UN environment

Resilience and Resource Efficiency *in Cities*

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Resilience and Resource Efficiency *in Cities*

Acknowledgements

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Foreword

Improving resilience was at the heart of the Third United Nations Conference on Housing and Sustainable Urban Development (Habitat III) held 17 - 20 October 2016 in Quito; and this was reflected in its outcome document, the New Urban Agenda. The New Urban Agenda recognized "environmentally sustainable and resilient urban development" as one of three transformative commitments to make the vision of a resource efficient city a reality. In paragraph 71 of the New Urban Agenda, world leaders outlined their commitment to, "strengthening the sustainable management of resources – including land, water (oceans, seas, and freshwater), energy, materials, forests, and food, with particular attention to the environmentally sound management and minimization of all waste, hazardous chemicals…in a way that considers urban-rural linkages and functional supply and value chains…" This report responds directly to Paragraph 71, the concepts behind it, and its implication in improving overall city resilience.

As a technical contribution to the Habitat III process, UN Environment and The Rockefeller Foundation co-led a series of meetings involving experts from around the globe to define and refine 'resilience'. What came from this process is a 'marriage' of the concepts of resilience and resource efficiency. The two have traditionally had different audiences and consequently different narratives, metaphors, and tools for understanding and shaping urban development. Resilience is often linked with the climate change adaptation perspective while resource efficiency – often looking into sustainable transport and mobility, energy, and resource efficiency – is seen more from a mitigation perspective.

The expert discussions highlighted that while there are differences, and at times tensions, between the two concepts, they are complementary. For example, latent stresses such as flaws in the food system and water supply, are not always prioritized within short political timelines, but are essential to city resilience. Integrating the resilience and resource efficiency agendas into the planning of a city can therefore help it withstand shocks and stresses, and enhance the safety, security, and survival of its citizens.

UN Environment believes that understanding the connections between resilience and resource efficiency helps cities in developing integrated solutions towards sustainable urbanization. It reinforces the need for horizontal (across sectors) integration and vertical (across different levels of governance) collaboration to harness benefits for people and the planet. Linking both concepts also supports countries in achieving the different milestone agreements that were recently concluded: the Sustainable Development Goals, the Sendai Framework, the Paris Agreement and the New Urban Agenda, all of which recognized the critical role of urbanization and action at the city-level.

Our hope is that this report contributes to a positive trend towards successful implementation of the New Urban Agenda and other international agreements while supporting urban practitioners in building and managing low carbon, resilient, and resource efficient cities.

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Director, Economy Division, UN Environment

Executive Summary

Rationale for the Report

Urban areas accounted for 54% of the total global population in 2014. Yet activities in cities account for 70-75% of natural resource consumption, with significant impacts for resource availability and ecosystems in areas far beyond urban boundaries. Cities are also disproportionately susceptible to a range of environmental hazards due to their concentration of people, infrastructure and economic activity; their exposure to risk is likely to further increase with climate change. The resource efficiency and resilience of cities will become even more significant as urban population and economic growth continues: the global urban population is projected to increase by approximately 1.84% every year between 2015 and 2020, with 90% of this growth occurring in Asia and Africa.

The major global challenges of the 21st century – urbanisation, climate change, resource scarcity and poverty – therefore have huge implications for urban planners and policymakers. This report looks at the relationship between building the resilience of cities in the face of global environmental change, and increasing the resource efficiency of cities to reduce their harmful impacts on the environment. It provides examples of effective ways to address these agendas, as well as the potential and challenges for integration. This speaks strongly to global policy agendas, including the Sustainable Development Goals, the Paris Agreement and the New Urban Agenda.

A focus on cities

Although cities are home to just over half the world's population, they generate more than 80% of global GDP. Cities require substantial inputs to support this level of economic activity. Local resource scarcity can require cities to import resources from far beyond their boundaries, constructing complex infrastructure systems to transport essentials such as water, food and energy. The social and ecological impacts of urban areas therefore stretch far beyond city boundaries.

Cities can also be hotspots of vulnerability, as illustrated by the growing number of urban dwellers in hazard-prone areas such as deltas and coastlines. Their exposure and susceptibility to risk is mediated by urban forms and functions, which often give greater access to resources to certain parts of the population at the expense of others. Low-income and other vulnerable urban residents (for example, women, children, elderly, migrants and people living with disabilities) are therefore likely to be particularly vulnerable.

In the face of both resource scarcity and environmental hazards, cities are strategically positioned to be leaders of change. Placed at an intermediary scale between individuals and nation-states, cities can take actions which affect other scales through a ripple effect. City governments often have relevant powers over (for instance) spatial planning, solid waste management and building standards; although their institutional, technical and financial capacity to address these varies greatly. The density and proximity of urban areas reduce the economic and environmental costs of providing most infrastructure and services. As hubs where people and economic activities are concentrated, they are important sites for knowledge sharing and policy experimentation.

Key Messages

- **A resilience agenda can help cities become more resource efficient by being more flexible and by being better able to learn and respond to changed circumstances**. The process of building resilience can therefore simultaneously offer opportunities to build resource efficiency.
- **A resource efficiency agenda can help cities to become more resilient by reducing exposure to the risk of shortfalls in essential inputs.** Various inputs addressed in a resource efficiency agenda (materials, products, water, energy, food) are all essential for urban functioning. The outcome of achieving greater resource efficiency can contribute to a city becoming more resilient, because it will rely less heavily on the systems that provide resources.
- **A number of areas of action are common to both concepts, therefore providing ground for mutual reinforcement.** City leaders aiming to achieve both resilience and resource efficiency can adopt measures for each with the potential to contribute to the achievement of both objectives.
- **Possible tensions between resource efficiency and resilience may also exist.** Redundancy and modularity may help cities to be more resilient to shocks and stresses, but could also be framed as representing inefficient use of resources. Overcoming these potential conflicts will require more integrated and responsive urban planning and governance.
- **Achieving resilience and resource efficiency at city-level can help meet broader sustainability objectives.** The urban resilience and resource efficiency concepts have overlapping objectives and both aim at addressing major challenges such as climate change and pressure on natural resources. They are concerned not only with short-term achievements, but also with providing key tools for the long-term sustainable development of cities.

Structure of the Report

The report has three main sections: on resilience, on resource efficiency, and on the nexus between the two. For each concept, it explores the state-of-the-art in understanding and implementation – looking at definitions, characteristics, benefits, limitations and practical applications. It then explores the links between the principles, objectives, and initiatives associated with urban resilience and resource efficiency.

This report draws on theoretical and grey literature. More importantly, however, it is informed by the inputs of city officials from Africa, Asia and Latin America at a series of workshops on resource efficient cities held in 2013 and 2014. The case studies presented here – largely initiated by city officials – show how urban areas around the world are grappling with the different ecological and social challenges, and indicate potential avenues for other towns and cities to achieve the transformative commitments of the New Urban Agenda.

The report concludes that resource efficiency is an essential element to urban resilience, and that resource efficiency can be accomplished more effectively when it is built in the context of a resilient system. The conceptual analysis and case studies make it clear that considering these issues together can help planners to address global challenges, such as climate change and poverty.

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Glossary

Biodiversity	Biodiversity means the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (Convention on Biological Diversity, 1993)
City	Cities are places where large numbers of people live and work; they are hubs of government, commerce and transportation. But how best to define the geographical limits of a city is a matter of some debate. So far, no standardized international criteria exist for determining the boundaries of a city and often multiple different boundary definitions are available for any given city. (United Nations Department of Economic & Social Affairs, 2016)
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. (United Nations Framework Convention on Climate Change, 2011)
Climate change adaptation	Adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. (United Nations Framework Convention on Climate Change, n.d.)
Climate change mitigation	Efforts to reduce the concentration of greenhouse gases in the atmosphere, either by reducing emissions or by removing these gases from the atmosphere. Mitigation can be achieved by using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior.
Decoupling	Relative decoupling: a lower rate in growth of a type of environmental pressure in relation to the rate of growth of a related economic activity. Absolute decoupling: an environmental pressure either remaining stable or decreasing while the related economic activity increases.
Disaster Risk Reduction	The concept and practice of reducing disaster risks through systematic efforts to analyse and reduce the causal factors of disasters. Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness and early warning for adverse events are all examples of disaster risk reduction. (United Nations Office for Disaster Risk Reduction, n.d.)
Ecosystems	A dynamic complex of plant, animal and microorganism communities and their nonliving environment interacting as a functional unit. (United Nations Environment Programme, n.d.)
Environmental Footprint	The environmental footprint is a means of measuring the impacts of a person, company, activity, product, etc. on the environment. The framework has been applied specifically to cities. (Wackernagel *et al.* 2006)
Governance	The exercise of economic, political and administrative authority to manage a country's affairs at all levels. It comprises the mechanisms, processes and institutions through which citizens and groups articulate their interests, exercise their legal rights, meet their obligations and mediate their differences. (United Nations Economic and Social Council, 2006)
Green Economy	A green economy is one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy is low-carbon, resource-efficient, and socially inclusive. (UNEP 2011)
Green Infrastructure	Green Infrastructure refers to natural or seminatural ecosystems that provide utility services that complement, augment or replace those provided by grey infrastructure. (United Nations Environment Programme, 2014)

Greenhouse Gases	The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). Less prevalent --but very powerful -- greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6). (United Nations Framework Convention on Climate Change, n.d.)
Infrastructure	The system of public works in a country, state or region, including roads, utility lines and public buildings. (United Nations Department of Economic & Social Affairs, 2000)
Institutions	institutions are rules and norms held in common by social actors that guide, constrain, and shape human interaction. Institutions can be formal, such as laws and policies, or informal, such as norms and conventions. Organizations – such as parliaments, regulatory agencies, private firms, and community bodies – develop and act in response to institutional frameworks and the incentives they frame. Institutions can guide, constrain, and shape human interaction through direct control, through incentives, and through processes of socialization. (IPCC 2014)
Local food systems	A system that embraces all the elements (environment, people, inputs, processes, infrastructure, institutions, markets and trade) and activities that relate to the production, processing, distribution and marketing, preparation and consumption of food and the outputs of these activities, including socio-economic and environmental outcomes. (United Nations Secretary General's High-Level Task Force on Global Food and Nutrition Security, 2015)
Metropolitan regions	Highly urbanized, city-regional areas that are characterized by a high population density as well as a concentration of economic, political and cultural activities. Metropolitan regions form part of the global city-network and exhibit a specific governance structure that provides mechanisms of inter-jurisdictional cooperation between core cities and their hinterland. (GIZ, 2014)
New Urban Agenda	An action-oriented document adopted at the United Nations Conference on Housing and Sustainable Urban Development, known as Habitat III, held in Quito, Ecuador from 17-20 October 2016. It sets global standards of achievement in sustainable urban development, and redefines the way in which cities are built, managed and lived in through drawing together cooperation with committed partners, relevant stakeholders, and urban actors at all levels of government as well as the private sector. (Habitat 3 Secretariat, 2016)
Planetary Boundaries	A planetary boundaries framework defines a safe operating space for humanity to develop and thrive, according to nine defined biophysical processes that regulate the earth's system. It provides a science-based analysis of the risks caused by human activities interfering with the earth's natural functions (although is less directly relevant at the scale of cities). (Rockström *et al.*, 2009; Steffen *et al.*, 2015).
Rainwater harvesting	Involves collecting and storing rainwater in reservoirs or tanks, or facilitating the infiltration of rainwater into subsurface aquifers before it is lost as surface runoff. Rainwater harvesting can reduce water deficits by increasing the supply available to prospective users.
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. (United Nations Office for Disaster Risk Reduction, 2009)
Resource Efficiency	Resource efficiency refers to a means of achieving more productive use of resources. By taking the whole lifecycle of resources into account – from the extraction of raw materials to final use and waste disposal – and considering them from a *value chain perspective*, practitioners can identify opportunities to reduce waste. Analysing value chains can help to identify potential externalities that might not be immediately perceptible over the long-term or within certain geographical boundaries. (UNEP 2010).
Risk	The combination of the probability of an event and its negative consequences. (United Nations Office for Disaster Risk Reduction, 2009)

Spatial Planning	A method used largely by the public sector to influence the future distribution of activities in space. Spatial planning is undertaken with the aims of creating a more rational territorial organization of land uses and the linkages between them, to balance demands for development with the need to protect the environment and to achieve social and economic development objectives. (European Commission, 28) – year??
Sustainable Development	Development which meets the needs of current generations without compromising the ability of future generations to meet their own needs. (United Nations, 1987)
Sustainable Development Goals	A set of goals to end poverty, protect the planet, and ensure prosperity for all as part of a new sustainable development agenda. Each goal has specific targets to be achieved over the next 15 years. Adopted on 25th September 2015. (United Nations, 2015)
Transformation	A change in the fundamental attributes of a system, often based on altered paradigms, goals, or values. Transformations can occur in technological or biological systems, financial structures, and regulatory, legislative, or administrative regimes. (IPCC 2014)
Urban Heat Island	An effect whereby urban areas have higher temperatures than those of the rural areas at their peripheries.
Urban Metabolism	A way of looking at cities and all the resources that flow within their complex networks ("material flows") of interlocked social and physical infrastructure. It conceptualizes the city as a living super-organism in which there are continuous flows of inputs and outputs helps in the study of the patterns of movements of matter and energy. This helps identify opportunities for sustainable resource management and can be linked with infrastructure in order to find alternative ways of using resources sustainably.
Urbanisation	Increase in the proportion of a population living in urban areas; the process by which a large number of people becomes permanently concentrated in relatively small areas, forming cities. (OECD, 2003)
Value Chain	The entire sequence of activities or parties that provide or receive value in the form of products or services (e.g. suppliers, outsourced workers, contractors, investors, R&D, customers, consumers, members) (ISO 14001 CD2, 2013). (United Nations Environment Programme, 2014)
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (United Nations Office for Disaster Risk Reduction, 2009)
Waste to Energy	The treatment of waste to generate energy in the form of electricity, heat or transport fuels. These can use different types of waste – solid, liquid and gaseous – although municipal solid waste remains the most common source. Methodologies include thermo-chemical conversion (e.g. incineration), bio-chemical (biogas production) and esterification (Eurostat, 2013; World Energy Council, 2013).
Sustainable Urban Development*	Sustainable urban development refers to the normative outcome of policies and actions related to the urban ecology, where "sustainable" is defined as the state wherein natural systems function, remain diverse and enable the ecosystem to remain in balance.

Figures and Tables

Acronyms

ACCCRN	Asian Cities Climate Change Resilience Network
ADB	Asian Development Bank
C40	Cities Climate Leadership Group
CRI	Climate Resilience Index
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Greenhouse Gas
GI-REC	Global Initiative for Resource Efficient Cities
GIZ	Gesellschaft für Internationale Zusammenarbeit (German Federal Enterprise for International Cooperation)
ICLEI	International Council for Local Environmental Initiatives
IDB	Inter-American Development Bank
IIED	International Institute for Environment and Development
IPCC	Intergovernmental Panel on Climate Change
MFA	Material Flow Analysis
TAMD	Tracking Adaptation and Measuring Development
UNEP	United Nations Environment Programme
UN-Habitat	United Nations Human Settlements Programme
UNISDR	United Nations International Strategy for Disaster Reduction
WB	World Bank

1 INTRODUCTION

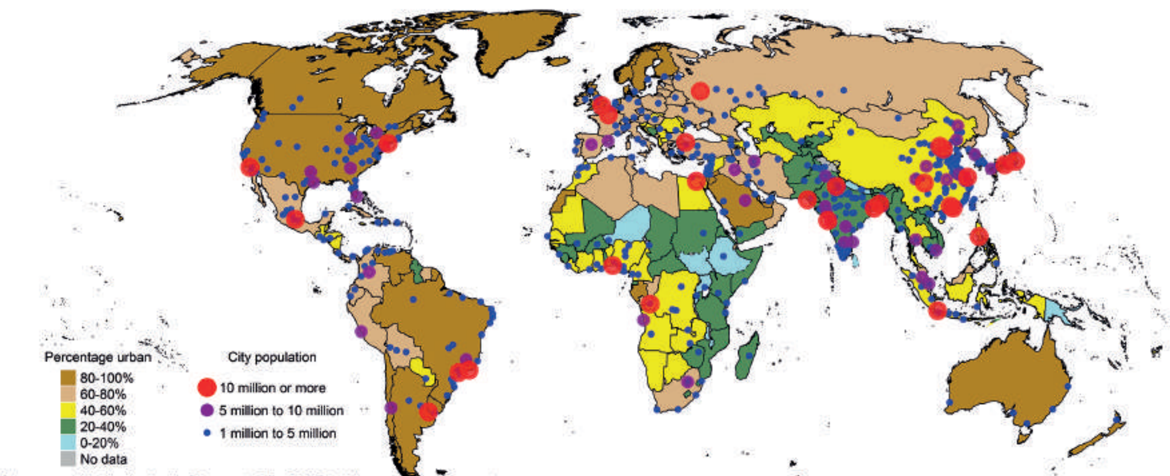
1.1 The global urban context

The major challenges of the 21st century – urbanisation, climate change, resource scarcity and poverty – have huge implications for urban planners and policymakers. According to the Global Health Observatory, the urban population accounted for 54% of the total global population in 2014, which represented a significant jump in comparison to 34% in 1960 (WHO, 2014). It is estimated that the global urban population will grow by approximately 1.84% every year between 2015 and 2020. Although the rate of urban population growth will subsequently slow, the world will still see 2.5 billion people added to the global urban population by 2050. Nearly 90% of this growth is occurring in Asia and Africa (UN-DESA, 2014).

Decision-makers must also grapple with climate change, with its range of short- and long-term risks. More frequent and intense droughts and floods, sea-level rise and storm surges add stress to people, infrastructure and ecological systems (IPCC, 2014). The growing number of urban dwellers in hazard-prone areas – such as coastlines – clearly illustrates the dangers to which cities are exposed. In low- and middle-income countries, hundreds of millions of urban residents are at risk from the direct and indirect impacts of climate change (Dodman *et al.*, 2009). Low-income and other marginalised groups are typically the most vulnerable. For example, 881 million urban dwellers live in informal settlements and lack access to at least one of the following amenities: durable housing, improved water, improved sanitation and sufficient living space (UN Habitat, 2016). The lack of risk-reducing infrastructure means that these people have low levels of adaptive capacity.

FIGURE 1: Urban areas with more than 1,000,000 inhabitants in 2014

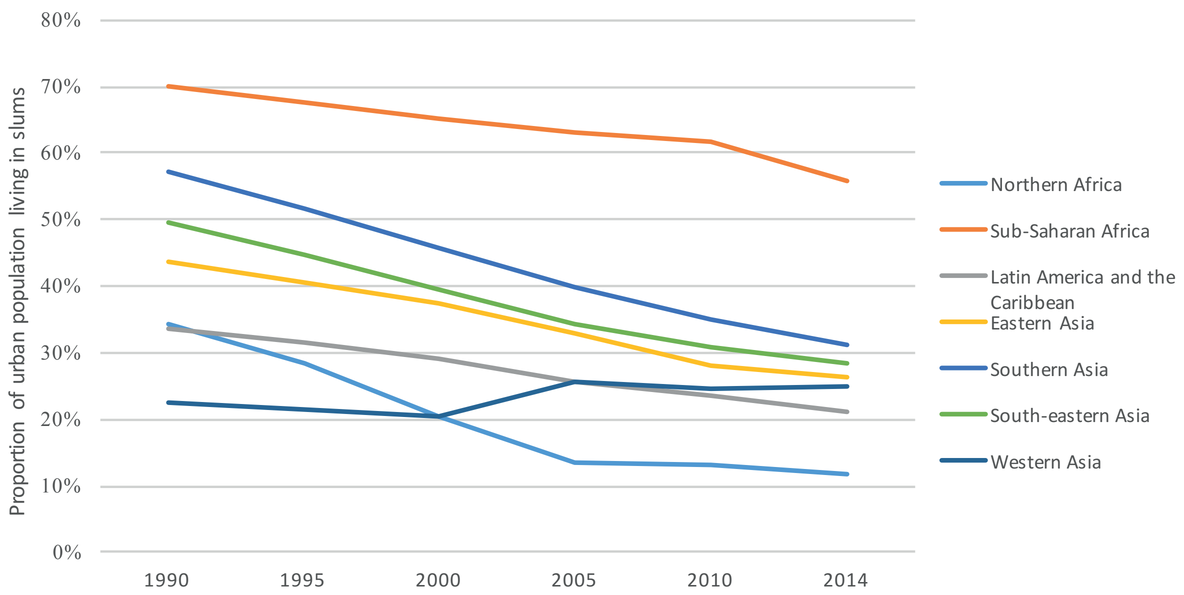
Source: UN-DESA 2014.



