URBAN PATTERNS FOR A GREEN ECONOMY

OPTIMIZING INFRASTRUCTURE

UN-HABITAT
FOR A BETTER URBAN FUTURE

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DISCLAIMER

Cover photo:	Redesigned shelter at a bus stop in Uberlândia, Brazil, whose public transport network connects the central areas of the city with the outlying neighbourhoods along three main arteries © UN-Habitat/Alessandro Scotti

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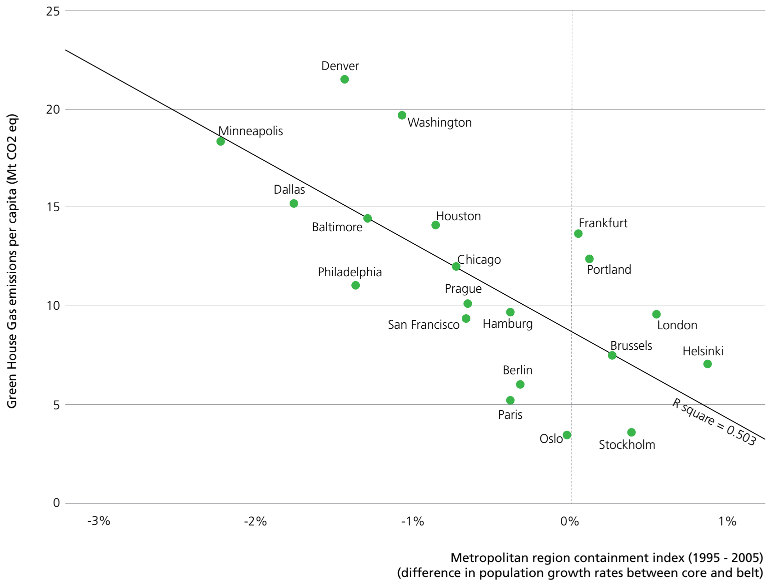
Foreword

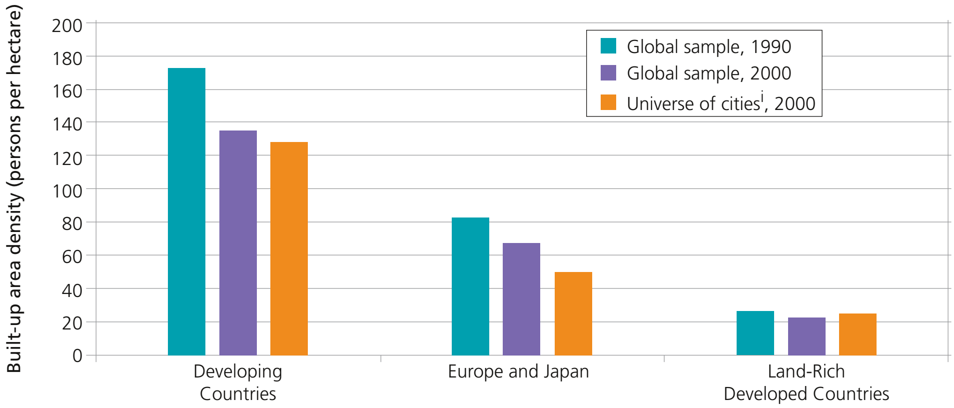
The city is one of the highest pinnacles of human creation. Concentrating so many people in dense, interactive, shared spaces has historically provided distinct advantages, that is, agglomeration advantages. Through agglomeration, cities have the power to innovate, generate wealth, enhance quality of life and accommodate more people within a smaller footprint at lower per-capita resource use and emissions than any other settlement pattern.

Figure I: **Greenhouse gas emissions and containment index for selected metropolitan regions**



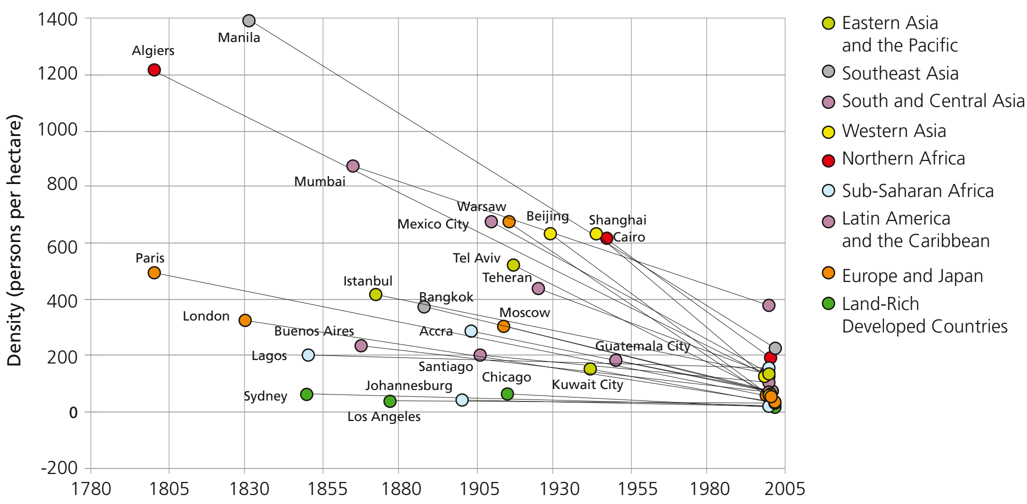
Or so they could. Increasingly, cities are forfeiting many of the benefits that agglomeration has to offer. Two meta-studies of urban land expansion have shown that over the last two decades most cities in the world have become less dense rather than more,[12] and are wasting their potential in ways that generate sprawl, congestion and segregation. These patterns are making cities less pleasant and equitable places in which to live. They are also threatening the earth's carrying capacity. And they are most

Figure II: **Average Built-up Area Densities in Three World Regions**



Source: Making Room for a Planet of Cites, by Shlomo Angel, Jason Parent, Daniel L. Civco, and Alejandro M. Blei. © 2011. Lincoln Institute of Land Policy, Cambridge, MA.

Figure III: **The General Decline in Built-Up Area Densities in 25 Representative Cities, 1800-2000**



Source: Making Room for a Planet of Cites, by Shlomo Angel, Jason Parent, Daniel L. Civco, and Alejandro M. Blei. © 2011. Lincoln Institute of Land Policy, Cambridge, MA.

i This refers to 3,646 large cities with a population of over 100,000 or more.

acute in fast-growing cities, particularly those with the lowest institutional capacities, weakest environmental protections and longest infrastructure backlogs.

Increasingly, city managers wish to learn by example. Rather than more theory and principles, they want to know what has worked, what has not, and which lessons are transferrable to their own contexts. There is much information available, but little time. UN-Habitat has developed these "quick guides" for urban practitioners who need condensed resources at their fingertips. The aim is to suggest patterns that can help cities and city-regions regain these inherent advantages in a time of increased uncertainty and unprecedented demographic expansion.

More than half the global population now lives in towns and cities. By the year 2050, UN-Habitat research projects that that figure will rise to two-thirds. This rapid, large-scale concentration of humanity in the world's cities represents new challenges for ingenuity, and numerous opportunities to improve the way in which human habitats are shaped. Most of this population growth will be in the cities of developing countries, which are expected to grow by an additional 1.3 billion people by 2030, compared to 100 million in the cities of the developed world over the same period.[3]

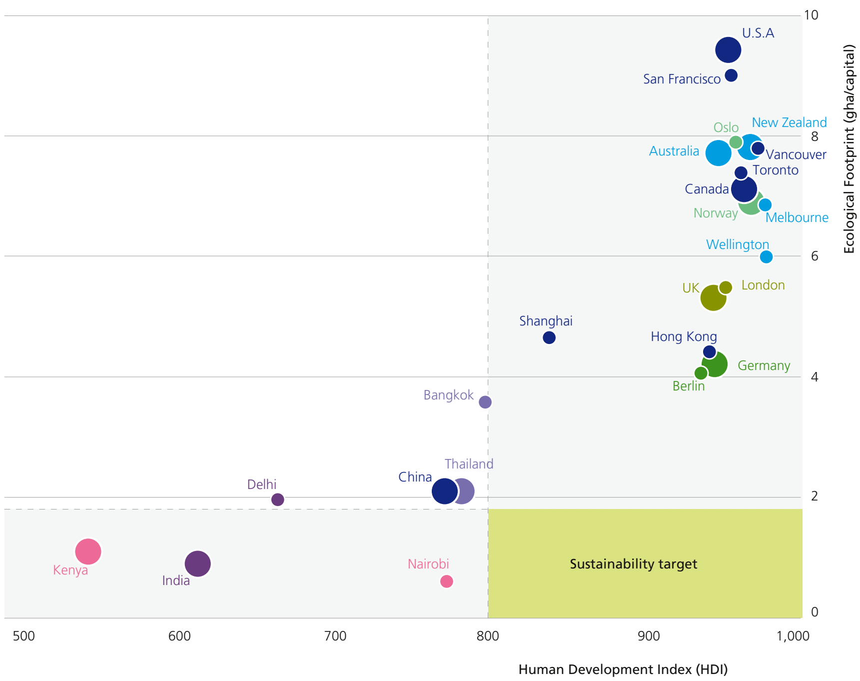
While urban population growth rates are stabilizing in regions which are already predominantly urban (such as Europe, North, South and Central America and Oceania), regions with a higher proportion of rural population (such as Asia and Africa) are likely to see exponential rates of urban population growth in the coming years.[4] Most urbanization is likely to occur in cities relatively unprepared to accommodate these numbers, with potential negative repercussions for quality of life, economic development and the natural environment.

Although the percentage of the urban population living in slums worldwide has decreased, the absolute number of people living in slums continues to grow.[5] No less than 62 per cent of all urban dwellers in sub-Saharan Africa live in slums, compared to Asia where it varies between 24 per cent and 43 per cent, and Latin America and the Caribbean where slums make up 27 per cent of the urban population.[6] If these growing cities are to be socially sustainable, new approaches will be required to integrate the poor so that the urbanization process improves inter-generational equity rather than entrenching socio-spatial fragmentation. Privatized models of service delivery that discriminate between consumers based on their ability to pay threaten to worsen inequalities,[7] and require carefully considered parameters to ensure that the poor are not disadvantaged.

According to a recent World Bank study, urban population growth is likely to result in the significant loss of non-urban land as built environments expand into their surroundings. Cities in developing countries are expected to triple their land area between 2005 and 2030, with each new city dweller converting an average of 160 metres^2 of non-urban land to urban land.[8] Despite slower population growth, cities in industrialized countries are likely to see a 2.5 times growth in city land areas over the same period due to a more rapid decline in average densities when compared to their developing country counterparts.[9] As built environments become less dense and stocks of built up land accumulate, the amount of reproductive and ecologically buffering land available for ecosystems and food production is diminished, reducing the ability of city-regions to support themselves.[10]

While international trade has made it possible for cities to meet their demands for food, water and energy with imports from faraway lands, it is becoming increasingly

Figure IV: **Ecological Footprint and Human Development Index for selected countries and cities.**



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apparent that the appetite of the world's growing and increasingly affluent population is coming up against limitations in the planet's ability to support human life on this scale. It is estimated that our addiction to oil will result in a peak in oil extraction within the next decade, leading to dramatic increases in the costs of fuel, mobility, food and other imports. Greater demand for potable water, combined with changing rainfall patterns, the depletion of aquifers and pollution of groundwater, is likely to see increasing competition for scarce fresh water resources, raising the possibility of conflict in the near future.

The ability of ecosystems to continue providing biotic resources like wood, fish and food, and to absorb manmade wastes - commonly referred to as the earth's "bio-capacity" - is also diminishing. Comparing global ecological footprints to the earth's available capacity shows that, at current rates of resource use, we are exceeding bio-capacity by 30 per cent,[11] and approximately 60 per cent of the ecosystems we depend on for goods and services are being degraded or used in an unsustainable manner.[12] We are living off the planet's natural capital instead of the interest from this capital, and there are already signs of the devastating effect this will have on our societies and economies in depleting fish stocks, loss of fertile soil, shrinking forests and increasingly unpredictable weather patterns.[13]

The global population is reaching a size where cities need to start thinking beyond their immediate interests to consider their role as nodes of human consumption and waste production in a finite planet that is struggling to keep pace with humanity's demands. If cities are to survive, they must acknowledge the warning signs of ecosystem degradation and build their economies in a manner that respects and rehabilitates the ecosystems on which life depends. If cities are to prosper, they must embrace the challenge of providing shelter and uninterrupted access to water, food and energy and improve quality of life for all of their citizens.

The way in which city spaces, buildings and infrastructural systems are planned, designed and operated influences the extent to which they encroach on natural ecosystems, and locks them into certain modes of consumption from which they struggle to deviate. Urban activities have direct and indirect consequences for the natural environment in the short, medium and long term, and their scale of influence typically extends far beyond the boundaries of what is typically considered to constitute "the city". Managing the indirect, distant and sometimes obscured impacts of city decision making in an increasingly globalized world requires appropriate governance mechanisms that improve cities' accountability for the resources they rely on.

As nexuses of knowledge, infrastructure and governance, cities represent a key opportunity to stimulate larger scale change toward green economies. In a world where cities are increasingly competing against each other economically, where weather patterns are unpredictable and low resource prices can no longer be assumed, cities need to proactively shape their economies and operations in preparation for an uncertain future. To manage risk in a democratic manner, a balance will need to be struck between deliberative decision making processes and centralized master planning. This can be done by empowering planning professionals to respond quickly and effectively to evolving developments without compromising longer term shared visions of a better city[14].

This guide is one of a set of four aimed at inspiring city managers and practitioners to think more broadly about the role of their cities, and to collaborate with experts and interest groups across disciplines and sectors to promote both human and environmental prosperity. The guides are based on the outputs of an expert group meeting hosted by UN-Habitat in February 2011 entitled *What Does the Green Economy Mean for Sustainable Urban Development?* Each guide focuses on one of the following cross-cutting themes:

Working with Nature

With functioning ecosystems forming the foundation for social and economic activity, this guide looks at how built environments can be planned to operate in collaboration with nature. It looks at how to plan cities and regions for ecosystem health, focusing on allowing sufficient space for natural systems to continue providing crucial goods and services like fresh water, food, fuel and waste amelioration.

Leveraging Density

This guide looks at the relationship between built and natural environments from the perspective of cities, and considers how their impact on ecosystem functioning might be reduced by making best use of their land coverage. Planning the growth of cities to achieve appropriate densities and providing alternative forms of mobility to private vehicles help to slow urban expansion onto ecologically sensitive land, and can reduce citizens' demand for scarce resources by sharing them more efficiently.

Optimizing Infrastructure

Considering urban infrastructure as the link between city inhabitants and natural resources, this guide looks at how infrastructural systems can be conceived differently in order to help all city residents to conserve resources. It introduces new concepts and approaches to the provision of infrastructural services, such as energy, water and waste treatment, and demonstrates how infrastructure investments can act as catalysts for urban sustainability.

Clustering for Competitiveness

Taking a broader perspective, this guide looks at city regions and how they can be more optimally planned to achieve economic objectives in a manner that does not waste local resources. It looks at how competitive advantage can be achieved at a regional scale by encouraging cooperation between cities with complementary areas of specialization. It also considers how innovation for green economic development can be encouraged through the clustering of industries, and through collaborations between government, the private sector and academia.

Each guide contains a selection of case studies from around the world that demonstrate how cities have approached sustainability challenges in a manner befitting the realities of their unique context. Showcasing a wide range of options, the case studies are not aimed at prescribing solutions, but are rather intended to inspire the considered development of contextually relevant approaches in other cities to enhance their sustainability.

Glossary

Black water: Waste water containing human faecal matter and urine.

Cogeneration: The generation of electricity and heat at the same time.

Dematerialization: Achieving an objective using a smaller quantity of a certain resource input than was previously the case.

Eco-efficiency: Improving profitability by reducing resource consumption and waste production.

Efficiency: Using fewer inputs to achieve an equal or better outcome.

Energy carrier: A substance or phenomenon that can be used to produce mechanical work, heat or light.

Grey water: Water that has been used by humans for washing (e.g. in basins, showers, baths and washing machines) but does not require processing by a water treatment facility before it can be used again for applications that do not require water to be potable.

Infrastructure: An interconnected network of physical artefacts and organizational structures that supply basic services to humans living in a built environment.

Infrastructure service: A beneficial service provided to humans by infrastructure, for example hydration and cleansing (from piped water), warmth and light (from the electricity grid), and hygiene (from sewage and solid waste management systems).

Lock-in effect: The limiting of infrastructural options due to the long lifespan of prior infrastructural investments.

Membrane bioreactor: A scalable technology for treating wastewater that combines a membrane filtration process with a suspended growth bioreactor containing organisms that digest organic waste.

Passive design: Approaches to the design of human environments that provide a comfortable living environment by maximizing the advantage of the natural features of a site to eliminate or reduce the need for electricity.

Pay-as-you-throw: A system of billing for waste collection services whereby service fees are based on the weight of landfill waste collected.

Rebound effect: The tendency for efficiency gains to encourage greater consumption of the saved resource, which cancels out some or all of the environmental benefit of the saving.

Rematerialization: Re-using resources once categorized as waste products as useful inputs to achieve an objective.

Resource flows: The movement of resources and products derived from them, from one point to another.

Rising block tariff: A tariff structure for infrastructure services whereby the first block of consumption is offered at a low rate or for free, with subsequent blocks costing progressively more.

Seasonal tariff: A tariff system whereby different rates are charged according to the time of year.

Smart meter: An electrical meter that records consumption of infrastructure services (e.g. water, electricity, gas) and communicates it with a central system.

Social inclusiveness: Incorporating the views of a broad range of interest groups in city decision-making – in particular those whose interests are typically sidelined by economic agendas – with the aim of reaching mutually beneficial solutions.

Strategic planning: A systematic decision-making process that prioritizes important issues and focuses on resolving them.

Substitution: Providing a human benefit in a fundamentally different manner to the current norm so as to manage resources in a more sustainable manner, possibly even eliminating the need for some inputs.

Urban agriculture: The growing of plants and the raising of animals within and around cities.

Urban metabolism: The consumption of resources and generation of wastes by an inhabited city, as likened to the metabolism of a living organism. Linear urban metabolisms refer to a direct flow from the extraction of resources from beyond the city, through to consumption within the city and the dumping of wastes beyond its boundaries. Instead of dumping wastes, circular metabolisms re-use them repeatedly within the city's boundaries to maximize the value derived from resources.

