maximum temperatures	25% increase in evaporation – affecting bushfire risk, runoff to dams and crop yields
25% increase in peak wind gusts	650% increase in building damage

Adapted from a presentation by Insurance Australia Group[23].

"Almost all of today's infrastructure has been designed…assuming that the average and extreme conditions of the past will represent conditions over the future lifespan of the structure"

Heather Auld,
Environment Canada's Adaptation and Impacts Research Division 2008

Established infrastructure is highly brittle

"*To a large extent, we live in 'yesterday's cities' in the sense that many of the urban patterns we see today – roads, buildings, land ownership, etc – reflect decision making periods of the past*."[24]

Infrastructure design can exaccerbate the risks from environmental change and resource scarcity. Established production and consumption systems are sensitive to volatility in external conditions; particularly those that are large, capital intensive, centralised and managed from the top-down[25 26]. These features are common -

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[18] Milich L (1999).
[19] See: Hansen J, Sato M*, et al.* (2008)
[20] Lenton T, Hermann H, Kreigler E, Hall J, Lucht W, Rahmstorf S, Schellnhuber H (2008).
[21] For a summary of this research see http://www.sciencedaily.com/releases/2008/02/080204172224.htm
[22] Auld H (2008)
[23] Gero A (2007)
[24] CSIRO, Arizona State University, Stockholm University (2007)
[25] Perrow C (1999)

Very large systems often struggle to detect and respond quickly to changes in the external environment.

reflecting an emphasis on efficiency, standardisation, 'economies of scale'[27], and the ability to resist, not adjust, to external change. They are based on a belief that external conditions will remain stable.

Systems managed and designed in this way are often stripped of the diversity and spare capacity (redundancy) that allows flexibility in the face of change[28 29 30]. By chasing efficiency, many industrial systems are becoming increasingly co-dependent. Energy, water, food and communications systems can no longer function without the other, meaning failures can cascade more easily from system to system[31]. Building immense 'economies of scale' also creates problems. Very large systems often reduce our ability to detect and respond quickly to changes in the external environment. This lack of 'adaptive feedback' caused by distance, time and organisational structures can amplify negative impacts, because decisions are de-coupled from their effects. Because large systems are capital-intensive, involving long pay-pack times, they are also slow to change. Technologies become 'locked-in' over many decades - stifling innovation and ensuring systems are forever designed to past conditions.

Futurist Jamais Cascio[32] summarises the situation like this: *"Centralized, hierarchical control is an effective management technique in a world of slow change and limited information -- the world in which Henry Ford built the model T, say. In such a world, when tomorrow will look pretty much the same as today, that's a reasonable system. In a world where each tomorrow could see fundamental transformation of how we work, communicate, and live, it's a fatal mistake"*.

FRAMING AN EFFECTIVE RESPONSE

While the risks posed by climate change are widely accepted, mitigation and adaptation strategies tend to ignore its systemic origins and the reasons behind infrastructure vulnerability. We can see this from the adoption of incremental change strategies that have failed to solve far less complex environmental problems.

Despite decades of environmental innovation in policy, technology and education, natural systems continue to decline. The problem comes from our focus on making production and consumption more efficient while ignoring the deeper causes of environmental impacts[33]. Dominant 'eco-efficiency'[34] strategies use market incentives, resource pricing, the allocation of responsibility for waste to producers and a focus on

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[26] Guy S, Marvin S, Moss T (2001)
[27] Costs per unit of production often decrease as the scale of production increases.
[28] Korhonen J, Seager T (2008)
[29] Ojima D, Corell R, Janetos A, de Bremond A, Nierenberg C, Carter L (2009)
[30] Peck H (2005)
[31] Little R (2003)
[32] Cascio J (2006)
[33] See for example the recent attention given to this issue by the UK manufacturing industry and university programs: Evans, S; Bergendahl, M. Gregory, M. Ryan, C. (2009)
[34] Essentially 'eco-efficiency' refers to the ratio of output to unit of resource input – this term is sometimes used in relation to the economy as a whole, as a short-hand for 'uncoupling' growth in the economy from resource consumption. See for example Ryan C (2004) (a)

product design and cleaner production to reduce pollution and resource demand[35]. They have successfully cut impacts per unit of production[36] but proven unable to reduce the environmental impacts of production and consumption overall. The following points show why:

- Consumption is simply increasing faster than technological eco-efficiency improvements. Most pollutant loads now come from products in-use or at end-of-life, not industries. More people are simply using and disposing of a greater volume of goods (within an economic system geared for consumption and obsolescence). In most product areas total pollution load is growing despite significant reduction in pollution per product.
- Efficiency gains in production can perversely drive up resource consumption by reducing operation and retail costs (freeing up capital that that is then spent on additional, often more resource intensive, goods and services). This is termed the 'rebound effect'.
- Many production and consumption processes have little room for further efficiency or pollution-prevention improvements. Large initial gains can be made as past inefficiencies are 'designed out' but further gains tend to be marginal or more costly[37].
- Recycling end-of-life products (a 'cradle to cradle' approach) can require so much energy for waste collection, transport and processing that overall gains are in some cases minimal or even negative (depending on system configuration).
- Barriers prevent people from changing consumption-intensive behaviour. Consumption is supported by governments through rebates and spending programs, by industry and business who heavily promote it and by wider systems such as car-centric urban design that 'lock-in' resource demand.

Eco-efficiency fails to generate significant environmental benefits because its influence is limited to marginal change and in system outputs with no attention to systems designs that lock-in high resource and energy use. Mitigation and adaptation strategies that focus on incremental reductions in carbon emissions or gradual improvements in infrastructure strength will fall into the same hole. Effective strategies need to address the structural reasons for environmental change and societal vulnerability. As the World Business Council for Sustainable Development (WBCSD) concluded in 2002 "*… we will not succeed in creating a sustainable world by merely doing more efficiently what we currently do*."[38]

Effective strategies need to address the structural reasons for environmental change and societal vulnerability

WE NEED AN EVOLUTION IN SYSTEM DESIGN

Long-term mitigation and adaptation strategies need to address the physical pattern, economic structures and entrenched behaviours that define how goods and services are created and used, and how people relate to the environment. This represents an

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[35] Ibid.
[36] For example, pollution from point sources has been considerably reduced, in some industries energy and resource efficiency has increased dramatically and a growing market now exists for 'green' products and services.
[37] See for review: Ryan C (2004) (b)
[38] WBCSD (2002)

'about-face' for current arrangements that encourage and 'lock-in' unsustainable behaviour.

- Successful models need to stem the tide of environmental change; delivering critical services at lower resource cost and ensuring lower consumption in one area will not translate to greater consumption elsewhere[39]. The degree of stress on natural systems also requires infrastructure to play a regenerative role - helping natural systems retreat from critical thresholds.
- We need to hedge against the possibility of critical thresholds being exceeded. The way we produce and consume therefore needs to be much more resilient; able to withstand, adjust and reorganise in response to large gradual shifts as well as sudden shocks.
- Successful models will assist the transition process; supporting and augmenting current systems so that locked-in resources and capital are used effectively while a shift in overall design occurs.

We face an unprecedented challenge. Innovative governments[40], industry groups and communities[41] are searching for alternative production and consumption systems and developing strategies to drive this socio-economic 'transition' or 'paradigm change'. Business strategists talk of this as the next industrial revolution. Whatever path this transition takes, as the Potsdam Memorandum[42] states "*…this way has to bring about, rapidly and ubiquitously, a thorough re-invention of our industrial metabolism — the Great Transformation*."