Data source: World urbanization Prospects: The 2014 Revision
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan.
The final status of Jammu and Kashmir has not yet been agreed upon by the parties.
Final boundary between the Republic of Sudan and the Republic of South Sudan has not yet been determined.

FIGURE 2: The proportion of the population living in informal settlements by region between 1990 and 2014

Source of data: UN Habitat, 2016.



Cities occupy 2-3% of the planet's land surface, but as much as 70-75% of natural resources are consumed within them (GI-REC, n/d; Fang, 2014). Local resource scarcity can require cities to import resources from far beyond their boundaries, requiring complex infrastructure systems to transport them. These systems often supply urban residents with water and food over large distances, especially in the Global North. The social and ecological impacts of urban areas and urbanisation therefore stretch far beyond city boundaries, with towns and cities re-shaping nature in their hinterlands through the extraction of water, the production of food, and the generation of waste and pollution. Major inequalities also exist within cities whereby urban forms and functions may give greater access to resources to certain parts of the population, at the expense of others. For example, in many cases low-income urban residents must rely on providers with high tariffs for their water and electricity supply because municipal systems do no serve the areas in which they live. This highlights how resource scarcity may be a product of social and economic processes, rather than merely ecological or geophysical context. A shift to a different kind of urban growth has the potential to dramatically reduce resource consumption compared to the current development path of many cities across the globe (Global Commission on the Economy and Climate, 2014). This understanding has encouraged the rethinking of urban development options and pathways.

There is also increasing recognition that cities must become resilient in order to manage hazards and threats. With their concentrations of people, infrastructure and economic activity, cities are sites of particular dynamism and productivity. However, they can also be viewed as hotspots of vulnerability – especially those with large proportions of the population living in poverty. Over time, "city structures have been subjected to tremendous shocks and reconfigurations, and have collapsed and been reshaped by wards, technological innovations, economics, shocks and environmental changes" (Chelleri ***et al.***, 2015: 13). Low-income and other vulnerable urban residents such as women, children, elderly, migrants and people living with disabilities face particularly high exposure to risk, and are also more sensitive to shocks and stressors. Today, many decision-makers emphasise the importance of building resilient cities in order to transform them from hotspots of vulnerability into sources of opportunity. Urban areas have particular opportunities to enhance resilience (Satterthwaite and Dodman, 2013): high population density means that local governments can provide critical infrastructure, such as water and energy supply, at lower per capita cost than in rural areas. Moreover, institutions and resources are typically concentrated in cities, even if it can be difficult to harness these for adaptation.

Indeed, cities are strategically positioned to be leaders of change. Placed at an intermediary scale between individuals and nation-states, cities can take actions which affect other scales through a ripple effect. As hubs where people and economic activities are concentrated, they allow creativity and innovation to germinate, and knowledge to expand. They can open opportunities such as technical change with the implementation of climate-friendly technologies as part of low-carbon development strategies. Cities have therefore been described as being part of the problem and of the solution at the same time (UNEP, 2013):

- Cities are part of the problem. Expanding urban areas are often associated with increases in resource consumption and waste production, which puts pressure on ecosystems and supply chains. Additionally as the number of people living in urban areas grows, so too may the concentration of people in vulnerable areas (Dodman and Satterthwaite, 2009). Cities and towns thus expose social and ecological systems to harm, and the impacts are likely to be exacerbated with urbanisation and climate change (Revi *et al.,* 2014).

- Cities are part of the solution. The density and proximity of urban areas reduce the economic and environmental costs of providing most infrastructure and services. Cities also have significant institutional and technical capacity. They are therefore strategic sites for engaging with environmental issues, offering proven opportunities to reduce risk and achieve sustainability as well as significant scope to innovate and experiment.

1.2 Resilience and resource efficiency in cities

In light of the challenges and opportunities facing cities, it is little surprise that international agendas emphasise the critical role that cities can play in ameliorating risk and reducing environmental pressures. The eleventh Sustainable Development Goal explicitly commits to making cities and human settlements more resilient and sustainable. "Resilient" and "resilience" feature 29 times in the New Urban Agenda, while "efficiency" and "efficient" feature 27 times.

Resilience represents a set of ideas that explore persistence, recovery, transitions and transformation of social and ecological systems and sub-systems. By pursuing increased resilience, cities can not only deal with climate uncertainty, but also tackle resource limitations. In this report, the concept of resilience is explored in parallel with resource efficiency, building on the fact that cities can manage resources in a way that helps them not only overcome shocks and threats, but also to survive and thrive. Although this report adopts an urban focus, it is important to recognise that cities function within complex regional metropolitan networks, catchments and hinterlands. For this reason, it is useful to conceive of issues of resilience and resource efficiency in ways that take these relationships into account.

Resources like water, energy, food and other products enter cities (inputs), are distributed and consumed within city systems, and generally leave the systems, in the form of waste (outputs). Understanding resource flows and undertaking resource assessments are ways of evaluating cities' resource base (i.e. what resources are available to them), mapping which resources are entering the system and from where, understanding what processes they go through, and where they are exported. These analyses also enable decision-makers to identify opportunities to transition to a more circular economy, whereby resources are extracted, transformed, recycled and re-used within the city as much as possible. Eventually, they help to define indicators and share strategies for sustainable production and consumption (Gi-REC, n/d; Guibrunet, 2013).

Resilience and resource efficiency both have a role to play in sustainable development, as acknowledged throughout the New Urban Agenda and in the Sustainable Development Goals. The complementarities and tensions between these two agendas are therefore important to consider. The core argument of this report is that recognising and engaging with the nexus between resilience and resource efficiency may open important opportunities for sustainable development in cities – and by extension, for the world as a whole.

1.3 Introduction to the report

This report explores the links between the principles, objectives, and initiatives associated with urban resilience and resource efficiency. It concludes that resource efficiency is an essential element to urban resilience, and that resource efficiency can be accomplished more effectively when it is built in the context of a resilient system. The conceptual analysis and case studies make it clear that considering these issues together can help planners to address global challenges, such as climate change and poverty.

Although they have potential for mutual reinforcement, it is also apparent that there are risks of tension and conflict between the two concepts. For instance, redundancy is a core characteristic of resilient systems, but is not compatible with minimising resource consumption. Similarly, efforts to reduce total levels of resource consumption may lead to distributional issues, jeopardising access to energy and water. This is particularly likely to impact the resilience of low-income and marginalised groups, for example by increasing the amount of time women need to spend collecting these resources. However, building preparedness to shocks and stresses while analysing the resources available to a system and planning accordingly is a way of reconciling this dichotomy.

The report draws on theoretical and applied literature that explores urban resilience and resource efficiency in order to provide a basis for understanding these concepts. More importantly, however, it draws on the inputs of city officials from Africa, Asia and Latin America at a series of workshops on resource efficient cities held in 2013 and 2014. The case studies presented here – largely initiated by city officials – show how urban areas around the world are grappling with the different ecological and social challenges, and indicate potential avenues for other towns and cities to achieve the third transformative commitment of the New Urban Agenda.

2 FRAMING URBAN RESILIENCE

2.1 What is resilience?

2.1.1 Definition and principles

Resilience is an increasingly widespread concept to frame risk reduction and sustainability. In recent years, it has been particularly adopted in relation to climate change, with climate resilience used to describe adaptation at different scales: from specific investments in infrastructure or individual behavioural changes, to entire societies and economies (Dodman *et al.*, 2009, Béné *et al.*, 2014). However, the notion of resilience goes beyond the climate change and disaster risk reduction contexts (Rodin 2014) – societies can build resilience to a range of disturbances, such as energy crises and food scarcity. It is therefore a multi-faceted concept that is adaptable to different contexts in various ways.

Resilience is usually used to describe the properties of a system (Elmqvist, 2014). The concept is originally associated with ecosystems' capacity "to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes" (Resilience Alliance, 2014; see also Folke, 2006). Resilient ecological systems are recognised as being able to rebuild themselves and return to a state of equilibrium after experiencing shocks. In social sciences, resilient communities have been described as able to build 'buffering capacity' into society and develop resistance to pressure (Timmerman, 1981). The further use of the concept for 'social-ecological resilient systems' is based on the idea that humans and nature co-exist and co-evolve. Linking ecological and social resilience highlights the fact that ecological resilience depends on whether human consumption patterns are sustainable, while communities are resilient if the resources they rely on are capable of buffering against, recover from, and adapt to shocks and stresses (Walker *et al.*, 2004; Folke, 2006; Ostrom, 2009; Elmqvist, 2013).

Although the meaning of resilience remains widely debated, it is typically associated with positive characteristics such as preparedness, collective action and flexibility (Torrens Resilience Institute, 2009). Three main criteria can be identified to characterise a resilient system (Resilience Alliance, 2014; Carpenter *et al.*, 2001):

1. The amount of disturbance it can undergo to resist change whilst retaining on the same structure and function;

2. The degree to which it is capable of self-organisation;

3. The ability to build and increase capacity for learning and adaptation.

There are also several key sub-characteristics and outcomes of resilience, shown in Table 1.

TABLE 1: Sub-characteristics and goals of a resilient system

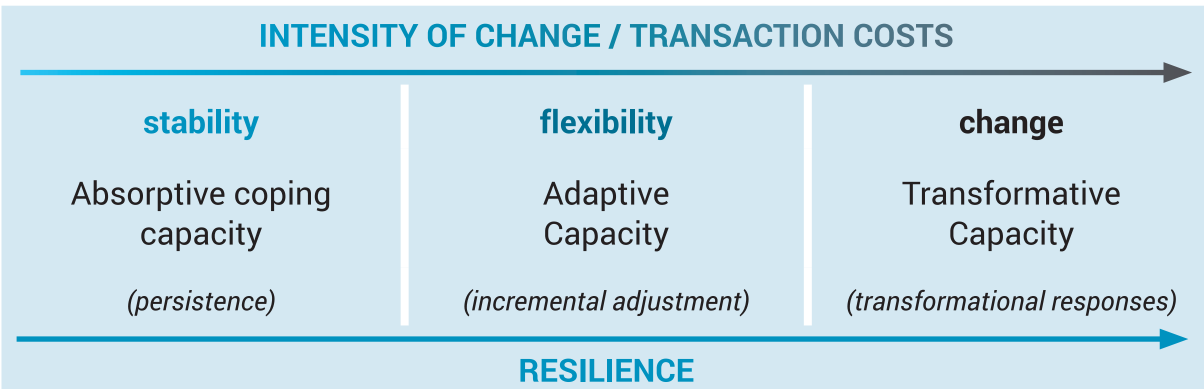
Source: adapted from Walker et al. (2004), Martin-Breen and Andries (2011); Barthel and Idendahl (2014), Béné et al. (2014).

Sub-characteristic	Desired outcome
Flexibility	Continuous interplay of evolution and adaptation
Bio- and social diversity	Multi-functionality and increased opportunities
Redundancy	Availability of extra resources and capacity in case of failure with other mechanisms
Modularity	Self-organisation
Safe failure	Minimum damage, key service delivery are maintained even under failure
Uncertainty and learning	Comprehension and anticipation, drawing from lessons
Resourcefulness and responsiveness	Rapid and adapted actions

For resilience theories to be practically useful, it is important to recognise the dynamic nature of systems. Béné *et al.* (2012: 23) propose a resilience framework focusing on three main components: "*resistance* in a period of small disturbance, *adaptation* in a time of greater disturbance, and *transformability* when conditions are becoming unviable or unsustainable" (Figure 3). This framework suggests three dimensions or stages of resilience depending on the nature and scale of the problem.

FIGURE 3: The resilience framework

proposed by Béné et al. (2012).



The response of a system (i.e. absorbing, adapting or transforming) depends not only on the severity of the impact, but also on whether the system is subject to single *shocks* (more sudden, turbulent, and hard to predict) or to ongoing *stresses* (usually causing gradual and continuous pressure on the system which can experience hardship on a daily basis). While societies tend to try and cope with shocks when these take place, longer-term stresses are by their nature less immediately apparent – and dealing with them may require transformation: the creation of "a fundamentally new system when ecological, economic or social (including political) conditions make the existing system untenable" (Walker *et al.*; 2004: 57).

A resilience approach also prompts decision-makers to consider the interaction between periods of sudden shocks and gradual stresses, and how systems can respond to disruption and change (Torrens Resilience Institute, 2009). It does not assume a unique equilibrium state for each system, but rather different states that the system can move among (Guiran, 2014).

A further way of understanding resilience is to look at the four following issues (Walker *et al.* 2004: n/d):

- **Latitude:** the maximum amount a system can be changed before losing its ability to recover (i.e. before crossing a threshold which, if breached, makes recovery difficult or impossible);
- **Resistance:** the ease or difficulty of changing the system;
- **Precariousness:** how close the current state of the system is to a limit or 'threshold';
- **Panarchy:** because of cross-scale interactions, the resilience of a system at a particular focal scale will depend on the influences from states and dynamics at scales above and below.

The New Urban Agenda explicitly identifies the pursuit of 'resilient cities and human settlements' as part of the third transformative commitment, encouraging signatories to seek to "increase urban systems' resilience to physical, economic and social shocks and stresses".

2.1.2 Linking resilience and climate change responses

In the context of climate change, resilience is often used alongside the concepts of vulnerability and adaptation. Adaptation specifically refers to the process of adjustments made in natural or human systems in response to actual or expected threats and their effects (IPCC, 2014). However, resilience goes beyond simply reducing risks, and aims at "enhancing a system's performance in the face of multiple hazards, rather than preventing or reducing the loss of assets caused by specific events" (Arup, 2014a: 3). Vulnerability can be defined as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger, 2006: 268), and in this regard, resilience and vulnerability can be seen as concepts existing at opposite ends of a continuum (Bahadur *et al.*, 2010). This lens implies that certain actions or interventions can strengthen resilience through reducing vulnerability (Osbahr, 2007; Tanner *et al.*, 2009). However, the concept of resilience can also be used provide insights into broader capacities for sustainable development rather than merely as a counter to vulnerability (Chelleri *et al.*, 2015). In this sense, resilience paradigms may offer opportunities to engage more fully with the ecosystems and supply chains on which communities rely, and thus generate insights into how these resources are managed to reduce, respond to and recover from disturbance.

2.2 Building resilience at city level: why and how

2.2.1 Resilience at the city level

Natural and human-induced disasters, climate change and ecological stresses such as loss of biodiversity, pressure on ecosystems and pollution are undermining efforts to end poverty and achieve sustainable development. The New Urban Agenda therefore commits to "Adopt and implement disaster risk reduction and management, reduce vulnerability, build resilience and responsiveness to natural and human-made hazards, and foster mitigation of and adaptation to climate change". Urban resilience can be defined as:

"The ability of a city or urban system to withstand shocks and threats, to survive stresses, utilise them, reorganise, develop whilst retaining the essential same functions and identity, and to adapt to social, political, economic and environmental change" (adapted from Carpenter and Folke (2006), Monteiro et al. (2012)).

Infrastructure endowments, legislative and policy frameworks, social norms, economic and political conditions and other factors shape urban residents' exposure to risks and their capacity to prepare for, respond to and recover from them. Different groups within a city will also face different levels and types of risk (Revi *et al.*, 2014). A resilience framing gives insight into the way complex systems respond to change, with feedback loops across time and space that may compound or ameliorate risk. Urban resilience strategies must directly engage with these factors and variations if they are to increase a city's capacity to absorb, adapt and transform.

Elmqvist (2014) argues that "resilience is an attribute of a system, not a locality". Addressing the question 'resilience of what?' makes it necessary to consider multiple scales (Martin-Breen and Andries, 2011). Urban planners and decision-makers must take into account the diverse systems within cities, as well as the wider systems within which they operate (such as river basins and regional electricity grids). From such understandings, integrative solutions for urban planning, policy and design can be elaborated to address interrelated issues in a coherent manner (Newman and Jennings, 2008; Rapoport, 2011; Elmqvist, 2013).

Closely related to this, it is necessary to consider 'resilience for whom?' In their report on future cities, Moir *et al.* (2014) review trends in urban development approaches and the characteristics of interest for city governments, businesses, institutions and citizens. These authors recognise that resilience may involve trade-offs against environmental, social and economic issues. To illustrate, programmes to conserve wetlands, mangroves or river banks may be intended to enhance the resilience of the city as a whole, leveraging these ecosystems' capacity to absorb tsunamis, storm surges and flooding. However, curtailing access to these spaces could also threaten the livelihoods of the urban poor, who may depend on these environments for food, transport or water. Resilience strategies therefore need to particularly safeguard those who are most vulnerable if they are not to compound risk and perpetuate injustices and inequalities within the city.

From this, it is finally relevant to ask 'resilient to what?'. Just as there are many different ways of understanding and approaching resilience, there are many different types of shocks and stresses to which systems can be resilient. Although the term resilience is usually used in relation to climate change related shocks (e.g. hurricanes, floods, storm surge) and stresses (e.g. changes in rainfall patterns, sea-level rise, erosion) (Arup and EWB-UK, 2012), it is also relevant for non-climate related hazards such as financial shocks, disease pandemics or earthquakes.

2.2.2 Characteristics of a resilient city

There are many characteristics that can indicate that a city is resilient. Although cities may build resilience through a diversity of ways, specific attributes that are common to resilient cities can be identified. Organised under four categories, the twelve following factors are considered useful urban resilience indicators (Arup, 2014a; 2014b):

LEADERSHIP AND STRATEGY (KNOWLEDGE)

- Integrated development planning
- Effective leadership and management
- Broad range of stakeholders empowered

HEALTH AND WELLBEING OF INDIVIDUALS (PEOPLE)

- Minimal human vulnerability
- Diverse livelihoods and employment
- Safeguards to human life and health

INFRASTRUCTURE AND ENVIRONMENT (PLACE)

- Reliable communications and mobility
- Continuity of critical services
- Reduced physical exposure of natural and manmade assets

ECONOMY AND SOCIETY (ORGANISATION)

- Economic prosperity and availability of financial resources and contingency funds
- Social stability, security and justice
- Collective identity and mutual support within communities

These elements underpin the characteristics of being reflective, robust, redundant, flexible, resourceful, inclusive and integrated.

A complementary approach is offered by Brown *et al.* (2012), who identify a range of action areas where the characteristics detailed above could help to achieve urban resilience: water demand and conservation systems; emergency management and early warning systems; responsive health systems; resilient housing and transport systems; ecosystems services strengthening; education and capacity building of citizens; diversification and protection of climate affected livelihoods; and drainage, flood and solid waste management.

Understanding resilience as Arup and Brown *et al.* suggest provides a holistic perspective of what the outcomes from building resilience can bring to urban areas. Cities and towns with high levels of poverty and social conflict, poor quality infrastructure, degraded environments and weak or exclusionary governance arrangements will find it difficult to prepare for or respond to shocks and stresses. Instead, their potential remain bound by problems related to lack of economic opportunity, land insecurity, violence and insecurity, scarcity of critical resources such as water, food and energy, and pronounced inequalities in access to services and infrastructure.