Whole-systems thinking: Developing creative solutions to human problems by considering the inter-connections between systems so that human and environmental problems can be addressed at the same time.

Contents

Solar hot water heaters on newly built apartment blocks in Hunchun, China
© UN-Habitat/Alessandro Scotti

Introduction

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Infrastructure has a critical role to play in the economic, social and environmental performance of cities. Its importance is evident in the significant funds that have been allocated to urban infrastructure investments in the financial "rescue packages" introduced since the 2008 financial crisis as a means of mitigating economic damage. It is estimated that a total of USD 41 trillion will be needed worldwide to restore old infrastructure systems in established cities and build new ones in rapidly growing cities between 2005 and 2030.[15]

The rationale behind extending infrastructural services to provide access to basic services is clear. However, resource-intensive approaches to achieving this are no longer appropriate as we approach planetary resource limits and pollution threatens the ability of ecosystems to provide goods and services.[16] A focus on how infrastructural services are delivered is required and, although many cities are already trying to reconcile social and environmental interests through their infrastructure investments, there is significant room for innovation in planning the sustainable cities of the future.

Section 2 of this Quick Guide starts with an overview of the challenge of ever-increasing resource consumption in the context of planetary limits, and proposes that cities can act as agents for change that allows their large populations to live less wastefully. It considers how infrastructure systems can be viewed as an opportunity to shift cities onto a more sustainable path by paying close attention to the resources that pass through them, and the manner in which they support the activities of the city. Emphasis is given to the need to treat each city context differently, based on its stage of development, pace of growth and the resources it has available.

Section 3 introduces two basic principles around which sustainable infrastructure can be designed: eco-efficiency and social inclusiveness. The three dimensions of eco-efficiency are explained and illustrated with the use of case studies from around the world, and the importance of social inclusiveness is highlighted as a means of ensuring that green interventions uplift marginalized groups rather than worsening inequality.

Section 4 introduces concepts that can inspire more eco-efficient approaches to the provision of infrastructural services and visions of what a sustainable city might look like. Section 5 highlights key considerations in the formation of a strategic plan for infrastructure that ensures social inclusiveness and encourages whole-system thinking.

Section 6 includes eight case studies that demonstrate examples of how infrastructure can be approached in a more sustainable manner than would otherwise have been the case:

- In Durban, South Africa, a new approach to the construction of landfills allows for greenhouse gases to be captured to generate renewable energy instead of contributing to global warming; for water to be recycled on site instead of fresh water being piped in and adding to wastewater burdens; and for the employment of poor people in the cultivation of indigenous trees to re-vegetate the site instead of destroying its biodiversity.

- In Linköping, Sweden, public buses are fuelled with biogas instead of diesel, significantly reducing air pollution, greenhouse gas emissions, landfill waste and vulnerability to oil price fluctuations, while providing bio-fertilizers to local farmers to improve their crop yields.

- In Lagos, Nigeria, a low-cost alternative to the public transport systems implemented in other countries was designed to make best use of existing city assets. It was set up in record time to address the city's crippling traffic congestion and improve mobility for the poor.

- In Lilongwe, Malawi, a community with inadequate access to water and sanitation developed their own alternative to waterborne sewage systems, allowing them to meet their sanitation needs affordably without needing expensive infrastructure to supply fresh water and carry away sewage.

- In Sofia, Bulgaria, poor households have been able to reduce the costs of heating their homes and reduce demand for electricity from polluting sources by improving the insulation of their apartments so that they retain more heat than they were originally designed to.

- In Curitiba, Brazil, poor people have been given incentives to collect waste and to recycle; items such as bus tickets and local food are offered in exchange for bags of waste brought to central depots. This allows for waste collection services to be extended to informal areas without requiring expensive and polluting waste collection vehicles, and promotes the use of public transport and healthy eating.

- In Portland, United States, an integrated Climate Action Plan (CAP) was formulated in collaboration with interest groups from government, the public sector and the community to reduce greenhouse gas emissions. The plan includes improvements to public transport, provision of paths for non-motorized transport routes, creation of marketplaces for trading locally-produced food, collection of recyclable and organic waste and generation of local renewable energy.

- In Singapore, a diverse group of stakeholders formed a comprehensive strategy to reduce reliance on water piped from Malaysia. This includes significant investments in the construction of additional reservoirs to retain rainwater, new water treatment plants to allow for water to be re-used, as well as enhanced efforts to repair leaks in the existing distribution system to reduce wastage.

While there are many more examples of the different ways in which infrastructure services can be delivered that allow for eco-efficiencies and social inclusiveness, those included here provide an insight into some of the options available from water and sanitation to energy and waste. The solutions have been developed to suit the realities of each context, and rather than demonstrating how cities "should" approach infrastructure, they can inspire the considered development of contextually relevant approaches in other cities.

Section 7 concludes with a summary of the key lessons from this guide.

Redesigned shelter at a bus stop in Uberlândia, Brazil, whose public transport network connects the central areas of the city with the outlying neighbourhoods along three main arteries
© UN-Habitat/Alessandro Scotti

Urban Resources and Infrastructure

2

2.1 Urban consumption is increasing, but natural limits are being exceeded

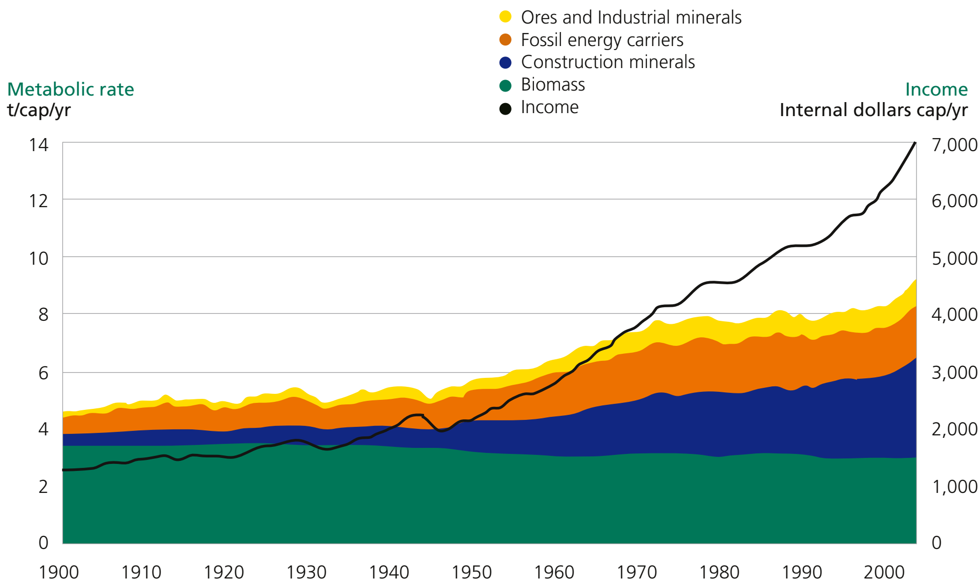
Cities are estimated to be responsible for the consumption of roughly 75 per cent of all natural resources and for the production of approximately 70 per cent of all CO2 emissions despite occupying only 3 per cent of the Earth's land surface.[17] In the second half of the twentieth century, a combination of natural growth of urban populations and urbanization (migration of rural populations to the city) has resulted in higher incomes for more people and an increasing demand for resources worldwide. As cities continue to attract investment and skilled workers, rising income levels, rather than population growth, are expected to be a more significant driver of economic growth.

Between 2010 and 2015, an additional 460 million people will enter the middle class in China, India, Russia, Indonesia, Brazil, Turkey, Mexico and South Africa.[18] By 2025, the number of households earning over USD 20,000 per year[i] in emerging economy cities will be 1.1 times greater than the number in developed region cities in the top 600.[19] Consumption driven by choice (for example, building swimming pools) as opposed to need (for example drinking water) is expected to increase substantially in these emerging markets as higher incomes raise demand for material possessions and modern lifestyles. It is estimated that India could potentially increase its aggregate urban consumption sixfold between 2005 and 2025, and consumption could increase more than sevenfold in China.[20]

As cities have grown, global resource consumption has increased faster than the global population and there has been a noticeable shift toward the consumption of non-renewable construction materials. Between 1900 and 2005, global material resource use increased by a factor of 8 - almost twice as fast as population growth.[21] Construction materials saw the most significant growth, increasing by a factor of 34, while industrial minerals and

i Households with incomes of USD 20,000 and above are commonly identified by companies as those with purchasing power beyond necessities.

Figure 2.1: **Global metabolic rates and income, 1900-2005.**



Source: UNEP (2011) Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme.

ores grew by a factor of 27. Fossil fuels grew by a factor of 12. Despite a fourfold increase in population over the period, biomass extraction only increased 3.6 times. Biomass's share of total material use has dropped significantly from three quarters to one third, indicating a significant shift away from renewable toward non-renewable resources over the past century (fig 2.1).

The rapid growth of cities will depend on significant increases in global resource extraction and consumption in the coming years. Under a "freeze and catch up" scenario, the world population will continue to grow but resource consumption per capita will stay roughly at 2000 levels in developed countries to allow developing countries to raise their consumption to the same levels by 2050. For developing countries, this will require increasing average metabolic rates by factors of 2 - 5, raising the global average to 16 tons per capita per year and tripling annual global resource extraction. By 2050, global resource extraction would be in the region of 140 billion tons annually. Average per capita carbon emissions would triple which, along with population growth, would result in a fourfold increase in total emissions to 28.8 GtC (gigatonnes of carbon) per year – higher than the worst climate change scenario envisaged by the Intergovernmental Panel on Climate Change (IPCC).[22]

The problem with the business-as-usual scenario is that it assumes an unlimited supply of goods and services to meet growing demand. It ignores the finite nature of many of the commodities on which growth depends, some of which have either reached the peak of their extraction potential or will do so in the foreseeable future (for example, oil). There are also limits to the Earth's carrying capacity or bio-capacity, which can be described as the ability of ecosystems to continue providing biotic resources like wood, fish and food, and its ability to absorb manmade wastes.

If current trends continue without major deviation, economic growth is likely to grind to a halt and then reverse dramatically within the next few decades. As scarce commodities come under pressure from growing demand, decreasing accessibility will lead to escalating prices (as has been evident in the years since 2003).[23] When it becomes more difficult to obtain natural resources, investment capital will need to shift from increased industrial output toward extracting resources from difficult to reach corners of the Earth. The industrial decline that will follow will damage the service and agricultural sectors, and the resulting shortage of food and health services will drive up death rates.[24] Increasing prices and competition for remaining resources will raise the possibility of conflicts, threatening to destabilize development and deepening inequalities between rich and poor.

2.2 Cities represent opportunities for more sustainable resource use

While the shift from rural to urban lifestyles has, in the past, been perceived as a "negative" phenomenon causing both social and environmental problems, cities are now being recognized as potential leaders in the response to global environmental challenges and climate change. The rapid decline in the Earth's natural resource stocks and pollution of natural ecosystems can be largely attributed to material- and energy-intensive economic activities typically found in cities, but their economic power, the clustering of expertise and their compact nature offers significant opportunities for re-shaping this consumption to be more compatible with planetary limits.[25,26,27,28,29,30,31,32,33]

Compact urban forms create opportunities for resource efficiencies by allowing for infrastructural services and amenities to be shared. Large populations make centralized infrastructure services, such as public transport, viable and the close proximity of different types of activity make it possible for people to live without private cars. Opportunities exist to realize synergies between the neighbouring activities that can allow for by-products to be re-circulated through the city, so that the value derived from resources can be maximized. Interactions between highly skilled individuals from diverse industries and backgrounds assist with the sharing of ideas and opportunities, and allow cities to act as incubators of innovation.[34]

The unprecedented construction of new cities in the developing world represents an ideal opportunity to pioneer new approaches to city development in pursuit of a better quality of life for more people using fewer resources than their predecessors. Given the anticipated impacts of environmental degradation, climate change and approaching resource limits on human wellbeing, the long-term viability of these cities will be determined by the extent to which they are able to learn from the mistakes of the past and break away from conventional resource-intensive modes of development to create new urban visions.

2.3 Infrastructure influences resource flows

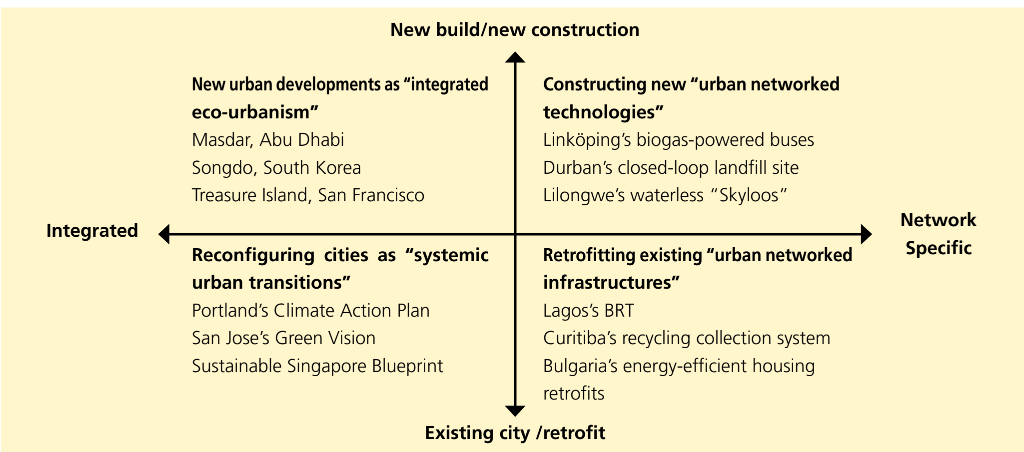
In the built environment of the city, humans rely on infrastructure systems to provide them with services like water, energy, sanitation and mobility. Infrastructure systems typically consist of manmade artefacts (power plants, dams, wires, pipes, roads etc.) and social arrangements (municipalities, utility companies, entrepreneurs, etc.) that interact in complex ways to ensure that people's needs are met, making it possible for life to continue in the city.

Infrastructure networks link city dwellers to the goods and services from nature that they rely on. These systems transform natural resources into a series of "flows" that allow for human needs to be met in the form of "infrastructural services". For example, oil is transformed into mobility services, coal is used for lighting and heating services, and water provides hydration and assists with sanitation. In addition to providing humans with access to beneficial inputs, infrastructural networks also channel away unwanted by-products in the form of wastes. From this perspective, the city can be compared to a living organism sustained by a "metabolism" of flows through its physical space.[35] Studying the patterns of matter and energy moving through cities is critical in finding solutions to improve them in a manner that allows for resources to be more sustainably managed.[36]

Technical infrastructure networks shape - and in turn are shaped by - socio-economic systems.[37] The manner in which they meet service needs has direct and indirect consequences for economic competitiveness, social inclusiveness, quality of life and the environmental impact of cities.[38] Policymakers who focus only on the direct and immediate benefits of infrastructure investments on the economy run the risk of making environmental trade-offs, but it is important to remember that cities can only support human life and economic activity if the ecosystems on which they depend for water, food and energy are functioning.

Infrastructural services can be delivered in a number of different ways, with different implications for resource use and environmental impact. Where new infrastructure investments are being made, it is important that the full range of options is considered and that space for innovation is allowed. Infrastructure typically has a long lifespan and, as a result, it commits cities to certain patterns of production and consumption for many years.[39] Once commitments have been made to an unsustainable form of infrastructure, like a coal-fired electricity network, the "lock-in effect" can prevent cities from implementing

Figure 2.2: **Four types of rebundled network ecologies.**



Source: Hodson, M. and Marvin, S. (2010). World Cities and Climate Change. Berkshire: Open University Press/McGraw-Hill more sustainable alternatives for decades. Rapidly growing cities that are yet to supply certain infrastructural services to their citizens have an opportunity to make choices that prevent them from getting locked into unsustainable methods, and allow them to gain competitive advantage over industrialized cities by ensuring that their investments promote sustainable resource use and do not harm the environment.

2.4 The uniqueness of each city requires customized solutions

While all humans share the same basic needs, each city faces different infrastructural challenges according to its context, pace of growth and level of development. Each city has a unique set of opportunities and obstacles to service delivery, which shape the options available. Developed cities may have more capital at their disposal for infrastructure investments, but the extent to which they are locked in to existing infrastructure networks may limit their options relative to a city that is growing rapidly and is yet to invest in infrastructure. Where rapidly growing cities may be focusing on investments in new infrastructure, established cities might better achieve resource savings by maintaining and improving existing networks, for example by fixing leaks in water pipes. City transitions toward more sustainable infrastructures can be broadly categorized into whether infrastructural systems are built from scratch or retrofitted, whether they focus on just one infrastructure type or an integrated network of infrastructural services, as demonstrated in fig 2.2.

In addition to leveraging the advantages of existing infrastructure (for example, using existing roads for bus rapid transport (BRT) systems instead of building new transport corridors, or re-opening abandoned mountain springs to supplement potable water instead of building new dams), cities need to take into account the natural and human resources they have at their disposal when deciding how to provide infrastructural services. Cities in areas where water is scarce (or is likely to become scarce in the foreseeable future) are not suited to providing sanitation services that rely on potable water; they need to be more innovative with the resources available so that they can provide the same infrastructural service level with less or no fresh water. This has been achieved in the development of waterless toilets in informal settlements on the outskirts of Lilongwe in Malawi. Similarly, cities with sizeable numbers of unemployed people and inaccessible road systems may wish to involve the poor in the collection of household waste as a means of creating jobs, as has been done in Curitiba in Brazil.

Depending on levels of informality, inequality and the resources and willpower to address these issues, aspirations as to the manner in which infrastructural services should be met require careful consideration. The growth of slum cities is transforming what is understood by the word "city"[40] to describe a unique set of urban dynamics and modalities in high density, low income areas that access some or all of their services via informal means. The "western city" is no longer the only legitimate template for defining the city and there is a growing need for non-western reference points for rethinking our deepest assumptions about the purpose, meaning and impact of the city.[41] The assumption that slums are only a "passing phase" while cities move from a primitive "pre-modern" urban form towards the "modern networked city" is no longer valid, and there is a strong need for innovative approaches to infrastructure that can connect the occupants of informal dwellings with services in a contextually relevant manner.