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[39] Ryan C (2009)
[40] VROM (2001)
[41] The 'Transition Town' movement is one example of the types of discussions and processes communities are engaged in.
[42] Potsdam Institute for Climate Impact Research (2007)

Part Two: The promise of a distributed approach

"*…we must refrain from merely allowing our technical and socio-economic systems to react to climatic developments, but rather adapt them to anticipate changeable climates*." Bruno Poro, 2002 - Chief Risk Officer, SwissRe[43]

DEFINING AN ALTERNATIVE APPROACH

Across Europe and in the UK and US, a transformation in energy infrastructure is underway. Regions that have historically generated heat and electricity from centralised oil, coal and nuclear power are shifting to bio-waste, natural gas, the wind and sun to supply their energy needs[44]. In the UK, this evolution is seeing a rapid spread of small, high efficiency gas-fired generators that are positioned close to where heat and electricity are needed. Electricity is generated specifically for local use with any excess being feed into the mains grid. The result is a wide network of distributed local suppliers. This approach has radical implications. It is decentralising both the production and management of electricity supply and shifting them closer to end-users. It is also cutting the size, wastage and carbon-intensity of energy generation and can even reduce energy use. Where energy production uses materials like forestry or farm waste, this 'distributed' approach is supporting local economies.

Defining the distributed systems model

The distributed model sees infrastructure and critical service systems (for water, food and energy etc.) positioned close to resources and points of demand. Individual systems may operate as separate, adaptive[45] units but are also linked within ever-wider networks of exchange – at the local, regional or global level. Services traditionally provided by large centralised systems are instead delivered via the collective capacity of many smaller diverse systems. Each is tailored to the needs and opportunities of unique locations but has the capacity to transfer resources across a wider area[46] [47].

Distributed systems can be found in both ecological and built environments. Some examples include:

- The brain, the immune system and fungal mycelium
- Home food production, food cooperatives and community gardens
- Peer-to-peer networks, reader-generated news and on-line flu tracking systems.
- Local water supply and treatment solutions: eg. rainwater tanks, greywater reuse, aquifer recharge and 'source-control' stormwater technologies.
- Local energy supplies: co/tri-generation, waste-to-biogas, biomass turbines, micro-hydro and solar water heating and cooling systems.

Distributed infrastructure and service systems involve a pattern of physical components, responsibility and operational processes that differs from most existing systems. With few exceptions, today's food, water and energy are delivered via arrangements that have concentrated ownership, operate under large centralised and

What are distributed systems?

USEFUL SOURCES:

World Alliance for Decentralized Eenrgy (WADE)
http://www.localpower.org/
This organisation is a good source of useful case studies and reports related to decentralised and distributed energy systems from around the world.

National Renewable Energy Laboratory – Distributed Energy Basics
http://www.nrel.gov/learning/eds_distributed_energy.html
This site gives an easy reference description (and animation) of the distributed energy approach and its advantages. Links to related research are also provided

National Decentralized Water Resources Capacity Development Project (NDWRCDP)
http://www.ndwrcdp.org
A US EPA funded project. Includes many papers, reports case studies and links relating to decentralised and distributed water systems.

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[43] Brauner C (2002)
[44] McCormick K (2008)
[45] 'Adaptive' in the sense that each production 'unit' can respond autonomously to changes in local conditions.
[46] Ryan C (2009)
[47] Biggs C, Ryan C, Wiseman J, Larsen K (2009)

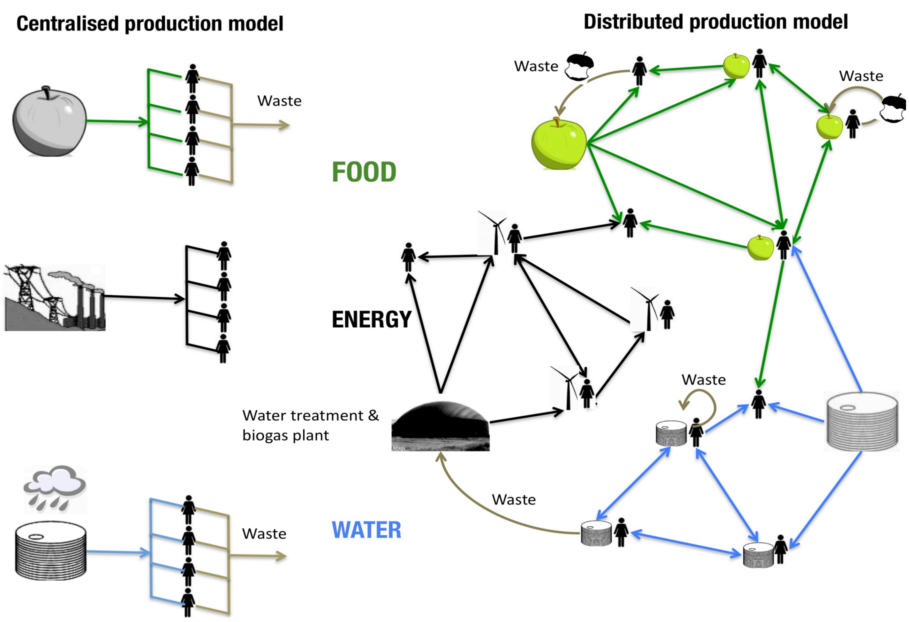
hierarchical management structures and distribute waste and resources in a highly linear fashion. In contrast, distributed systems involve a decentralised division of physical components, ownership and responsibility, overseeing a more cyclic movement of resources.

As simplified in Figure 2, people in the current 'paradigm' (to the left) are mainly passive recipients of resource supply and waste removal services. Services are provided from a distance via rigid industrial sized processing and distribution hardware. A person's contact with any resource is limited to the point of consumption; disconnected from its source or final destination. In a distributed system (to the right), resource production and waste treatment occur at many locations creating a mix of responsible parties. These may range from largely self-sufficient individual 'prosumers[48]' - who produce what they consume, to larger dedicated producers who extract and distribute from points of surplus. The result is a diversity of sources and access pathways; a web of flexible interdependence in which no single actor or supplier is vital.

Figure 2: Contrasting centralised and distributed systems.

This shows how resource flows in conventaional systems are tend to be highly linear –from source to user - to point of disposal.

On the other hand, the distributed model shows resources originating from many (multi-scale) sources. Resource flows are also more cyclic.



The distributed systems model has four defining characteristics. They are…

- **Localised:** Systems are designed for and positioned as close as feasible to points of resource supply and demand - reflecting the scale and context of local needs, conditions and resources.
- **Networked:** Systems are linked and have the capacity to exchange - allowing information and resources to be transferred. Networks exist at a range of scales and reflect the varied intensity of supply and demand between individuals, suburbs, regions and nations.
- **Modular:** Critical resources or services are generated by the collective capacity of multiple systems that can operate autonomously but also in connection with each other (via distribution networks). Networks of linked systems may also be modular –

48 The term 'Prosumer' originates from Philip Kotler (1986).

having the capacity to operate independently *and* combine with other networks to enable even wider resource distribution.

- **Open:** Ownership and responsibility for the operation of systems is (more) democratic. This reflects the right for people and organisations to produce and exchange resources they generate within a more transparent environment where local stakeholders have a greater understanding and role in determining how resources are exploited.

Case studies and research indicate that these characteristics give distributed systems advantages over the current efficiency-driven model. The following sections show how a distributed systems approach offers an integrated response to human 'unsustainability' and to the risks and uncertainties of 'peak-oil', climate change and ecosystem failure. This model offers considerable promise as a strategy to:

A. Increase the physical resilience of infrastructure
B. Foster social and institutional flexibility and innovation
C. Reduce the environmental footprint of production and consumption

A. INCREASING INFRASTRUCTURE RESILIENCE

The distributed model can improve the resilience of energy, water and food systems. Its characteristics - diversity, redundancy and modularity - are widely considered critical to the flexibility and robustness of complex systems[49 50 51 52].