The New Urban Agenda commits its signatories to enhance urban resilience through "the development of quality infrastructure and spatial planning, by adopting and implementing integrated, age- and gender-responsive policies and plans and ecosystem-based approaches in line with the Sendai Framework for Disaster Risk Reduction for the period 2015–2030". It additionally highlights the sectoral opportunities to prepare for and recover from hazards, including retrofitting and upgrading housing stock (including in informal settlements) and to protecting urban deltas, coastal areas and other environmentally sensitive areas that are important for resilience. The relevant section of the New Urban Agenda therefore clearly recognises the importance of leadership/strategy and infrastructure/environment in enhancing resilience. Referring back to the four categories identified by Arup above, it becomes clear that the New Urban Agenda places less emphasis on health/wellbeing and economy/society in its framing of urban resilience.

2.3 Co-benefits from building urban resilience

Although primarily understood in contexts of climate change and disasters, building resilience opens opportunities for more inclusive and sustainable urban development at many other levels. For example, a focus on resilience can provide the political impetus to address inequalities that constrain lives and livelihoods. Cities in which residents have adequate and affordable access to food, water, energy and other materials are better prepared to face a variety of shocks and stresses. One of the reasons why low-income urban residents in the Global South tend to be disproportionally vulnerable to disturbances is that they do not have access to basic services and infrastructure, such as drains, sanitation, health care and emergency services (UNISDR, 2009; Mitlin and Satterthwaite, 2013; Revi *et al.*, 2014). Meeting the needs of low-income and other marginalised residents, and establishing more responsive and inclusive decision-making processes, contributes to good urban governance.

Increasing resilience is often considered an economic necessity as a means to reduce or eliminate the financial costs of loss and damage (Dodman *et al.,* 2009). This framing means that the costs of increasing resilience can be offset against the economic savings due to the reduction of maintenance and repair costs in the event of disaster. There are many challenges involved in making judgements about the return on investment from disaster risk reduction activities, particularly concerning the current value of avoided future costs. However, both direct and indirect economic benefits can be identified, including extended benefits from activities such as building flood protection structures and shelters, improving civil society networks and linkages, and undertaking proper planning processes (Vorhies 2012).

A broader perspective suggests that many of the characteristics associated with resilient cities also increase the economic productivity of urban residents (Turok and McGranahan, 2013; Colenbrander, 2016). To illustrate, the construction of affordable mass transit systems can enhance resilience in multiple ways. It can improve public health by reducing air pollution and road accidents associated with high dependence on private vehicles. It can reduce average travel times and expenditure on transport, freeing up time and money for risk reduction or other productive uses. In the longer-term, it can also encourage densification of cities as people choose to live near public transport hubs: this density in turn reduces the investment needs of other trunk infrastructure, as well as the extent of land use change (and therefore habitat loss) around the periphery of the city (Duranton, 2008; Floater *et al.*, 2014; Gouldson *et al.*, 2015a), thereby enhancing the economic and ecological resilience of the city.

Similarly, the ecological wellbeing that so often underpins urban resilience also generates significant co-benefits for a city. For example, conserving and restoring urban forests constitutes a strategy for climate change mitigation through absorption of carbon dioxide and by reducing the urban heat island effect, and thereby reducing consumption of energy for cooling purposes. Urban forests also reduce the impacts of extreme weather events (through reducing windspeeds, increasing rainwater absorption, and slowing run-off), provide recreational opportunities, and can offer resources such as food and energy.

These examples illustrate the co-benefits of mainstreaming resilience considerations at multiple scales, from specific infrastructure investments to city and regional development plans. Considering the resilience 'of what', 'to what' and 'for whom' (Elmqvist, 2014) can help urban decision-makers to identify hotspots of vulnerability, as well as the drivers of that vulnerability. Redressing these can deliver immense social and political returns, empowering low-income and other marginalised groups to contribute fully to urban societies and economies and enabling cities to help achieve the Sustainable Development Goals.

← **FIGURE 4:** New York City High Line

Source: U.S. Department of Agriculture (20150915-OSEC-LSC-0294), CC BY 2.0, via Wikimedia Commons

2.4 Critiques and challenges to resilience

Resilience has become an increasingly influential concept in many fields including disaster risk reduction, climate change and the humanitarian sector. Its application is now a central theme for many international institutions and organisations such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations International Strategy for Disaster Reduction (UNISDR). However, many still perceive resilience as too broad a concept, and one that rests on contradictory principles (Carpenter and Brock, 2008; Alexander, 2013).

Embracing the idea of resilience as 'transformation' is essential to move away from the idea of 'bouncing back'. In its early use in environmental science, resilience was understood to mean the capacity to return to equilibrium after disturbance (Walker *et al.*, 2004; Folke, 2006). Yet in many cities, particularly in low- and middle-income countries, citizens face problems such as inadequate food and water supplies, institutions lack the capacities to effectively stimulate economic development, and ecological problems are overlooked. Resilience strategies that seek to simply return to this same state of poverty or inequality are not desirable. In response to this ambiguous aspect of resilience, it is argued that vulnerable cities, instead of 'bouncing back', must seek to 'bounce forward' (Dodman *et al.*, 2009; Linnerooth-Bayer, 2014).

Various efforts have been made to develop approaches to assess the extent to which cities are – or are becoming – resilient. This is important because of the need to evaluate progress, and to understand whether activities and projects are generating the anticipated outcomes. At the same time, "given that resilience is primarily a theoretical construct, it is difficult to translate it into practice, therefore to implement it, measure it and evaluate it concretely" (Martin-Breen and Andries, 2011). The issue is further complicated by the range of interpretations and applications of the concept that are used by different stakeholders, meaning that a common evaluation framework is not likely to be applicable. Despite this, a wide range of approaches have been developed and started to be tested to enable practical application and assessment of resilience, some of which are described in the Appendices.

Resilience is often treated as an apolitical concept that is applicable to any system. Hornborg (2009) particularly points out that too often researchers and practitioners considering resilience do not engage with questions of agency and power, and argues that the processes of resilience exercised within a system risks ignoring the individuals within this same system. This means that resilience interventions can cause further distributional issues and externalities, exacerbating injustice faced by the poor. Notable urban examples include gentrification, eviction or territorial stigmatisation (Schilderman and Lyons, 2011; Slater, 2014; Chelleri *et al.*, 2015).

Khalil *et al.* (2013) argue that it is crucial that resilience does not reproduce the urban injustices already existing in a city. If it is to meaningfully address vulnerability, resilience needs to tackle issues of inequality, exclusion and marginalisation (Béné *et al.*, 2014; Friend and Moench, 2013). Analysing the resilience of a socio-ecological system should therefore not be limited to the most general level, but should also consider possible asymmetries between different groups and individuals within a system (Béné *et al.*, 2012). To illustrate, the role of the urban informal economy in enhancing or detracting from resilience receives little attention and/or remains unclear. If the strategies deployed and promoted in the name of resilience marginalise the informal economy, this will not only jeopardise those who depend on it for their livelihoods, but will also omit its potential contribution to urban resilience (Brown *et al.*, 2014). A commitment to urban resilience must therefore be understood as a concerted effort to amplify the voice and increase the capabilities of those who are most vulnerable. To borrow the conceptual framework of the SDGs, resilience is contingent on "leaving no-one behind".

2.5 Case Studies

SEMARANG, INDONESIA

Flood Warning Systems and Sustainable Water-Use Patterns

RESILIENCE TO	RESILIENCE MECHANISMS	RESOURCE EFFICIENCY ACHIEVEMENTS
▪ Climate change related shocks: floods, droughts ▪ Climate change related stresses: water scarcity, sea-level rise ▪ Non-climate change related stresses: poverty, water contamination	▪ Use of vegetation (mangroves, forest plantation) ▪ Construction of wells and biopores ▪ Rainwater harvesting	▪ Limited environmental impacts ▪ Water savings ▪ Biodiversity and land conservation

Semarang was selected by the Rockefeller Foundation's 100 Resilient Cities challenge in 2013 as one of the hundred cities worldwide demonstrating capacity-building and preparedness. Located in Indonesia, Semarang City is the capital city of the Central Java Province. It is a major port city with a population of over 1.5 million inhabitants, of which almost half are not supplied by the municipal water system (ACCCRN, 2011; Sutarto and Jarvie, 2012; Mulyana *et al.*, 2013). Based on the current practices of water supply and the population growth, it is projected that the city's water demand will exceed its supply by 2025 (ACCCRN, 2013).

In common with many other coastal cities, Semarang is at severe risk of climate-induced sea-level rise, and associated coastal erosion, land subsidence, regular floods and landslides. Climate projections indicate these issues will be magnified by more frequent extreme weather events, with increased precipitation during wet seasons and a decrease in rainfall days during dry seasons (Mulyana *et al.*, 2013). This means that floods and droughts will be more severe, exacerbating existing pressures on water resources, including groundwater on which the population heavily relies. Without strategic planning, the growth of Semarang's population and the anticipated changes in hydrological patterns will increase the risk of water scarcity and flooding.

FIGURE 5: Coastal flooding in Semarang

Source: Wicaksono: 2014.

Semarang has recently started to engage actively with resilience-building initiatives and became part of the ACCCRN (Asian Cities Climate Change Resilience Network) programme in 2008. As a pioneer in urban climate change resilience, Semarang carried out a vulnerability assessment, before developing City Resilience Strategy (CRS) that prioritises actions to reduce vulnerability to climate change and integrate climate resilience into city planning. Cooperation between government, non-government organisations, international agencies and urban residents enabled the construction of flood early warning systems at community-level, starting with a pilot project completed in December 2014 (Basnayake *et al.*, 2015). To address the risks of landslides and droughts, water and land conservation measures have been implemented including reforestation and mangrove planting, plot terracing, and the installation of recharge wells and biopores (organic holes increasing the soil's water absorption capacity) (Saroso, 2014).

Furthermore, the city is currently in the process of scaling-up its rainwater harvesting pilot project in order to develop a city-wide system. The project aims to build climate resilience by increasing clean water accessibility, reducing run-off during flood events, reducing communities' reliance on groundwater extraction and increasing the quantity of groundwater reserve while addressing land subsidence problems. Such initiatives demonstrate the possibility of building resilience through a supply-driven strategy for resources at the city level (Sutarto and Jarvie, 2012).

FIGURE 6: Rainwater harvesting as a way of building urban resilience to climate impacts on water resources

Sources: ACCCRN, 2013.

LUSAKA, ZAMBIA

CHANGING URBAN AGRICULTURE METHODS

RESILIENCE TO

- Climate change related shocks: flash floods, droughts
- Climate change related stresses: soil erosion
- Non-climate change related stresses: poverty, urban population growth, food insecurity and malnutrition

RESILIENCE MECHANISMS

- Crop switching
- Aquaculture
- Erosion control

CHANGES IN FARMING METHODS

- Resource efficiency achievements:
- Secured food production
- Water efficiency
- Energy savings

FIGURE 7: Lusaka, Zambia at Night

Source: Lighton Phiri – Flickr.com, CC BY 2.0

Lusaka, the capital of Zambia, accounts for 32 percent of the country's total urban population (UN-HABITAT, 2007). It is facing myriad urban challenges, including inadequate service availability, unemployment and land tenure insecurity (Lusaka City Council, 2008). Climate change is exacerbating embedded issues through the higher occurrence and intensity of extreme weather events, such as floods, cold spells, heavy rainfall and heat waves (Thurlow *et al.*, 2009; Simatele, 2010).

Resilience depends on achieving better food security, sustainable livelihoods and poverty reduction. There is much potential in Lusaka's old tradition of urban agriculture (Rakodi, 1988). In addition to the significant amount of food it provides to the population, urban agriculture is important to the city life for generating income and livelihoods (Simatele *et al.*, 2012; Peter, 2014). According to several studies conducted between 2003 and 2006, approximately 45% of Lusaka's households are involved in urban agriculture (Arku *et al.*, 2012). Due to the serious effects of climate change on traditional urban agriculture practices, new methods have been established. Taking advantage of flooding events, farmers have started to grow rice, an activity that came from West Zambia. Aquaculture – and particularly fish farming – has also been adopted to take advantage of flood water. In response to droughts, a gradual shift from exotic to drought resistant crops (such as sorghum and millet) has been initiated, alongside different farming practices such as erosion control and new methods of tillage (Simatele, 2012).

By adapting their practices and crops to changing weather conditions, urban farmers have turned climate risks into opportunities. The use of flood water for fish farming and rice production has enabled water-use efficiency, while substantial water savings are being made with the use of drought-resistant seeds. In terms of energy, the need to transport food is decreased when urban agriculture can provide food that is grown locally. The value of crop diversification and aquaculture are recognised at the national level (Republic of Zambia, 2011). However, legal recognition of the existing practices remains lacking at the city level. This means that, despite their significant contribution to food security and income generation, informal urban agriculture activities have not been sufficiently integrated into urban development and planning (Mbiba, 2001; Hampwaye *et al.*, 2007; Simatele *et al.*, 2012). Informal producers and vendors in Lusaka therefore need support from municipal government structures. The effective development of climate-change specific legislative instruments regarding food security will represent a major step towards urban resilience.

TORONTO, CANADA

GREEN ROOFS TO COUNTER THE URBAN HEAT ISLAND EFFECT

RESILIENCE TO

- Climate-related shock: heat waves, more frequent and intense storms and hurricanes, flash floods
- Climate-related stress: less rainfall, increased freezing-thaw cycles, declining lake and stream levels
- Non-climate related stress: urban heat island effect, air pollution, health risks

RESILIENCE MECHANISMS

- Use of cool/reflexive materials on roofs
- Green infrastructure on roofs
- Resource efficiency achievements:
- Energy efficiency

With a population of over 2.7 million, Toronto is Canada's most populous city and one of the largest in North America (Toronto City Planning, 2014). The city is exposed to significant shocks and stresses caused by climate change, including more violent storms, floods, heat waves and lower lake levels (City of Toronto, 2013a; MacLeod, 2013). Climate-related issues are leading to substantial environmental and social change accompanied by economic costs leaving the city operating budgets vulnerable to hazards. For example, a single rainstorm in 2013 cost $1 billion in insurance claims (City of Toronto, 2014). Health risks due to extreme temperatures and problems of energy supply during floods or heat waves are often identified as major problems interdependent to climate change in Toronto (Birkmann *et al.*, 2010). To tackle these, the city government has undertaken a number of strategies, comprising the creation of an Adaptation Steering Group which developed a framework document informing internal and public discussion about climate change impacts and adaptation ('*Ahead of the Storm: Preparing Toronto for Climate Change*') (City of Toronto Climate Change Adaptation Steering Group, 2008; Penney and Dickinson, 2009).

FIGURE 8: Opening of the new green roof on the podium of City Hall during Doors Open 2010, Toronto, Ontario, Canada

Source: Tabercil, 2010.

According to the Grosvenor's Resilient Cities Research Report, Toronto is the most resilient city in the world (Michael, 2014). Toronto's agenda of actions includes a range of schemes to upgrade infrastructures (e.g. sewers and culverts), health programmes (e.g. smog alerts, air quality health index), and further support provided to vulnerable people (e.g. cooling centres) (Toronto City Clerk, 2014). To counter the urban heat island effect (whereby urban areas have higher temperatures than those of the rural areas at their peripheries), the city is developing an agenda that integrates green strategies, including the installation of green roofs, tree planting and care and building code changes (Rinner and Hussain, 2011). Widespread implementation of green roof infrastructure is a target set by the city government for the specific purposes of reducing local ambient temperature and saving energy, but also to improve the city's air quality and thereby public health.

According to research conducted in 2005 on the environmental benefits and costs of green roof technology in the city, the initiative could cool down the temperature between 0.5 and 2° C (depending on the time of the year and the scale of action). Energy demand and use can also be significantly reduced as 2.37 kWh can be saved per square meter of green roof area per year. This represents a reduction in energy demand in summer by between 0.7-10% (Banting *et al.*, 2005). The 'Toronto Green Standard' and 'Green Roof Bylaw' initiatives have been launched in accordance with the principle that the use of green roofs also enables lower GHG emissions, the control of water run-off and thus, energy and water conservation (Toronto Financial District, 2013; Toronto Green Standard, 2013).

Toronto is the first North American city requiring the construction of green roofs on new developments by law. According to Toronto's Chief Planner, Toronto will have built the equivalent of 40 football fields in five years (Athlyn, 2014). By explicitly integrating green strategies in architecture and urban design through regulation, Toronto is positioning itself at the forefront of sustainable urban planning. The effective green roof strategy countering the urban heat island effect is part of the wide range of green methods that enable the city to combine resilience building with mitigation, but also with resource saving and improved social well-being.

FIGURE 9: Green roof at Mountain Equipment Coop, Toronto, Canada.

Source: By sookie (Flickr) CC BY 2.0, via Wikimedia Commons

2.6 Conclusions

Cities must move beyond the precarious state of continuously recovering from hazards, and start foreseeing prospective stresses and shocks. The case studies demonstrate that cities must understand the resources available to them and the hazards to which they are exposed in order to design and implement successful urban resilience strategies. With this information, it is possible to develop a resilience agenda that allows enough flexibility to absorb shocks, and that enables incremental capacity building to prepare for anticipated disturbances.

The cases of Semarang and Lusaka both demonstrate the importance of coordination among actors to facilitate the implementation and scaling up of resilience measures. Cooperation between stakeholders at different scales presents multiple benefits including the execution of long-term and far-reaching resilience strategies. In Semarang, a more coherent division of responsibilities between actors has facilitated a transfer of knowledge throughout the spectrum of stakeholders. In this way, city resilience has been built progressively through small-scale methods reinforced by local knowledge and public engagement. In Lusaka, the legal recognition of existing community practices around urban agriculture ought to enhance resilience at the scale of the city. In this context, where the urban economy depends on climate-sensitive resources, an efficient and adequate translation of the national strategy into local agricultural policies needs to take into account the informal sector and integrate marginalised urban dwellers into the system, thereby boosting climate and poverty resilience simultaneously.

In cities that already have much of the necessary infrastructure to reduce harm from hazards of various types, the importance of anticipating and planning over the long-term must be recognised. The challenge lies in mobilising investment in resilience to something that is not yet visible or immediately harmful. The case of Toronto is an example of such preparedness. The city government has been developing measures of resilience to counteract the urban heat island effect and reduce energy and water consumption. . It has done this by integrating green strategies within the law in an incremental and consistent way, which has effectively disseminated the practice of building green infrastructure. This case study demonstrates that there can be short-term co-benefits to adopting resilience initiatives beyond reduced exposure to shocks and stresses.

Achieving greater resilience may also require trade-offs. For example, addressing resilience at one single scale may lead to an erosion of adaptive capacities at another. As explained by Chelleri *et al.* (2015:14), it is therefore important to manage "different coexisting strategies that frame the corresponding medium- and long-term terms lock-ins or windows of opportunities for change". Resilience thinking involves considering long-term thresholds to achieve sustainable transformation. Resource and hazard mapping enable urban decision-makers to understand possible trade-offs and make informed decisions about urban planning, policies and investments.

3 FRAMING RESOURCE EFFICIENCY

3.1 Resource efficiency in context

3.1.1 Introduction

Growing awareness of the importance of resource efficiency is based on evidence that humans are consuming resources at a greater rate than the planet can sustain. Human beings depend on natural resources for their survival. As the global population grows, so too does the demand for these resources. However, an even more significant driver is the growth in consumption by individuals and societies that are becoming more and more affluent.

In 2000, Oceania was extracting the highest amount of resources per capita (approximately 158 kg/day), followed by North America (68 kg/day), Latin America (41kg/day), Europe (36 kg/day) and Africa and Asia (15kg/day) (SERI-Global 2010; Friends of the Earth Europe, 2009). Per capita consumption varies significantly within regions as well, particularly according to wealth. Rapid economic development in countries like China and India is creating a large and growing middle class, which is creating greater demand for goods and services. Such consumption and production patterns cannot be sustained, as continued growth in the extraction of particular resources and production of particular wastes will push the planet outside a "safe operating space" (Rockström *et al.*, 2009).

There is therefore an urgent need to transition towards more sustainable development pathways. Resource efficiency can support this transition by minimising resource extraction, resource consumption and waste generation. The purpose of resource efficiency is to enable the design, production, distribution and disposal of products and services with minimum environmental impacts while meeting human needs (UNEP, 2010). A resource efficient system seeks to create more with less, and to deliver greater value with less input (European Commission, 2014).