Main access road to the newly built "second link" bridge from Johor Bahru, Malaysia to Singapore
© UN-Habitat/Alessandro Scotti

Principles for more Sustainable Urban Infrastructure

3

If infrastructure is to be used as a means of breaking the negative relationship between city growth and sustainability, a new understanding of the role of infrastructure is required. Sustainable infrastructure has to meet the needs of the people it services without incurring environmental damage. Possibly, it even needs to move beyond this to achieve net environmental benefits by rehabilitating damaged natural environments.[42] However, in cities where there is limited access to basic services, the needs and voices of those who have no access to them cannot be ignored. Sustainable infrastructure therefore should reconcile environmental interests with human interests, particularly those of underprivileged groups. This can be captured in two central concepts: eco-efficiency and social inclusiveness.[43]

3.1. Eco-efficiency

The term "eco-efficiency" can be defined as the delivery of competitively priced goods and services to satisfy human needs and improve quality of life whilst reducing resource intensity and negative environmental impacts wherever possible. In short, deriving more value with less impact. It was coined by the World Business Council for Sustainable Development in the early 1990s as the business community's solution to sustainability. Eco-efficiency focuses on identifying and capitalizing on opportunities that improve profitability (i.e. economic benefit) by reducing resource consumption and waste production (i.e. ecological benefit).[44] It fosters innovation and competition by encouraging businesses to identify opportunities for environmental improvements that yield an economic benefit, and in the process improve value for consumers.

Applying the principles of eco-efficiency to the operation of cities allows citizens to derive greater benefit from their tax contributions and rates whilst reducing the amount of resources required and pollutants emitted.[45] It allows for quality of life, competitiveness and environmental sustainability to be maximized at the same time, and is of great relevance to governments making infrastructure investment decisions on a limited budget due to its economic logic and ability to attract private investment.

The rebound effect

Efficiency improvements may not always achieve net reductions in resource usage due to what is known as the "rebound effect". This describes the tendency for efficiency gains to encourage greater consumption of the saved resource, which cancels out the net environmental benefit.[46] The rebound effect can be particularly high in developing countries, where there is unmet demand. However, the "negatives of an overall increase in resource use in such contexts might be counter-balanced by social development "positives" that contribute to enhancing overall sustainability in a less resource-intensive manner than might otherwise have been the case.[47] (For example, savings from energy efficient appliances might be used to power additional lighting for studying at night).

Eco-efficiency encompasses the following three objectives:[48]

- Reducing consumption of resources
- Reducing environmental impact
- Increasing service value

3.1.1 Reducing consumption of resources

This includes a range of approaches to reduce the amount of inputs required to achieve a given output. It is primarily about improvements in resource productivity, which can be described as the amount of useful output acquired per unit of natural resource input. This can be achieved on multiple scales, from household appliances up to cities and city regions, depending on the scope considered. Improvements in resource productivity are often recommended as a "first step" towards sustainable resource use due to the financial benefits of deriving greater benefit from inputs. In the case of infrastructure, examples of this principle include repairing leaks in water distribution pipes to reduce non-revenue losses, replacing streetlights with energy efficient LED bulbs to save electricity, and using fuel-efficient buses for public transport to save on fossil fuels.

This principle also covers the recycling and re-use of resources so that they may be reincorporated into the system as inputs, thus reducing net requirements for new resources. The metabolism of typical modern cities can be described as "linear" in that they extract resources from beyond their boundaries, make use of them within the city and deposit the resulting solid wastes back into the external environment - often in dangerous concentrations.[49,50,51] By re-using wastes as inputs or "closing waste loops", cities can move towards a more "circular" urban metabolism. Wastes that might serve as valuable substitutes for new resources include packaging and other materials sent to landfill, solid and liquid wastes generated

Case study: Durban's closed-loop landfill site

The Mariannhill landfill site in Durban, South Africa, is an example of how the principles of waste re-use have been applied to a landfill site in order to save on resources and minimize the environmental impact of its operations. Liquid run-off is contained and "polished" onsite using natural reed beds for irrigation water and to settle dust, thus eliminating fresh water requirements. Methane gas released by the waste is captured and used as a fuel to generate renewable electricity, which the site sells on to the grid. Indigenous vegetation removed from the site is being cultivated at an onsite nursery that supplies plants to other municipal projects, and will ensure that ecosystems can be re-established when the landfill is closed. (Full case study in Section 6.)

by humans and animals, methane generated by decomposing organic matter, and waste heat from electricity generation and industrial processes.

Moving toward circular metabolisms is necessary if cities are to build their resilience to climate change and other external shocks.[52,53,54,55] By viewing waste, pollution and resource depletion as systemic inefficiencies to be avoided, cities can be re-arranged in pursuit of "zero waste" societies that make efficient use of all the resources at their disposal (including those once viewed as wastes). Where cities have traditionally expanded the boundaries of the hinterlands on which they depend for survival as a means of supporting growth, there is a growing trend towards re-localization and attempts to create self-supporting circular metabolisms in some of the world's leading cities.[56] Efforts to re-incorporate wastes into the economy instead of dumping them on the natural environment allow for them to circulate within the city for longer, delivering more value and reducing the total throughput of resources required.[57]

For an example of collaboration between industries to promote a circular metabolism, see the Kitakyushu case study in the "Clustering for Competitiveness" guide.

3.1.2 Reducing environmental impact

This refers to efforts to avoid or reduce pollution and emissions into the air, water and soil, as well as fostering the sustainable use of renewable resources so that they are not depleted. This can be applied to infrastructural services in the manner in which energy is generated (for example, using wind turbines instead of coal-fired power plants), a city's approach to solid waste management (for example, waste minimization instead of incineration), or the manner in which "green infrastructure" (for example, watersheds, forests and arable lands) is managed as a provider of valuable ecosystem services that alleviate some of the pressures placed on manmade infrastructure networks.

Case study: 100 per cent biogas-fuelled public transport in Linköping, Sweden

In the 1970s, the city of Linköping was suffering from air pollution as a result of emissions from its diesel-fuelled public buses. Methane-rich biogas was identified as a clean-burning substitute fuel that would save the city money by reducing the public transport system's dependence on expensive oil imports. The city's wastewater is combined with residues from local agricultural activities, meat processing industries and restaurants, and the methane this releases is captured and used to fuel its fleet of public buses. In addition to reducing air pollution, the process has cut the volume of waste sent for incineration in Linköping by around 3,400 tons annually, and the solid residues can be re-used as bio-fertilizer to allow nutrients to return to the soil in a useful form instead of being buried in toxic concentrations at a landfill. (Full case study in Section 6.)

3.1.3 Increasing service value

In some cases, there may be opportunities to provide more benefits to the end-user by adopting different approaches to infrastructure systems than those commonly imagined. Instead of limiting infrastructural solutions to a predefined set of outcomes, a holistic understanding of citizens' needs can open up opportunities for multiple benefits to be derived through a single investment. An example of this is using natural watercourses to manage storm water instead of constructing unsightly concrete channels, thus providing beautiful recreational spaces whilst purifying the water free of charge. Another example

Case study: A simple approach to Bus Rapid Transit in Lagos, Nigeria

Lagos is an example of a rapidly growing African megacity that has, until recently, been struggling to provide mobility services to its growing population. Rising incomes have resulted in the increasing ownership of private vehicles and the use of unregulated, privately-owned transport companies. Their addition to the inadequate and poorly maintained road network contributes to severe traffic congestion that raises commuting times, stress levels and air pollution. In 2006, the government formulated a Strategic Transport Master Plan aimed to address poor mobility in the city, especially for the poor. Instead of adding more roads, the existing road network was incorporated into the design of a Bus Rapid Transit (BRT)-Lite system. The first phase of this system was operational in just 15 months and cost significantly less than the overseas systems it was inspired by. In addition to providing a safer alternative to cars and poorly maintained private buses, average journey times have decreased substantially. Time spent waiting at bus stations has been reduced from around 45 to 10 minutes, reducing exposure to air pollution and lowering passengers' risk of contracting respiratory diseases. Instead of relying on a private transport model, the use of existing road infrastructure to provide an organized public transport system has provided value to residents in many forms, and has helped to make the city more liveable. (Full case study in Section 6.)

is providing shared public transport as an alternative to promoting cars through road infrastructure, thereby reducing commuter stress and encouraging social cohesion whilst saving time, fuel and money.

3.2. Social inclusiveness

Social inclusiveness requires that all city residents are treated equally in their access to employment and services like fresh water and mobility. The term "inclusive" is generally used to refer to the involvement of a broad range of people from across the city in decision making processes, with the aim of incorporating their contributions and reaching mutual agreement.[58] It is often assumed that poor people are not interested in environmental issues, yet their occupation of marginal lands in areas prone to flooding, pollution and illegal dumping means that their lives are directly affected by the city's poor environmental management. Sometimes, they have more at stake than wealthier members of society who are physically further away from these realities.[59]

Local governments struggling to cater for expanding demand for infrastructural services in growing cities often resort to outsourcing them through private-based models, which reinforces disparities in service quality and costs determined by the area they are serving.[60] The provision of niche services to those who can afford them results in barriers being erected to exclude those who cannot, with negative

Case study: Community-driven sanitation in informal settlements in Lilongwe, Malawi

A deficency in piped water and sanitation infrastructure within the Mtandire informal settlement outside Lilongwe, Malawi, posed a sanitation challenge to landlords wishing for an alternative to the space-intensive and groundwater-polluting pit latrines. Without infrastructure, waterborne sewage was not an option, so civil society groups worked with landlords and builders to develop a response which was contextually determined and responsive to householders' needs and aspirations. After some trial and error, the "Skyloo" was developed. Some of its many benefits are that water is not required, groundwater is no longer being polluted and waste can be easily and safely collected for re-use in agriculture. The development of this solution took time, but involving the community has ensured their buy-in, and the use of Skyloos is spreading without outside intervention because they are well suited to the needs of the context. (Full case study in Section 6.)

consequences for social inclusiveness, equality and sustainability.[61] Engaging with disadvantaged communities in forming infrastructure strategies allows for areas of common interest between city managers and the poor to be identified, and this can inspire social entrepreneurship and innovative solutions that are less costly to the city than those that may otherwise have been implemented by governments or development agencies.[62]

For an example of how innovative public transport can be used to include marginalized groups, see the Medellín cable car case study in the "Leveraging Density" guide.

An Energy park (solar panels, pumped-storage hydroelectricity) in Geeshacht, Schleswig-Holstein, Germany © Wikipedia/Quartl

Promoting Sustainability through Infrastructure Choices 4

The adoption of standard infrastructure "models" in rapidly modernizing cities around the world runs the risk of limiting creativity and sidelining more innovative opportunities for making cities more sustainable. With this in mind, this section will introduce the following key ideas that can assist in the formation of new visions for cities and infrastructure systems that support the sustainability principles described in Section 3:

- Passive design.
- Incentives for research conservation.
- Cascading resource use.
- Decentralization and semi-centralization.
- Food infrastructure.
- Whole-system thinking.

4.1 Passive design

Although buildings might not be considered a part of the infrastructure system, they represent the spaces in which most infrastructural services are accessed, so their design and operation has an impact on the resource efficiency of these services. Buildings provide shelters for people and their most important role is to keep out the elements and maintain indoor temperatures within a comfortable range. Nearly 60 per cent of the world's electricity is consumed in commercial and residential buildings, varying according to consumption patterns, climate and geographical location.[63] While many modern buildings use electric heating and cooling systems to moderate indoor temperatures, the incorporation of "passive design" principles into built environments can significantly reduce or even eliminate these energy demands.

Passive design aims to provide a comfortable living environment by maximizing the advantage of the natural features of a site (for example, sunlight and airflow) to eliminate or reduce the need for "active" space heating, cooling, ventilation or artificial lighting powered by electricity.[64] Passive design principles include facing windows towards the equator to harness the warmth of the sun, using insulation and materials with high thermal mass to retain heat or coolness when required, using courtyards and opening windows for cross-ventilation, and shading windows to block out the hot summer sun but to allow in the lower-angle winter rays.

In many cases, the planning and design of modern human settlements unwittingly ignore the advantages presented by the location, and in so doing commit residents to unnecessarily high energy bills. Passive design principles relevant to the local context can often be found in traditional approaches to the design and construction of buildings that were used before electricity became widely available. While the international green building movement embraces passive design principles and continues to augment them with new, high tech materials and automated products that make buildings even more energy efficient, the use of locally developed approaches to create passive buildings are by far the most cost effective solutions – particularly for the developing world.[65]

The application of passive design principles to new building projects can have a major impact on their future energy requirements, but it is also possible to retrofit existing buildings so that they require less electricity. The installation of ceiling, wall and floor insulation, double-glazing, roof lights, window coatings, opening windows and vents can be used to improve the thermal efficiency of existing buildings, and it is no surprise that the retrofitting of buildings for energy efficiency is becoming big business. A recent study estimates that the retrofitting of 40 per cent of the building stock in the United States by 2020 represents a USD 5 billion market that can generate 6.25 million jobs over 10 years.[66]

While passive design is most commonly applied at the building level, neighbouring structures in the city can rob a site of its natural benefits. For example, tall buildings can block out sun and wind, industrial activity can pollute the air, and streets running in certain directions make it difficult for buildings to orientate themselves toward the sun whilst maximizing available space. This has repercussions for city planning, zoning and height restrictions in the city, and should be considered when formulating or revising regulations.

Case study: Retrofitting apartments for energy efficiency in Sofia, Bulgaria

Bulgaria's "Demonstration Project for the Renovation of Multi-family Buildings" was started in 2007 to address the poor energy efficiency of apartment buildings constructed during the socialist era. Energy performance was on average 2.5 times worse than the recommended minimum standard, making it extremely costly for residents to heat their homes when state energy subsidies were withdrawn. Buildings in the project were selected on a needs basis for a package of energy efficiency upgrades, including the installation of insulation, replacement of doors and windows, sealing of air gaps and renovation of facades and public areas. Residents were brought together in homeowners' associations to contribute their time and labour, and a combination of loans and subsidies were offered to enable homeowners to repay the cost of the upgrades from the savings on their energy bills. By February 2011, 1,063 households in 27 multifamily buildings had been upgraded resulting in an estimated 8.5 megawatt hours of energy savings and reduced CO_2 emissions of 2.2 tons per annum. The project has created 219 jobs per annum, and has resulted in improved comfort levels, lower energy bills and greater community cohesion. (Full case study in Section 6.)

Suggested reading: Van Lengen, J. (2008). The Barefoot Architect – A handbook for Green Building. California: Shelter Publications;

Behling, S. & Behling, S. (2000) Solar Power - The evolution of sustainable architecture. New York: Prestel.

4.2 Incentives for resource conservation

Eco-efficiency should not be viewed as a supply-side intervention alone. Changing the behaviour of end-users in support of a more resource efficient city can be encouraged by economic measures that give them incentives them to consume more wisely. The environmental costs incurred in the provision of infrastructural services are often not adequately reflected by their costs, allowing the market to send the wrong signals to end-users.[67] If resources are to be conserved so that cities can operate within environmental limits, these signals need to be adjusted to reflect reality whilst allowing for basic human needs to be served.

With potable water and waterborne sewage services in water-scarce areas, water prices that are low or unrelated to the volumes consumed provide little incentive to save, and can result in an ever-escalating demand for more expensive sources of water as population and affluence levels rise. The following are ways to promote more prudent use of water.[68]

- **Metering** allows for water charges to reflect the volumes consumed, and encourages end-users to use less potable water. Regular, accurate and clear billing is a useful means of drawing attention to water consumption behaviour, and comparisons with the consumption of neighbours can harness the influence of social norms to reduce consumption[ii]. Pre-paid or post-paid metering can be adopted, and both can be executed in a manner that allows for a free basic water allowance for low-income households. "Smart" meters allow for data to be analysed remotely, whereas manually read "dumb" meters can be used as an opportunity to create jobs and spread information about water saving.

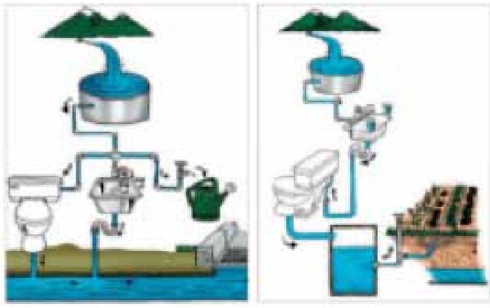
- **Differential tariffs** can be used to encourage users to keep potable water usage low ("rising block tariffs") or influence consumption behaviour at different times of the year to suit weather conditions ("seasonal tariffs"). Free basic water allowances, cross-subsidized by higher tariffs for larger consumers, can help the poor to meet their needs whilst ensuring that metering does not conflict with their human rights. Charging different rates for different grades of water can encourage the recycling of non-potable water as a replacement for potable water in irrigation, toilet flushing and industrial uses.

- **Regulations** that specify water efficiency standards (e.g. for taps, appliances or industries) or water consumption behaviour (e.g. irrigation or car washing) can be used to ensure that end-users consume potable water within a recommended range. In water scarce areas, this may require specifications on rainwater harvesting and grey water recycling in new buildings to minimize their impact on demand for water.

While water is a useful example of how to incentivise eco-efficiencies, the principle of incentivising appropriate behaviour can also be applied to the consumption of electricity, and to a certain extent to other infrastructural services. Smart electricity metering can allow for differential tariffs at

ii For example, U.S. energy company, Opower, achieved an average 2.75 per cent reduction in household energy use over 16 months by automatically sending personalized information on each household's energy consumption relative to their neighbours'.

Figure 4.1: **Cascading water use.**



Source: World Bank (2010) Suzuki et Al. Eco2Cities: Ecological Cities as Economic Cities. Washington D.C.: World Bank.

different times of day to shift some energy use to off-peak periods, reducing the need for additional supply capacity during peak. Combined with household generation of renewable energy, it can reduce energy bills or even earn households revenue from contributions to the grid. Similarly, the principle of measurement can be applied to solid waste management services, where "pay-as-you-throw" billing systems charge for waste collection according to the weight of waste to be sent to landfill, which encourages household separation of recyclables and organic waste.