The distributed approach fosters these features by creating a series of linked production systems, each designed to a range of unique demand, supply and environmental contexts. Provided they can operate autonomously (even temporarily), a level of system modularity is developed. Provided they reflect local conditions that are varied, diversity is increased. Through the existence of multiple systems that can all generate and distribute similar resources or services, redundancy also exists.

Analysts argue that a distributed approach to energy production can improve energy supply certainty. They point out that existing systems are highly vulnerable to natural, political and deliberate (e.g.terrorist-related) threats because:

- Main electricity, oil and gas supply lines are few and easily disrupted
- Fuel diversity is low
- Power generation facilities are technically very similar

USEFUL SOURCES:

Kombikraftwerk - Germany
http://news.mongabay.com/bioenergy/2007/12/germany-is-doing-it-reliable.html This link points to a short video of their distributed energy system that incorporates the use of a reservoir and hydro-turbines to modulate electricity loads in national grid.

Brittle Power – Amory Lovins
http://www.natcapsolutions.org/publications_files/brittlepower.htm This book is the most detailed examination of energy infrastructure design and its implications for energy security. Many of the same arguments apply to non-energy sectors. A pdf version of the book can be downloaded from this site.

Diversity refers to the range of different elements and functions in a system. It ensures that when shocks occur, not all elements are affected equally – reducing the possibility of widespread failure[53].

Redundancy provides 'back-up' capacity. This can include spare resources or the existence of multiple system elements that perform the same function[54].

Modularity describes the ability of systems or elements within them to function collectively or independently as required. This capacity for autonomous operation is important for preventing the propagation of failures. If one element or subsystem is shocked and fails, the ability for others to 'decouple' can help prevent impacts cascading from one part of the system to another[55].

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[49] Fiksel J (2003)
[50] Walker B, Salt D (2006)
[51] Rasmussen N, Niles S (2005)
[52] Gunderson L (2009)
[53] Two examples are the use of share diversity as a means of reducing risk in investment portfolios and gene diversity in crops acting as an insurance against pests and disease outbreaks.
[54] For example, many species perform similar functions (eg. grazing). Having multiple data transfer pathways in communication networks also represents a level of redundancy.
[55] Personal computers connected through an office network provide modularity. If a virus is detected in one PC, the others can be separated physically or via 'firewalls' to spreading infection. In a similar way, forest managers use firebreaks and stagger the harvesting of trees to create a patchwork of coups that help prevent the impact of fires or pests.

Proposed solutions involve a diverse mix of energy systems situated within networks that do not have a clear hierarchy of supply[56 57] and which emphasise a range of low-carbon sources[58].

Because the distributed model involves networks of many linked systems, the loss of production from one site can be compensated by increased input at another. Size is also important. Having services provided through many smaller systems, limits the amount of capital invested in each and means fewer people are directly affected by any one system failure. For this reason, local water supply schemes can have a lower and more stable risk profile over their lifecycle than centralised alternatives[59]. Contrast the implications of an algal bloom or fire shutting down a main reservoir, to a contamination in a smaller suburban water-recycling scheme. In the first instance, tens of thousands of people might be affected while in the second, maybe a few dozen.

Research and practice shows that a distributed approach can overcome problems of supply uncertainty from renewable energy sources. In one German demonstration study[60], a network of 36 hydro, solar, wind and biomass generators spread across the country was able to produce constant and stable electricity supplies without input from centralised sources. When poor weather at one location cut input from wind or solar systems, systems at different locations compensated. The security and functioning of the network was also improved due to the different properties of each system. While the solar and wind generators were passive – relying on external conditions to work, the hydro and biomass systems could act as energy storages and be turned on or off on-demand to prevent power fluctuations.

In research from the University of California, Berkeley, detailed energy modelling of actual demand curves showed that distributed energy generation combined with four hours storage capacity could meet all of America's current pattern of electricity demand[61].

Managing uncertainty:

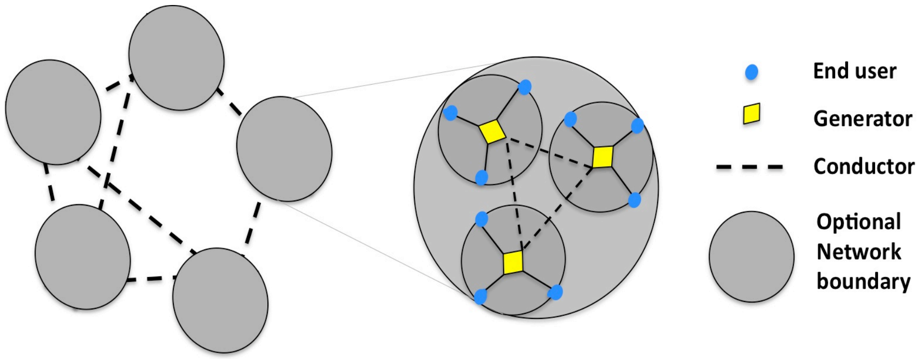
The distributed model offers a strategy for reducing the impact of shocks when they overwhelm system components. This ability to 'fail gracefully' is a function of distributed systems working like a series of semi-autonomous 'modules'. Hospital back-up generators or rainwater tanks are very simple examples of distributed capacity that reduce the impact of wider system failures[62]. Analysts argue that a distributed energy model can take the advantage of both self-sufficiency and connectivity by creating modular networks that have optional connectivity. In this 'mini-grid' scenario, individual production units, drawing on local resources, have the capacity to operate and provide services independently if needed. However, they also sit within networks of exchange that can operate as a whole. The result sees networks existing within larger

[56] Lovins A, Lovins L (2001a)
[57] Lovins A, Lovins L (2001b)
[58] Grubb M, Butler L, Twomey P (2006)
[59] Pamminger F (2008)
[60] Kombikraftwerk (2007)
[61] Mills, D. [Ausra Inc.] Pers. comm., October 2009
[62] For a description of how local energy systems reduce the impact of power failures: WADE (2007) See link to left.

networks, with each having optional connectivity [see figure 3]. Provided each network can connect and disconnect when necessary, this type of system design could help reduce the likelihood of rolling power blackouts or the spread of food and water contamination.

Figure 3: Modular system designs

Systems of resource generation can be designed to opperate in autonomous networks that have the capacity to connect and disconnect from each other. This model can provide added security from system-wide shocks like blackouts.



A distributed approach is increasingly being applied to increase water supply. Utilities like Gold Coast Water (GCW) are diversifying supplies using urban rainwater collection, recycled water and other sources such as desalination and stormwater to complement traditional inland water catchments[63]. As GCW puts it: "*Diversity of supply is the key to our water future…*". Shifting to a more varied portfolio of sources creates an array of options that are differently exposed to threats. Shifts in rainfall patterns, volatile energy costs or even sabotage, would affect the proposed sources differently. Some distributed water sources may also suffer less from the impacts of climate change compared to traditional sources. For example, while higher temperatures and evaporation rates will reduce runoff to inland catchments[64], non-porous surfaces in urban areas would still provide a fairly constant rate of runoff when rain occurs[65]. Roads, roofs and pavements offer a vast range of untapped catchments that may be less susceptible to climate variability.

The distributed approach can help service providers manage uncertain demand or supply conditions. When a systems' capacity is made up of many smaller, modular production units, output can be adjusted incrementally and 'on-demand'. This arrangement contrasts with the rigidity of large product and service systems that require years to plan and install, lock-up investments for decades and cannot be reconfigured without major cost[66 67].