Resource efficiency typically involves technical and/or institutional solutions to adjust the components of the systems and reduce the amount of resources (water, fuel, minerals and so on) wasted, thereby delivering more outputs per unit of input (Swilling *et al.* 2013). At another level, entirely designing new systems can be a way of facilitating more radical changes, such as techniques to make use of renewable resources in order to reduce pressure on those that are finite. Closing loops by re-using resources to avoid extracting more resources and producing additional waste is essential.

3.1.2 Definition and principles

In general terms, resource efficiency involves a more productive use of resources. By taking the whole lifecycle of resources into account – from the extraction of raw materials to final use and waste disposal – and considering them from a *value chain perspective*, practitioners can identify opportunities to reduce waste (UNEP, 2010). Analysing value chains can help to identify potential externalities that might not be immediately perceptible over the long-term or within certain geographical boundaries. This is significant considering territorial constraints on environmental and industrial governance. Many cities function as gateways for goods, which means that municipal governments have limited opportunities to enhance the efficiency of the value chain (Bancheva, 2014; Dodman, 2009).

Six goals and principles can be directly associated with the idea of resource efficiency:

1. Increasing the productivity achieved from the **same amount of resources** already used, for example by reducing the proportion that is wasted by modifying production processes.
2. Producing more with a **smaller resource base**, for example by making better use of existing stocks of materials through recycling.
3. **Reducing environmental impacts** during the whole lifecycle of a given resource by minimising waste outputs or managing their disposal. Improving the efficiency of fossil fuel use, for instance, lowers greenhouse gas emissions, so energy efficiency is strongly related to climate change mitigation.
4. **Reducing demand for goods and services** in order to encourage lower consumption of resources. This is particularly relevant in high-consuming societies.
5. **Switching to renewable resources** (e.g. sunlight, wind) away from the use of finite resources (e.g. fossil fuels, rare earths) in order to reduce the pressures on limited resource stocks.
6. In line with environmental justice goals, moving towards **more equal distribution** of resources is also a mean of achieving efficiency. Inequalities in distribution patterns are widening at multiple scales and allocating resources more equally could help address high production needs and waste issues. This is essential for resources like water and food.

Resource efficiency has been defined in multiple ways. Dawkins *et al.* (2010: 5) focus on resolving over-consumption issues and define resource efficiency as "the supply-side measures that tackle inefficiencies across supply chains; overuse of resources and waste when products and services are produced." This enables producers and consumers to use less resources to produce the same level of output". The European Commission (cited in the Science Communication Unit, 2013: 5) integrated environmental considerations into its understanding of resource efficiency, defining this agenda as allowing "the economy to create more with less, delivering greater value with less input, using resources in a sustainable way and minimising their impacts on the environment".

The range of resources targeted by resource efficiency programmes varies from one context to another. In its 'vision for 2010-2013' on resource efficiency, the United Nations Environment Programme (UNEP, 2010) focused on water, biomass, land, energy and materials. The European Commission defines resources in a broader way and refers in its framework to "all natural resources that are inputs to [its] economy, including both physical resources and ecosystem services" (Jansen, 2013: 3). Therefore, on top of the resources usually considered, the European Commission adds soil, fish, timber, biodiversity, clean air and sea to its scope. Minerals and flow resources such as wind, geothermal, tidal and solar energy, are also covered in many resource efficiency agendas. This report approaches resources from a sector perspective and therefore focuses specifically on energy, water, food, and waste.

As part of the third transformative commitment, the New Urban Agenda requests its signatories to "driv[e] sustainable patterns of consumption and production". Among other elements, achieving this goal will depend on producers enhancing the efficiency of resource use and consumers' reducing demand for resources.

Related concepts

The idea of resource efficiency cannot be understood in isolation from a range of other concepts and agendas (Table 2). The concepts described in this table have been used at different times and in different contexts, but share some features with resource efficiency, either in terms of process or expected outcome.

3.2 Resource efficiency at the scale of the city: implications and trends

3.2.1 Why resource efficiency at city-level?

A resource-efficient city can be defined as "a city that is significantly decoupled from resource exploitation and ecological impact and is socio-economically and ecologically sustainable in the long-term" (GI-REC, 2012: 2). A resource efficiency approach at the city-scale aims to reduce the total environmental impact of the production and consumption of goods and services – but can also achieve financial savings and reduce pollution. Resource efficiency in cities opens the path to addressing environmental challenges while simultaneously generating social and economic opportunities, for example by freeing up resources for alternative uses or (where cost savings are passed on to consumers) improving the affordability of goods and services.

Cities are important sites for driving resource efficiency because such a large share of resource consumption and waste production can be attributed to them. For example, urban areas account for between 67–76% of global energy use and between 71% and 76% of CO_2 emissions from global final energy use (Seto *et al.*, 2014). This means that efficiency gains in cities have the potential to have a larger impact. The proximity, density and variety intrinsic to cities also has the potential to enable significant improvements in resource efficiency (Rode and Burnett, 2011). For example, mass transit and district heating/cooling are only cost-effective in contexts of relatively high population density, but offer much more energy-efficient means of moving people around and regulating temperature than decentralised alternatives (such as private vehicles or individual air conditioners).

TABLE 2: Concepts related to resource efficiency

Source: Authors.

Concept	Key features	Relationship to resource efficiency
Sustainable development	Defined as "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (United Nations, 1987).	Premised on a use of resources by current generations that does not interfere with the capacity of future generations to reach a similar level of well-being. Implies that current generations should pursue efficient resource management (Jansen, 2013).
Decoupling	Relative decoupling refers to a lower rate in growth of a type of environmental pressure in relation to the rate of growth of a related economic activity. Absolute decoupling refers to an environmental pressure either remaining stable or decreasing while the related economic activity increases (Watson *et al.*, 2014).	Decoupling can contribute directly to resource efficiency. Cleaner production practices and technologies provide opportunities for small business development and the creation of green jobs (UNEP, 2010; Swilling *et al.*, 2013).
Green economy	A green economy is one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. In its simplest expression, a green economy is low-carbon, resource-efficient, and socially inclusive (UNEP 2011).	The definition of a green economy makes explicit reference to resource efficiency as one of its key pillars.
Planetary boundaries	A planetary boundaries framework defines a safe operating space for humanity to develop and thrive, according to nine defined biophysical processes that regulate the earth's system (Rockström *et al.*, 2009). It provides a science-based analysis of the risks caused by human activities interfering with the earth's natural functions (although is less directly relevant at the scale of cities) (Steffen *et al.*, 2015).	The planetary boundaries framework highlights the constraints on total levels of resource consumption or waste production (e.g. greenhouse gas emissions, phosphates). It therefore informs resource efficiency targets at a global scale. The 1.5-2°C target in the Paris Agreement, for example, reflects a 'safe operating space' for humanity, which in turn sets an upper limit on the level of greenhouse gas emissions that can be produced.
Environmental footprint	The environmental footprint is a means of measuring the impacts of a person, company, activity, product, etc. on the environment. The framework has been applied specifically to cities (Wackernagel *et al.,* 2006).	The concept of an environmental footprint is intended to raise awareness of the total level of natural resources a particular actor or product uses, and therefore encourage conservation, restoration or replacement of those resources (Jensen, 2013).
Carbon budget	The maximum amount of carbon that can be emitted to the atmosphere in order to avoid dangerous climate change with a translation in terms of a maximum of fossil fuels we can extract from the ground (IPCC, 2014)	Staying with a carbon budget will require actors to manage the total level of fossil fuels they consume, in order to minimise associated emissions. Assuming constant levels of consumption, this requires actors to use less energy to achieve the same output, to capture and store the resulting emissions or to switch to low-carbon generation options.
Poverty alleviation and equity	Current patterns of production and consumption lead to a wasteful use of resources – but also to inequality and poverty (Rode and Burnett, 2011; UNEP, 2011).	Resource efficiency can lead to investment in the creation of jobs and the enhancement of human well-being.

As cities grow in size, connect to the global economy with globalisation, and face transboundary issues, complexity increases. There is considerable scope to improve resource efficiency within individual sectors, but the largest opportunities are arguably at the intersection of different systems. In particular, resource efficiency at city-level depends on urban planning and design aspects, which shape characteristics such as densification and mobility (Suh, 20015). Achieving these gains depends on integrating spatial planning, transport projects and building regulations to promote compact, connected urban form (Floater *et al.*, 2014). Yet cities often take action in different urban sub-systems as they were isolate entities concerned with different plans, policies, budgets and even timelines (Moffat *et al.*, 2013). This underscores the importance of focusing on cities as a unit, and of adopting a value chain approach: an increase in the efficiency of activities within a particular place means very little if the residents and industries located there rely on goods and services produced in a less efficient manner elsewhere. The need for an cross-sectoral, city-scale approach is echoed in the New Urban Agenda, which states that "We recognize that urban form, infrastructure and building design are among the greatest drivers of cost and resource efficiencies, through the benefits of economy of scale and agglomeration, and by fostering energy efficiency, renewable energy, resilience, productivity, environmental protection and sustainable growth in the urban economy."

Urban metabolism: a way of looking at resources flowing through cities

The concept of 'urban metabolism' offers a helpful way of looking at cities and all the resources that flow within their complex networks of interlocked social and physical infrastructure. Conceptualising the city as a living super-organism in which there are continuous flows of inputs and outputs helps studying the patterns of movements of matter and energy (Ravetz, 2000). Girardet (2004) metaphorically describes railways and watercourses as the veins of cities, food markets as stomachs, and waste dumps as part of the digestion system. Analysing the metabolism of a city helps to identify opportunities for sustainable resource management. Linking material flows with infrastructure through such analysis can help to identify alternative ways in which infrastructure could be organised to use resources sustainably.

It is not enough to consider solely the physical form of infrastructure: cultural, social, political and ethical aspects of urban metabolism must also be considered. Between 20% and 80% urban dwellers of low-income countries are not directly connected to formal infrastructure systems, but often rely on informal services (e.g. from informal vendors of water or energy). These systems are not necessarily as efficient as trunk infrastructure: Swilling *et al.* (2013) argue that an increasing number of people without direct connections to networked infrastructure increases in unmanaged quantity of material flows by service delivery systems. This waste can result in harmful environmental and health impacts. Yet these informal systems may also allow marginalised urban residents to access services and find alternative livelihoods where the state is not able or willing to meet their basic needs (Dodman *et al.*, 2016). Solutions to this problem do not necessarily lie in the replication of technologies with conventional networked infrastructure, but rather could be achieved by community-led projects and the recognition of the informal sector. At the same time, it should be remembered that low-income urban residents have small environmental footprints because of their low levels of consumption, and their frequent involvement in re-use or (informal) recycling activities.

3.2.2 A sectoral analysis of resource efficiency in cities

Climate change, economic development, pressure on natural resources, and rapid technological and social change are challenges to urban sustainability (Peter and Swilling, 2012). These challenges directly affect urban sectors such as transport, buildings and water and sanitation, on which cities depend for their functioning. This section therefore considers resource efficiency at the city-level from the perspective of sectors rather than from the perspective of a single resource. Methods to improve resource efficiency in these sectors encompass a wide range of technical complexities and scales that depend on many factors, including the type of resource used.

Energy

Today's development choices are crucial for avoiding urban dwellers being locked in patterns of high-energy demand over the future decades. The largest opportunities are arguably in small and medium cities in developing countries, which are making significant investments in new infrastructure (Seto *et al.*, 2014). Decisions that are taken now will therefore create path dependencies, shaping urban form and function in ways that will determine the energy intensity of social and economic activity for decades (Bulkeley *et al.*, 2011). Recognising the importance of immediate action, many cities have already made significant progress in increasing energy efficiency by changing their behaviour, choosing more efficient technologies and pursuing more sustainable urban forms.

EXAMPLES OF ENERGY EFFICIENCY INITIATIVES IN SUB-SAHARAN AFRICAN CITIES

Energy supply is discontinuous in many cities of Sub-Saharan Africa (SSA), a constraint that affects productivity and exacerbates poverty. As a result, urban dwellers, particularly those who are not connected to the energy infrastructure network, tend to be reliant on bottled gas, liquid fuel, paraffin, charcoal and diesel (Peter, 2014). Urban sprawl – the spatial expansion of cities at a rate that outstrips population growth – also leads to higher use of fuel for transportation and higher prices for travellers (especially for households living in peripheral areas, who are likely to be drawn from low-income or other marginalised groups). The low economic productivity of most sub-Saharan cities can be partially attributed to the unreliability and high costs of fuel supplies, and to inadequate energy distribution infrastructure. Urban populations therefore either live in energy poverty or rely on back-up options (such as diesel generation systems) to meet their needs. Biomass – especially from waste – continues to constitute an important portion of energy supply, and particularly in informal settlements (UNECA, 2009).

Many countries are seeking to improve and modernise small-scale biomass energy, for example with the use of bio-digesters (Peter, 2014), while other countries including Kenya are producing growing amounts of electricity from solar power (Njeru, 2014). In the coastal city of Mombasa, the second-largest city of Kenya, solar energy is increasingly used for salt processing plants (Awuor *et al.*, 2008), and for street lighting, schools and houses (GIZ, 2011; Mwita, 2014). The low-income settlement of Khayelitsha in Cape Town is also using solar energy to heat household water (with 'solar-water-heaters'), with the help of a local NGO (Peter, 2014).

Strategic planning to improve public transportation is taking place in many Sub-Saharan cities such as Kigali (Rwanda) and Kampala (Uganda). Although the primary motives here are enhanced mobility, safety and affordability, investments in mass transit and pedestrianisation are likely to enhance transport efficiency in the long run. As part of its 2020 goal of becoming a dynamic, liveable and environmentally sustainable city, as well as a centre for national economic growth, Kigali is combining transportation strategies and green initiatives (James, 2013). Its plan includes the expansion of the Bus Rapid Transit (BRT) and Mass Rapid Transit (MRT) networks as well as cycling and walking paths (Kigali Municipality, 2013). The overall objective is to develop a 70% public transit modal share, and 10% of non-motorised trips. Similarly, the Kampala City Authority (KCCA) has a 2022 transport plan that aims to enable 50% of trips by non-motorised modes and 80% of trips by sustainable modes. At least 200 km of cycle lanes are under development (Dodman, 2014).

A range of approaches and initiatives can be identified that are currently adopted by cities in the building, industry and transport sectors and for the use of renewable energy resources:

- **Buildings:** Buildings account for more than one-third of all final energy consumption and half of global electricity use. In addition, buildings generate around one-third of the world's carbon dioxide emissions (Layke and Perera, 2014). Current trends in energy efficiency in buildings address both the energy required to extract, transport, process and install materials for buildings, and the energy to provide services for lighting, appliances, heating/cooling, ventilation, water heating and so on. Programmes and technologies have been developed to reduce energy consumption and demands: the New Urban Agenda identifies "building performance codes and standards, renewable portfolio targets, energy-efficiency labelling, retrofitting of existing buildings, and public procurement policies on energy, among other modalities". Insulation, gazing and proofing, and the use of heat waste are particularly significant measures. Current trends also encourage focusing on cost-effective solutions to reduce buildings' environmental impacts, mainly by cutting greenhouse gas emissions whilst making energy savings (Yi-bin and Yong-shi, 2006; Swilling *et al.*, 2013).

- **Transport:** Cities have been adopting measures in the transport sector to reduce fossil fuel consumption, as well as to improve access and mobility. These have included improving mass transit, providing walking and cycling paths and improving freight planning and logistics. The New Urban Agenda recognises that more efficient transport infrastructure and services offers a range of benefits, including "reducing the financial, environmental and public health costs of inefficient mobility, congestion, air pollution, urban heat island effects, and noise". Initiatives for energy efficiency in transport can extend from retrofitting existing areas to new zoning of an entire city network to reduce commuting distances (Moffat *et al.*, 2013; EECi, 2014). Energy efficiency for transport is closely linked to spatial planning, as population density will define the viability of these transport systems. Investing in green transport can also produce major impacts in terms of sustainability and climate change mitigation. As stated in the GER report on transport (2011; cited in Peter and Swilling, 2012: 35), "(s)everal scenarios show that a green, low carbon, transport sector can reduce greenhouse gas emissions by 70 per cent without major additional investment".

- **Renewable energy:** Renewable energy – produced from wind power, hydropower, solar energy, biomass and geothermal energy – offers one means to reduce fossil fuel consumption without necessarily improving energy efficiency. The climate imperatives combined with improving rates of return mean that renewable energy technologies are now attracting large-scale investment. A growing number of cities worldwide has demonstrated the possibility of moving towards energy autonomy through the use of decentralised renewables, such as the case of Seville (Spain) where solar towers are supplying considerable amounts of electricity (Droege, 2010). In other cases, the composition of electricity supply is largely outside the control of municipal authorities, as the city is served by a regional grid. In either case, coordination across different levels of government is necessary to create the enabling policy environment and financing mechanisms necessary to adopt low-carbon energy options at scale (Betsil and Bulkeley, 2006; Gouldson *et al.*, 2016).

Water

Water is not only essential for human survival, but also for many different activities ranging from agriculture to industrial processes. Water efficiency in cities can involve reducing the amount of water used in municipal or industrial settings, and also ensuring that different types of wastewater (depending on the level of pollution) are re-distributed to meet demand for non-potable water.

The New Urban Agenda pledges "to [promote] the conservation and sustainable use of water by rehabilitating water resources within the urban, peri-urban and rural areas, reducing and treating wastewater, minimizing water losses, promoting water reuse and increasing water storage, retention and recharge, taking into consideration the water cycle." There are opportunities to improve efficiency in the storage, distribution and use of water itself, but also in the energy required for treating and pumping it. Strategies to increase water efficiency need to address both the supply side (water extraction and reticulation) and demand side (water consumption and disposal). For this reason, the sustainable management of water resources can rarely be resolved through a single intervention or technology: it requires action at different scales. Adopting a landscape or watershed approach can help in understanding the linkages between water flows for multiple users in urban contexts (Moriarty *et al.*, 2001). Once levels of water availability, use and latent demand have been mapped, appropriate measures can be deployed at different points. The following examples present a range of activities that can be undertaken to enhance water efficiency:

- **Rainwater harvesting** involves collecting and storing rainwater in reservoirs or tanks, or facilitating the infiltration of rainwater into subsurface aquifers before it is lost as surface runoff. Rainwater harvesting can reduce water deficits by increasing the supply available to prospective users.

- **Infrastructure maintenance:** An increased demand for water can be met by reducing losses rather than necessarily increasing supply, for instance by repairing and/or maintaining aging water infrastructure (Banovec *et al.*, 2014). Losses can be apparent (i.e. not accounted for due to the absence of proper metering or pirating) or real (i.e. leakages from pipes or connections) (Delgado, 2008). Non-Revenue Water levels (NRW) of many water systems in Asia and Africa range from 20 to 70% due to leakage and poor water meter management (Sharma and Vairamoorthy, 2008). Reducing water losses can help to expand service provision without requiring additional extraction or storage.

- **Water and sewage treatment:** Many cities experiencing water supply issues like Beijing have made considerable efforts to encourage recycling of water resources by promoting the installation of both offsite and on-site water treatment systems (Mels *et al.*, 2006). This can also lead to substantial reductions in the environmental impacts of wastewater. A range of 'natural' methods are now being used to treat wastewater more efficiently. Blue and green infrastructure (i.e. natural and semi-natural ecological features that can treat wastewater) have gained considerable popularity because of the wide range of benefits and ecosystem services they present (Gill *et al.*, 2007). For example, green infrastructure such as urban woodlands can reduce surface runoff while providing a source of biomass for fuel, while blue infrastructure such as ponds and wetlands can both filter wastewater while reducing environmental shocks such as floods and heatwaves. Unfortunately, often "physical and institutional mismatch inhibits recognition of ecosystem services benefits" (Keys *et al.*, 2012: 47).