4.3 Cascading resource use

Cascading resource use refers to matching different resource grades to specific end uses, thus reducing the need for resources to be in their highest quality form (for example, electricity or potable water).[69] Obtaining electricity and water that is pure enough to drink often comes with a sizeable environmental and resource impact, and yet many of the functions these resources perform could be met using lower grades of energy or water. Cascading resources from one use to another as the quality deteriorates allows for more utility to be

Figure 4.2: **Energy wastage incurred in the use of coal-fired electricity to meet infrastructural service needs**

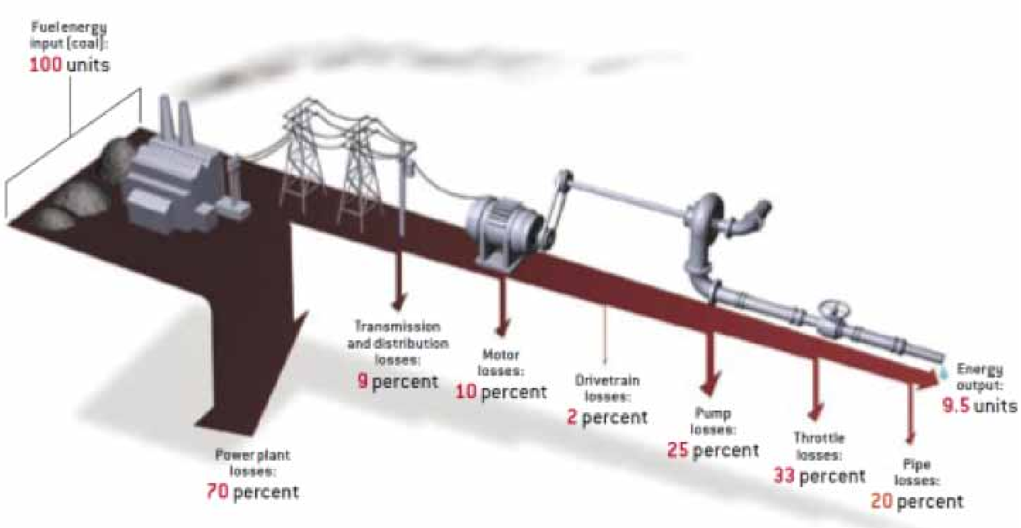


Illustration by Don Foley

derived from the same amount of resources, and saves on the costs of delivering highest-grade resources for all applications.

Perhaps the best example of this is the use of potable water for a range of functions from drinking, to cleaning, to irrigating and removing waste. By matching water quality to needs, a water system can be reconfigured to allow for more demands to be met with the same volume of water. Image 4.1 shows how a conventional system relying only on potable water on the left can be reconfigured to use partially soiled "grey water" from a hand basin or shower to flush a toilet, and the nutrient-rich "black water" from the toilet can, in turn, be used in sub-soil irrigation systems to grow crops. By eliminating the need for fresh water for toilet flushing and irrigation, this approach significantly reduces the demand for fresh water, whilst reducing the volumes of water sent to treatment works. If combined with rainwater harvesting from the hard surfaces of the city, there is also the potential to alleviate some of the burden on storm water systems.

The principle of cascading resource use can also be applied to energy. While electricity can provide a convenient, high-quality, versatile, controllable, clean-to-use and generally reliable source of energy, it is seldom the most energy efficient means of providing infrastructural services such as light and heat. The work potential or "exergy" of electricity is higher than most other energy carriers, and is typically generated by concentrating lower grade energies.[70] When electricity is generated by combusting fossil fuels, it is one of the highest emitters of greenhouse gases in the world and a significant contributor to environmental pollution. The process of generating, transmitting and converting electricity into useful services is also wasteful, and over 90 per cent of the original energy can be lost in the form of heat and light, as demonstrated in Figure 4.2.

The built environments of cities require three basic forms of energy: (1) electrical energy for lighting and appliances, (2) mechanical energy for motors and moving equipment, and (3) thermal energy for controlling temperatures. In many cases, electricity is used to serve all three functions, yet the conversion of lower energy sources to electricity and back to light, motion or heat incurs a high energy debt due to energy losses in conversion and distribution.[71] For low grade applications like light and heat, it is more energy efficient to make use of energy carriers other than alternating current (AC) electricity.

An energy mix that makes use of lower forms of energy and aligns them to the energy services required by end-users can help to reduce energy wastage with positive benefits for urban temperatures, climate change, pollution and resource depletion. Waste heat from electricity generation and other thermal processes can be used in domestic and industrial heating, drying, cooking and water heating applications, and even for cooling in warmer climates. "Cogeneration" refers to the production of electricity and heat at the same time, and combined heat and power (CHP) plants are becoming more popular in the colder parts of Europe, where the heat generated in the production of electricity can be piped to heat nearby buildings.[72]

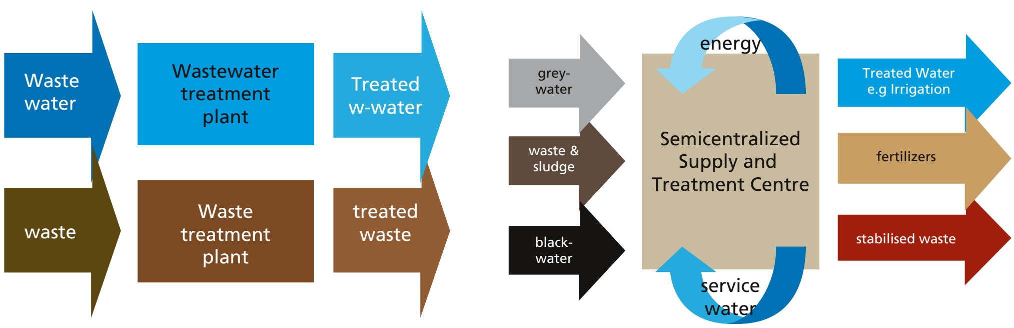
4.4 Decentralization and semi-centralization

For most of the twentieth century, new infrastructure facilities for the generation of electricity, processing of wastewater and management of solid waste were large in scale and located on the outskirts of human settlements where they were less of a nuisance to ratepayers. This centralized, supply-driven approach persists today, reliant on extensive service delivery networks of wires, pipes, vehicles and roads to connect these facilities to their end users. As indicated in Figure 4.2, inefficiencies in these networks can result in significant resource wastage, while ongoing maintenance expenses add significantly to the costs of operation. In addition, large centralized facilities that exceed the needs of their customers can incur disproportionately high maintenance costs if run below capacity, for example corrosion resulting from low flow velocities in water treatment works. For new infrastructural facilities to be eco-efficient, they need to be sized and located to match the service needs of consumers.

Justifying large centralized facilities on economies of scale alone runs the risk of overlooking larger dis-economies of scale, which raise the costs and financial risks of these investments (for example, the requirement for larger areas of land restricts site options to those further out of town, requiring a more extensive grid network). In the United States, recognition of these dis-economies has noticeably reversed the trend toward the construction of ever-larger central thermal power plants since the 1970s.[73] The economic advantages of better matching power generation capacity to customer needs have become apparent, and micro power generators, like solar cells, wind turbines and fuel cells, are being seen as less risky investments due to their relatively quick installation time and ability to respond swiftly to changing energy demand and disasters.

Recent technological advances, such as the generation of electricity from the sun and wind, and package water treatment plants using membrane bioreactors and other technologies, now allow cities to consider alternatives to centralized infrastructure facilities that do not cause offense or harm to neighbours, they deliver services tailored to local needs, require less substantial investments in distribution networks and facilitate cascading resource use. While fully decentralized household-level infrastructure services may be an option for wealthier homeowners, semi-centralized facilities at a district or neighbourhood level present a

Figure 4.3: **Comparison between conventional centralized infrastructure facilities for wastewater and solid waste (left), and a Semicentralized Supply and Treatment Centre (right) that combines infrastructural functions and generates multiple useful services**



Source: Schramm, S. (2011). Semicentralised water supply and treatment: options for the dynamic urban area of Hanoi, Vietnam. Journal of Environmental Assessment Policy and Management, 13 (2), 289. Illustration by Susanne Bieker.

middle ground approach that can be set up on smaller pockets of land within less time, making them suitable to rapidly growing urban areas that are not adequately serviced by infrastructure.[74]

Semi-centralized Supply and Treatment Centres (STCs) located within a neighbourhood are an example of semi-centralized infrastructure. As illustrated in figure 4.3, the centres manage and treat different types of waterborne waste flows separately and can supply reclaimed, or "service" water, for applications like irrigation, toilet flushing and street cleaning; can salvage nutrients for use as fertilizer; and can generate biogas from sewage sludge for generating electricity and heat.[75] The anaerobic digestion process used in the extraction of biogas stabilises the biodegradable fraction of the sludge, reducing the volume sent to landfill by as much as 60 per cent. By integrating various infrastructural services, semi-centralized STCs can be tailored to suit the unique needs of the local context, and allow for numerous economies from matching service demand to supply capacity.

Suggested reading: Gutterer, B., Sasse, L., Panzerbieter, T. and Reckerzügel, T. (2009). Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries: A Practical Guide. Water, Engineering and Development Centre, Loughborough University, United Kingdom, in association with Bremen Overseas Research and Development Association (BORDA), Germany.

4.5 Food infrastructure

Although food is not typically considered to be an infrastructural service, viewing the city as a life-supporting system that needs to provide food and deal with wastes opens up opportunities for synergies between infrastructural systems to support food production as a key function of the city. One of the oldest approaches to closing organic waste loops was to use solid and liquid organic wastes in the production of food in urban and peri-urban farms. Where these wastes once provided nutrients for agriculture, they are now typically either dumped in open land or water, or transported to landfills while food is imported from elsewhere. In many cities, the perpetuation of this approach has resulted in the twin problems of rising food prices and mounting wastes, which can either result in pollution or rising landfill costs when suitable sites fill up and garbage has to be transported to evermore distant locations.

To address these issues and move towards a more circular economy, cities can encourage the development of localized food systems that re-incorporate organic waste streams as inputs for urban agriculture (fertilizer, animal feed, irrigation). Urban agriculture can be loosely defined as the growing of plants (for food, materials and fuel) and the raising of animals within and around cities. It is different from rural agriculture because it is integrated into the urban economic and ecological system, employing the labour of city residents, using organic wastes for irrigation and fertilization, and becoming part of the urban food system.[76]

Incorporating food production into the functions of the city creates numerous opportunities for organic solid wastes and liquid wastes to be re-used, and this can be facilitated by decentralizing the treatment of solid waste and waste water. Solid wastes associated with food preparation, garden maintenance and certain manufacturing processes can be processed and composted to deliver nutrients to the soil and improve its water retention properties. In arid areas, a cascading approach to water management allows for lower grades of "waste" water to replace potable water for irrigation. Care needs to be taken to ensure that this water does not contain toxic chemicals and other contaminants, and that it does not pass on pathogens and vectors to humans. For example, plants grown for use as construction materials, fuel, fibre and so on, are better suited to irrigation with waste water than food crops are, but if food is to be grown then fruit from trees has a lower risk of pathogen contamination than leaf crops. Low cost approaches, such as the use of sunlight, time and intermediate plants or animals (for example, the use of waste water to grow algae to feed livestock) can also be taken to reduce risks.[77]

Case study: Portland's climate action plan, United States

As part of a comprehensive strategy to prepare for climate change, Portland has identified food and agriculture as one of eight key areas through which it can achieve its ambitious target of cutting carbon emissions by 80 per cent from 1990 levels by 2050. To reduce emissions generated by the transport and cold storage of food, the city actively promotes local food production and a culture of local consumption. It does this by supporting farmers in and around the city, providing land for farming activities, educating urban farmers and schoolchildren, and encouraging entrepreneurship via farmers' markets and community supported agriculture (CSA) schemes. Instead of dumping organic waste in centralized landfills, municipal facilities collect food scraps and compost them to provide a rich source of soil nutrients for urban gardens and farms. By replacing chemical fertilizers with compost, the costs of farming and emissions generated in the production of artificial fertilizers can be reduced whilst alleviating pressure on landfill sites. (Full case study in Section 6.)

In addition to promoting circular resource flows within the city, urban agriculture can help to make fresh food more affordable by reducing the need for chemical fertilizers and insecticides, and reducing the need for long-distance transport and cold storage of food. This can result in significant savings in fossil fuel consumption and reductions in greenhouse gas emissions. It also has the potential to make better use of parts of the city and its periphery that are under-utilized or considered unsuitable for building (rooftops and floodplains).[78] Urban agriculture can have positive effects on health, improve living environments and provide part-time employment opportunities for teenagers, the elderly and child-carers in low-income areas. As a low capital, high labour sector, the considered inclusion of farming and informal food trading into city planning (for example, by creating allotment gardens and market places) creates opportunities for entrepreneurship and stimulation of the local economy, while reducing dependence on imported food and improving resilience.

Suggested reading: Resource Centres on Urban Agriculture and Food Security (RUAF) website link: www.ruaf.org

4.6 Whole-system thinking

A "whole-systems thinking" approach to design entails "...a process through which the inter-connections between systems are actively considered, and solutions are sought that address multiple problems at the same time".[79] In the case of infrastructure, this involves consideration of the points of intersection between water, energy, waste and food systems as opportunities for achieving multiple benefits for people and the environment. A whole-systems approach is based on the understanding that humans and their built environments rely on functioning natural ecosystems for water, food and energy, and that damaging natural systems can have severe negative implications for the viability of cities.

The present configuration of cities, infrastructure systems and the policies and regulations that shape them run the risk of getting stuck in a particular way of thinking that is tied to industrial models of development. This can be characterized by unhindered exploitation of renewable and non-renewable resources - in particular a heavy reliance on fossil fuels for energy – that disregards the Earth's limits and is inherently unsustainable.[80] While presently available technologies may help to reduce the energy and resources consumed by cities, without expanding thinking beyond current sectoral paradigms to achieve whole system efficiencies, such interventions can only serve to prolong the status quo rather than challenging it.

Instead of approaching urban sustainability through engineering interventions with a limited focus that considers only immediate environmental impacts, a wider scope and timescale is required at the conceptual stage to ensure that projects are aligned to the healthy functioning of the whole system in the interests of current and future generations. Such vision is best achieved via collaborations within and between sectors to allow for the contribution of diverse perspectives[81] when creating visions to which engineering solutions can be aligned.

Suggested reading: Stasinopoulos, P., Smith, M.H., Hargroves, K. & Desha, C. (2008). Whole System Design: An Integrated Approach to Sustainable Engineering. Oxford: Earthscan.

Road access to the causeway linking Johor Bahru, Malaysia and Singapore
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Strategic Planning for more Sustainable Infrastructure

5

Cities contain a great deal of knowledge about how to construct and operate infrastructure systems, but the replication of resource-intensive and environmentally damaging approaches may cause unnecessary environmental damage and render a city unprepared for future crises. A strategic approach to infrastructure planning based on a strong vision of a sustainable future is required to ensure that all citizens benefit from infrastructure investments, and that the long-term interests of people and the natural environment are advanced once the city is locked into the resulting modes of operation.

The term "strategic planning" refers to a systematic decision-making process that prioritizes important issues and focuses on resolving them. It provides a general framework for action by identifying priorities, making wise choices and allocating resources (for example, time, money, skills) to achieve specified objectives.[82] All planning – spatial, economic, sectoral, environmental, or organizational – is more effective if it is strategic. Strategic planning has become an important tool for local governments to ensure efficiency and effectiveness in policy design and implementation, and it is useful for making sound infrastructure decisions in line with sustainability.

A strategic approach helps move away from ad-hoc and short-term decision-making towards better long-term decisions. Given that linear approaches to planning complex technical networks are becoming increasingly inappropriate,[83] the iterative process of strategic planning is well suited to infrastructure planning because it allows planners a degree of flexibility to respond to changing circumstances and needs over time.

5.1. Who should be involved?

Strategic planning ensures that the aspirations of different stakeholder groups are combined in a common vision that gets translated into objectives, which in turn provide criteria to select win-win solutions. Moreover, it ensures the right timing and maximizing of public-private cooperation and public participation. To start the process, a dedicated task team should be formed to ensure input from a diverse range of interest groups, including representatives of the following:[84]

- Public authorities involved in infrastructure development and operation (for example, suppliers, regulators, coordinators);
- Academics specializing in urban sustainability and infrastructure who can provide access to the latest local and international research;
- Consultants with expertise in infrastructure implementation and financing in the local context;
- Representatives from local and international non-governmental organizations whose work addresses local needs and challenges amongst marginalized groups; and
- Community organizations and unions who might play a role in mobilizing support for the shared vision amongst the public and workers.

Once the core group has been identified and the individuals concerned have expressed their commitment to the strategic planning process, specific roles and responsibilities should be assigned to ensure that everyone plays their part.

5.2 Where are we now?

Implementing sustainable infrastructural solutions requires a strong footing in the local context. International "best practices" are not guaranteed to work in all settings, and promising ideas can fail if they are not adapted to local realities.[85] Infrastructural decisions should be firmly grounded in an understanding of the challenges facing the city as a whole, and the opportunities presented by its location and the resources at its disposal.[86]

As a starting point, the city can be profiled to identify the needs of its inhabitants and the resources it has available to satisfy those needs. This process should look at:

5.2.1 Basic needs

In order to ensure that infrastructure promotes human dignity and social inclusiveness, it is important to understand the magnitude and location of the greatest need for access to basic services. The focus of this exercise should be on basic human needs, for example warmth, light, sanitation and mobility, and should not prescribe solutions like grid electricity, waterborne sewage systems or freeways at this stage. When calculating the magnitude of these needs, care should be taken to account for the possibility of average resource consumption levels diminishing as a result of improvements to the eco-efficiency of service delivery.

5.2.2 Local resources

To make the best use of the city's location, renewable natural resources, such as sunlight, wind, sources of fresh water and forests, should be identified and evaluated to build an understanding of the opportunities they present. In addition to new resources, this study should include solids, liquids and gases currently considered to be wastes so that opportunities for closing waste loops can be identified in the interests of a more circular urban metabolism.

5.2.3 Patterns of resource use

Measuring the resources used and wastes produced by a city is an important part of analysing eco-efficiency and, over time, these figures can be used to track its progress. Once this data has been collected, eco-efficiency can be calculated by relating resource usage back to human utility to calculate, for example, the number of passenger miles a public bus derives from a litre of fuel, or the number of hours of light a street lamp provides per watt of electricity. Similarly, eco-intensity can be used to relate the environmental burden of pollutants to the utility derived as a measure of the damage caused in the delivery of a product or service.

Within these measures, categorization of consumption and waste production according to sector or location allows for a more detailed picture of urban resource flows to be developed. This helps to identify areas where resource loops can be closed and wastage can be reduced to improve the performance of the system as a whole.