Figure 4 illustrates the comparative flexibility of the distributed model relative to current systems[68]. Increasing capacity in small increments offers a resource and cost advantage while building capacity in large steps involves major investments followed by long periods of inefficient operation. Where supplies of raw materials (such as fuel) may

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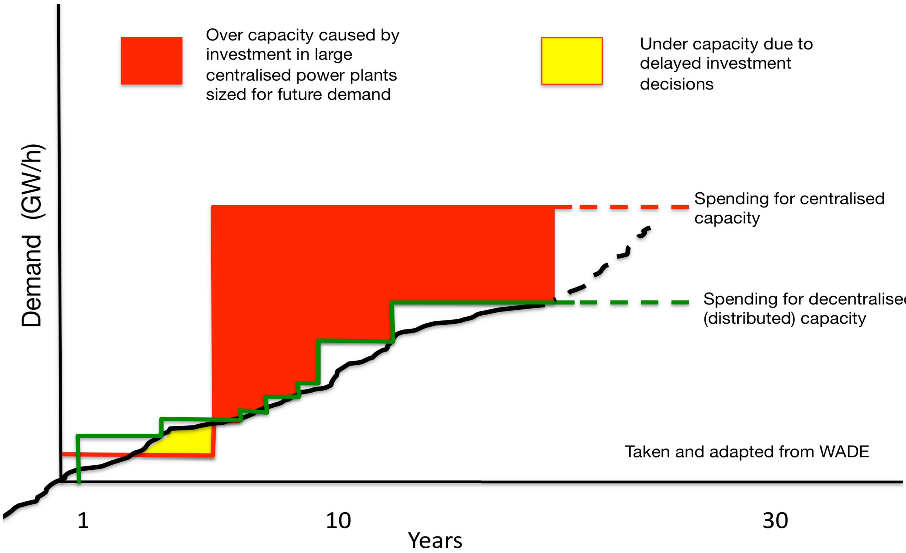
[63] Gold Coast Water (2004a)
[64] Victorian Department of Sustainability and Environment (2006) '
[65] Coombes P (2009)
[66] WADE (2007)
[67] Pinkham R, Hurley E, Watkins K, Lovins A, Magliaro J (2004)
[68] WADE (2007)

be at risk of volatile price conditions, the ability to increase and decrease capacity without incurring major costs would represent a significant advantage.

Figure 4: Comparative costs and resource advantages of modular system design.

A modular approach can help avoid long periods of over investment where systems are opperating at over-capacity.



B. FOSTERING SOCIAL INNOVATION

Adaptation to conditions of scarcity and volatile environmental change depends on social and governance issues as much as infrastructure hardware. The distributed model can play a key role by improving community cohesion and economic resilience, by building local economies and strengthening the management of natural resources – and by offering a 'test-bed' of adaptation strategies. This can be an important source of innovation in organisational systems and systems of provision. Many of these values stem from the distributed model fostering greater feedback and adaptability.

"…complex social and ecological systems are often better protected by local, decentralised management approaches…"

- **Feedback** (sensitivity) determines how quickly one part of a system detects changes in another and therefore the speed of response. Problems occur when feedbacks from decisions or events are disrupted or delayed[69].
- **Adaptability** relates to the capacity of a system to learn from, assimilate and respond flexibly to change.

The distributed approach tightens feedback and fosters adaptation by bringing production and consumption closer together and by shifting decision-making and responsibility closer to their point of impact.

[69] For example, farmers in southern Australia didn't realise that clearing vegetation would lead to the rise of saline water tables until symptoms occurred decades later – a slow feedback process in natural systems. The equally slow response of governments to deal with the issue is another example of slow feedback - this time in social and political systems.

Flexible and adaptive governance

Adapting to climate and ecosystems stress requires better understanding and management of natural resources. We need to ensure that our extraction of raw materials is both more sensitive and flexible. The distributed approach to consumption and production contains many of the characteristics cited as vital for adaptive, sustainable resource management.

One of these characteristics is greater decentralisation. The distributed system model marks a shift away from centralised management of resource extraction, processing and distribution, toward smaller resource extraction systems that are tailored to local conditions. This decentralisation should allow the management, ownership and benefits from resources to remain part of the local economy. Studies indicate that complex social and ecological systems are often better protected by local, decentralised management approaches, rather than by centralised, hierarchical ones[70 71 72]. People have a strong incentive to look after a local resource if they directly benefit from it and can ensure that external parties don't exploit it. The key here is to ensure that people who are exploiting a resource have a stake in its long-term survival[73].

"…local actors…are in a better position to assess and make 'real-time' decisions in response to changing 'on-ground' conditions."

Distributed systems offer a strategy to improve the understanding and retention of knowledge about local conditions. Both are key to the resilience of ecosystems as well as technical and organisational systems[74 75 76]. Because distributed systems are relatively small scale, they are more sensitive to fluctuations in local conditions. This can foster the collection and retention of local knowledge. Where distributed systems are owned and operated by communities, households or individuals, the ability for knowledge to be retained long-term is improved further because these actors don't have the 'personnel' turnover that governments and businesses do.

Local knowledge can play a crucial role in the early detection and response to crises. A shift to distributed production and consumption may improve the role and effectiveness of this 'font-line' flexibility by ensuring local actors have greater autonomy when responding to climate and energy shocks. Even within large, centrally managed organisations, 'shop-floor' improvisation and 'font-line' deviation from set rules often help avert crises[77]. Compared to higher-level managers and regulators, local actors often have a better understanding of local conditions and are therefore better able to decide effective responses and understand the limits of system flexibility. They are also in a better position to assess and make 'real-time' decisions in response to changing 'on-ground' conditions.

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[70] Milich L (1999)
[71] Ostrom E (1999)
[72] Cash D, Adger W, Berkes F, Garden P, Lebel L, Olssen P, Pritchard L, Young O (2006)
[73] Elinor Ostrom has covered this ground widely. See for example Ostrom E (1999)
[74] Buckle P (2006)
[75] Dietz T, Ostrom E, Stern P (2003)
[76] Ostrom E (1999)
[77] Dekker S (2006)

Distributed systems may also provide a valuable platform for developing more flexible and adaptive forms of governance. The dislocation between the level at which planning and regulatory decisions are applied and the natural and social systems they affect is a key problem that retards adaptive capacity[78 79]. As a solution, researchers and policy analysts argue for forms of governance that allocate assessment and decision-making responsibilities to a greater diversity of agents that exist at different scales but which interact and share overlapping responsibilities[80 81 82].

This 'multi-layered' and cooperative style of governance has many parallels to the distributed approach. Actors at a local level are more specialised 'niche' operators, while those operating at wider scales are increasingly generalised. Rather than being isolated and hierarchical, agents sit within networks of resource and information exchange. This better reflects the co-dependency that links diverse organisations and increases the potential for improved mutual learning, cooperative management and innovation. For example, a greater level of resource exchange could allow local system managers to crosscheck experiences while helping higher-level agencies to collect and learn from the aggregation of detailed local data.

A tool-kit of adaptation strategies

"..one way for institutions to better prepare for disturbance is to deliberately create small-scale shocks and learn from the weaknesses exposed."