Methods of anaerobic digestion are also becoming more effective, and offer different benefits to cities. For example, some processes produce biogas and fertilisers, which can displace fossil fuel alternatives and help communities to become self-sufficient (Elmitwalli *et al.*, 2006; Garoma and Williams, 2013).

Food

Food demand in cities is increasing with the growth of urban populations and rising per capita incomes. This trend is occurring in parallel with changes in the cost and availability of food; as well as of fertile land, water, and the energy and oil which are required for food production. More than 1 billion people currently live with food insecurity (OECD and FAO, 2010). In 2011, the GER (2011: 14; cited in Peter and Swilling, 2012) pointed out there was no existing international consensus on the problem of global food security or on possible solutions for how to nourish a population of 9 billion by 2050. Achieving food security in cities requires not only addressing food production (as it is the case in many current policy prescriptions), but also engaging with a broader approach that encompasses all aspects of food production, storage, distribution, consumption, and waste generation. All of these stages of the supply chain will be affected by climate change, and especially by the growing frequency and severity of extreme weather events (Tacoli 2013).

- **Local food systems:** As strengthening the efficiency of food systems is a key prerequisite to reduce food insecurity (particularly for the more vulnerable), boosting local food production and consumption can generate significant advantages for cities and their inhabitants. Urban and peri-urban agriculture can enhance security in food supply, boost local economies, and reduce cities' carbon footprint by cutting the energy required to transport food (Peter and Swilling, 2012; FAO, 2014). City-region food systems also help to move beyond the dichotomy of rural producers and urban consumers by strengthening urban-rural linkages (Okpala, 2003; Lucatelli and de Matteis, 2011; Dubbeling, 2013).

Local production of food also offers opportunities to improve agricultural efficiency by promoting good practice. Examples include the adoption of agro-ecological practices that seek to enhance ecosystem services, such as nutrient cycling and carbon sequestration, or rainfed crop production to reduce demand for surface and groundwater (an approach that can be coupled with rainwater harvesting).

- **Reducing food waste:** Food waste can be understood as wholesome edible material intended for human consumption that is instead discarded, lost, degraded or consumed by pests (FAO, 1981). The distribution of food waste varies between high- and low-income countries, and between high- and low-income consumers (Hodges et al., 2010). This has significant economic and environmental implications. There are opportunities to reduce food waste through technological and policy interventions, for example around refrigeration and expiry dates. However, Papargyropoulou *et al.* (2016) highlight that food waste is often a function of social and cultural practices associated with food preparation and consumption. There is therefore a need to engage with producers and consumers to ensure that edible food is made available for human consumption, and that inedible food is distributed to animals or composted to reduce landfill waste and recirculate nutrients in the city.

Waste

From megacities to small towns and villages, waste management, and especially solid waste management, represents one of the biggest concerns for city leaders (UN-HABITAT, 2010). Global municipal solid waste generation is currently approximatively 1.3 billion tonnes per year, a number that is estimated to reach 2.2 billion tonnes by 2025 (Hoornweg and Bhada-Tata, 2012). In cities and towns of the Global South, waste management is a recurrent issue that often reflects low institutional capacity and causes serious hygiene problems and environmental pollution, thereby adding further burdens to city governments (Awomeso *et al.*, 2010). Only 25 to 55% of the waste generated in large cities in developing countries is collected by municipal authorities – although municipalities may spend 20 to 50% of their budgets on solid waste management (World Bank, 2014). Urban waste management in the Global North is generally more comprehensive, but is also problematic, largely due to increased affluence and consumption: according to the GRDC (n/d), over half of the world's municipal waste is generated in high-income countries. This suggests that these countries have greater opportunities to improve resource efficiency by reducing, re-using and recycling waste.

In order to avoid the hazardous impacts caused by poor waste management, waste must be collected, disposed and treated responsibly by municipalities. Linear visions tend to perceive solid waste as an unwanted resource output which must cleared, for example, through waste disposal or incineration, with landfills remaining the most common method in use. Landfill sites that are well-designed and appropriately managed enable to prevent waste from contaminating the environment, in opposition to open dumps. Nevertheless, they require rigorous management that can be costly, and necessitate significant amounts of land. In contrast, waste can be valuable if it is considered in terms of circularity, i.e. as a resource input itself. Re-using waste presents the advantage of closing resource loops and enhancing self-sufficiency (Bancheva, 2014).

Current trends in waste management that can contribute to resource efficiency include:

- **Waste-to-energy:** Waste can be treated to generate energy in the form of electricity, heat or transport fuels. These can use different types of waste – solid, liquid and gaseous – although municipal solid waste remains the most common source (Eurostat, 2013). Methodologies include thermo-chemical conversion (e.g. incineration), bio-chemical (biogas production) and esterification (World Energy Council, 2013). These are particularly popular in the Asia-Pacific region which has the fastest growing waste-to-energy market. Waste-to-energy systems can also be attractive to decision-makers because they create a product which can be sold, generating a revenue stream to offset the costs of capital equipment and collection (Papargyropoulou *et al.*, 2015).

However, some of these technology-based measures can have significant environmental and social implications. Some combustion systems have been found to emit trace organic compounds where the systems are poorly designed and/or operated (Ruth, 1998). In other cases, waste-to-energy approaches can jeopardise the livelihoods of waste pickers, who comprise a significant and highly vulnerable component of the urban population in low- and lower middle-income countries: for example, covering landfills to facilitate methane capture can reduce access for waste pickers, who might otherwise recover and re-use waste (Colenbrander *et al.*, 2016). This underscores the importance of a circular economy approach to waste management, which recognises different uses and users throughout the lifecycle of a product or products.

- **Bio-utilisation:** Various waste streams such as human and organic household waste can be rendered harmless by natural systems that neutralise pollution. Many conventional pollution control systems are capital-intensive and expensive to operate, whereas natural systems tend to be much cheaper to maintain (Heal, 2004). By making use of regulating ecosystem services, bio-utilisation methods (i.e. the domestication of natural organisms) are more resource efficient than technological approaches, and often offer aesthetic benefits and/or architectural features (Barlest, 2010). In Dhaka (Bangladesh), nearly 80% of the waste is organic and used as compost for agriculture through community-based initiatives (Rahman, 2011). Marsh plants can also be used in waste treatment for the ecosystem services they provide in filtering nutrients and pollutants (Swilling *et al.*, 2013; Keys *et al.*, 2012; Todd and Josephson, 1996).

- **Building deconstruction and material reuse:** 40% of waste in landfills comes from building materials. Evaluating the volumes of solid waste generated from construction and demolition, determining recycle potential, evaluating options for disposal, and matching these disposal options to the volume and composition of wastes are crucial steps in the elaboration of construction-waste-management systems (Gavilan and Bernold, 1994).

In India, almost 50% of construction and demolition waste is re-used: for example, bituminous material is recycled through different cold and hot in-situ methods in Kolkata to build roads (Gosh and Aich, 2014). In cities prone to disasters, waste from damaged buildings can be a valuable resource, either as primary construction material (e.g. bricks, stone masonry, roof timber, roof tiles) or as secondary material (e.g. rubble for foundation) (ProAct-DWR-Shelter Centre, 2010). However, local building regulations may restrict the re-use of materials, or banks may be un-willing to provide loans for the use of unconventional constructions. This is a structural issue that can be engaged with to encourage resource efficiency.

Although it significantly affects the quality of life of urban residents, municipal waste management is often neglected. Furthermore, 'new' types of waste such as electronic and radioactive waste are posing major challenges for transport and disposal. These hazardous types of waste are produced in significant quantities, but only a limited proportion is recycled and a major part is illegally dumped in low-income countries. From collection to re-use, waste management is a key element to resource efficiency because of its potential to minimise impacts and increase productivity using the same or smaller resource base.

3.3 Benefits of building resource efficient cities

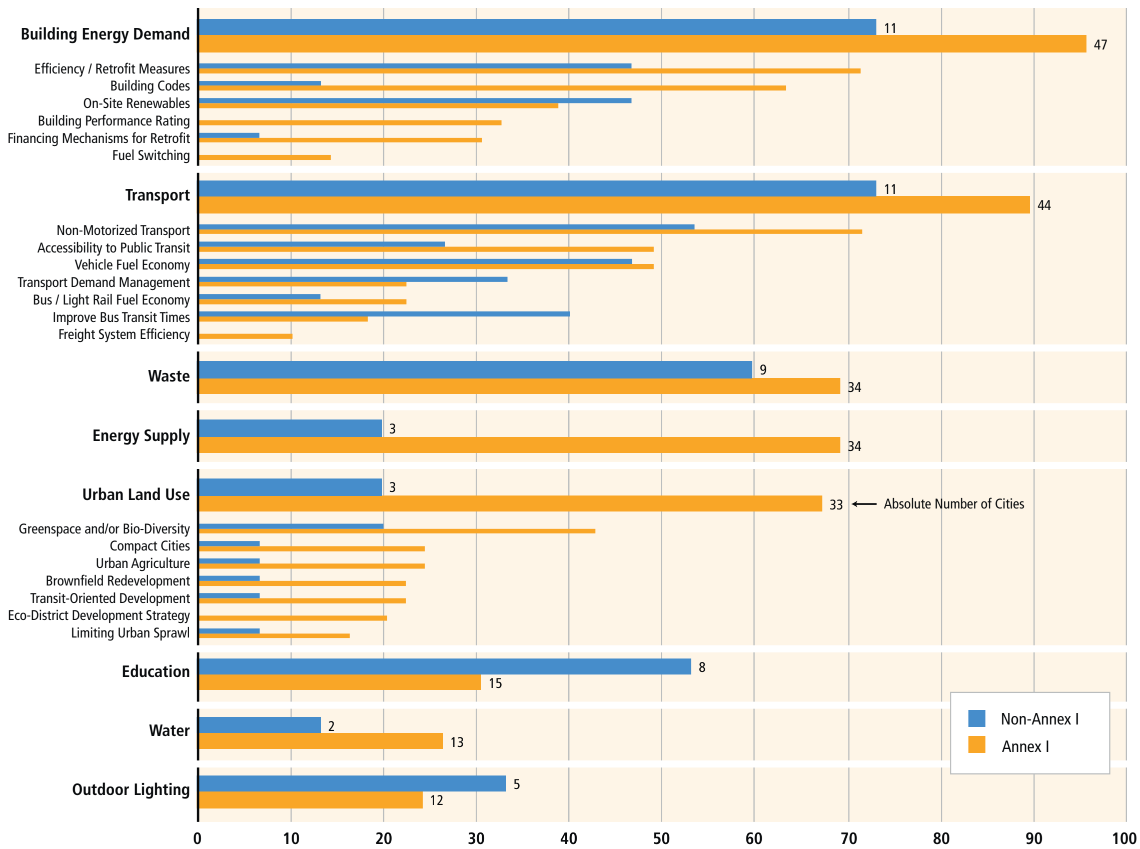
3.3.1 Higher productivity at a lower cost

Significant economic benefits can be associated with improving urban resource efficiency. This can partially be attributed to the growth of green industries. According to Moloney and Churchward (2015: 1), "a recent study by the Waste and Resources Action Programme (WRAP) found that across the EU, there could be £330 billion economic growth potential from resource efficiency in just the next seven years". The waste sector is a good example of the opportunities created for new firms and industries. In the US, recycling accounted for more than $236 billion in annual revenue in 2001 (date at which the last extended survey was conducted).

Resource efficiency provides scope to produce more value with the same or lower resource base, releasing financial benefits and enhancing the competitiveness of existing firms. In the case of infrastructure, investments to renovate or extend aging urban infrastructure of old cities and address the infrastructure deficit of burgeoning cities are

FIGURE 10: Mitigation activities being undertaken by cities

Source: Figure 12.22 in Seto et al., 2014.



a major financial opportunity for the future. One estimate suggests that investments in retrofitting, upgrading and expanding urban transport, buildings and waste management could have a net present value of $16.6 trillion to 2050 through avoided energy costs (Sudmant *et al.*, 2016).

Current market systems and policies frequently work against the goal of resource efficiency. For example, direct and indirect subsidies for fossil fuels were estimated to be $5.3 trillion or 6.5 per cent of global GDP in 2015 (Coady *et al.*, 2015). These subsidies lead to low fossil fuel prices, which reduce the financial incentives to conserve energy. Phasing out fossil fuels subsidies could release fiscal resources, which can be reallocated in ways that primarily benefits low-income groups, therefore leading to economic and social benefits as well as reducing greenhouse gas emissions. By comparison, carbon pricing – achieved through nationally appropriate taxes or emissions trading schemes – can raise new revenues while discouraging the use of fossil fuel energy (Global Commission on the Economy and Climate, 2014). These are often but not always set at the national level: a number of Chinese and Japanese cities have established municipal carbon pricing schemes in the absence of national frameworks.

3.3.2 Job creation and local economies

The process of making the urban fabric greener in a sustainable way can lead to major employment opportunities. Firstly, upgrading to greener infrastructure can create either temporary or permanent jobs in many sectors: for example, labour is required to improve roads, retrofit buildings, construct or repair drainage and sewerage systems, and manage recycling services. These jobs necessitate knowledge of new technologies and working practices, and involve training and support within local authorities, private companies and small enterprises (Rode and Burnett, 2011).

Some sectors and firms are likely to combine remote or off-shore production with highly urbanised consumer/service/support markets (Chapple, 2008). This means that there is potential for cities to grow both green ‘tradable’ activity (high value, exportable) and develop greener ‘non-tradable’ activities (lower value, goods and services for local consumption). However, job creation must evolve in parallel with improvements in workers' rights, their social protection and social dialogue. Attention must be given to engaging effectively with informal labour markets in order to eliminate inappropriate working conditions while creating opportunities for decent employment. The informal sector provides a major source of livelihoods in many cities and can contribute to the generation of a green economy (Brown *et al.* 2014).

3.3.3 GHG emissions, ecological conservation and integration

Reducing greenhouse gas emissions is one of the most important environmental benefits of resource efficiency. This is by reducing emissions from fossil fuel consumption (by buildings, transport and industry) and the decomposition of waste.

There are large opportunities for cities to reduce greenhouse gas emissions through the adoption of renewable energy, energy efficiency measures and better waste management. Many of these generate a significant economic return by reducing energy expenditure: looking across a range of cities, one estimate finds that investments in cost-effective options – defined as generating an annual return of at least 5 per cent – could reduce urban carbon emissions by 15-24% (relative to business-as-usual trends) within a decade (Gouldson *et al.*, 2015b). Many low-carbon measures generate wider social, economic and environmental benefits as well, such as improved air quality, road safety and mobility.

As recognised in the IPCC Fifth Assessment Report, cities are already undertaking a range of activities that contribute both to resource efficiency and climate change mitigation, ranging from managing energy demand in buildings, to upgrading transportation infrastructure and considering urban land use (Seto *et al.*, 2014) (Figure 10).

3.4 Challenges, limits and debates

3.4.1 Does resource efficiency resolve problems of dependence?

While resource efficiency can be described as a strategy of using fewer resources to achieve the same goals, this does not necessarily remove dependence on limited resources, and runs the risk of being pursued without understanding the problem of resource depletion. This is particularly relevant in the context of non-renewable resources: where efficiency gains deliver economic savings, the resulting consumption increases can cancel out environmental benefits . This phenomenon is known as the 'rebound effect' and – while variable – can reduce the environmental benefits associated with the efficiency gains by up to 30% (Hertwich, 2005; Sorrell *et al.*, 2009).

Particularly when coupled with rising per capita incomes, this means that improvements in resource efficiency do not necessarily offset the growing demand for resources. This suggests that resource efficiency strategies alone will not be sufficient to stay within planetary boundaries. Rather, efficiency measures need to be adopted alongside a switch from high consumption of finite resources, to the widespread use of renewable resources, lower consumption patterns and reduced waste production.

3.4.2 Tension between resource efficiency and cross-sectoral thinking

Interdependencies between resources can cause issues if interactions are not understood and properly managed. Indeed, increasing efficiency for one type of resource might impede the management of another. There are many examples of such tensions with respect to the water-energy nexus. Large amounts of energy are sometimes required to transport water from remote distances, or large quantities of water can be required to produce energy (e.g. hydropower). Desalination is an increasingly common example, as new plants are constructed in some water-scarce contexts to produce more freshwater. Yet desalination is an energy-intensive process and one that produces significant amounts of wastewater: almost two litres of wastewater are generated for every litre of freshwater produced (Xevgenos *et al.*, 2014). Cities have to recognise these trade-offs, particularly when they face both water and energy shortfalls.

Cross-sectoral thinking and coordination are essential to resolve these types of issues. Certain resource efficiency methods, such as the construction of green infrastructure or rainwater harvesting, can address multiple challenges simultaneously or generate diverse co-benefits beyond the obvious sectoral applications.

3.5 Case studies[1]

1 Many of the examples and case studies draw on information presented at a series of workshops on Resource Efficient Cities hosted by IIED, UNEP and the Sustainability Institute in 2013 and 2014.

GUANGZHOU, CHINA

ENERGY-EFFICIENT ARCHITECTURE AND TRADITIONAL TECHNIQUES

ISSUES WITH RESOURCES

- High energy demands
- Limited energy resources
- High greenhouse gas emissions

RESOURCE EFFICIENCY INITIATIVES

- Adoption of green construction standards
- Architecture centred on energy savings
- Green transport

SIMULTANEOUS ACHIEVEMENTS IN BUILDING RESILIENCE TO

- Local climate constraints
- Energy resource shortages

Conflicts between economic growth and environmental sustainability are particularly relevant in countries like China. The country's per capita GDP has increased by more than 92 times between 1978 – the year it adopted its open door policy – and 2011 (World Economic Outlook database, 2013; cited in Law *et al.*, 2013). Its national population has expanded considerably over the same period, and rapid urbanisation has resulted in more than 690 million people currently living in Chinese cities (Chan and Xu, 1985; National Bureau of Statistics, 2013). Added to this, higher affluence, industrial expansion, and growing transportation demands have all led to the fastest increase in energy demand in the world. China depends heavily on imported resources (including oil), and could not meet growing demand from domestic sources (Law *et al.*, 2013).

In 2004, China initiated efforts to build a 'resource-efficient and environmentally-friendly society'. Since then, important activities to improve resource management in the country's development plans have been initiated, particularly in relation to energy. According to West *et al.* (2013), energy efficiency in China has improved at a compound rate of more than 3.9% per year between 1970 and 2009. 'Greening buildings' is considered as a priority at national level, given that the country's building-related energy consumption accounts for 30% of the total energy use (Law *et al.*, 2013). Nevertheless, progress at city-level generally remains slow, and the majority of Chinese cities do not yet translate and integrate national environmental regulations into municipal action.

Guangzhou, capital of Guangdong Province and third largest city in China, is located along the south coastline of the country. According to the Asian Green City Index, Guangzhou – alongside Beijing, Shanghai, Nanjing and Wuhan – was in the top five of the cities consuming the highest amount of energy per $US of GDP in 2011. Today, the city has growing awareness of energy consumption issues and Guangzhou municipality has adopted a series of measures to promote the construction of environmentally-friendly buildings. Among other policies, consumption of clay bricks has been banned, while the use of innovative wall materials is widely encouraged (Legislative Affairs Office of Guangzhou Municipal Government, 2014). All large infrastructure projects are now required to be designed according to 'green standards', of which the gigantic Pearl River Tower based on clean technology, is a flagship example (Figure 11) (Dodman, 2013; Frechette and Gilchrist, 2008).

For other types of buildings such as houses, the Lingnan culture has been promoted for its energy-efficient design (Figure 12 and Figure 13). Lingnan architecture responds to the hot and humid subtropical climate of the region in many ways, including natural cross ventilation systems, heat insulation performance and natural lighting methods (Linortner, 2012). Lingnan modern architects are increasingly combining traditional and modern structures, including energy-saving elements inspired by foreign styles that are adapted to local environmental conditions (Yi-bin and Yong-shi, 2006). With the rapid growth of building stocks in Guangzhou, these policies have the potential to considerably improve the energy intensity of social and economic activities in the city.