5.2.4 Existing technical infrastructure

The process of transitioning toward sustainable infrastructure is seldom a matter of switching from one technology to another, and cities may have several mutually compatible technologies in coexistence at any one time.[87] This means that there are numerous paths toward sustainable resource management through infrastructure, and optimal city solutions may require the incorporation of outdated technologies in their transition instead of abandoning them outright. It is thus important to start with a thorough understanding of existing facilities and networks, such as water treatment, transport and power systems, so that they can be used to maximum advantage. This study should take into account the remaining useful lifespan of operating facilities and networks, as well as redundant infrastructures that have the potential to be brought back into service.

5.2.5 The social organization of infrastructure

Mapping the social organization of infrastructure is important due to the socio-technical nature of infrastructural services. This area is likely to require new research due to the rapid changes in infrastructure management being brought about by new technologies, commercial pressures and institutional arrangements.[88] Conventional roles and actors are changing as new technologies allow consumers to get increasingly involved in how services are managed and accessed, and private companies take over responsibilities once held by government monopolies. Specialized, customized and privatized networks run the risk of entrenching inequalities within cities as barriers are erected to those unable to afford them,[89] and the impact this has had or is likely to have on social inclusiveness should be noted here.

Together, these analyses provide the basis for a deep understanding of the context. This process can be followed by an analysis of the city's strengths, weaknesses, opportunities and threats from an environmental, social, economic and institutional perspective to process the information gathered and identify areas for action.

5.3 Where do we want to go?

Engaging with diverse city stakeholders to build a shared vision of what they would like their city to be like in the future is an important starting point for strategically planning integrated infrastructure networks in line with whole system thinking. A vision statement describes the future state of the city, and includes the most important values and principles that will define it so that there is a common point of reference for all parties, regardless of their individual agendas.[90] The tension between this vision and the current situation helps to mobilize action to close the gap, and a period of about 20 years is typically allocated to achieving this.

The formulation of a vision should include a wide range of stakeholders to ensure support and ownership of their part in the process. To guard against visions being shaped purely by economic and social needs, it is important that stakeholders include individuals and groups willing to speak on behalf of the environment who can adequately explain sustainability concepts like those discussed in Sections 3 & 4 to other interest groups. To promote innovation, it is also worthwhile to include leading thinkers in the field of sustainable cities, who can provide inspirational case studies and visuals to stimulate creative thinking. Once the vision has been formulated, it should be shared widely to encourage buy-in from as many interest groups as possible.

Translating city visions into practical infrastructural interventions requires that vision statements be reconciled with the opportunities and challenges presented by the local context. These are, in turn, captured in the form of clear objectives.[91] For example, Linköping citizens' desire for cleaner air (the vision) was being restrained by pollution from the city's diesel public buses (the challenge), while its wastewater treatment plants and solid waste were emitting methane into the atmosphere (the opportunity). These challenges and opportunities were translated into the following objective: replace the diesel public bus fleet with buses powered by locally generated biogas.

Carefully worded objectives allow for the ambitions of the vision statement to be applied to decision making, and should be expressed in such a way as to assist with the comparison of actions and strategy options.[92] They should be designed to be used as a checklist for action that embodies the values brought to the fore in the visioning process, covering all the important factors identified to ensure that trade-offs are avoided.

Case study: Singapore: doing more with less

The island state of Singapore set up an Inter-Ministerial Committee on Sustainable Development in 2008 to craft a strategy that would ensure its sustainable development in light of domestic and international challenges. An inclusive participatory process involving representatives from government, the private sector, media and academia resulted in the formation of the Sustainable Singapore Blueprint document. This outlines a plan for economic growth in the context of resource constraints, and sets aggressive objectives to be met by 2030. These include improving energy efficiency levels by 35 per cent from 2005 levels, achieving a recycling rate of 70 per cent, improving accessibility for pedestrians and cyclists, and reducing domestic water consumption to 140 litres per person per day. Goals will be reviewed every five years and adapted to improvements in technology and international developments, and the government will monitor and inform the public of progress. (Full case study in Section 6.)

5.4 How do we get there?

Once objectives have been identified, they need to be translated into actions that can be combined into strategies. Using the objectives as a starting point, brainstorming and other tools can come up with a range of actions to address them. These actions must be compared to each other in a consistent manner to evaluate their potential consequences. During this process, it is helpful to categorize actions as common actions (those that all actors can play a part in), "low-hanging fruit", low-regret options (those that directly respond to large goals and may already be part of city strategies), win-wins that are more difficult to achieve, or high-return policies that come with trade-offs.[93]

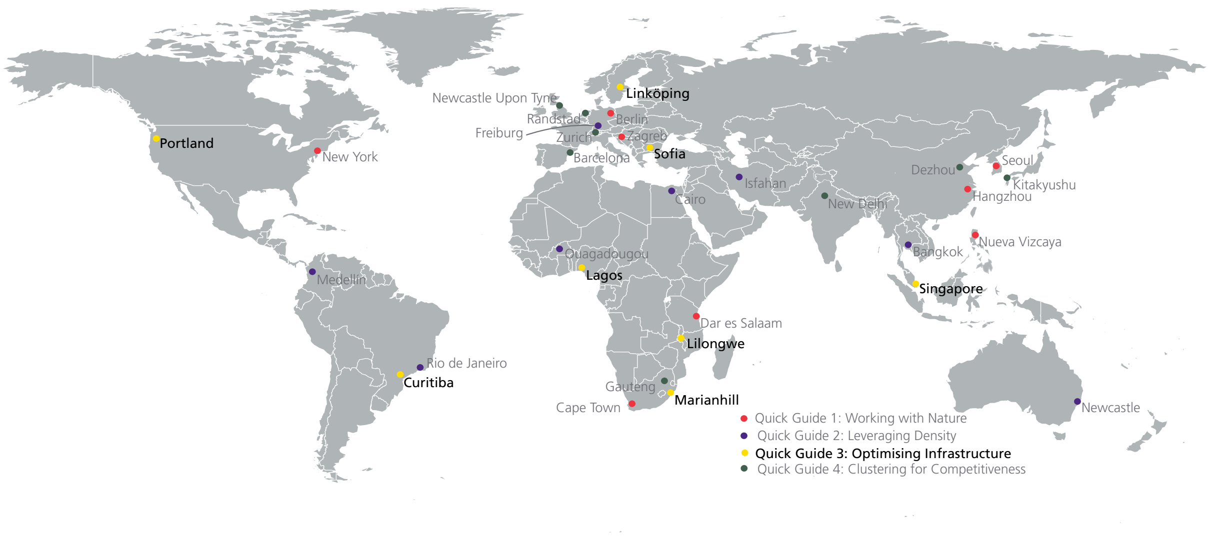
Prioritizing these actions according to the categories they fall into helps to ensure that early actions make best use of the resources and opportunities available. Strategies can now be formulated to tie a sequence of chosen actions together across multiple sectors and locations. Once the main opportunities have been identified, they can be "mainstreamed" into existing plans, programmes or policy initiatives.[94] This requires that stakeholders make connections between priority actions and initiatives they are involved in or aware of, and helps to avoid duplication of efforts.

Once strategies have been formulated, work can commence on implementing them. Poorly implemented plans result when there is a lack of political will, cooperation and organization, and where thinking is short term and reactionary rather than long term.[95] In moving from ideas to action, integrated planning and design teams made up of experts from different fields (engineers, ecologists, community representatives, urban designers, sustainability experts etc.) should be formed to promote trans-disciplinary, whole-system thinking. Institutions and individuals within these teams must be identified to take the lead, and a detailed document specifying what must be done by whom, how and when is required to ensure that all parties understand their role in achieving the city vision.

The social structures associated with providing infrastructure services are crucially important to ensuring that technical systems are able to meet sustainability objectives. Institutional and governance gaps identified during the social mapping process should be addressed, and in some cases new governance structures (e.g. feed-in tariff models to allow private companies to contribute renewable electricity to the grid supply) may be required to facilitate more sustainable outcomes.

Long-term plans require a degree of flexibility to cater for the rapidly changing reality of complex cities. A well designed monitoring and evaluation process will allow for a regular review of the vision, objectives and plans at least every five years. For example, Portland's Climate Action Plan is evaluated every three years and rewritten every ten. If adjustments are needed, new information, knowledge and innovations can be incorporated into development plans at this point to ensure that they remain relevant.

Suggested reading: Free training material on strategic planning for eco-efficient and socially inclusive infrastructure can be found at www.unescap.org/esd/environment/infra/ or www.eclac.cl/ecoeficiencia/default.asp?idioma=IN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Portland
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Case Studies

6

6.1 Durban's closed-loop landfill site

About 450 tons of waste arrives daily at the Mariannhill Landfill Site, located 20 kilometres from Durban, South Africa. Far from an ecological hazard, this clean development mechanism (CDM) project sets new standards for sustainable urban infrastructure by combining natural, robust and low-cost technologies.

When the Mariannhill community heard that the city wished to establish a landfill in their area, they set up a monitoring committee to ensure that it did not conflict with their interests.[96] By persistently raising their concerns about the ecological impact of the landfill, they applied pressure on the engineers at Durban Solid Waste (DSW) and the environmental department at the eThekwini Municipality to pursue a more sustainable design than would normally have been the case.[97] The engineers acknowledged the problems associated with conventional landfills and were open to trying new methods to prevent environmental degradation at the Mariannhill site.[98]

The project began with an Environmental Impact Assessment, making Mariannhill the first landfill in South Africa to undergo such a study.[99] It found a need to restore local ecosystem functioning, minimize the loss of biodiversity, and connect the site to other nature reserves to support natural migration patterns.[100] The Mariannhill landfill had to be designed to prevent environmental contamination and to restore damaged areas.[101] The key aims of the project were to collect and treat harmful landfill emissions using natural, robust and low-cost methods, and to rescue soil and indigenous vegetation removed during construction and store it in a nursery on site.[102] Other objectives were to help mitigate climate change by reducing greenhouse gas emissions, and to provide an income to the city through the sale of electricity and carbon credits generated from the captured methane.[103]

The design of the Mariannhill landfill thus included three core approaches:

- **The "naturalistic" containment, treatment and reuse of leachate**
  Conventional landfill design is

responsible for leachate, a liquid waste that can become toxic and contaminate land and water.[104] In collaboration with Enviros UK, Durban Solid Waste designed a treatment system whereby the cells of the Mariannhill landfill are lined with a geomembrane that prevents the escape of leachate. Above the lining, a layer of rock and sand allows leachate to drain off and be collected in a reservoir.[105] Here 30m^3 are treated by aeration and settlement daily, before being passed through a reed bed.[106,107] This "polished" leachate is reused for on-site irrigation and to settle landfill dust.[108] In addition, constructed wetlands help to remove toxic materials.[109] This closed-loop approach means that environmental contamination by toxic leachate is prevented, and the water and energy costs of piped council water are significantly reduced.

- **The capture of landfill gas for electricity generation**
  Traditional landfills are responsible for significant methane emissions from rotting organic waste. Methane is ten times as potent as carbon dioxide in its global warming effect, but this can be significantly reduced by burning it. The Mariannhill landfill turns this waste product into a resource by using it to generate between 450,000 kWh and 650,000 kWh of electricity per month.[110] The allows the site to generate approximately R200,000 (USD 24,500) per month from the sale of electricity at a power purchase tariff of between R0.24 (USD 0.03)/kWh (off-peak) and R0.36 (USD 0.04) /kWh (peak).[111] Income from the sale of Certified Emission Reductions (CERs) has not yet been received due to the lengthy CDM process, but about R40 million (USD 4.9 million) worth of CERs have been generated since 2007 by the 1MW Mariannhill and 6.5MW Bisasar Road plants together.[112,113] The Bisasar Road plant on its own has brought in more than R48 million (USD 5.88 million) since commissioning. The capital cost of the combined gas-to-electricity project has been approximately R130 million (USD 16 million), with operational costs of about R10 million (USD 1.2 million) per year.[114] These have been partly covered by a R58.74 million (USD 7.2 million) loan from the French Development Bank and a R17.7 million (USD 2.2 million) donation from the South African Department of Trade and Industry.[115] Subject to verification and the sale of CERs, the combined project is expected to break even in approximately five years.[116]

- **The protection and restoration of indigenous vegetation**
  The restoration of the original vegetation to closed cells and border areas of the site is another example of how the Mariannhill design surpasses that of conventional landfills.[117] Where existing vegetation is usually destroyed during construction, the Mariannhill design included an onsite nursery called the Plant Rescue Unit (PRUNIT), to save displaced indigenous plants. The unit now also provides low-cost rehabilitation to other closed dumps in the area.[118] The saving and propagation of indigenous vegetation supports local biodiversity and has also provided jobs for previously unemployed people. Further, the unit has saved the municipality more than R3 million (USD 370,000) on new plants.[119] It was the community's monitoring committee that convinced Durban Solid Waste to start a plant rescue process in 1998.[120] The committee also worked towards registering the site as a national conservancy, which was achieved in

2002 - a world first for an operational landfill.[121]

The Mariannhill Landfill Site is a significant contributor to urban sustainability. Dependence on fossil fuels and greenhouse gas emissions are reduced by the generation of electricity from landfill gas, the supply of indigenous plants by the on-site nursery, and the re-use of biologically cleaned water on site. Local biodiversity is protected by the restoration of indigenous vegetation, the removal of alien plants, and the creation of wetlands and migration corridors. Economic viability is improved by the sale of electricity and carbon credits as well as the cost savings associated with on-site landfill rehabilitation and reuse of water. The creation of employment, realization of skills development opportunities, and education programmes each contribute to social sustainability. A community centre and bird hide on the site are used to educate school children about sustainability, landfills, wetlands and the dangers of alien vegetation,[122] helping to spread sustainability messages to the surrounding community.

The Mariannhill Landfill Site is regularly evaluated for effectiveness. It is audited twice a year to retain its permit to operate, and the Conservancies Organization frequently assesses whether the site should retain its status as a conservancy. The gas-to-electricity project at the landfill is also audited annually to produce mandatory CDM Monitoring Reports.

The landmark nature of the Mariannhill Landfill Site brought with it significant obstacles along the way. Municipal bureaucracy and the obligations of the Municipal Finance Management Act (MFMA) impaired the design team's ability to find innovative solutions and required time-consuming reports.[123] The Act was a particular constraint on the development of the CDM project and on the sale of carbon credits.[124] The rate at which the World Bank's Prototype Carbon Fund agreed to buy the emission reductions was, in retrospect, too low to make the project financially sustainable, and the United Nation's CDM compliance process was also "exhausting".[125] South Africa's shortage of technical skills required to design and maintain landfills and gas-to-electricity plants also proved to be a challenge.[126]

Despite these obstacles and disappointments, a committed and enduring management team and a dedicated monitoring committee have meant that the Mariannhill Landfill Site has achieved its key aims.[127,128] The willingness of the municipal engineers to think outside the box and persevere despite the "red tape" have been vital to the project's success. Perhaps Mariannhill's greatest value is the model it has provided for other landfills to build on and other sites, such as the nearby Bisasar Road, are already improving on its successes in gas-to-electricity production.[129] From this case study, it is clear that managerial commitment and a community-driven demand for accountability can achieve infrastructure innovation in the interests of more sustainable urban resource flows.

6.2 100 per cent biogas-fuelled public transport in Linköping, Sweden

Sweden's interest in renewable fuels began after the 1970s oil crisis, which led to a massive hike in fuel prices. The country drew up plans for a natural gas pipeline that would run near Linköping, stimulating talk about the possibility of methane exports. Worsening urban air quality from vehicle emissions required swift intervention, and the development of gas as an alternative fuel for Linköping's public buses was identified as an opportunity to address rising costs and environmental issues simultaneously.[130]

Emissions from diesel buses were causing smog and soot to cover the city.[131] Leaders came together to discuss how to clean up the environment, while transforming the area and boosting the local economy.[132] The city opted for buses powered by natural gas, which could be supplied via the proposed pipeline.[133] However, plans for the pipeline later fell through due to financial concerns.[134] Still enamoured by the potential of gas, the city decided that the public transport system should run on locally-produced biogas.[135] The fuel is suitable for the city context as it can easily be collected from wastewater treatment plants and landfills. Also, it does not need extensive fuelling infrastructure, which means it can be introduced in stages, and it does not require as significant an investment.[136]

The main objective of the initiative was to reduce the pollution caused by public transport and provide a high quality environment for the citizens of Linköping.[137] Key aims were to develop an integrated system to turn waste into biogas, which would connect rural and urban areas and fuel city buses.[138] It was envisaged that over a number of years, the entire bus fleet would be replaced by bio-methane buses.[139]

In 1991, Tekniska Verken (TVAB), the municipal services provider, set up a pilot project of five buses powered by methane collected from the city's wastewater treatment plant.[140] Close collaboration between TVAB and Linköping University helped to speed up the development of biogas knowledge and production.[141] A project evaluation revealed that the wastewater treatment plant would be unable to provide sufficient methane to power the entire bus fleet. It concluded that a separate production plant should be built to control the input of feedstock and increase the output of biogas.[142]

The source of feedstock was then expanded to include waste from the local slaughterhouse owned by Scan-Farmek. The Federation of Swedish Farmers (LRF) also came on board to supply feedstock in the form of crop residues and manure.[143] The federation agreed to purchase the digested residue (a by-product of the methane manufacturing process) for use as a valuable fertilizer.[144] To solidify their co-operation, the three stakeholders started an associated company with shared ownership called Linköping Biogas AB (now Svensk Biogas) in 1995. The company received government funding to build a €140,000 (USD180,500) methane production facility, which was completed in 1996.[145] The plant can treat 100,000 tonnes of waste per year, and produces 4.7 million cubic metres of upgraded biogas per annum.[146] The newness of the biogas concept made it too risky for the city to shoulder the financial and intellectual burden alone, so additional funding and expertise came from the municipality of Linköping, the county, the regional bus authority LITA and TVAB.[147]

The overhaul of the city's public transport system began in earnest in 1997, when 27 buses were replaced.[148] In 2001, the sources of feedstock were again expanded to include waste from local restaurants. By 2002, all buses in the fleet were bio-methane driven and, in 2005, the world's first biogas train became operational in Linköping.[149]

The transition from a fossil-fuel driven public transport system to one powered by biogas has improved more than just air quality in the city.[150] Using biogas as a fuel results in minimal hazardous emissions and greenhouse gases.[151] The biogas from the plant replaces about 5.5 million litres of petrol and diesel each year, substantially decreasing the need to import fossil fuels.[152] Carbon dioxide emissions have been reduced by more than 9,000 tons per year

Biogas bus in the city of Linkoping, Sweden © Wikipedia/Mr3641

since 2002, lessening the city's contribution to global warming.[153]

The production of biogas turns waste products into a valuable resource and this reduces the need for environmentally-destructive landfills and waste incinerators, and creates circular rather than linear resource flows through the city.[154] Specifically, the project has cut the volume of waste sent for incineration in Linköping by 3,422 tons annually.[155] A by-product of the biogas process is biological fertilizer, which is purchased by the farmers' association to replace energy-intensive, fossil-fuel based fertilizers. As bio-fertilizers are made from a waste products, nutrients such as phosphorus are able to cycle through the economy, returning to nourish farmlands rather than accumulating in toxic concentrations at landfills.[156]

The project has also contributed positively to the city's economy. Including local farmers in the production of biogas and sale of bio-fertilizers has increased their competitiveness and kept financial flows within the local economy.[157]

It would not have been possible to implement such a novel project if it had not had strong political support.[158] Long-term co-operation between the city, the farmers' association, Linköping University, transit authorities, and other actors has arguably been the most significant factor contributing to the project's success.[159] Stakeholders were involved early on and were allowed to make important decisions and raise difficult questions, which encouraged their commitment.[160] This involvement was extensive enough to be thought of as co-design. Most of the people involved were from the region and were well-acquainted with Linköping's ecological, social and economic situation. Sufficient funds and a good measure of courage amongst decision-makers also helped the project come to fruition.[161]

Despite strong political and social support, the project faced several challenges. Biogas production in Linköping was not considered to be profitable enough, so the company decided to expand regionally and also to supply the private transport market.[162] The decision to expand was not unanimous, however, and Scan-Farmek and the Federation of Swedish Farmers sold their shares in the company to TVAB, which became the sole owner.[163] A focus on large-scale production plants meant that the opportunity to include small-scale biogas plants connected to a biogas grid was missed. This could have allowed greater coverage, reduced material handling costs and stimulated local economic development.[164] Although the project is a leading example of the ambitious use of renewable energy in the transport industry, infrastructure issues, vehicle limitations, and legislation continue to limit biogas development in the region.[165]

The transition to a biogas public transport system has improved air quality for the citizens of Linköping and has contributed to reducing the city's greenhouse gas emissions. Co-operation between the city and local industries has helped to identify linkages that allow for wastes to be re-used in the creation of biogas as a substitute for fossil fuels, decreasing volumes of waste sent to landfill and prolonging their lifespan. While this case study has focused on public transport, there are significant opportunities for the expansion of a biogas grid powered by city waste products and the inclusion of smaller-scale production plants to fuel a range of sustainable transport options.