In the absence of proven fixes to sustainability challenges, strategic decision makers need to be 'stress-testing' a wide range of potential solutions. A diverse range of infrastructure systems – each representative of unique conditions – would offer governments an array of strategies from which to base long-term investment and strategic decisions. It would also provide a test-bed for learning what types of regulatory conditions can support or hinder different systems. As studies in the resilience field suggest, one way for institutions to better prepare for disturbance is to deliberately create small-scale shocks and learn from the weaknesses exposed[83]. This type of crisis 'rehearsal' would also expose innovative responses that can improve system resilience. The modular nature of distributed systems might provide a valuable low-risk environment in which to test the resilience of different design options (with 'natural-selection' playing a vital role alongside political decisions in selecting adaptation strategies).

Strong and innovative local economies

Economic security is a pre-requisite for healthy, adaptive communities**.** Distributed systems display characteristics that are supportive of healthy local economies. They may help diversify and stabilise a regions' economic base, so that it can better retain financial capital and engage in continued business innovation.

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[78] See for example, Cash D, Adger W, Berkes F, Garden P, Lebel L, Olssen P, Pritchard L, Young O (2006)

[79] Nelson D, Adger W, Brown K (2007) .

[80] Olsson P, Folke C (2004)

[81] Ostrom E (1999).

[82] These 'co-management' or 'poly-centric' governance models contrast with existing structures in which decisions are increasingly centralised in hierarchical organisations as a way to reduce complexity and streamline the decision processes.

[83] Folke C, Colding J, Berkes F (2003)

Distributed production and distribution systems can form a valuable part of local business networks. They can use local resources, employ local people and provide services targeted specifically to local needs. Critical infrastructure can therefore become deeply embedded within local financial flows and help retain financial capital locally. In this way, a distributed systems approach may help reduce the impact of economic shocks. As the UK New Economics Foundation notes: "*Diverse local economies, where local business can keep money circulating by trading with each other, are more flexible, more able to survive global recession, and more innovative, than ones which are dominated by a handful of [brand] names*"[84]. The ability for vital infrastructure to avoid or adjust to conditions of scarcity and sudden change would also help buffer dependent local businesses.

Distributed systems may be more conducive to economic innovation and adaptation than large centralised systems. One reason is that they don't lock-in huge amounts of financial capital for many decades[85]. Because they are smaller and more modular, distributed systems can evolve more rapidly with technical change. The lower cost of localised systems also allows developers, small business, communities and even households to play a greater role in resource provision - reducing demand on centralised services and cutting the financial burden on governments and utilities.

"…people who produce part of what they consume have a unique understanding of users needs and greater freedom to test new methods of meeting them."

The development of distributed systems creates a whole range of new business opportunities. Two factors are particularly important to support innovation and service improvement:

- A diversity of people with the ability to produce some of the resources and services they consume
- Closer relationships between producer and consumer

In the first instance, people who produce part of what they consume have a unique understanding of users needs and greater freedom to test new methods of meeting them. In the second instance, localising production and consumption tightens the feedback between producer and consumer - allowing faster exchange of information about new demands and changing conditions.

Empowering local communities

Distributed systems are likely to improve community resilience through the creation of strong social networks. Many studies of community resilience and vulnerability note that social networks are critical for building community resilience and adaptive capacity[86]. They can help the exchange of information, enable the building of partnerships and facilitate innovation that is important for avoiding risks or overcoming the impact of disasters[87]. Research has also shown how simple personal interactions through a

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[84] NEF (2009) citing NEF (2002)
[85] Pinkham R, Hurley E, Watkins K, Lovins A, Magliaro J (2004).
[86] See for example: Adger W (2001)
[87] Buckle P (2006)

shared purpose and community engagement can help 'forge' adaptive capacity in hazard-prone areas whether or not those interactions relate to hazard preparation[88].

The networked structure of distributed systems can generate social interaction among people within a local area and between people across different areas. In a recent UK study, Gill Seyfang showed that a particular characteristic of local food systems was the strength and importance of personal interaction and close inter-organisational networking. People involved in these systems explicitly valued this feature - identifying it as lacking in current (industrial) food markets[89].

> "…Infrastructure, including technology, determines the degree to which a commons can be exploited, … the extent to which waste can be reduced, … and the degree to which resource conditions and the behavior of humans users can be effectively monitored."
>
> Dietz, *et al.* (2003)
> The Struggle to Govern the Commons

C. REDUCING OUR ENVIRONMENTAL FOOTPRINT[90]

Mitigating environmental change requires a radical restructure in the way we produce and consume goods and services. A distributed approach can assist by tailoring production to local resource and demand conditions and by bringing production and consumption closer together. This re-localisation process, if appropriately designed as a networked system, creates opportunities to reduce the inherent energy and material intensity of service provision. It can even regenerate environmental conditions.

Cutting resource transportation

Moving resources long distances involves a 'built-in' demand for energy and material resources that is usually not addressed by eco-efficiency strategies. Designing systems that locate resource and service provision close to where resources and demand exists can deliver significant environmental benefits. One example is the ability to reduce the size of transport infrastructure.

In the US[91] and Australia[92], distributed stormwater systems are cutting the size (and even avoiding) drainage and retention systems. This is possible through context-specific water retention and infiltration points that reduce the peak volume and rate of water flows at their source. The same strategy applied to wastewater systems can also reduce the wear and tear on physical components because distributed wastewater systems often require lower pressure and flow rates[93].

Delivering resources and services over long distances can substantially increase the energy (and carbon) intensity of production and consumption. For example, outside of gravity-fed water reticulation systems[94], energy for pumping can constitute the largest environmental impact of water distribution systems[95]. Shifting service systems closer to users offers a pathway to reduce this 'locked-in' carbon footprint. Modelling by the

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88 Paton D, Auld T Ibid.
89 See for example Seyfang G (2007)
90 Dietz T, Ostrom E, Stern P (2003)
91 Seattle Public Utilities 'Seattle: Managing Stormwater.' Seattle Public Utilities, Seattle.
92 Coombes P, Kuczera G, Kalma J, Argue J (2002)
93 Nelson V (2008)
94 A shift to desalinated water sources will see an increase in the energy intensity of water distribution in Australia due to the extra pumping requirements – particularly in areas like Melbourne which have traditionally relied on gravity fed water.
95 See for example: Herstein L, Filion Y, Hall K (2009)

Institute for Sustainable Futures has shown how a distributed approach to wastewater treatment and reuse at one urban development in Queensland could reduce the carbon emissions of water services by around 6%[96].

Localising agriculture and food processing also represents an opportunity for reducing the carbon footprint of food. This is particularly the case in countries like Australia where processed food is increasingly imported[97] and most fresh food is distributed via complex national freight systems. While transport accounts for a small fraction of the 'embodied' energy of foodstuff[98], a typical food basket can nevertheless have a cumulative travel distance of tens of thousands of kilometres[99].

Moving resources long distances can be highly wasteful. Between 7 and 15% of electricity generated in Victoria is lost between point of source and final use[100]. Electrical resistance in distribution cables and voltage adjustments are key factors – both are functions of distance. Localising energy and water services can reduce this problem. Studies by organisations like CSIRO, WADE and RMI suggest that strategically positioning distributed generators throughout existing networks can significantly reduce electricity losses. Modelling has shown that network losses can be cut by up to 45% - 84%[101] [102]. Moving water also involves wastage. From 2005 to 2008, leakage from reticulated water mains run by Australia's largest utilities averaged 32000 litres per kilometre of piping per day[103].

Maximising the value of local resources

The distributed model offers a way to cut the energy and material consumption of services by capitalising on local resource opportunities. Existing infrastructure systems are often highly efficient at delivering a standard, high-volume, high-quality service but unable to target specific needs. The use of potable water for industrial cleaning and cooling or agricultural production are common examples. This 'over-servicing', represents an inefficient use of energy and materials that is designed-in at a systems level. This problem is exacerbated wherever suitable lower quality resources (eg stormwater[104]) exist close by, but are unused.