FIGURE 11: The Pearl River Tower in Guangzhou makes use of wind pushing turbines to produce energy for the building

Souces: 21th Century Architecture, 2012 (sketch) and GuoZhongHua / Shutterstock.com (picture)

FIGURE 12: Example of a porch designed according to the principles of traditional Lingnan vernacular architecture

Source: Linortner, 2012.

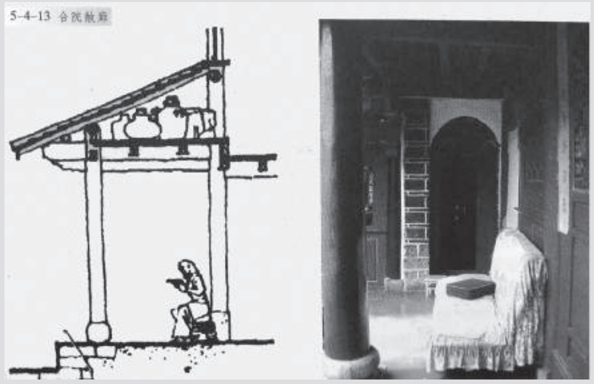
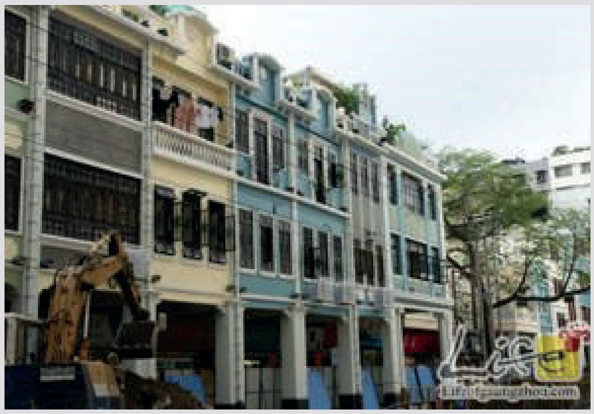


FIGURE 13: Lingnan-style Qilou buildings in Guangzhou

Source: Guangzhou Daily in Wang and Keyton, 2010.



LIMA, PERU

COUPLING LAND AND WATER EFFICIENCY

ISSUES WITH RESOURCES

- High demand in water resources
- Water depletion
- Land contamination

RESOURCE EFFICIENCY INITIATIVES

- Freshwater conservation
- Re-use of wastewater
- Green open space generation

SIMULTANEOUS ACHIEVEMENTS IN BUILDING RESILIENCE TO

- Climate change impacts (higher temperatures)
- Water resources shortage

FIGURE 14: San Juan de Lurigancho desde Cerro San Cristóbal (Lima, Perú)

Source: Par KaMpEr, 2012, CC BY 2.0, via Wikimedia Commons.

Metropolitan Lima, the capital of Peru, is located on the desert coast of the Pacific Ocean. After Cairo, it is the most populous city located in a desert (Kerres, 2010). Lima is facing problems of fragmented urban planning and major water management issues. High population growth is not supported by appropriate development strategies, an issue that is particularly affecting low-income groups in the city who consequently lack access to basic infrastructure and services. Lack of planning causes enormous pressure on the few open water bodies and on groundwater supplies. The city is mostly dependent on water flowing from the Andes mountain range, as well as from water resources transported from the other side of the range. Freshwater is pumped and diverted through complex mega-infrastructure that travels over large distances and supplies the city through the Rimac River. However, high inequalities in the city imply that only a certain part of the population benefits from the distribution system. Although potable water is used for irrigation, urban wastewater is not currently recycled in sufficient amounts and is often directly released into the environment (Figure 17). Current water management is thus highly unsustainable and resources are additionally threatened by climate change that causes the rapid melting of the Andes Mountains (Hordijk *et al.*, 2013).

FIGURE 15: Wastewater rejected in the Rimac River without treatment

Source: Loan Diep

FIGURE 16: Industrial wastewater directly rejected into the ocean in Metropolitan Lima

Source: Jan Hoffmann.

FIGURE 17: Constructed wetland for wastewater treatment in Metropolitan Lima

Source: ILPÖ, 2013; cited in Eisenberg *et al.*, 2014.

The 'Lima Ecological Infrastructure Strategy' (LEIS) has been developed as part of a broader initiative funded by the German Ministry of Education and Research (BMBF) called the LiWa-project. It aims at improving spatial planning, land-use efficiency and urban water management in order to support sustainable urban development in arid climate conditions (Eisenberg *et al.*, 2014). Based on the concepts of Integrated Urban Water Management, Water-Sensitive Urban Design and Green Infrastructure, LEIS has developed guidelines and principles for the creation of urban water-sensitive systems. This initiative is directly concerned with the balance between urban development and water resources, and seeks to use green spaces to restore equilibrium (McElhinney, 2012).

The LEIS can be described as a series of multifunctional green open spaces. Recognising the multiple values of ecosystem services, this approach seeks to make use of vegetation to purify urban wastewater, recycle nutrients, protect groundwater from contamination and enable its recharge. It takes into account the local dry conditions and seasonal variations of the vegetation and rivers. LEIS promotes theories of integrated urban management of urban areas, water cycles and open spaces. It is thus a way of promoting land and water efficiency simultaneously (Poblet *et al.*, 2013; LiWa, n/d).

LEIS has recently been developed and its implementation in Lima is yet to be fully achieved. The strategy offers potential to significantly improve city water management, landscape planning and ecological assets. It also serves to create recreational space (Miranda Sara and Baud, 2014). Very importantly, it can help reducing dangerous dependency on dwindling freshwater resources, and to make use of alternative sources for activities that do not require water that could otherwise be used for drinking. In a context of water resources endangered by both unsustainable practices and the impacts of climate change, restoring and preserving the integrity of the hydrological cycle through water and land efficiency initiatives is also an opportunity to enhance the city's resilience to water shortfalls caused by increasing climate variability. Lima offers a good example to other cities seeking to implement the New Urban Agenda, with its commitment to "preserving and promoting the ecological and social function of land… and to fostering ecosystem-based solutions to ensure sustainable consumption and production patterns, so that the ecosystem's regenerative capacity is not exceeded."

KHON KAEN, THAILAND

ISSUES WITH RESOURCES

- Waste accumulation
- Land and water contamination

RESOURCE EFFICIENCY INITIATIVES

- Construction of waste-to-fuel station
- Land reconversion

SIMULTANEOUS ACHIEVEMENTS IN BUILDING RESILIENCE TO

- Energy shortage
- Health risks

Khon Kaen City is a municipality with about 100,000 inhabitants in northeast Thailand. Solid waste is a considerable issue for the city and more broadly, for Khon Kaen Province, which has the largest waste dump in the north-east region of Thailand and the eighth largest in the country. There are currently 800,000 tons of rubbish accumulated for future disposal at the dump sites of 26 districts. The province generates about 1,224 tons of new garbage per day, of which the urban communities of Khon Kaen city produce 210 tons (Kamthorn Thavornsathit in Nathanri, 2014). These dumps create significant public health risks for urban dwellers, including increased risk of disease and exposure to fire hazards, as seen in Bangkok in 2014 (Jones, 2014).

Khon Kaen municipality is expected to shortly start the construction of a power plant that will use solid waste as a resource to produce energy. Working in partnership with Alliance Clean Power over the 2013-2033 period on this project, the municipality has made available a budget of $22 million (GEF, 2011). The city conducted a pilot project in 2013 which turned six tons of plastic waste into 5400 litres of fuel (Royal Thai Embassy, 2014). Once the approval from the Ministry of Energy is received, Khon Kaen will construct the trash-to-fuel station that is aimed to be finished in early 2015. It is designed to treat 450 tons of garbage on a daily basis, thereby eliminating the currently accumulated garbage over a period of seven years. It is envisioned that the dumpsite will eventually be transformed into a recreation space for the local community.

The waste-to-energy project is intended to both use the waste resources more efficiently, and to displace prospective fossil fuel consumption. This helps Khon Kaen tackle two resource constraints simultaneously, while countering future health and environmental risks. In this way, a resource efficiency intervention also has the scope to build the city's resilience.

FIGURE 18: Accumulated garbage in Kohn Kaen city

Source: Wannapreuk in Nathanri, 2014

FIGURE 19: Pyrolysis plant proce ssing plastic garbage into oil

Source: Hongyon , 2013.

3.6 Conclusions

The resource efficiency agenda is increasingly gaining traction due to a combination of the reduced environmental impacts, real or perceived scarcities in supply and – perhaps most importantly – the potential for economic savings (Moloney and Churchward, 2013). There is scope to improve the efficiency of resource use in key sectors of the city, such as building design and waste management, but even greater opportunities where urban planners and policymakers can shape or re-shape urban form and function. The largest opportunities may therefore be in fast-growing cities that are making large investments in infrastructure – but most of these are in low- and lower middle-income countries that may lack the technical, institutional and financial capacities to effectively guide urban development (Seto *et al.*, 2014).

Concepts related to resource efficiency, such as 'circular economy' and 'closed loops', are enabling city governments, firms, civil society organisations and urban residents to re-imagine the way they understand and approach resource management, production and consumption. Such ambitious initiatives have the potential to deliver significant economic, social and environmental benefits. For example, the adoption of more energy-efficient transport modes (cycling, walking, mass transit and efficient cars) can reduce levels of air pollution within a city, with particular benefits for low-income groups who tend to live in more polluted areas and to spend more time outside (Foster, 2011; Garg, 2011).

4 EXPLORING THE NEXUS BETWEEN RESILIENCE AND RESOURCE EFFICIENCY

4.1 Introduction: linking the concepts

Resilience and resource efficiency thinking provide different languages, metaphors and tools for understanding and shaping urban change and, where appropriate, more radical transformation. Exploring the ideas of resilience and resource efficiency independently and in association enables the identification of common features to both concepts. At their core, the resilience and resource efficiency agendas share similar values, objectives and approaches at city level. However, there are also tensions that perhaps go unacknowledged in agreements such as the New Urban Agenda.

The critical messages that emerge from the different city case studies across the world are:

- the process of building resilience offers opportunities to also build resource efficient cities;
- the outcomes of achieving resource efficiency can contribute to a city becoming more resilient.

Thus, the nexus between resilience and resource efficiency shows potential for gaining co-benefits from considering both agendas together. City-leaders who adopt these concepts jointly to develop urban planning strategies will be able to achieve greater objectives. Together, they provide a framework to manage cities in a sustainable manner.

4.2 Shared principles and objectives

4.2.1 New thinking on approaches to and preparedness for challenges

Resilience and resource efficiency represent two sets of principles providing ideas to help individuals, communities, organisations and ecosystems cope with the uncertainties and risks they face in a changing world. They both aim to avoid the decline and eventual collapse of systems. They provide useful frameworks to make a switch to innovative thinking to better understand challenges. Although urban resilience tends to be seen as the way to respond to more sudden impacts, it can also enhance the adaptive and transformative capacities of social-ecological systems. Resilience and resource efficiency together can provide insights to evaluate a range of short-, mid- and long-term challenges. They aim to move away from business-as-usual approaches towards sustainable development and planning. In the case of transformative initiatives, change can be incremental and continuous, while in other cases it can be sudden, disorganised and turbulent. While this might involve whole system design perspectives for more radical changes (engineering and/or institutional solutions), working on existing systems can also be substantially easier.

4.2.2 Making use of learning to deal with uncertainty

Both concepts advocate ideas that help systems to be strengthened in order to overcome predicted and unpredicted threats and events. It is about reinforcement built upon lessons learnt from the past, and framed according to the anticipation of forthcoming disturbances. Strategies may be informed by experience or by studying lessons from others, by gathering data, conducting research and communicating the findings, conclusions, and recommendations (Torrens Resilience, 2009). Both resilience and resource efficiency are essentially driven by the anticipation of risks, based on learning through continuous feedback processes. Resilience and resource efficiency equally promote the adoption of measures that can capture the complexity of city systems and foster solutions that are flexible enough for systems to adapt over time according to different scenarios.

Adaptation to future risks involves dealing with uncertainty. A focus on flexibility implies an engagement with experimentation and the consideration of different levels of uncertainty. Resilience thinking directly considers uncertainty by having as prime objective the creation of systems that can adapt and maintain an acceptable level of functioning and structure when facing diverse types of shocks and stresses (Welsh, 2012). Resource efficiency advocates the need to return to forms of circularity for cities to survive resource limitations associated with environmental and climate uncertainties, as well as to multiple and sometimes unpredictable internal and external limiting factors. Therefore, both encourage cities to prepare for and manage risks of various types.

4.2.3 Understanding risks

The notion of risk reflects the probability and the magnitude of an adverse effect. Recent definitions recognise that individuals take risks to achieve potential benefits, thereby highlighting the notion of trade-offs. For example, people living in coastal cities can be exposed to floods, cyclones, sea-level rise and coastal erosion. It is often impossible to completely remove the probability of a disruptive event. However, identifying, evaluating and formally communicating the risks enable societies to make decisions on how to reduce the probability and/or the impacts of disturbance, and sometimes better accept certain consequences (Torrens Resilience, 2009).

The idea of risks is also directly relevant from a resource perspective. In cities, resource scarcity and supply chain risks threaten the future of societies. Risk management is therefore a core principle of resource efficiency in the way it seeks the reduction of environmental impacts that can lead to further environmental degradation, economic costs, and social issues such as health problems. Restoring ecosystem services, as promoted by certain aspects of resource efficiency, is also a manner to avoid relying on technical solutions which can provoke the emergence of new risks. Indeed, achieving sustainability does not necessarily mean relying on innovation and adopting technocratic approaches, but to fundamentally re-think urban growth. As seen in the case of Guanghzou, this can sometimes require returning to traditional practices or restoring ecosystems and cycles that have been degraded.

As demonstrated with the case studies, cities aim towards different levels of transformation. They build preparedness starting by developing plans, standards and operational procedures, or by developing economic and/or social capital according to expected and/or uncertain scenarios. Building resilience against risks to prevent crises is about response, but also for recovery. From a resource perspective, preparedness can for example take the form of avoiding 'resource depletion' so to avoid social injustice, economic crisis or further environmental degradation. The adoption of renewable energy technologies is a proactive way of addressing energy resource shortage, but also to mitigate climate change risks.

4.2.4 Optimising and preserving resource flows

Adopting urban resilience and resource efficiency agendas means that societies can survive and ideally, that they can thrive sustainably. The link between cities and resource flows is particularly important if this is to be achieved. On the one hand, resource flows themselves have underpinned and shaped cities, their development structure and spatial organisations (Atkinson, 2014). On the other hand, cities have impacted the way resources travel, supply urban activities and support the needs associated with their growth. Both urban resilience and resource efficiency find opportunities from making use of this mutual connection. They explore the ways in which dependency can be reduced so cities become more self-reliance, but also remain open systems.

Combining resilience and resource efficiency thinking would prioritise optimising resource chains and flows that make sub-systems run, and thus preserving the metabolism of the city system as a whole. Resilience and resource efficiency principles advocate the benefits of adopting holistic perspectives that explore the links between components of a given system, and also understand how several resources are sometimes interlinked and mutually dependent on each other. In a joint agenda, material flows assessments can help to define actions reflecting the dynamics between urban socio-economic activities, and considering the environmental conditions in which these take place.

4.2.5 Maintaining diversity

In addition, preserving diversity is a common goal for the two concepts and a key condition for maintaining the identity and stability of urban systems (Nwachukwu and Robinson, 2011). Resilience encourages diversity to make a system redundant and safer in case of failure of a single or several components, thereby reducing dependency on single components and providing alternatives. As argued by Ahern (2011: 342), "cities with higher levels of economic and social diversity have a more complex response by which they are better positioned to adapt to change and socioeconomic disturbance". Diversity in resource efficiency is also a way of conserving resources by reducing dependence. An integrated approach to resilience and resource efficiency can therefore help cities to understand what range of resources is available to them and plan accordingly for different time frames. Resource base analyses offer opportunities to lower dependence on finite resources and ecosystems, and to develop more viable alternatives, such as the use of renewable resources.

4.2.6 Minimising impacts on environmental assets and conserving ecological functions

Reducing environmental impacts is another key common objective. Resource efficiency directly aims to minimise negative impacts on the environment: it attempts to plan according to ecological limits; encourages climate change mitigation; and values ecosystem services to restore natural loop systems. In a more indirect manner, resilience – and particularly ecological resilience – considers reducing ecological footprints and preserve ecosystems' natural ability to respond to disturbance. In disaster risk reduction, it seeks minimal vulnerability and the minimisation of hazards impacts by protecting or strengthening ecological systems which are exposed to damage. Developing resource efficient and resilient strategies in parallel will thus ensure the limitation of impacts at multiple levels, thereby leading to greater achievements regarding environmental protection.

4.2.7 Saving costs

Direct financial savings, improved cost efficiency, and the reduction of externalities are important common economic goals targeted by resilience and resource efficiency. As the costs of socioeconomic and environmental crises are growing, building and maintaining a solid economic structure to prevent cities to collapse is one of the most problematic challenges. As now widely recognised in the context of climate change, the costs of no-action are generally greater than early investment, for example in low-carbon growth (Global Commission on the Economy and Climate, 2014). Resilience aims at preventing the diverse costs of impacts from disturbance on physical or socio-political systems. Amongst these, economic costs are addressed by minimising the most threatening risks by attempting to offer structural change answers, and to eventually generate long-term savings. Economic resilience more particularly aims to make economic growth stronger and human development greater, often by considering scales of governance as determinant factors of the making of resilient economies (Bahadur and Tanner, 2014).

From a resource perspective, resilience seeks to derive the economic insurance value of ecosystem resilience thereby providing incentives for environmental protection. Resource efficiency also directly generates economic savings in multiple ways. This starts with the goal of producing the same with less resources or producing more with the same amount of resources. As more and more measuring and gauging economic methods are developed, there is increasing evidence from both resilience and resource efficiency resulting in financial advantages that can attract investment. Furthermore, if these two cost-effective agendas are well-designed together, further economic benefits can be generated.

4.2.8 What boundaries and scale for action?

Shocks and stresses affect societies in complex and interconnected ways that require understanding systems in their wider context and adopting multiple-scale perspectives. For instance, this is obvious when disruptive events (e.g. industrial disasters, epidemics, economic crash) have immediate global impacts, which in return require collective responses. Cities depend on ecosystems, resources, and populations from other places – they are often supplied with resources that originate outside their boundaries requiring large infrastructure systems to transport and convey them to societies, and also export resources or transport waste elsewhere. This signifies cities need to be explored at scales that include peri-urban and rural areas, sometimes even at the national or international level.