6.3 A simple approach to Bus Rapid Transit in Lagos, Nigeria[166,167,168,169]

Lagos is the hub of business and economic development in Nigeria, and is the foremost manufacturing and port city in West Africa. From 305,000 inhabitants in 1950, Lagos's population has expanded to about 18 million. The phenomenal increase in population and economic growth of Lagos has resulted in the spatial integration of central Lagos with its surrounding settlements and those of the neighbouring Ogun state, aided by an expansive road network. Until recently, however, Lagos's transport system was struggling to meet the needs of its population, making it a challenge for residents to commute between home and work.

Before public transport, Lagos's 5,180 km of roads facilitated approximately six million passenger trips across the city daily, of which about 75 per cent were transported by the 100,000 passenger buses of different types operated by the private sector. Many of these vehicles were old and in a state of disrepair, and they seriously affected the surrounding environment. Rising incomes also led to greater ownership of private vehicles and the proliferation of motorcycles in the city. The existing road network was grossly inadequate, with insufficient tarred roads, a limited number of multi-lane arterial roads and generally poor maintenance. The typical journey for commuters from the main residential areas in the north and west of the city to Lagos Island, the largest commercial and central business district in Lagos could take more than two hours, resulting in time wastage and economic losses. The urban transport system was typified by congested roads and highways, high fuel consumption, polluted air from vehicle emissions and an unreliable and inconvenient public transport system.

In response to what had been, until then, insurmountable challenges to the transportation system, the Lagos state government developed a Strategic Transport Master Plan in 2006. This would address the multi-faceted problems with the transport system and provide Lagos with an efficient public transportation system within two decades. In line with this plan, a feasibility study for an initial Bus Rapid Transit (BRT) system corridor was commissioned in August 2006. The primary aim of the Lagos BRT was to provide more transport choices for all users, with a focus on meeting the mobility needs of the urban poor. Specifically,

Demarcation of carriageway on Ikorodu Road © Ibidun Adelekan 2011

Lagos BRT was developed to reduce traffic congestion and urban transport-induced emissions, while optimizing the use of the current road network. It also aimed to help the poor by reducing their household expenditure on public transport and time spent on the road.

The Bus Rapid Transit system, called "BRT-Lite" was implemented by the Lagos Metropolitan Transport Authority (LAMATA), modifying the BRT model by making use of a dedicated lane to prevent interference from other motorists. The BRT-Lite runs along a major commuting route from Mile 12 in the northern axis of the city through Ikorodu Road to Lagos Island, the largest commercial and business district in Lagos megacity. The design and implementation of BRT-Lite was prompted by study tours undertaken by key transport sector stakeholders to three Latin American countries in 2004 and 2006. These stakeholders included the transport authority officials and representatives of the Lagos state branch of the National Union of Road Transport Workers (NURTW) and Road Transport Employers' Association of Nigeria (RTEAN). They visited Brazil's IPPUC (Instituto de Pesquisa e Planejamento Urbano de Curitiba) in Curitiba, Colombia's Transmilenio BRT in Bogota and Chile's Transantiago. The tours were used to educate the team and build their support for a Nigerian BRT by exposing them to best practices in public transport.

The design of the 22 km of BRT lanes featured 65 per cent of them being physically demarcated by 400 mm high kerbs, 20 per cent separated by road markings from existing roads and 15 per cent mixing with other traffic. The advantage of this approach was that new road construction for the exclusive use of BRT buses was not required. The median of carriageways were narrowed instead to ensure that road widths remained, largely, unaltered. Huge savings on construction costs were therefore realized, and BRT-Lite was delivered at a total cost of USD 1.7 million per kilometre compared to an average of USD 6 million per km for the better known premium BRT systems. Supporting infrastructure consists of a 3.3 metre wide BRT lane, three terminals, two bus garages, 26 bus shelters, and ten 100KVA generators to

A BRT-Lite bus at CMS terminal, Lagos Island © Ibidun Adelekan 2011

provide backup power for street lights. The construction of infrastructure began in February 2007 and became operational in March 2008 despite a break in construction work for four months due to the laying of gas pipes in the city. The BRT-Lite took only 15 months to complete from conception to implementation, setting an example for swift implementation of public transport systems to other cities.

The financing of the scheme benefited from the provision of USD 100 million credit granted by the World Bank to LAMATA to implement the Lagos Urban Transport Project (LUTP). This was in addition to a USD 35 million contribution by the Lagos state government. The private sector also participated through the financing of rolling stock for 100 high capacity buses by Ecobank Plc.

The wide acceptance of the BRT scheme has been facilitated by involving different groups of stakeholders through community engagement programmes. These interactions have ensured that BRT-Lite is seen as a project created, owned and used by the people of Lagos. A sense of local ownership was developed that resulted in BRT-Lite being seen as a design for its users, rather than for bureaucrats. Third party advocacy was also employed whereby opinion leaders (local government chairmen, local chiefs and community leaders) were invited to discussions on the operation of BRT and its benefits for the people. This group of stakeholders went on to endorse the scheme in their local communities. A public education campaign on the BRT was also carried out, including advertising along the BRT route and in print and electronic media. Brochures explaining the new system were produced in different local languages and distributed to the general public at road-shows.

Key to stakeholder engagement and wider marketing was the engagement of National Union of Road Transport Workers and its members at the local level. This was achieved by encouraging the best drivers of large buses to retrain to become "pilots" of BRT buses. Care was taken to ensure that bus drivers who did not qualify to drive BRT buses would not feel threatened by the scheme,

Passengers at a bus station in Lagos © Ibidun Adelekan 2011

and the operation of their transportation services was restricted to service roads rather than being replaced by the BRT outright. This enabled passengers to choose between transport modes and also secured political and community support for the scheme. New regulations were implemented in 2007 to support BRT-Lite, prohibiting all vehicles except the BRT-Lite buses from using the designated infrastructure.

BRT-Lite operations have resulted in significant improvements in public transportation within Lagos metropolis, and have contributed positively to urban sustainability. It is estimated that BRT-Lite carries 25 per cent of all commuters along the 22 km route while accounting for just 4 per cent of vehicles. Ten per cent of trips to Lagos Island are now made using the BRT. A series of surveys conducted by Lagos Metropolitan Transport Authority (LAMATA) indicated that 195,000 passengers travel on the BRT-Lite on an average weekday. Within the first six months of the BRT's operation, its buses had carried a total of 29 million passengers.

The use of BRT buses has the potential to mitigate the environmental challenges associated with transport systems, especially by reducing fuel use and consequent emissions of carbon dioxide and other greenhouse gases typically emitted by private vehicles. The BRT system has contributed to reducing urban transport carbon dioxide emissions by 13 per cent. Average journey times have also reduced significantly, in some cases by more than 50 per cent. Furthermore, passenger waiting time at stations has been cut from 45 to 10 minutes, reducing their exposure to air pollution and lowering their risk of contracting respiratory diseases. The major limitation of the scheme is that it is not able to meet demand at peak periods due to limited capacity.

The successful performance of Lagos' BRT-Lite is the result of a holistic approach that has involved not only the provision of infrastructure, but also the re-organization of the bus industry, private sector financing of new bus purchases, and the creation of a new institutional structure and regulatory framework to support it. Strong political commitment on the part of the state government together with good leadership within LAMATA ensured that the blueprint developed for the system was followed, and that the project was implemented swiftly and at relatively low cost.

6.4 Community-driven sanitation in informal settlements in Lilongwe, Malawi

Rapid urbanization and associated growth in informal settlements has aggravated sanitation problems for the urban poor in Malawi. Estimates show that between 1987 and 2010, the urban populations in Blantyre, Lilongwe, Mzuzu and Zomba trebled.[170] Faced with limited options for affordable formal accommodation, the largely poor, urbanizing population best met their housing needs through informal dwellings. Consequently the "urbanization of poverty"[171] is associated with a mushrooming of informal settlements.

In Lilongwe, informal settlements expand and densify as poor landlords build rental dwellings on their plots to meet the growing demand for informal accommodation.[172] As part of the rental agreement, landlords provide sanitation services, usually by digging their own pit latrines. With an average of four or five dwellings per plot, a shared pit latrine fills up every three to four years. Given the problems with pit emptying in informal settlements, it is not uncommon for the full pit to be abandoned and left to decompose while a new pit is dug elsewhere on the site.[173]

Continued reliance on pit latrines incurs problems related to land-use competition, environmental contamination and sanitation-related health problems. The need to relocate latrines when pits become full means that densification is restricted by the need to reserve space for future pits.[174] This means a loss of rental income for impoverished landlords, and it limits the supply of low-income places to rent that are close to the city.

Covering and leaving full pits can lead to the contamination of groundwater, with serious health implications if groundwater is used for domestic purposes.[175] Observations suggest that this is the case in Lilongwe's informal settlements. A common strategy for people who cannot afford to purchase water from kiosks is to dig a shallow well on their plot to extract groundwater for household use.[176] Although people know that drinking water from wells near pits is making them ill with diarrhoea and dysentery, they continue to do it because they have few alternatives, and because "mostly it does not kill anyone".[177]

In 2003, a group of women's savings clubs in Mtandire (an informal settlement in Lilongwe) formed the Malawian Homeless Peoples' Federation (MHPF). The Centre for Community Organization and Development (CCODE) was established to support the federation in its goals related to upgrading services and shelters in informal settlements.[178] The CCODE and the MHPF are the Malawian affiliates of Slum/ Shack Dwellers International (SDI).

When the federation and centre were established, Mtandire's sanitation problems were visible and urgent. Since 2004, landlords have worked with CCODE and the federation to develop a response which is contextually determined and responsive to households' needs and aspirations. To do this, new approaches to sanitation needed to:

- provide a safe way to deal with human excreta on site
- be affordable and accessible to the poor

- eliminate the periodic need to dig another pit
- eliminate the periodic need to relocate the top structure
- be convenient and user friendly
- be acceptable and wanted by users
- support and improve on longstanding practices

The aim of the initiative was to devise a sanitation response that would resolve problems related to space scarcity in rapidly densifying informal settlements and health problems associated with pit latrines. The improvement of sanitation is regarded as a "process, not a project"[179] developed in situ and driven by those directly affected by inadequate sanitation. The approach is pragmatic because it tries to determine viable solutions through trial and error. The initiative came about via a process aimed at sanitation provision, so sanitation improvements are triggered by the process itself, not the organization.[180]

When the project began, government responses to sanitation in urban informal settlements were non-existent and aid agencies working on water and sanitation mostly focused on rural interventions. It is reported that government agencies were unwilling to service informal settlements because they feared it would stimulate further expansion of them.[181] In the absence of expert assistance, the Centre for Community Organization and Development used the internet to access information regarding design and construction of toilets and, over the past eight years, the federation and the centre have experimented to find a sanitation technology that is suited to the local context.

Front view of the ecosan toilet (raised structure on left) and adjoining shower (ground level on right). The ecosan toilet is raised above two composting chambers with access to the chambers at the rear of the structure © Lauren Tavener-Smith, September 2011

Inside the ecosan squat toilet, urine is diverted through a hole at the apex of the v-shaped gutter where it is soaked away or collected in jerry cans. The brick and bucket cover two holes for faeces, above two chambers. At any one time, one hole and chamber is in use, whilst the contents in the other chamber decompose © Lauren Tavener-Smith, September 2011

Initially, Forsa Alterna toilets were constructed but these proved unsuccessful due to functionality and aesthetic problems, which made them socially unacceptable. User problems with these toilets were taken seriously and triggered a revision of the approach. Experimentation with Skyloos began in 2008. Skyloos are urine-diverting dry toilets situated on top of above ground, dual-chamber vaults. Urine is diverted into soak-aways or jerry cans, for use as fertilizer. At any one time, one chamber is in use while the other chamber is sealed so that decomposition of the faecal matter can occur. It takes on average of six months for the chamber in use to fill up, which is approximately the period required for complete composting of the matter in the sealed chamber. By the time the human waste needs to be handled it is benign. Tests done by the Bunda College of Agriculture at the University of Malawi revealed that, after an additional two week waiting period, the manure was safe to use for growing food crops.[182]

The Skyloo is a form of ecological sanitation (ecosan): it allows for the safe management of human waste without burdening water resources and it facilitates the reclamation and re-use of sanitation by-products.[183] It is interesting to note that this ecological technology was chosen despite a lack of ecological motivations. As discussed above, the initial impetus for the initiative was demand from landlords, who recognized that their traditional sanitation response was no longer viable in an urbanizing and densifying world. The determinants of demand are evolving while the benefits of using the compost to grow crops for household consumption are becoming more apparent.

To amplify the natural trajectory of demand, federation members, who were the first adopters of the ecosan, organized mobilization task teams. Their function was to create awareness around the space saving, food security and health benefits of ecosan. Once demand has been catalysed, households that wish to adopt the ecosan work with other sanitation task teams to build the toilet.

In the absence of either state capital subsidies or donor funding (water and sanitation projects in Malawi usually target rural areas) it was critical to develop a funding mechanism. Through the Mchenga Fund, which is a revolving capital fund backed by federation savings and international donor finance, a Sanitation Loan is available to ecosan adopters. Households that adopt ecosan are responsible for covering the full cost of the toilets, which range from approximately USD 260 for the simpler version to USD 368 for the newest version with extra features (for example, outside hand washing basins). The principle and 12 per cent annual interest are payable over two years.

To date, there have been no formal evaluations to isolate and ascribe the impacts of the ecosan intervention. Although causation is difficult to infer without carefully designed evaluations, a number of positive impacts have been observed in parallel with the ecosan initiatives.[184]

- Demand for Skyloos has grown, based on the space saving benefits for landlords and potential gains in household food security[185] and the mobilization efforts of the Federation Sanitation Task Teams.

- Skyloos free up space for other land uses – instead of the 450 m^2 previously required, 180 m^2 is sufficient to accommodate up to five dwellings.

- Composted faeces and harvested urine are being used, albeit on a small scale, to successfully grow maize for household consumption, sharing and sale.

- Compost and urine have economic value at the household level - less as a source of income generation and more as an expenditure saving on fertilizer and or food. This in turn allows the households to take the risk of loan repayments on an ecosan investment.

- Less buried faecal matter is linked to reduced groundwater contamination and associated health problems.

Ecosan adopters in Mtandire, Lilongwe. Ecosan adopters are predominantly landlords who invest in the facility for their own use as well as for use by their tenants © Lauren Tavener-Smith, September 2011

Formal impact evaluations have less instrumental value to the initiative compared to process evaluation. The former are seen to divert scarce capacity, notably human resources, away from the initiative's primary objective of supporting a sanitation movement driven by the federation. Informal self-evaluation has been critical in the evolution of the response and is continually undertaken as the initiative develops. There is ongoing dialogue between users, builders, the CCODE and the federation sanitation task teams informing an iterative strategy of improving the design of the ecosan toilets.

According to CCODE activist, Siku Nkhoma, workable and acceptable sanitation is "achieved through a process not a project",[186] and building a social process around sanitation takes time. This time would not have been available with the target-driven approach practised by development agencies and governments, and this has been the most significant factor contributing to the success of the initiative. A patient process has allowed time for learning so that technology development and social embedding evolved simultaneously. People have watched and seen what makes sense to them, and Skyloos are self-replicating because of the process, not the organization.

The initiative was also able to take advantage of landlords' demands for new sanitation solutions in response to the problems they were experiencing and anticipating. The centre and the federation worked with and supported those who recognized the impending obsolescence of pit latrines but did not have access to the knowledge, technology or finance to change their circumstances.