"Distributed systems may capitalise on low volume or low(er) quality local resources more easily and cost effectively…"

Distributed systems may capitalise on low volume or low(er) quality local resources more easily and cost effectively since transportation and processing are minimised. Combined heat and power systems are an important example. These can dramatically

[96] Results also suggested that as wastewater treatment systems became increasingly distributed, overall energy efficiency and cost effectiveness would peak and then decline. Fyfe J, Abeysuriya K, Mitchell C, Grimes S (2009)

[97] Flanders Investment & Trade (2009)

[98] Significantly more energy is used for food production and processing. One UK study found only 3.5% of the embodied energy in food came from transport. See: Garnett T (2003)

[99] See Gaballa S, Abraham A (2007)

[100] Depending on the distance from supply to consumption.

[101] Borges C, Falcao D (2006).

[102] CSIRO (2009)

[103] National Water Commission (2009)

[104] More than half of Melbourne's water needs fall on the city as rain but remain unused. City of Melbourne (2008) .

cut the carbon footprint[105] of electricity and heating (or cooling) services compared to conventional power systems because they maximise the value of heat produced from combustion (which is otherwise wasted) and involve shorter (average) distances between production and consumption). Moving heat is costly and inefficient, so at a local level, small 'co-generation' plants can utilise this resource effectively by heating and cooling water or spaces in buildings - achieving efficiency levels of 85-90%[106]. In contrast, the long-distances between conventional power plants and customers prevent heat energy being used. These systems struggle to achieve efficiency levels above 33%.

The ability for distributed systems to use lower-grade resources is seen in many recycling schemes that (generally) only exist at a household to municipal level. The use of organic waste and greywater for food production are common small-scale examples. More sophisticated arrangements include:

- Recycling unwanted food materials back into production[107]
- Diverting food waste to agriculture[108]
- Industrial heat recovery systems[109]
- Nutrient recovery from wastewater[110]
- Biogas generation from organic waste[111]

In some cases distributed systems can re-incorporate wastes many times through a hierarchy of uses and multiplying the value of resources. In urban developments like WestWyck and Pimpama Coomera, water is used once for washing, twice (as greywater) for toilet use, and again (post treatment) for irrigation[112] [113].

Modifying consumption behaviour

Well-designed distributed systems can increase feedback between production and consumption and foster more 'environmentally friendly' behaviour. Feedback can enable learning, create a mechanism for stimulating new habits and help embed habits as norms[114]. For example, improving the quality of information people get about the energy use and cost of specific consumption behaviour (eg through digital displays in

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[105] It is estimated (conservatively) that distributed energy - involving mainly combined heat and power generators, could reduce London's CO2 emissions by 27.6% by 2025. Parsons Brinckerhoff Power (2006).

[106] LeMar P (2002) .

[107] One example in Melbourne is *Second Bite:* http://www.secondbite.org/

[108] Edwards F, Ryan C, Larsen K (Forthcoming) Social Innovations in Food Systems. Victorian Eco-Innovation Lab. (Melbourne) .

[109] While waste heat from boilers and ovens has been used in industrial contexts for decades, heat recovery systems have developed to the stage where heat can be captured from shower wastewater to pre-heat hot water at an apartment scale.

[110] See for example: http://www.ete.wur.nl/UK/Projects/DESAR/; Water utilities such as Yarra Valley Water are also investigating the feasibility of nutrient recovery in rural Victoria.

[111] Wett B, Buchauer K, Fimmi C (2007)

[112] Gold Coast Water (2004b).

[113] Hill M (2009)

[114] Verhallen T, Raaij W (1981).

the home) can drive a sizeable reduction (>10%) in energy consumption[115]. People respond by changing the timing and intensity of their energy use.

People who sell surplus energy they produce from small-scale generators have an incentive to reduce their own consumption and shift their higher energy use behaviours to times when demand on the electricity grid (and therefore energy price) is low. A study of households with photo-voltaic (PV) arrays in the UK noted how after installation, energy use declined (by around 6%) and almost half of the households changed the timing of high consumption behaviours[116]. A separate report from the UK[117] also showed a strong link between people's attitudes and behaviour, and their proximity to various small-scale energy systems. The report cites how, "*Living with the technology… seemed to encourage far greater understanding and awareness around energy issues and often had an impact on behaviours too*". People became more energy-literate, developed greater knowledge of system operations and were sensitive to decisions that affected energy consumption[118]. An Alternative Technology Association survey of households with solar systems found similar results. In the majority of cases, peoples' awareness and consumption of energy changed after their systems were installed[119].

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[115] See for example Wood G, Newborough M (2003).
[116] Keirstead J (2007).
[117] Dobbyn J, Thomas G (2005) .
[118] Ibid.
[119] Brandao M (2007) .

Part Three:

The shift to distributed systems is underway

"*We believe companies need to prepare now for a participatory network that enables customers to choose from a wide variety of supply options, actively manage their consumption and even sell back surplus power they generate.*" IBM [121]

A STRONG TREND ALREADY EXISTS

This review of the role of distributed systems in creating resilient communities and economies takes place against a background in which a shift to distributed service and resource provision is already underway. Across developed and developing countries there is growing investment and implementation of networked localised resource and service systems. Underpinning this shift is a set of interrelated factors:

- The distributed nature of critical renewable resources
- The drive for increased resource efficiency
- The need to reduce oil dependency
- New technical capacity for system management and control
- A desire from social and business organisations to reduce risk and uncertainty

Because distributed systems are often easy to integrate with existing (centralised) infrastructure, investment, innovation and experimentation in distributed systems is springing up where specific local conditions make it an appropriate response.

Taking local opportunities:

Distributed systems exploit distributed resources

The spatially distributed nature of valuable resources such as solar and geothermal energy, water and fertile soils, underpin the shift to more localised service provision. New technologies[121] are enabling these distributed resources to be captured and utilised. The re-configuration of network systems (including information networks) is taking place to allow these captured resources to be shared beyond their local utilisation. The model of distributed electricity production and consumption, using diverse energy sources (solar PV, wind, geothermal, high-temperature solar-electric) feeding-in to a distribution grid (which acts both as a 'load sharing' system and a form of energy storage) is already widely familiar. As a model of a sustainable electricity system, diverse grid-linked renewable supply is seen as a desirable future state by an increasing number of countries and regions[122].

Analogous models for water and food production and consumption are also receiving a lot of attention. In Melbourne, with climate change posing serious challenges for water supply, many of the elements of a distributed system (rainwater tanks, grey and black water recycling) are already widely developed and there is a growing expectation that some level of local self-sufficiency in water will be part of the urban future[123].

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[120] Valocchi M, Schurr A, Juliano J, Nelson E (2007)
[121] This is often seen as new improvements to old technologies
[122] McCormick K (2008) .
[123] This appeared to be a consistent theme, for example, across all 'user groups' at the Melbourne Water Liveable Cities consultation in Melbourne in October 2009. (Report still under development by Melbourne Water).

Information technology is enabling the shift

Information and communications technology (ICT) plays a vital role in the process of change since the management of distributed systems is often dependent on information handling. The Internet has been particularly important. It acts both as a ubiquitous platform for information management and as the largest, most resilient system of networked distributed production distribution and consumption.

Innovation in ICT continues to play a strong 'game-changing' role – particularly in regard to economies of scale. The miniaturisation and cost-reduction of sophisticated sensing technologies is creating new opportunities for distributed systems to develop. Systems can be cost-competitive without being large, particularly when ICT systems enable the centralised or internet-based monitoring and control of decentralised physical production technologies. ICT is enabling system owners to overcome the disadvantages of small size while benefiting from its many advantages relating to flexibility and responsiveness.