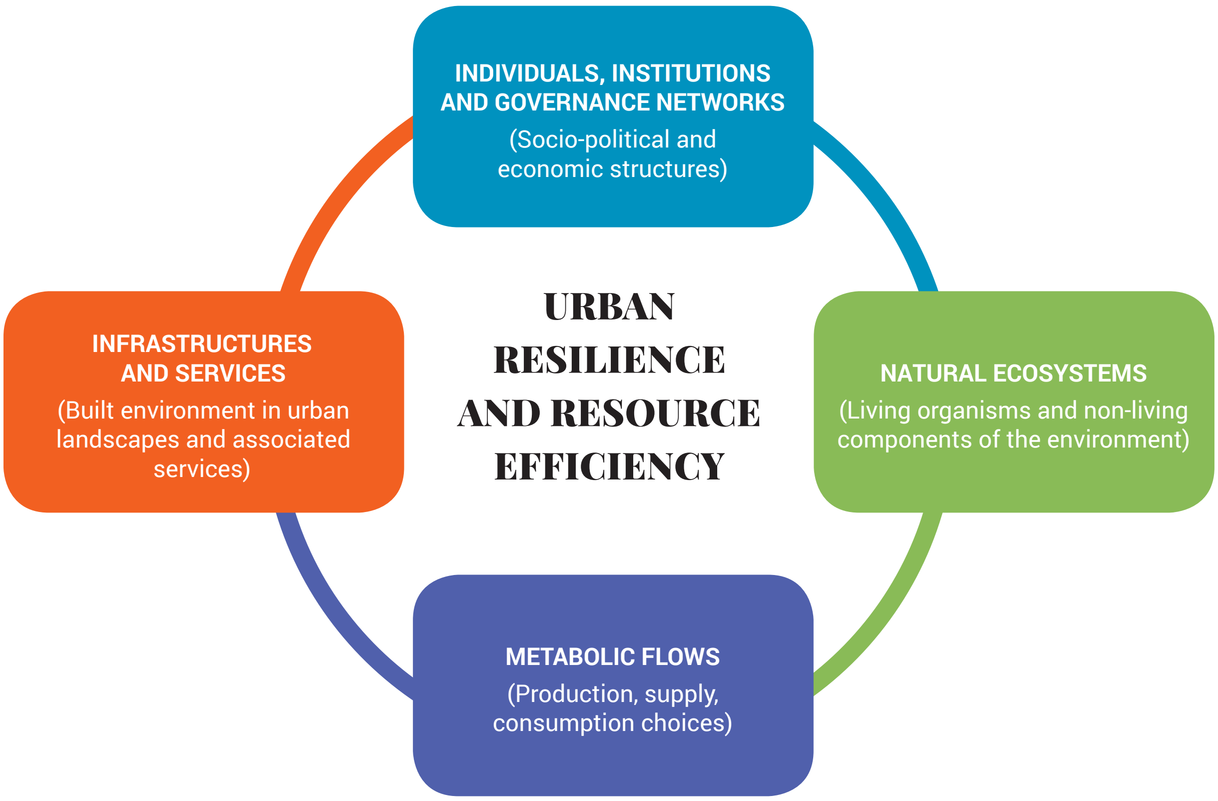
The resilience and resource efficiency frameworks both consider the notions of scale and boundaries. Both concepts approach cities through multiple-scale perspectives and recognise the need to move away from narrow boundaries analyses. Instead, the urban resilience and resource efficiency perspective start to increasingly view cities as large open systems with a range of short- and long-distance connections. From the resilience perspective, being able to travel from a scale to another is crucial to evaluate the way transformation at small levels can help maintaining resilience on a larger scale (Elmqvist, 2014).

4.3 Distinct and common characteristics between resilient cities and resource efficient cities

The aim of this section is to compare and contrast the characteristics of sub-systems of a resilient city with those of a resource efficient city.

FIGURE 20: Areas of action to build resilience and resource efficiency

Source: authors.



4.3.1 Characteristics of a resilient city and its sub-systems

Infrastructure and services

Resilient infrastructure and services are able to resist to shocks so as to keep functioning or to quickly recover. Additionally, redundancy is a key property of resilient services, so they can assure safe failure by offering alternative ways of functioning (e.g. extra elements which are not strictly necessary to functioning are available in the case of failure in crucial elements). If the system does stop functioning, it must be able to rapidly rebound in order to minimise disruption. Engineering resilience signifies that infrastructure is robust enough to withstand physical shocks and to provide protection to human life and health. In the case of a transport system, mobility and accessibility is assured. Resilient communication systems assure reliable connections, for example through continuous power supply through secondary lines in IT hubs.

Individuals, institutions and governance networks

Social sub-systems in cities include governmental bodies, civil societies, and businesses. Resilient individuals and institutions are able to adapt to an uncertain environment, anticipate risks, and organise themselves in a collaborative manner in the occurrence of shocks and stresses. Innovation is sometimes necessary for more resourcefulness during shocks and stresses and for recovery. In line with diversity as a core objective, social pluralism paired with coordination can also be a core requirement to provide flexibility and be resourceful for better response. Social resilience also reflects an ability to reflect, learn from and share experience.

Socially resilient governance tends to be associated with decentralised systems in which participation and polycentrism is promoted (Béné *et al.*, 2014). Stability, coordination and effective leadership are important resilient characteristics. This is also the case for economic characteristics and where spare resource capacity is key for responsiveness to risks. Social resilience is also associated with prosperity of livelihoods. Many associate social resilience with a social justice approach where stakeholders are empowered, and support is provided to the development of marginalised groups (Arup, 2014*a*; Khalil *et al.*, 2013, Béné *et al.*, 2014).

Natural ecosystems

The resilience of natural ecosystems, directly associated with 'urban ecological resilience', generally refers to reducing the vulnerability of natural assets. From this perspective, a resilient city is characterised by low impacts of urbanisation and human activities on ecosystems, biodiversity and cycles (Béné et al, 2014). Ecosystem resilience is a direct consequence of the adaptive capacity of social-ecological systems: human activities can cause unexpected consequences causing ecosystem collapse. In a resilient city, pollution is kept at a minimum for the absorption capacities of ecosystems to be maintained at reasonable level without being irreversibly damaged (e.g. avoiding soil degradation from land-use change) (Peter and Swilling, 2012). From a different perspective, resilient ecosystems have the capacity to buffer the effects of the shocks they face (i.e. absorb disturbance), or to adapt to the stresses from which they suffer. This type of resilience is directly related to the social, economic and infrastructural value and functions offered by ecological processes and natural dynamics.

4.3.2 Characteristics of a resource efficient city and its sub-systems

Infrastructure and services

In resource efficient cities, infrastructure and services are able to function while meeting the demand of the population with the use of the lowest amounts of resources possible. This implies that production is maximised in a way it can meet the needs of the population while not causing additional environmental impacts. It also means that waste is produced at minimum rates and/or reused as much as possible. In resource efficient cities, infrastructure and services are well-connected to ensure that resource flows are maximised. For example, smart infrastructure and services promote circularity so inputs are treated for one use and outputs for another.

A directly related notion is that of 'urban ecological security' which refers to the protection of resource flows, services and infrastructure through the reconfiguration of cities and their infrastructures to enable ecological and material reproduction (Hodson and Marvin; cited in Peter and Swilling, 2012). Physical infrastructure is well-integrated so as to ensure there is a good balance between the built and non-built environment. This includes the preservation or restoration of the hydrological cycle (e.g. connected rivers and streams) which is often disturbed by human activities and infrastructure.

Individuals, institutions and governance networks

In resource efficient cities, consumption and production patterns are in equilibrium with resource availability, often resulting from changes in behaviour and thus minimising ecosystem degradation. Social innovation is often described as a crucial factor for the improvement of resource productivity: cities with limited resources are forced to be innovative in order to optimise the opportunities from the use of what little is available.

Resource efficiency in cities can thus be enhanced by knowledge sharing and creativity. Furthermore, dependency on limited resources is decreased, while autonomy and self-reliance are enhanced, thereby increasing flexibility. Resource efficiency at city-level also entails cross-sector and inter-institutional coordination. This is to make the most of interactions between resources, and between resources and the environment in which they flow. At the institutional level, the environment is integrated into urban governance, and urban perspectives are embedded into environmental policy-making to avoid negative impacts between city sub-systems.

Natural ecosystems
Cities where resource efficiency is promoted apply less pressure on the resources that are available to them. They have better control on resource flows, and make the most of natural cycles within and outside city boundaries. This is particularly true where ecosystem services are restored, or even where they are imitated (e.g. artificial wetlands). Therefore, this enables the return to, or the maintenance of an environmental equilibrium state. Resource efficiency also enables biodiversity conservation; while waste reduction means that land degradation, soil contamination and waterbodies pollution are minimised.

4.4 Towards an integrated agenda

4.4.1 Complementary activities vs conflicting activities

What does achieving resilience and resource efficiency at city-level mean in more practical terms? Translating goals that are shared by both resilience and resource efficiency agendas into concrete actions enhances the potential ways of achieving common objectives through one set of activities to implement at city-level, but may also highlight potential contradictions. Some short-term strategies to strengthen economic resilience may increase pressure on ecosystems and thus lead to inefficient resource use: for example land-use change through intense cultivation and livestock production might lead to irreversible soil degradation as well as require large quantities of water. Engineering or technological solutions that reduce dependence on non-renewable sources of energy (e.g. dams and nuclear power plants) may not contribute to resilience (or, indeed, to broader environmental objectives). However, this does not mean that the two agendas are contradictory, but rather that they need to be viewed in association with each other, and possible areas of tension reconciled, if mutually-reinforcing goals are to be achieved.

The use of urban vegetation is a particularly effective example of a complementary activity. On the aspect of resource efficiency, some types of vegetation – such as those of wetlands – can store water and release it slowly, thereby enabling the natural continuous recharge of groundwater. In addition, vegetation can have an important role in absorbing carbon dioxide and contributing to climate change mitigation. On the aspect of resilience, it has a crucial role in increasing groundwater absorption and slowing surface run-off (hence reducing flooding), and reducing urban heat island effects (thereby keeping temperatures lower).

In the case of market systems, adjusting subsidies for fossil fuels in favour of green technologies will create incentives for making infrastructure and services more energy efficient, as well as reducing GHG emissions. In parallel, it could enable resilience building by decreasing reliance on fossil fuels, particularly in the context of uncertainty around future costs and available reserves. Such measures offer the promise that these outcomes contribute to the transformation of a system towards sustainability.

As argued by Karlenzig (2010), "growing a green economy will be a fundamental facet of urban resilience". Job growth will particularly take place in sectors such as green building and landscaping, water conservation, low-carbon transportation, green information, public transport and waste management. City-scale decoupling can also support businesses in providing green jobs and meeting the needs of the new economy with green technologies and services. A resilient and resource efficient model of city planning would ideally support local, national, and global economies in adapting to new prices, including volatile energy supplies.

Figure 21 schematically illustrates a set of activities that can be undertaken to help meet the objectives of resilience and resource efficiency and how these may reinforce each other, and helps to set the frame for an integrated agenda.

The definition of policies associated with the resilience-resource efficiency nexus can start by defining key parameters and related thresholds based on the understanding of the city-system and of the potential shocks and stresses anticipated. Guiran (2014), using the four different aspects of resilience defined by Walker *et al.* (2004), applies this approach to different areas of action, including natural ecosystems (e.g. food and hydrological ecosystems, see Table 3) and socioeconomic structures (e.g. economic income, local employability rate). This approach provides a starting point to elaborate actions that could combine resilience and resource efficiency visions.

FIGURE 21: Examples of mutually reinforcing activities meeting both the resilience and resource efficiency agendas

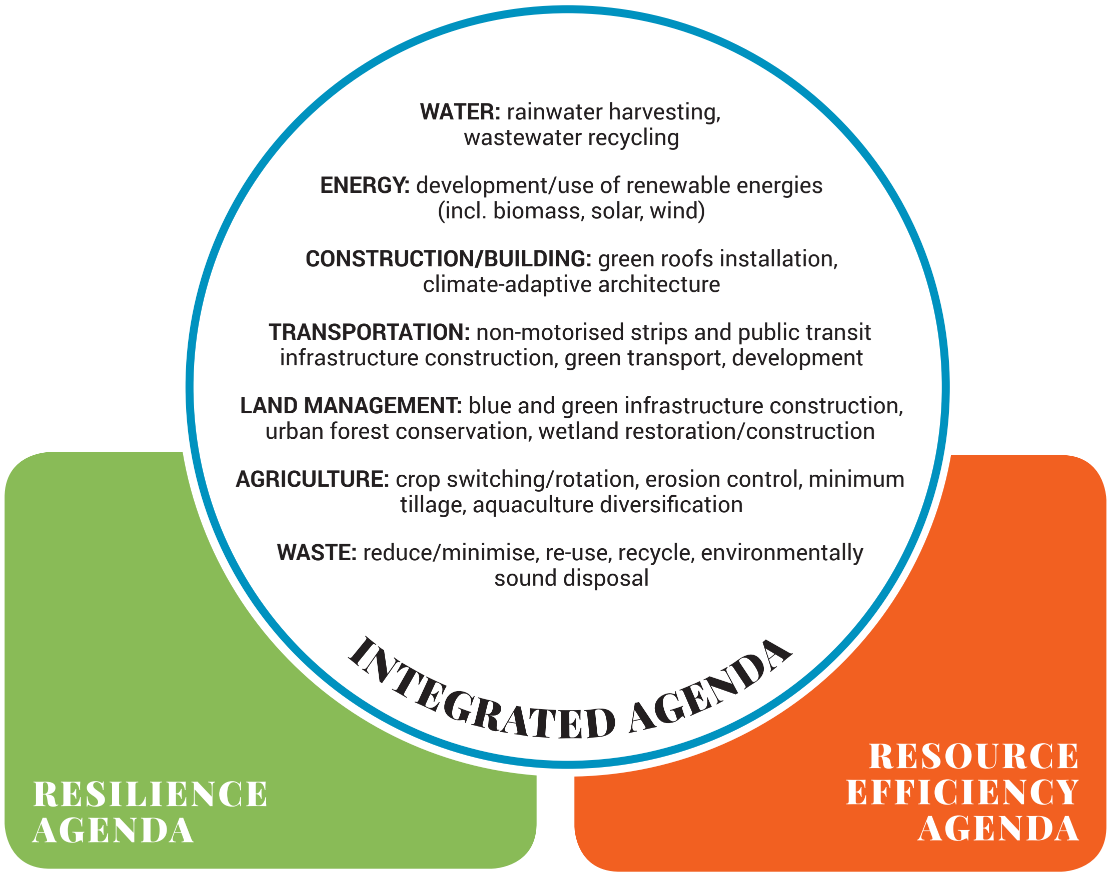


TABLE 3: Example of threshold definition for a system exposed to water and food unavailability

Source: Guiran, 2014; adapted from Walker et al., 2004.

Potential direction for action	Water availability	Food availability
Changing threshold (latitude axis)	Changing the water requirements (e.g. less than 60 L)	Changing the food requirements (e.g. changing family diets)
Move the current state of the system away from or closer to the thresholds (precariousness axis)	Changing water availability (e.g. improving water provision from existing wells by digging deeper)	Changing average food availability (e.g. via improved agricultural productivity rate, promotion of self-supporting agriculture)
Make the thresholds more difficult or easier to reach (resistance axis)	Changing ways of access to water (e.g. water recycling)	Changing sources of food provision (e.g. via adjusted agricultural mix…)
Manage cross-sale interactions to avoid or generate loss of resilience at ad from other scale (Panarchy axis)	Anticipate new water needs (e.g. if development of new activities); Wide scale raising awareness on the issue and solutions (e.g. dissemination on information of water scarcity)	Interaction with larger scale food security programmes. Wide-scale raising awareness on the issue and solutions (e.g. dissemination on information of crops adaptation

4.4.2 Identifying and addressing trade-offs

As much as understanding common objectives and features of the two concepts, it is important to understand where tensions might exist. For instance, the resilience agenda may sometimes approach redundancy of infrastructure without addressing the need to reduce resource consumption. In the case of energy services (e.g. services that are specialised in power production and supply), energy security is sought through spare capacity. However, this requirement can fundamentally be at odds with 'minimum [energy] consumption', as stipulated in resource efficiency principles which promote the provision of basic energy services with the least amount of resources used.

Comparing 'extreme' resilient systems and 'extreme' resource efficiency systems is a way to understand what trade-offs a city might have to address. Regarding resilience, Elmqvist (2014: n/d) explains that "many examples can be found of highly resilient systems (e.g. oppressive political systems) locked into an undesirable system configuration or state with high levels of environmental inequity." For instance, a system that would prioritise rapid economic growth (socio-economic resilience) through trade, and do so at the expense of its resources, is unlikely to be resource efficient.

On the contrary, too strong an emphasis on resource efficiency, for example in the objective to maximise outputs, can decrease resilience. This is illustrated by Elmqvist (ibid) with a deliberate reduction in redundancy in modes of governance: a system with too few actors would have poor predictability and controllability capacities. A resilience approach would lead to multiple and alternative connections, perhaps through redundancy in governance at the local and at the global scale, and thereby engaging collaboration between cities. City networks can enable the management of resource chains, an element which can also be overlooked in cases where very highly resource efficient cities are self-independent and thus, perhaps isolated. Cities that are too isolated may lose their position in regional, national, or global systems, lose their competitive character, and even collapse.

In particular, possible tensions between resource efficiency and social resilience need to be reconciled. A green transport system powered by renewable energy can be efficient and yet not contribute to equitable access to serve the resilience requirements of low-income populations in cities. Capital/output ratios for photovoltaic technology and tariff systems are sometimes not conducive for significant scale-up in low-income contexts. How can these trade-offs be resolved though different state regulatory instruments and research and development in 'green' technologies? That particular example also raises the fundamental question of how to integrate human communities as integral components of ecosystems (Collins *et al.*, 2000). Furthermore, this also highlights how particular urban areas and particular social interests might be selectively privileged over others (Peter and Swilling, 2012).

The nature and importance of trade-offs directly depend on the context of implementation and the circumstances in which the system is considered. In some contexts, resource security is not targeted in a short-term social agenda (e.g. spare resources will be required to meet social needs in the occurrence of a hazard). However, it will be a priority in a long-term ecological resilience agenda (Roelich *et al.*, 2013; Roelich *et al.*, 2015). Various scales of action thus help define objectives and will determine how these objectives might vary from one scale to another. This takes us back to the necessity of analysing resilience "of what, to what, and for whom", as well as analysing resources "what is available, what is under pressure and how do different types of resources interact".

4.5 Case studies

NEW YORK CITY, UNITED STATES

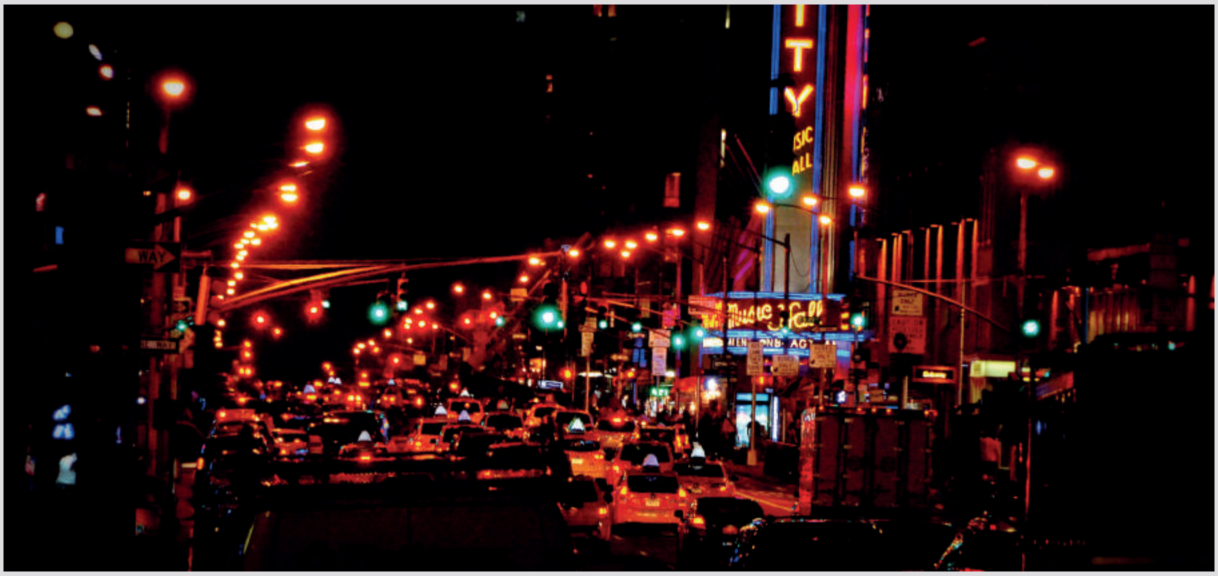
New York City is currently one of the world's leading cities in terms of investment for building resilience. This is in part a response to recent disasters: in 2012, Hurricane Sandy destroyed entire neighbourhoods and paralysed utility facilities and networks. According to Sanders and Milford (2014), more than 400 housing authority buildings containing around 35,000 housing units lost power, heat and/or hot water during the superstorm. New York's exposure to environmental hazards and the prospect of continued population growth have driven significant public planning and investment in recent years (Keenan and Chakrabarti, 2013). Six months after Sandy hit the northeastern coast of the United States, the city government upgraded its PlaNYC strategy – initially released under the title 'A Greener, Greater New York - and launched 'A Stronger, More Resilient New York' in 2013, a long-term plan to tackle issues related to climate change impacts (NYCEDC, 2013).