CCODE has had to assume multiple roles in addition to their primary goal of mobilizing a social process around informal settlement upgrading. Additionally, the centre had to develop its own technical capacity and learn about ecosan from scratch before they could begin translating their new knowledge into local action. Without knowledge partners, the process of technology development was unnecessarily encumbered and, as a result, a number of substandard products were built during the early stages.[187]

The demand for Skyloos is now at a point where additional sources of capital finance are needed. If the scale of demand is to be taken seriously, a partnership with government is required. The social process established around sanitation will benefit the centre/ federation initiative during the initial engagement with government, where the heightened bargaining power of the poor will ensure that the terms of engagement are fair.

The implementation of ecosan technology as a solution to a human problem in Lilongwe shows how human needs can be met using practical, ecologically sensitive approaches. The centre and federation approach illustrates that the process of understanding what works for a specific context is critical in determining whether the technology will be accepted and demanded by users. Contextual learning has been critical to the success of project, and the ability to learn from mistakes has shaped this response into something that is beginning to self replicate.

6.5 Retrofitting apartments for energy efficiency in Sofia, Bulgaria

Following the transition from a socialist regime in Bulgaria, 97 per cent of the country's 3.7 million dwellings had become privately owned by 2007, and 65 per cent of these were multi-family buildings (residential apartment blocks). Mostly built on an industrial scale during the 1960-1980 period using prefabrication methods, many of these buildings are now in a very poor state of repair. In a typically non-participatory, post-communist culture, the buildings are often poorly managed by the owners and there is little local organization. The energy performance of these buildings is typically 2.5 times lower than the prescribed minimum national standard. Although Bulgaria has a relatively low residential energy consumption (23 per cent of total),[188] its energy intensity, as a function of Gross Domestic Product (GDP), is significantly higher than other transitioning economies in the region (132, 46 and 104 per cent higher than Poland, Romania and Hungary respectively in 2009).[189] Thus there is a pressing need in Bulgaria for energy efficiency programmes wherever possible, including the country's building stock. Previously in Bulgaria, the poor energy efficiency of residential buildings was off-set by cheap, subsidized energy from the state. However, in the new market-based economy, the escalating cost of heating for residents has provided the impetus for homeowners to start participating in schemes to retrofit their homes, which will improve energy efficiencies, the quality of private and shared living spaces.[190]

In 2007, the United Nations Development Program (UNDP) partnered with the Bulgarian Ministry of Regional Development and Public Works (MRDPW) and started a demonstration project called "Demonstration Project for the Renovation of Multifamily Buildings". Its objective was to develop a sustainable programme for the renovation of dilapidated, energy inefficient multi-family buildings.[191] The first step in the programme was to bring homeowners together via new, formal homeowners' associations, which became the representative bodies with whom the project leaders liaised and negotiated. Although residents had strong incentives to get involved in this scheme, the project team had to embark on an intensive multi-pronged campaign to engage homeowners and help them overcome their scepticism about working together to retrofit their homes and to convince them of their financial responsibility for the project. Public and one-on-one meetings, flyers and extensive use of the media have all been used to good effect.[192]

The three main components of the scheme are the provision of a subsidy, the provision of loans and the formation of homeowners' associations. The incentive for increased levels of organization and cooperation from residents is that the formation of full-membership homeowners' associations is a pre-requisite for funding and the start

Apartments at 6 Saglasie Str., bl. Poshtenetz 2, Burgas - before renovation

Apartments at 6 Saglasie Str., bl. Poshtenetz 2, Burgas - after renovation of work. The UNDP-MRDPW partnership provided funding for the project in the form of a 50 per cent subsidy for the homeowners and a 50 per cent loan to the homeowners. The loans are structured to enable homeowners to pay them off from the savings on their energy bills. Typically, a homeowner's portion is from €2,000 (USD 2,500) to €3,000 (USD 3,750) each.[193,194]

Target buildings are selected on a needs basis, taking into account the structure, age and energy characteristics of the building. Homeowners' associations that manage to get 100 per cent resident buy-in are selected on a first-come-first-served basis.[195] Following a technical scoping and tender phase, the following typical interventions are made:

- Installation of thermal and hydro insulation,
- Replacing of windows and doors,
- Treating of the external façade panel joints,
- Refurbishing of common areas for energy efficiency and safety, including repairs and renovation of the entrance areas and stairwells,
- Replacing plumbing systems,
- Upgrading of surrounding grounds and common areas ,
- Redecorating and repainting of buildings and stairwells, passages and hallways.[196]

All work is done by experienced contractors who are selected by tender to achieve high quality standards and, generally, residents do not participate practically in the renovation themselves.[197] Typical "before" and "after" examples showing striking transformations are shown on page 47.[198]

The broader outcomes of the renovations include improved health and living conditions, reduced cost of living for the beneficiaries, reduced greenhouse gas emissions, enhanced social capital and local community coherence via the homeowners' associations and the revitalization of shared living spaces.

By February 2011, 27 multi-family buildings (totalling 1,063 households) had been fully renovated. Work on a further 23 buildings is currently underway. The energy efficiency measures implemented to date have resulted in an estimated 8.5 megawatt hours of energy savings and 6,700 tons of averted CO_2 emissions. This equates to approximately 2.2 tons of avoided emissions per resident per annum (assuming 2.9 residents per household).[199,200] Given that the national average is 6.6 tons per capita (2008 figure),[201] and that approximately two million Bulgarians live in buildings in similar need of comprehensive retrofitting, this project, if rolled-out en masse, has the potential to significantly reduce total national emissions. The project has also created 219 jobs per annum.[202] In 2012, once all 50 buildings have been retrofitted, the demonstration project will end. However, based on the lessons learned, a much larger programme, co-funded with European Union Structural Funds, will be run over the coming years.[203,204]

The in situ, total upgrade model used in this demonstration project is considered to be better than other approaches because it requires participation and self-organization by the homeowners and encourages their active support for the project – financial and otherwise.[205] This has helped to make the project financially viable for the state, and has engendered a sense of ownership and shared endeavour amongst the beneficiaries. Importantly, the scheme does not allow for partial renovations; the total overhaul of each building (rather than piecemeal or partial upgrades) is likely to maximize knock-on benefits of community cohesion and encourage ongoing stewardship of the buildings by the homeowners. The project has also had a positive influence at a policy level. The learning outcomes from the demonstration project have been used by the Bulgarian Government to amend legislation to facilitate the formation of homeowners' associations for the purpose of energy retrofitting.[206]

A survey conducted in September 2010 found that 80 per cent of 240 households interviewed reported high or very high satisfaction with their participation in the programme; 96 per cent reported improved levels of comfort in their living spaces following the retrofitting; 99 per cent reported at least a 20 per cent drop in their monthly heating and hot water costs; 83 per cent reported improved attitudes towards their homeowners' associations; and over 75 per cent believe that the professional expertise in the process was necessary and useful.[207]

Although 60 per cent of respondents cited the availability of a subsidy as the highest motivating factor for their participation in the programme, the project administrators think that a large scale roll-out of this model is not viable if it relies on large grants for all beneficiaries. They have suggested the formation of a revolving fund that provides low-interest loans to enable a self-funding, long-term programme. They suggest that grants be available only for indigent households.[208]

This example of in situ multi-dwelling upgrades demonstrates how substantial reductions in domestic energy consumption and carbon emissions can be achieved using decentralized interventions. Numerous social benefits in the form of improved communal spaces, living conditions, community cohesion and social capital show that household level interventions in low income areas can improve lives while achieving broader sustainability objectives for the city. Larger-scale duplications of this model will require a conducive policy environment and an appropriate, sustainable funding model.

6.6 Incentivized recycling in Curitiba, Brazil [209,210,211,212,213,214,215]

The city of Curitiba in southern Brazil has become famous for its achievements in urban planning, and is often considered to be a model of urban sustainability for developing countries. Its long-term planning policy and well-known interventions in public transport and environmental protection have helped the city to achieve a high quality of life for its citizens at a relatively low cost, allowing it to grow sustainably.

Informative pamphlet for the "Garbage that is not Garbage" campaign © IPPUC Instituto de Pesquisa e Planejamento Urbano de Curitiba 2011

Some of Curitiba's most remarkable successes are its solid waste management and recycling programmes. Population growth rates of 5.34 per cent per annum during the 1970s, combined with changes in consumption patterns, resulted in a higher proportion of non-organic waste being generated than ever before and a much faster depletion of the city's landfill capacity. In response to this, Curitiba started the first recycling programme in Brazil's large cities in 1984, which turned out to be one of the most successful in the world and a leading example of a low cost but effective waste management programme.

A queue of recyclers receiving fresh produce as part of the Cambio verde programme © IPPUC Instituto de Pesquisa e Planejamento Urbano de Curitiba 2011

The recycling programme - loosely translated as "garbage that is not garbage" (lixo que não é lixo) - was based on encouraging home separation of garbage into organic and non-organic components. Recyclable waste was collected once a week by a private contractor and taken to a processing centre owned by the city. The facility employs homeless people and recovering alcoholics to sort the garbage into different types of materials that are sold on to recycling factories.

Extensive publicity and education campaigns encouraged residents to separate their garbage, with a strong focus on the role of children as change agents. Several communication campaigns specifically encouraged children to separate their waste at home, mainly through the city's elementary schools. A cartoon family known as the Leaves (Família Folhas) enacted common household scenarios in comics and plays, and the campaign was designed to be fun and child-friendly. Young students were very effective in disseminating ecological concepts to their families and making sure that their parents participated in domestic garbage separation. The city has since also included children in a water conservation programme, teaching them how to test water for pollution so that they may have a greater appreciation for it.

As in many cities in Latin America, shantytowns and squatter settlements in Curitiba form high-density settlements in vulnerable areas such as hillsides and flood plains. The uncontrolled dumping of garbage in these areas soon started to affect watercourses, resulting in flooding and the spread of disease. It is often difficult to extend conventional, mechanized methods of solid waste removal to these areas due to irregular alleyways and the interference of criminal elements. Formal waste collection in Curitiba also faced resistance from autonomous garbage and recycling collectors whose livelihoods were threatened by municipal collections.

In response to these challenges, the city created the "Garbage Purchase" programme. This encouraged neighbourhood associations to get involved in the management of centralized garbage containers on the periphery of areas that are difficult for collection trucks to access. Residents' associations work with the city government to distribute bags and control

A Brazilian family collecting a wheelbarrow of fresh produce from a Cambio Verde truck © IPPUC Instituto de Pesquisa e Planejamento Urbano de Curitiba 2011

the recyclables collected by each family. As an incentive for the public to get involved, every bag filled with 8 to 10 kg of waste could be exchanged for a bus ticket. The value of these tickets was equivalent to the cost of conventional garbage collection, but did not involve any direct expense by the city because bus operator companies are remunerated based on mileage and not passenger numbers.

Following initial success, an undesirable side effect of this approach became apparent when informal collectors started to encroach on areas serviced by formal collections. Formal collection soon became unprofitable because the domestic waste was removed before the trucks had a chance to collect it. Also, the informal collectors' carts started causing traffic problems as they made their way around the city without adhering to the rules of the road or safety protocols.

After a cholera outbreak in Brazil in 1991, the consumption of vegetables dropped sharply and there was a surplus of agricultural products in the city's green belt. To capitalize on this opportunity, a programme called "Green Exchange" (Câmbio Verde) was started to ensure that this food did not go to waste. The city now buys food items from regional producers at a reasonably low price and distributes it to recycling collectors at a number of distribution points around the city. Initial tests were a great success and the Green Exchange has now become a permanent programme in Curitiba with over 80 distribution points around the city. Currently, every four kilograms of recyclable materials can be traded for one kilogram of locally cultivated, seasonal produce, improving access to healthy food for the poor whilst tidying up the city.

The waste management programmes established in Curitiba have helped to promote a better quality of life for people living in shantytown communities and small agro-producers. In addition to improved garbage collection in areas that are difficult to access by road, the poor have benefited from improved diets and small local farmers have benefited from more stable demand for their agricultural produce. The city's recycling initiatives have extended the life of its landfill by diverting 2,400 m³ of recyclables each day – which represents around 25 per cent of daily production of garbage. In 2010, the regular collection of recyclables by trucks amounted to around 21,800 tons, and the Green Exchange programme a little more than 2,500 tons. The largest part of the recyclables collection – 190,000 tons - was carried out by informal collectors. Part of the revenue from the recyclables is used to maintain the collection process and for research, but most of it goes to Instituto Pro Cidadania de Curitiba, a non-governmental organization that operates the city processing centre and promotes citizenship.

Curitiba's approach to recycling shows how the poor can be integrated into the delivery of infrastructural services, and they can be given incentives other than money to improve their living conditions. Instead of seeing underused buses and excess agricultural produce as problems, the city identified them as opportunities to deliver value to the poor at minimal cost to local government, while building social inclusiveness and facilitating a more circular economy for the whole city.

6.7 Portland's Climate Action Plan, United States (US)[iii]

In 1993, Portland (in Oregon State) was the first US local government to institute policy around anticipated global warming. Multnomah County – of which the city is a part – joined this initiative in 2001, and the culmination of these policies was an integrated, city-based plan to prepare the region for potential climate change impacts called the Climate Action Plan (CAP). The primary goal of the plan is to reduce the carbon emissions of the county and city by 80 per cent from 1990 levels by the year 2050.[216]

Perceived threats to the region include changes in weather and rainfall patterns that could affect stream flow leading to flooding and low groundwater recharge resulting in drought.[217] Specific threats include those to power supplies, food and water sources, public safety and health as well as local economic decline due to the rising cost of fuel and continued degradation to the natural resource base in and around the city. An additional "threat", due to its relatively cooler Pacific Northwest location, is that the region might become a favoured destination for climate refugees.

Recognizing that climate change, deepening social inequities, degraded environmental systems and rising energy prices are related challenges, CAP sets out a range of

Hawthorne bridge © City of Portland Bureau of Planning and Sustainability

iii All information in this case study, unless otherwise indicated, has been drawn from the Portland Climate Action Plan 2009: CAP (2009) City of Portland and Multnomah County Climate Action Plan. Available: http://www.portlandonline.com/bps/index.cfm?a=268612&c=49989. [Accessed August 2011.

Bicycle Bridge © City of Portland Bureau of Planning and Sustainability

interlinked objectives to address the inherent complexities. By reducing and redirecting existing resource flows (energy, waste and food) through the city and county, they hope to increase both the resilience and adaptability of the region to climate change as well as radically reduce carbon emissions. The first status report on the progress made by the Climate Action Plan was released in December 2010.

The plan's initiative is the result of collaborations amongst county and city governance structures, members of the public, businesses, academic institutions and non-profit organizations. It aims to achieve its ambitious emission reduction goal through eight core areas of action: buildings and energy; urban form and mobility; consumption and solid waste; urban forestry and natural systems; food and agriculture; community engagement; climate change preparation; and local government operations. The plan is a holistic one that integrates economic, environmental and social imperatives; it is also iterative in that there are built-in opportunities to review, revise and change the focus.

When the plan started, coordinated carbon emission reduction efforts at the regional and state level were already in place and a cap-and-trade system for the larger region had recently been introduced (Western Climate Initiative). Portland, through sound land-use management and previous investment in public transport infrastructure, had already managed to reduce emissions close to 2000 levels.[218] The supportive environment was further enhanced by the state and local policy environment, existing transit and bicycle infrastructure, a tax credit system to encourage alternative energy consumption and production, progressive land-use and building codes which encouraged development geared towards "green" transit options, and the creation of dense, mixed-use buildings.[219]

Portland's economic vision revolves around the harnessing of the potential that the green economy offers the city[220] and the city aims to position itself as a leading centre for sustainability in the United States. It was already home to a significant concentration of renewable energy firms as well as strong recycling, green building and environmental services sectors.[221] Human resources include a growing supply of experienced workers for the clean technologies industry (84 per cent higher than in similar-sized regions for renewable energy), and environmental services and recycling.[222] The 2009 Portland Economic Plan closely aligns with the Climate Action Plan to ensure that growth and investment is guided along lines of carbon emission reduction; introduction of renewable energies and alternative water technologies; and pursuing opportunities for local manufacturers to fill supply chain gaps and replace imported components for the clean tech industry.[223]

Portland has therefore significant knowledge resources to draw upon, including academic resources from local universities, but

Salmon fountain © City of Portland Bureau of Planning and Sustainability

sourcing finance for investment purposes remains a challenge,[224] particularly in the current economic climate.

Portland's emission reduction target is broken down into specific objectives that have measurable action points attached to them. An interim goal of a 40 per cent reduction of emissions by 2030 has been set with annual reports on progress. The plan will be evaluated every three years and rewritten every ten. The 2010 annual status report indicates that carbon emissions decreased by 15 per cent between 2000 and 2010, resulting in emission levels that were 1 per cent below 1990 levels,[225] despite a 24 per cent increase in population over that period.[226]

CAP focuses on reducing emissions through a combination of high and low-tech initiatives. These include the implementation of policy restrictions around building materials in order to reduce emissions, investments in public transportation and the encouragement of bicycle use. Over 24 km of bicycle friendly streets have been built and "20-minute neighbourhoods" have been promoted to enable residents to meet all of their non-work needs by walking or cycling as opposed to driving. A 2010 assessment found a 10-15 per cent reduction in single passenger vehicle trips and a 2.6 per cent increase in the use of public transportation in the space of a year.[227]

To lower the carbon-intensive nature of the food system, and to improve the vibrancy of the local economy and the health of citizens, there is a focus on increasing local food production and consumption. This is done though supporting urban farming, demonstration gardens and unemployed youth training schemes, including food issues in the school curriculum and encouraging farmer's markets and community-supported agriculture schemes (CSA). In 2010, in addition to the existing 32 community gardens, 150 new ones were opened, along with a CSA farm and a further 75 gardens in partnership agreements.[228] There is a dedicated Food Policy Council in place and information about local food – both growing and purchasing it – is readily available on the city's website.