The following examples illuminate these points:

- Mobile telephony systems are enhancing the functioning of distributed systems. In the latest electric vehicles, connection via mobile phone enables charging rates and battery conditions to be remotely monitored (as can the position of the vehicle and so on). Clever telemetry and control systems also enable these vehicles to connect to the electricity grid as short-term 'network-storage' – an option being seriously discussed and tested in the USA and Europe. Smart electricity meters in households also allow for the sale of electricity to the grid and feedback on consumption for residents.
- Small-scale residential sewerage systems in Australia ('septic tanks') based on active aeration, or colonies of worms and micro-organisms, operate on the basis of a 'service contract' for maintenance utilising remote ICT monitoring[124].
- Other small-scale wastewater treatment systems are now being used to fit out whole suburbs in a networked fashion. New telemetry technologies are also allowing remote operation of the whole system in real-time – requiring a fraction of the operation and maintenance costs needed for centralised systems[125].

ICT can re-connet people with the 'impact' of their decisions through real-time, relevant, information[126].

Distributed strategies reduce risk and increase innovation

The emergence of distributed systems reflects a widespread response by organisations to conditions of greater uncertainty, higher risk and more competition. As futurist Jamais Cascio writes…"*The notion that self-assembling, bottom-up networks are powerful methods of adapting to ever-changing conditions has moved from the realm of*

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[124] See: http://www.biolytix.com.au

[125] Biggs C, Ryan C, Wiseman J, Larsen K (2009) .

[126] This is one of the promoted values of smart electricity meters and the basis of numerous electricity-consumption digital display products on sale to consumers in most industrialised countries.

academic theory into the toolbox of management consultants, military planners, and free-floating swarms of teenagers alike."[127]

Like the origin of the Internet, much of the design and strategic thinking around the structure, operations and management of distributed systems derives in part from military research (responding to the vulnerability of centralised structures)[128 129]. Other organisations are also adopting variations of the model and for similar reasons; to overcome greater uncertainty, operate more effectively and reduce operational risks. In the area of logistics for example, supply chain models show how greater decentralisation of distribution hubs can reduce costs under higher fuel prices[130].

Under conditions of high competitive pressure, collaborative networks between small groups of independent organisations and businesses can offer a more effective way to solve problems and develop new products than large in-house research and development units. In periods of rapid technology innovation – as for the ICT revolution – it is often loose networks operating across established R&D institutions that generate break-though products and systems[131].

Distributed and Centralised Systems can be integrated

The advantages of small-scale, localised systems do not extinguish the need for larger systems. In the words of engineers D'Amato and Tukker "*…in a distributed infrastructure model a combination of infrastructure scales is often most appropriate and efficient. As such, one should not look at decentralized versus centralized (i.e., "big pipe") systems, but rather at a continuum of options that might coexist (and in fact integrate and work synergistically) within a given management or service area.*"[132]

Where developers, governments, utilities and businesses are looking beyond yesterday's infrastructure model, distributed systems are increasingly added to existing centralised systems as a way to:

- Avoid major capacity expansion of centralised systems – The government in New York City has developed incentives to encourage developers to opt for local storm and wastewater treatment and reuse options in order to avoid costly upgrades in the city's sewers[133].
- Improve customer convenience – Food retailers in the US and Europe are moving to small stores in a bid to match people's desire for less time in large, concentrated retail outlets[134].

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[127] Cascio J (2006)
[128] Callahan W (2008) .
[129] Eilstrup-Sangiovanni M, Jones C (2008) .
[130] Closs D, French D (2006)
[131] This has been strongly argued and documented in the many analyses of the ICT revolution – for example: Brown J, Duguid P (2000)
, Buderi R (2000) ; Or for a review of this aspect of innovation see: Ryan C (2004a) Section 4 pp159- 186.
[132] D'Amato V, Tucker B (2009)
[133] Clerico E (2009).
[134] FoodsLine LLC (September 2009)

- Modulate peak demand on existing infrastructure – Projects in Seattle are using 'source-control' methods such as infiltration swales to reduce peak stormwater loads to sewers[135].
- Reduce the carbon intensity of service delivery – The Utility Yarra Valley Water has used detailed maps of energy use to identify locations where small-scale treatment systems could be added to existing centralised sewerage systems to reduce the energy and carbon intensity of services[136].
- Increase the flexibility and resilience of centralised systems – Numerous countries including Denmark, Sweden (and even the US and UK) are diversifying their energy sources using more distributed systems as a means to improve overall security of existing energy infrastructure[137].
- Avoiding the cost of building up centralised infrastructure from scratch – Developing nations around the world are developing distributed mobile, solar and telemedicine technologies and avoiding the costs associated with their centralised alternatives[138].

Distributed systems are co-evolving with social innovation

Distributed systems reflect part of a wider willingness for individuals to express their creativity and identity through producing, sharing and distributing resources. As writer and Harvard Professor Yochai Benkler describes it…"*We are seeing individuals and groups of all shapes and forms beginning to take advantage of networked communications to form collaborative networks, sharing effort and material resources in decentralised networks to solve problems once thought amenable only to centralised control. These approaches are not an aberration, but are at the core of what happens when human beings are entrusted with the capacity and authority to act together to improve their lot.*"[139]

"We are seeing the ability of distributed systems to transform the role of consumer, from passive participant, reliant on one large, centralised service providers, to that of a more active 'prosumer'…"

However, individuals are not just avidly harnessing networked communication; this new capacity is spawning an increasing population of people producing software, music, video content, food, clothes and even electricity from distributed sources. There is a cultural shift away from relying on large, central organisations for goods and services. We are seeing the ability of distributed systems to transform the role of consumer, from passive participant, reliant on one large, centralised service providers, to that of a more active 'prosumer' – being both producer and consumer.

The recent rethink of the Australian governments' solar rebate scheme due to its 'over-popularity' is one indication of how widespread people's desire is to embrace new technologies that enable them to produce resources themselves. An IBM survey of energy customers from 2007 seems to support this. In it, a clear majority of those

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[135] Seattle Public Utilities 'Seattle: Managing Stormwater.' Seattle Public Utilities, Seattle.
[136] Saliba C, Gan K (2005) 'Energy density maps in water demand management.' Yarra Valley Water, Melbourne.
[137] See Part Two of this paper
[138] Article 13 (September 2005) Leapfrogging: a different route to development. In 'CSR expert review'. (Online)
[139] DEMOS (2007) 'The Collaborative State.' DEMOS, London.

surveyed expressed a desire to produce and sell electricity to the grid[140].

BUT… LARGE PROJECTS CAN UNDERMINE INNOVATION

The development of distributed systems exists at the periphery of political and industry strategies to tackle resource scarcity and climate change. Decisions to pursue large-scale desalination or carbon capture and storage - and calls for nuclear power - reflect an ingrained belief that 21st Century challenges can be solved with 20th Century thinking. Emphasising 'silver bullet' solutions poses considerable risks. Part One of this paper has outlined some of them. Delivering socially critical resources and services via generic, resource intensive infrastructures that rely on stable supplies of distant and dwindling raw materials is inherently risky. It assumes the next 30-100 years will be much the same as the last. Pursuing this strategy also involves a deeper strategic risk that is difficult to quantify - *the loss of flexibility* to change.

Large projects can have a profound impact on social and market behaviour. Even where mega-projects represent a 'stop-gap', their ability to delivery key resources at low-cost undermines economic and strategic incentives for business and industry to develop alternative processes. Innovation is unlikely until large infrastructure systems are at risk from changed environmental conditions, near the end of their life span or themselves undermined by new lower cost technologies.