Amongst its 257 programmes, the new PlaNYC includes initiatives directed to upgrade infrastructure and protect critical services to ensure continuity in the occurrence of hazards (Siemens and C40, 2014). To protect its energy networks, the city has adopted a holistic approach to secure 'grid resilience', i.e. a system of electricity storage composed of interconnected microgrids acting as single controllable entities that can operate in island mode should any individual modules be damaged (Ton, 2014). Building grid resilience involves upgrading power poles and increase energy storage to allow the reliable and fast reconfiguration of the energy system when portions of the grid are down. Such power grid enables continuity of service provision by safeguarding energy against power outages and allowing rapid power restoration in case of disruption caused by a man-made or climate-induced event (Momoh, 2009).

Although enabling resilience, building such a system is financially expensive and can be considered inefficient in multiple ways. Lichter (2014) argues that "nearly two-thirds of every megawatt US power plants produce never does a bit of useful work. Some of it is lost due to the natural resistance of power lines. Some is lost as heat during generation. […] some is lost by design when utilities deliberately generate more electricity than they need and shed the access". As part of New York's efforts to enhance grid resilience, the system is capable of producing much more energy than it is normally required. On top of this, the system's transmission lines are buried underground and often prevent potentially more productive land-use. Alternative or supplementary initiatives to address these problems can include the construction of photovoltaic panels and wind turbines to generate renewable power in sufficient amounts for redundancy reserves. These are also decentralised technologies, so could be linked to separate microgrids to further support modularity. In order to mainstream this type of activities, New York needs to combine visions of resilience and resource efficiency in its city strategy and translate it into concrete actions such as the adoption of regulations.

FIGURE 22: Energy is a vital part in the daily life of the citizens of New York City

Source: Jan Hoffmann.



JOHANNESBURG, SOUTH AFRICA

RE-PLANNING AN 'INSIDE/OUT CITY'[2]

The City of Johannesburg is South Africa's economic powerhouse, as well as the most populous metropolitan area in the country, with a population of more than 3 million (Planact, 2014). Although per capita incomes are high on average, Johannesburg faces significant poverty and unemployment (above 30%), and is grappling with rapid urbanisation (3-4% per annum). The city is also threatened by the impacts of climate change on already fragile resources. Securing adequate supplies of freshwater and energy represent major issues, while increasingly frequent and intense flooding and heatwaves are likely to threaten the wellbeing and productivity of low-income residents in the city.

The city's development has resulted in the deterioration of the urban ecological infrastructure, while its history has also generated stark social and spatial divisions. Today, Johannesburg is a city of contrasts which provoke tensions between policy agendas of economic growth and sustainable development (Parnell and Robinson, 2006).

In 2006, Johannesburg developed long-term development strategies which align with its vision of becoming "a World Class African City of the Future": 'the Growth and Development Strategy 2040' (GDS 2040) (City of Johannesburg, 2011). The GDS 2040 consists of medium-term spatially-oriented plans for the infrastructure, housing and transportation sectors. One of the objectives of the strategy is to: "provide a resilient, liveable, sustainable urban environment – underpinned by infrastructure supportive of a low-carbon economy". This aims to be achieved through the establishment of ecoefficient infrastructure solutions for housing, water, waste, sanitation, transport and communications technology. Initiatives regarding energy efficiency are progressively evolving and the city plans to develop grid-connected renewable energy systems.

Since 2012, the city's agenda has also included the 'Corridors of Freedom' initiative (CoF), a spatial restructuring plan developed in accordance with the GDS to enhance the city population's mobility. Johannesburg's concept of 'Corridors of Freedom' aims at connecting strategic nodes through the development of corridors linked through affordable and accessible public transit, which includes bus and passenger rail. One of the key features of this plan is to reduce the use of private transport.

Land-use transformation goes along each of these corridors which involve the construction of social infrastructure, such as schools, offices, community-facilities, parks, and clinics. The creation and maintenance of an urban green infrastructure and urban forest network are also included in the scheme, as is the construction of water drainage systems to address flood hazards (City of Johannesburg, n/d). The Corridors of Freedom are presented as a comprehensive plan that will act as a catalyst to drive a long-term spatial and social transformation process across Johannesburg (Pieterse, 2014).

In order to assess progress towards its goals of productivity, good governance, inclusivity and environmental sustainability, the city has developed sets of indicators against which it collected data. Indicators such as the reduction of waste to landfill and the percentage of clean energy demonstrate efforts to keep track of achievements made towards the efficient use of resources.

Johannesburg is tackling embedded challenges of spatial division, poverty and resource scarcity through a transformative process. The institutional policies recently developed by the city include explicit objectives of resilience and sustainable resource use, as well as goals associated with the reduction of poverty and spatial division. While it is too early to evaluate the success of such objectives given the recent start of implementation of the Corridors of Freedom, this case demonstrates the possibility of concretely defining policies that integrate resilience and resource efficiency together.

2 This case study draws on an interview with Yondela Silimela, City of Johannesburg.

SAO PAULO, BRAZIL

Brazil is one of the most urbanised countries in Latin America, which is in turn the most urbanised region in the world: 80% of the region's population lives in cities (Arsht, 2014). After absorbing more than 80 million new urban residents between 1970 and 2000, Brazil has today completed its urban transition and 85% of its population is urban (Martin and McGranahan, 2010). São Paulo, Brazil's largest urban area, is one of the most populous cities in the world. Nearly 12 million people live in the city (World Population Review, 2015), which is the financial and cultural centre of Brazil and Latin America (Ribeiro, 2004).

In parallel, the city is facing major urban issues such as poverty and unemployment, inadequate housing and basic service provision, ageing infrastructure, urban sprawl and increasing levels of pollution (Bucalem, 2012). Forty percent of the population (including the majority of low-income and vulnerable citizens) lives in the urban periphery where access to water, sanitation and electricity is lacking (World Bank, n/d). For example, the average consumption of water in high-income areas reaches 350 litres per person per day, in contrast with 120 litres per person per day in poorer areas (Interview with Mauricio Piragino, 10th April 2015). With climate change, the city is projected to experience more frequent, heavy rain and higher temperatures. 900,000 largely low-income households located in peripheral areas also face environmental risks because of the location on slopes and in flood-prone areas) (World Bank, n/d). Issues of water availability and access are increasingly prominent and reflect a lack of institutional involvement and capacity.

Despite some plans and policies, concrete actions to tackle these issues remain poor. The lack of institutional initiatives and the non-existence of participatory processes in urban governance are repeatedly pointed out. São Paulo misses coordination between governmental policies but also with society's actions which prevents the city from developing in a sustainable way. Nevertheless, the city has considerable financial, economic, educational, technological, cultural and social resources. Many social movements and grassroots initiatives in the city have emerged: a wave that reflects the need for "affirmation of democracy" (Caldeira, 2003). Rede Nossa Sao Paulo ('Our Sao Paulo Network'), for example, is a network of actors that involves around 700 organisations, citizens, and businesses, and which has for overall objective to transform the city into a just, democratic and sustainable city where the quality of life of citizens is improved. The network seeks to mobilise citizens to tackle problems in the city, increase the civil society's participation in decision-making, debate on urban governance and call politicians for action (Rede Nossa Sao Paulo, 2015). Rede Nossa Sao Paulo believes that such mobilisation may be capable to build a political, social and economic force bringing society and governments to a set of medium and long-term sustainable development goals.

A range of different types of actions have been conducted by the network which focuses on political activism, advocacy and community capacity-building. Amongst many initiatives and actions, it launched the Sustainable Cities Program (PCS) in 2011, in partnership with two other social organisations. More than 270 Brazilian cities have participated in PCS. The programme's goal is to engage city representatives to take action in a platform of sub-programmes ('Foundations') to improve governance, protect common natural assets, promote equity, social justice, and culture of peace, better mobility and less traffic, etc. The programme provides cities with an administrative agenda for urban sustainability, including indicators and targets defined to measure progress with regard to sustainable development. It also focuses on public participation, and enhances the exchange of information and experiences between local and global levels (Nossa Sao Paulo, 2014).

What does this imply in terms of resilience and resource efficiency? Organisations like Rede Nossa Sao Paulo attempt to undertake initiatives where governmental bodies may fail to fulfil their role, and thereby demonstrate the value of coordination, participatory processes and knowledge sharing to achieve goals of sustainable development. Through the mobilisation of stakeholders who are engaged with values and principles around themes such as energy efficiency, climate mitigation, and healthy environment, socio-environmental and political initiatives were born. The movement has thus enabled to engage key actors to build a type of grassroots social resilience against political instability, and to demonstrate that while the role of municipal governments in achieving resource efficiency and resilience is essential, organised civil society also has a central role to play in this.

4.6 Conclusion: co-benefits from achieving resilience and resource efficiency

Cities around the world are facing a range of interconnected challenges and opportunities linked to changing demographic and environmental pressures. For urban centres to survive and thrive, they need to be well-coordinated and to respond effectively to these different pressures. Moving towards resilience and resource efficiency is one key element of this preparation.

This report – and in particular the city case studies it contains – demonstrates some of the ways in which cities are responding to these challenges, and identifies some promising areas for action that can be taken on board by urban areas elsewhere. The key messages that it presents can be summarised as follows:

- **A resilience agenda can help cities become more resource efficient by being more flexible and by being better able to learn and respond to changed circumstances.** The process of building resilience can therefore simultaneously offer opportunities to build resource efficiency.
- **A resource efficiency agenda can help cities to become more resilient by reducing exposure to the risk of shortfalls in essential inputs.** Various inputs addressed in a resource efficiency agenda (materials, products, water, energy, food) are all essential for urban functioning. The outcome of achieving greater resource efficiency can contribute to a city becoming more resilient, because it will rely less heavily on the systems that provide resources.
- **A number of areas of action are common to both concepts, therefore providing ground for mutual reinforcement.** City leaders aiming to achieve both resilience and resource efficiency can adopt measures for each with the potential to contribute to the achievement of both objectives.
- **Possible tensions between resource efficiency and resilience may also exist.** Redundancy and modularity may help cities to be more resilient to shocks and stresses, but could also be framed as representing inefficient use of resources. Overcoming these potential conflicts will require more integrated and responsive urban planning and governance.
- **Achieving resilience and resource efficiency at city-level can help meet broader sustainability objectives.** The urban resilience and resource efficiency concepts have overlapping objectives and both aim at addressing major challenges such as climate change and pressure on natural resources. They are concerned not only with short-term achievements, but also with providing key tools for the long-term sustainable development of cities.

The case studies support many of these lessons. It is clear that cities in a wide range of contexts are making significant commitments and progress towards either enhanced resource efficiency or improved urban resilience, and that efforts to achieve one are often contributing to the other. These city case studies also reveal a wide range of potential entry points to these environmental agendas. In New York City, an environmental disaster has helped to drive the resilience agenda; in Johannesburg, the social and political stresses created by historic patterns of governance and planning are catalysing transformative actions; and in Sao Paulo, civil society groups have engaged in the absence of action by the formal structures of government.

The examples above also reinforce the scale of the challenge facing cities. To quote the New Urban Agenda, "the persistence of multiple forms of poverty, growing inequalities and environmental degradation remain among the major obstacles to sustainable development worldwide, with social and economic exclusion and spatial segregation often an irrefutable reality in cities and human settlements". Enhancing urban resilience and resource efficiency will be critical to addressing the social, economic and environmental challenges facing not just cities, but the planet. These agendas are fundamental to delivering a range of global commitments beyond the New Urban Agenda, including the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals.

Cities are uniquely positioned to see the need for, and to address, an integrated approach to resilience and resource efficiency. City governments are often the most effective actors at directing capital into more resource-efficient activities, and are placed at the most effective scale to respond to shocks and stresses. Moreover, shared urban identities can mobilise the private and civic sectors to support a city's environmental agenda, adding a dynamism and creativity to local initiatives that can underpin transformative change. With their concentration of people, ideas and infrastructure, cities have unique opportunities to deliver improved resilience and resource efficiency. The growth of urban populations and economies could be an engine for sustained and sustainable development – if it is possible to readdress the way cities and human settlements are planned, designed, financed, developed, governed and managed. This is an immense challenge – but it is also an opportunity that cities cannot afford to miss.

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6 APPENDICES

Appendix 1. Initiatives for building resilience around the world

Alongside the growing concern over the range of threats faced by cities and their inhabitants, the recognition that urban transformations will be playing a major role in economic, demographic, social and environmental change has led to a rising number of urban resilience agendas worldwide (Moir *et al.*, 2014). A range of institutions and networks are supporting these, most frequently with an explicit link to climate change risks. Inter-governmental organisations supporting urban resilience include:

- **The United Nations institutions:** Among UN institutions focusing on the city-level, UNHabitat is currently working with local governments of 40 cities, most of them in the Asia-Pacific Region. Through its Cities and Climate Change Initiative (CCI), it supports them in resilience building with climate change vulnerability assessments, climate change action plans, and with the definition of climate change and urban policies. The United Nations International Strategy for Disaster Reduction (UNISDR) has launched the 'Making Cities Resilient' campaign to encourage and give recommendations to Mayors and local governments with a particular emphasis on the application of the Hyogo Framework for Action 2005-2015.
- **The C40 Cities Climate Leadership Group (C40):** Aiming to highlight the leadership role of cities in addressing issues of the 21st century, the C40 Cities Climate Leadership Group (C40) is a network of the world's megacities committed to take action regarding climate change. Founded in 2005, it serves cities as a forum where they can collaborate, share knowledge on successful achievements, and drive sustainable and measurable action. It has held a risk assessment workshop in Rio de Janeiro in November 2014, and will host the C40 Mayors' summit in Mexico in 2016, bringing together global C40 mayors and urban sustainability leaders in order to build up collective research for climate solutions.
- **The Asian Cities Climate Change Resilience Network (ACCCRN):** Funded by the Rockefeller Foundation, the Asian Cities Climate Change Resilience Network (ACCCRN) initially operated in 10 cities in India, Indonesia, Thailand and Vietnam. It seeks to develop practical strategies for cities to be equipped with the right resources, tools and methods to be able to respond to the impacts of climate change. ACCCRN's main goals are centred on capacity building, networks for knowledge and learning, and engagement and the scaling-up of actions.
- **The International Council for Local Environmental Initiatives (ICLEI):** ICLEI was established as the International Council for Local Environmental Initiatives in 1990. It is a global association of local governments and national, regional and local government organisations. ICLEI establishes links within its network that comprises over 1200 members, and works collaboratively with hundreds of other governments through campaigns and programmes aiming at supporting the implementation of sustainable development strategies at the local level. In relation to resilience, ICLEI has been hosting the 'Resilient Cities Congress' on an annual basis.
- **The City Resilience Profiling Programme:** led by UN-Habitat and supported by C40, ICLEI, the Inter-American Development Bank (IDB), UNISDR, the Rockefeller Foundation, United Cities and Local Governments (UCLG) and the World Bank, this programme aims to enhance effectiveness of response to humanitarian crisis and subsequent development issues. Beyond common approaches adopted in disaster risk reduction, the CRPP has developed a multi-sectorial, multi-hazard, multi-stakeholder model for building resilience while taking into account the complexity and diversity of cities in which it is implemented. Four objectives are pursues within its 4-5 year implementation timeframe: 1) research on operational framework; 2) indexing and profiling; 3) tools/software development; 4) normative guidance. The CRPP involves key partnerships founded on integrated approaches to urban resilience.
- **100 Resilient Cities:** Also financed by the Rockefeller Foundation, 100 Resilient Cities is a programme that works with cities to build resilience to notable social, economic and physical challenges. Cities submit their own analysis of the risks they are exposed to and for which they consider the most important to be prepared. Key elements of support involve the recruitment of a Chief Resilience Officer for each selected city, as well as aid to develop an urban resilience plan and access to services to implement this plan.

In addition, UN-Habitat, UNISDR, the World Bank, GFDRR, ICLEI, the Inter-American Development Bank (IDB), the Rockefeller Foundation and its 100 Resilient Cities programme and C40 are some of the signatories of the 'Global Collaboration for Urban Resilience'. This collaboration seeks knowledgesharing, the harmonization of the approaches and tools currently available, and the facilitation of the flow of financial resources by forging alliances between governments, institutions and the private sector (UN-Habitat, 2014).

These city networks tend to have been developed with the aim of informing decision-making and policy implementation at local level through bridging the gap between research and practice in urban adaptation and resilience. They are often based on the idea that national governments have taken insufficient actions to address complex issues like climate change at the local scale. Being part of an influential network should provide the cities with opportunities to take parts in debates and learn from the experiences of others (Moir *et al.*, 2014; Schreiber, 2014).

Appendix 2. Examples of tools to apply, measure and assess resilience

TAMD (IIED): The International Institute for Environment and Development (IIED) is currently working with its partners on the piloting of a framework designed to track adaptation and measuring its impact on development in low- and middle-income countries. Called 'Tracking Adaptation and Measuring Development (TAMD)', this method is used to monitor and assess the actions deployed in climate risk management at the international, national and sub-national scale, and make use of vulnerability and development indicators to evaluate the outcomes relative to local climate resilience. Already used in Pakistan, Ethiopia, Cambodia, Uganda and Tanzania, it is aimed to be tailored in a manner it can be used effectively by local and national government officials, NGOs and development partners.

World Bank: Through the Resilient Cities Program, The World Bank has developed the "City Strength Diagnostic Methodology, a qualitative, rapid diagnostic process that uses a combination of guided interviews, exercises, and review of existing studies to determine sectoral and crosscutting recommendations." The process is divided into four stages: 1) Pre-diagnostic data collection; 2) Launch workshop; 3) Interviews and field visits; 4) Prioritization of actions and investments to enhance resilience. This methodology has for key purpose to facilitate a dialogue amonst stakeholders about risks in their city and the performance of urban systems.

City Resilience Index (Arup): With support from the Rockefeller Foundation, Arup has recently defined the City Resilience Index (CRI), aimed at enabling the measurement of resilience at the city scale. It has been designed and tested from fieldwork for the particular purposes of enabling urban communities to thrive despite the occurrence of social, environmental, and economic stresses and disruptions. It seeks to inform research on resilience and to be easily accessible to urban planning practitioners and investors. CRI does not recognise *asset-based*[3] and *system-based*[4] approaches as comprehensive as each of them tends to overlook questions of scale, interdependencies between different systems and power dynamics. Instead, CRI follows a *performance-based approach* defining resilience according to a city's capacity to fulfil and sustain its core functions, which are achieved by multiple city assets, systems and actors simultaneously (Arup, 2014c). The index is based around assessing the performance of key urban sectors and activities against a set of defined characteristics of resilience.

LSE Cities: Exploring the interplay between the designed and built qualities of urban form and urban governance in creating resilience, LSE cities has defined four main measures and a set of indicators to evaluate *urban form resilience*. By framing the 'resilient urban form' as "dense, inclusive of a diversity of building types, founded on co-ordinated and robust movement infrastructure and accommodating of multipurpose or 'flexible' open spaces", LSE cities has established four key measures to explore the resilience of urban form:

- Physical: a) population and built form density over time; b) adaptabilities of street layouts and building types; c) evidence of the adaptability of street layouts and building types over time;
- Environmental: a) public transport accessibility; b) green space accessibility and open land preservation;
- Social: degrees of land-use and tenure diversity; - Economic: property values in a wider urban context.

These interlinked measures have the capacity to provide insight into the way change can impact on places. This framework has been applied to a series of case studies which led to the conclusion that "assessing the relative overall resilience of different urban typologies is not a straightforward process" (Davis and Uffer, 2013).

3 Asset-based approaches look at the resilience of individual infrastructure components but neglect the role of these components in city systems.
4 System-based approaches take into account the role of individual infrastructure components but do not consider the interdependencies between different systems at different scales, nor the governing structures that influence the way systems work. (Arup, 2014c)

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