Mega-projects can constrain investment flexibility. Large capacity projects require stable, guaranteed returns on investments over decades - limiting the availability of capital for other investments and creating a disincentive for investors to consider alternatives. Locking up a large financial resource also creates powerful incentives for stakeholders to protect those investments – even where this may not be in a regions' best interest.

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[140] Valocchi M, Schurr A, Juliano J, Nelson E (2007) Plugging in the consumer: Innovating utility business models for the future. In. (Ed. IBM Global Services). (Somers)

Conclusion:

Implications and challenges

This decade will see significant investment and planning decisions directed toward climate mitigation and adaptation. This paper has aimed to raise awareness about the vulnerability of current infrastructure and to prompt new thinking about how we respond to climate change and resource scarcity. A redesign of production and consumption systems offers significant potential for addressing environmental change and resource scarcity.

Action can be taken - now

Meaningful action on climate change can be taken now - without national and international leadership. Examples in this and earlier VEIL papers[141] show that individuals, communities, businesses and regional governments can act independently to address the structural causes of global change and societal risk by following a distributed approach.

- These actors are better placed to adopt strategies like shortening supply chains, shifting reliance to local resources and developing context-specific services that reduce environmental impacts and avoid carbon emissions. Sub-national actors can show pro-active leadership through their links to social networks, sensitivity to environmental change and ability to identify opportunities for action.
- Pursuing change through smaller, modular and therefore less costly interventions gives small business, community groups and local governments the ability to participate in the change process. Interventions can be applied wherever suitable conditions exist; to address failure points in existing systems or sites of high resource supply and demand.
- Initiatives at the building, suburb and regional level can be implemented without major structural reform or policy innovation and by applying technical applications that are widely available, relatively low cost and easily managed. Systems can be as simple as opportunities allow. The distributed model therefore aligns well with the needs of agents that do not have significant financial or specialised technical capacity.

The distributed model offers a simple approach to mitigation and adaptation that people can easily understand, relate and contribute to. The overwhelming scale and complexity of global problems creates the perception that individuals and small organisations have little influence. This is exacerbated by national and international policy agendas that are difficult to understand and confine responses within complex regulatory mechanisms. Strategies that change local systems of production and consumption give people a tangible understanding of how their actions can make a difference. People are already partly familiar with how energy, food and water systems work, so a proliferation of photovoltaics, diverse water sources and urban food systems offers an important measure of progress that is visible and easily measured.

Adaptation and mitigation are compatible:

The distributed model offers a way to integrate diverse initiatives at multiple scales. It is founded on simple principles that can be universally applied. Attributes like redundancy, modularity and proximity to points of resource supply and demand can improve the resilience of systems at the suburb, region and even national level. Provided different initiatives aim to minimise resource consumption, increase sensitivity

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[141] Biggs C, Ryan C, Wiseman J, Larsen K (2009) *Distributed Water Systems: A networked and localised approach for sustainable water services*. Victorian Eco Innovation Lab, Melbourne.

to change and expand flexibility at a specific scale, actions at smaller and wider geographical contexts can be synchronised.

We don't need to trade off the needs of adaptation and mitigation strategies against each other. Because infrastructure vulnerability and environmental change are both linked to issues of development – economics, technology and lifestyles; they can both be addressed by transforming how development occurs. We do not need to improve resource security by re-applying the same engineering approaches that have lead to current problems. Attributes like flexibility, sensitivity, diversity and modularity can compensate for strength, large capacity, and the ability to resist (and recover from) external shocks.

Changing physical systems can affect behaviour change:

Changing infrastructure design can contribute to social and behavioural change. The distributed model offers a way to shift consumption patterns in a way that education and economic incentives don't:

- By improving feedback on actions - bringing the environmental impact of people's decisions closer their sphere of understanding.
- By embedding low(er) resource consumption behaviours into everyday habits
- By encouraging people to take a tangible stake in the long-term health of local resources
- By creating a medium through which people redefine themselves - from isolated, individual consumer, to collaborative, connected producer - identifying with the resources they provide and their place of origin.
- By giving people the capacity to make consumption choices that better align with their values.

Key Challenges

Accepting systemic change:

The distributed model exists at the periphery of traditional infrastructure planning and management. While we have argued it offers an approach that can be applied immediately for valuable results, a thorough transformation in production and consumption demands a widespread adoption of networked-localised solutions. This is unlikely to occur unless we address a number of barriers. The following issues are not definitive but outline some of the main challenges.

Understanding the difference between achieving targets and delivering long-term change. The distributed model may offer a better way to target the origins of unwanted global change. This is why it shows significant potential but also why implementing it will be difficult; it means changing established ways of doing things. It is much easier to develop strategies that address the causes of climate change at 'end of pipe' and by incremental improvements in current goods and services. This is why eco-efficiency is the dominant approach; it is easy to think that progress is made without changing behaviours or underlying structures of development. Whether the distributed model is widely adopted or not, solutions will only be found through strategies that address the origins of global problems. This will require uncomfortable change.

Changing the institutions of production and consumption:

Driving a parallel shift in institutional and regulatory systems. This paper has emphasised the ease with which distributed systems can be developed. However, most working examples have evolved in response to significant unmet demand, opportunities presented by unutilised resource surpluses, or due to shifts in regulations. We should focus on finding and making use of easy opportunities but rigid institutional arrangements need to be restructured before the real potential of distributed systems can be realised.

- Currently, resources and services are mainly delivered by profit-driven businesses or corporate utilities. As more diverse agents gain the capacity to deliver the same services the incentives shaping the market will shift. Our policy frameworks and regulations need to catch up to a world in which resource providers may be increasingly opportunistic – delivering services only when prices are right - or driven by charitable, ethical or even barter incentives[142]. How do we regulate these new arrangements? Remembering that many existing resource providers already have clear incentives for protecting territorial service monopolies and are at risk if these are broken.
- Lines of resource ownership, operating responsibility and liability will also become increasingly complicated. Access rights to as yet unvalued resources will also need to be designed. If homeowners are required to reduce stormwater runoff for example, do they have the right to harvest and market it?
- Divisions of institutional responsibility will also need to be re-drawn. In many situations, local governments and even communities are in a better position to regulate sustainable use of local resources but don't have the capacity or power to do so; controls lie with higher level institutions. We need to develop and test different methods of devolving this responsibility, while also being aware of new emergent risks such as corruption.

The success of distributed systems as a holistic mitigation and adaptation strategy will require regulatory innovation. However, it is important to note that the issues raised above will need to be dealt with regardless - due to the way technical and social trends are already pushing us toward more distributed systems of ownership.

Managing the social risks:

Maintaining equity. The distributed model may advantage people with access to critical resources. In open urban environments some house-owners may have greater ability to capitalise on wind, solar and rain (and even soil) as potential income streams and means of reducing their vulnerability to resource scarcity. Renters and owners of apartments and other residences in dense urban environments may not be so lucky. Perhaps we can develop new arrangements that reduce this disadvantage - allowing access to resources on public land for example. Networking, local distribution systems and resource sharing will become a critical issue in dealing with equity issues.

Valuing what does not work:

Accepting the role of experimentation (and failure). We need to be willing to test new arrangements and accept that problems will occur. In the absence of proven strategies this is all the more important since we need to be testing a diverse range of strategies and systems. This will necessarily involve surprises and results we wont like.

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[142] This ground is shifting rapidly. For example, people are being encouraged to 'adopt a tree' in response to water shortages in places like Adelaide and Melbourne. http://www.unley.sa.gov.au/site/page.cfm?u=1541

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