The plan also recognizes solid waste as a resource flow that can be radically minimized through increased recycling efforts and by encouraging residents to be aware of how much waste they generate. A food-scrap collection programme that transforms food waste into compost has been launched at municipal composting facilities, and this, in turn, is used to enrich the soil in urban farms and gardens. Standards for household and business recycling collection are currently being developed. By 2010, the city had decreased total wastage by 8 per cent from 2008 figures.[229]

There has been substantial investment in renewable solar power energy options for homes, neighbourhoods and businesses with up-front financing provided for both purchasing and installation,[230] and incentives for conversion to less carbon-intensive energy sources and reduction of energy usage in homes (more than 3,000 homes in 2010 alone). The city has installed five megawatts of solar energy and is in the process of doubling its renewable energy capacity through investments in wind power, which currently supplies just over 4 per cent of power to the region. Hydroelectric sources supply close on 50 per cent of the region's power, and the balance is supplied by coal (37 per cent), natural gas (12 per cent) and nuclear (4 per cent). A 279 kilowatt solar electric system has been installed on city premises, and overall reductions in energy consumption have allowed for an approximate 19 per cent savings on the city's annual energy bill of USD 18 million.[231]

The city is in the process of formally assessing the region's vulnerability to climate change so that it can anticipate and manage risks, which will increase its adaptability and resilience. One of the challenges is a lack of standardized quantitative measuring tools available for aspects such as the absence of waste and carbon emissions from the production, transportation, use and disposal of goods. Funding is also limited - in particular for transport infrastructure currently funded by the tax on fuel - and some of the action items have uncertain funding from 2013 making long-term planning difficult.

The emphasis on strong policy action, extensive public-private partnerships, as well as active community participation has been pivotal to Portland's success. Instead of being prescriptive, policymaking focuses on creating an enabling environment for a range of interventions, while partnerships have resulted in collaborations around a range of issues. Public participation has been strongly encouraged through campaigns, and information about the initiative is easily accessible. In addition to the climate change and resilience benefits of the Climate Action Plan, the citizens of Portland have received greater service value through improved infrastructure and easy access to renewable energy sources. They have also been able to realize direct cost savings from the city's reduced reliance on oil and other improvements in resource efficiency.

6.8 Singapore: doing more with less

The island-state of Singapore has undergone one of the fastest transitions from a developing economy to a leading first world economy in history. It has one of the highest per capita incomes in Asia and its population is steadily increasing to close on five million people.[232] However, Singapore has finite land space, limited water resources and a growing population dependent on imported energy, food and water; and all of this in the face of climate change challenges.

The country is dependent on global trade for access to the resources that it needs for economic growth, and the rising cost of resources such as oil, energy, raw materials

Marina Barrage, Singapore River, Singapore
© PUB, Singapore's national water agency, 2008

and water will increasingly put pressure on Singapore's ability to maintain its economic growth. Currently, Singapore imports most of its food and water as well as the resources and raw materials needed for industry, including construction materials and oil.[233] In addition, it is vulnerable to climate change impacts such as flooding, loss of coastal land and impacts on fresh water resources.[234] The city has acknowledged the importance of securing access to resources, conserving energy and reducing water use; in other words, doing more with less to decouple the future growth of the city from increased resource use.

In 2009, Singapore released the Sustainable Singapore Blueprint document, which outlined a plan that would allow for economic growth within the limitations posed by resource scarcity and rising resource prices. The strategy rests on four primary principles: improved resource efficiency, improved environmental quality, increased knowledge about sustainable development, and community ownership.[235] Aggressive goals have been set in all four areas to be met by 2030, including improving energy efficiency by 35 per cent from 2005 levels, achieving a recycling rate of 70 per cent, improving accessibility for pedestrians and cyclists, and reducing domestic water consumption to 140 litres per person per day.[236]

Aligning economic growth with environmental sustainability has meant the acceptance of certain operating principles that have come to be known as the "Singapore Way". These include recognizing the importance of integrating and aligning planning; taking a long-view of development although it entails short-term costs; and adopting a flexible approach, recognizing that there will be many changes in technology and the global environment in the coming decades.[237]

NEWater Visitor Centre, Koh Sek Lim Road, Singapore © PUB, Singapore's national water agency, 2009

In 2008, an Inter-Ministerial Committee on Sustainable Development was set up to craft a strategy to ensure Singapore's sustainable development in light of domestic and international challenges. The result was the Sustainable Singapore Blueprint document that was jointly created by government, public and the private sector. It was an inclusive and participatory process that had input from media editors and academia.[238] Goals will be reviewed every five years and adapted to improvements in technology and international developments, and the government will monitor and inform the public of progress.[239]

SGD 1 billion (USD 0.8 billion) was set aside by government as a budget to roll-out the initiative and since 2009 additional investments have been allocated, in particular for improving energy efficiency in buildings, improving public transportation and for testing solar technology and applications.[240] Almost SGD 700 million (USD 558 million) of the initial funding was set aside for research and development and manpower training, with large allocations for implementing and incentivising the Green Mark efficiency system for buildings and the installation of solar panels. Testing for the viability of electric vehicles was conducted in 2010 and part of the budget was set aside to build cycling networks.[241] It is estimated that the investment of SGD 680 million (USD 542 million) to build capability in the energy and water technology sectors could contribute a value-add of SGD 3.4 billion (USD $2.7 billion) to these industries and generate employment of close to 20,000 people by 2015.[242]

One of Singapore's biggest success stories is its water resource management. Water sustainability and security is vital for Singapore as there is no groundwater and the land area is not sufficient for collecting and storing water to meet its requirements.[243] Although it has historically low water consumption levels in comparison to other first world countries, when its two water agreements with Malaysia end in 2011 and 2061, the price that it pays for water could increase radically, making it difficult for government to ensure affordable and adequate supplies.[244] The interim goal of the Sustainable Singapore Blueprint initiative is to reduce domestic water usage from 154 litres per person per day (2009 figures) to 147 litres by 2020, and 140 litres by 2030.[245]

Storm water collection infrastructure is integrated into public green space
© UN Habitat/Andrew Rudd

Over the past four decades, the government has invested considerably in research and technology for water conservation, and in implementing the first stage of a deep tunnel sewerage system to redirect wastewater flows towards water reclamation plants.[246] The current water supply is drawn from four sources, known as the "Four National Taps": the local reservoir catchment, imported water, NEWater and desalinated water.[247] NEWater refers to the collection, treatment and purification of used water using advanced technologies, rendering it even purer than World Heath Organization standards and perfectly safe to drink.[248] It is estimated that at the end of 2011, once the fifth plant has been completed, NEWater will meet 30 per cent of the nation's needs.[249] Singapore currently has one of largest desalination plants in Asia, using reverse-osmosis to transform seawater into drinkable water. In 2010, this plant was supplying 136,000 cubic metres of fresh water per day, providing roughly 10 per cent of Singapore's water needs.[250]

In efforts to reduce the amount of water used and wasted, lessen the country's dependence on imported water and prevent water wastage through leaks, a series of projects has been launched to clean up the Singapore River, increase the number of reservoirs, fix leaks in the water distribution system and encourage the public to reduce their water usage.[251] These water conservation programmes include a 10 per cent Challenge and 10-Litre Challenge to citizens, schools and businesses to use water responsibly and to save it.[252] A Watermark Award is given annually to individuals and organizations that have significantly contributed to the "water cause"; those who raise awareness around water issues in Singapore are recognized in the Friends of Water Programme, and an Our Waters initiative encourages schools to adopt water bodies and look after them.

In 2010, the number of leaks per 100 km in potable water pipelines had been reduced by 1.2 per cent, and the number of sewerage disruptions per 1,000km of sewer lines reduced by 6 per cent from 2007 levels. During the same period, the number of reservoirs increased from 14 to 17, sales of NEWater increased from 49.2 to 96.4 million cubic metres, and sales of industrial water (non-potable, reused water) decreased by five million cubic metres.[253] Progress towards the goal of 140 litres per person per day in 2030 is ongoing as consumption has decreased from an average of 165 litres per person in 2003 to 157 litres in 2007, and 154 litres in 2010. The Singapore Government has said that the country can be self-sufficient in water by 2061 when the water agreements with Malaysia run out.[256]

The very clear vision presented by the Singapore Government following extensive public and private sector participation, combined with strong commitment to action, has been vital for the success observed so far in this initiative. The focus on integrated planning at all levels and the inclusion of the public in education and awareness campaigns has also been extremely important. Citizens of the country have benefited through cost savings of energy- and water-efficient appliances following the mandatory labelling campaigns, as well as through being able to enjoy the cleaner city; lifestyle events held at reservoirs and waterways increased from 74 in 2007 to 288 in 2010 signifying the increased value and appreciation that Singapore's citizens place on its water.[257]

Water infrastructure in Singapore © UN-Habitat/Andrew Rudd

Conclusion

7

Current resource consumption patterns cannot continue for much longer in a world where human populations are growing in numbers and affluence. City infrastructural systems represent an opportunity to change the relationships between an increasingly urbanized population and the resources from outside the city on which they depend. Each city requires unique solutions tailored to its context and circumstances, but the principles of eco-efficiency and social inclusiveness are crucial to all sustainable infrastructure plans.

The eco-efficiency of infrastructural systems can be improved in the following three ways:

- **Reducing consumption of resources** (e.g. fixing water leaks, improving energy and water efficiency, closing waste loops by using solid and liquid wastes as resources);

- **Reducing environmental impact** (e.g. using "clean" energy instead of fossil fuels to reduce pollution and emissions, minimizing waste dumped in nature, protecting functioning ecosystems);

- **Increasing service value** (e.g. providing public transport as an alternative to cars to reduce the costs, time and stress associated with commuting, and build social cohesion).

While eco-efficiency deals with ecological and economic aspects of sustainability, building social inclusiveness is important to ensure that the environment and economy are not favoured over the needs of the poor. It is important that economically disadvantaged groups are included in city decision making, particularly where their lives stand to be affected. Collaborating with them to identify ways to connect them with services can generate innovative, cost effective alternatives to conventional approaches that are contextually appropriate.

Where conventional approaches to the delivery of infrastructural services are limited in their ability to improve eco-efficiency and social inclusiveness, the following concepts are useful as a means of visualizing how cities as a whole might achieve these goals:

- **Passive design:** The design of built environments to maximize the natural benefits of the site (e.g. sunlight and prevailing winds) so as to minimize the need to use electricity for climate control.

- **Incentives for resource conservation:** Charging consumers according to how much they use of a resource (e.g. water or electricity), and instituting effeciency regulations to discourage excessive consumption.

- **Cascading resource use:** Gaining multiple uses out of a resource such as water, by using different grades for different applications instead of using the highest quality for all uses.

- **Decentralisation and semi-centralization:** Shifting from large, centralized infrastructure facilities toward smaller home or neighbourhood level alternatives to meet local needs.

- **Food infrastructure:** Using organic wastes as a source of nutrients in the production of food in urban gardens and farms, and providing infrastructure to support urban farming and food trading.

- **Whole-system thinking:** Considering the interconnections between infrastructural systems to identify opportunities for city-wide resource efficiencies

To break away from the inertia of current infrastructural approaches, a strategic planning process involving a diverse range of experts and city stakeholders is required. Starting with a thorough assessment of the current situation and its challenges, a vision of the ideal future city needs to be captured and agreed upon as a goal towards which all parties are aligned. This vision needs to be translated into clear infrastructure-related objectives, from which actions can be identified and ordered into strategies for implementation. Over time, these strategies will need to be reviewed and updated at regular intervals to keep pace with changing realities and innovation.

Endnotes

1 Angel, S. et al. (2011). *Making Room for a Planet of Cities*. Lincoln Institute of Land Policy, Cambridge.

2 Seto, K. et al. (2011). *A Meta-Analysis of Global Urban Land Expansion.* PLoS ONE.

3 Boston Consulting Group (2010). Winning in Emerging Market Cities: A Guide to the World's Largest Growth Opportunity. BCG, USA. p. 5.

4 United Nations. (2010). *2009 Revision of World Urbanisation Prospects.* New York: United Nations Population Division.

5 UN-Habitat (2011). *State of the World Cities Report 2010/2011*, Bridging the rural divide. Nairobi: UN-Habitat, Nairobi.

6 UN-Habitat. (2008). *State of the World's Cities 2008/2009:* Harmonious Cities. London: Earthscan.

7 Graham, S. and Marvin, S. (2001). *Splintering urbanism:* Networked infrastructures, technological mobilities and the urban condition. United Kingdom: Routledge.

8 Angel, S., Sheppard, S. and Civco, D. (2005). The *Dynamics of Global Urban Expansion*. Transport and Urban Development Department, Washington D.C.:World Bank

9 Angel, S., Sheppard, S. and Civco, D. (2005). The Dynamics of Global Urban Expansion. Transport and Urban Development Department, Washington D.C.:World Bank.

10 Bringezu, S. (2002). Construction ecology and metabolism – rematerialisation and dematerialisation. In Kibert, C., Sendzimir, J. and Guy, G. (eds.). Construction ecology: nature as the basis for green buildings. London: Routledge, pp. 196-219.

11 WWF, Zoological Society of London and Global Footprint Network (2008). *Living Planet* Report 2008. WWF: Switzerland.

12 Reid, W. V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah,A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, M.B. (2005). *Millennium ecosystem assessment synthesis report. United States: Island Press.*

13 SERI Global and Friends of the Earth Europe (2009). *Over consumption? Our use of the World's Natural Resources.* Vienna/Brussels: SERI Global.

14 Amin, A. (2011). Urban planning in an uncertain world. In Bridge, G. and Watson, S. (eds.). The New Blackwell Companion to the City London: Blackwell Publishing Ltd.

15 Doshi, V., Schulman, G. and Gabaldon, D. (2007). Light! Water! Motion! Strategy and Business, 47. pp. 39-53.

16 Reid, W. V., H. A. Mooney, A. Cropper, D. Capistrano, S. R. Carpenter, K. Chopra, P. Dasgupta, T. Dietz, A. K. Duraiappah, R. Hassan, R. Kasperson, R. Leemans, R. M. May, A. J. McMichael, P. Pingali, C. Samper, R. Scholes, R. T. Watson, A. H. Zakri, Z. Shidong, N. J. Ash, E. Bennett, P. Kumar, M. J. Lee, C.

Raudsepp-Hearne, H. Simons, J. Thonell, and M. B. Zurek. (2005). Millennium ecosystem assessment synthesis report. United States: Island Press.

17 United Nations. (2011). *Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure*. Thailand: Clung Wicha Press. p. 15.*inclusive infrastructure*. Thailand: Clung Wicha Press. p. 15.

18 Boston Consulting Group. (2010). *Winning in Emerging Market Cities:* A Guide to the World's Largest Growth Opportunity. United States: USA. p. 13.

19 McKinsey Global Institute. (2011). Urban world: mapping the economic power of cities. McKinsey & Company.

20 McKinsey Global Institute. (2011). Urban world: mapping the economic power of cities. McKinsey & Company.

21 UNEP. (2011). Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme, p. 10.

22 UNEP. (2011). Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme. pp. 28-29.

23 SERI Global and Friends of the Earth Europe. (2009). Overconsumption? Our use of the World's Natural ResourcesVienna/Brussels: SERI Global.

24 Meadows, D., Randers, J. and Meadows, D. (2004). Limits to Growth: The 30-Year Update – A Synopsis. United States: Chelsea Green.

25 Rees, W. and Wackernagel, M. (1996). Urban ecological footprints: why cities cannot be sustainable – and why they are a key to sustainability. *Environmental Impact Assessment Review,* 16. pp.223-248.

26 Ravetz, J. (2000). City Region 2020: *Integrated Planning for a Sustainable Environment*. London: Earthscan.

27 Birkeland, J. (2002). Design for sustainability. A sourcebook of integrated eco-logical solutions. London: Earthscan.

28 Girardet, H. (2004). Cities People Planet – liveable cities for a sustainable world. United Kingdom: Wiley Academy.

29 Costa, A., Marchettini, N. and Facchini, A. (2004). Developing the urban metabolism approach into a new urban metabolic model. In Marchettini, N., Brebbia, C., Tiezzi, E. and Wadhwa, C. The Sustainable City III. United Kingond: WIT Press.

30 Wackernagel, M., Kitzes, J., Moran, D., Goldfinger, S. and Thomas, M. (2006). The ecological footprint of cities and regions: comparing resource availability with resource demand. *Environment & Urbanisation*, 18(1). pp. 103-112.

31 Hodson, M. and Marvin, S. (2009). "Urban *ecological security": a new urban paradigm? International Journal of Urban and Regional Research*, 33(1). pp.193-215.

32 Wuppertal Institute (2009). *Sustainable Urban Infrastructure: Munich Edition – paths toward a carbon-free future*. Munich: Siemens AG.

33 UNEP. (2011). Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. United Nations Environment Programme.

34 Rode, P., Burdett, R. and Soares Gonçalves, J.C. (2011). Buildings: investing in energy and resource efficiency. In *Towards a Green Economy – Pathways to Sustainable Development and Poverty Eradication*. United Nations Environment Programme.

35 Ravetz, J. (2000). City Region 2020: *Integrated Planning for a Sustainable Environment.* London: Earthscan.

36 Costa, A., Marchettini, N. and Facchini, A. (2004). Developing the urban metabolism approach into a new urban metabolic model. In Marchettini, N., Brebbia, C., Tiezzi, E. and Wadhwa, C. *The Sustainable City III*. United Kingdom: WIT Press. p 32.

37 Guy, S., Marvin, S. & Moss, T. (2001). *Urban Networks, Buildings, Plans - Infrastructure in Transition.* London: Earthscan.

38 United Nations (2011). *Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure.* Thailand: Clung Wicha Press.

39 United Nations (2011). *Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure*. Thailand: Clung Wicha Press.

40 Pieterse, E. (2008). *City Futures*. Cape Town: Juta.

41 Swilling, M., Khan, F. and Simone, A. (2003). "My Soul I Can See": The limits of governing African cities in a context of globalisation and complexity. In P. McCarney and R. Stren (eds.). *Governance on the Ground: Innovations and discontinuities in cities of the developing world.* Baltimore and Washington D.C.: Woodrow Wilson Centre Press and Johns Hopkins University Press.

42 Birkeland, J. (2008). *Positive development* – from vicious circles to virtuous cycles through built environment design. London: Earthscan.

43 United Nations (2011). *Are we building competitive and liveable cities? Guidelines* for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

44 WBCSD. (2000). *Eco-efficiency – creating more value with less impact*. Switzerland: World Business Council for Sustainable Development.

45 United Nations. (2011). *Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure.* Thailand: Clung Wicha Press.

46 Von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. & Stasinopoulos, P. (2009). Factor Five: Transforming the global economy through 80% improvements in resource productivity. London: Earthscan. p. 277.

47 Roy, J. (2000). The rebound effect: some empirical evidence from India. *Energy Policy*, 28 pp.433-438.

48 World Business Council for Sustainable Development. (2000). *Eco-efficiency – creating more value with less impact*. Switzerland: WBCSD.

49 Costa, A., Marchettini, N. and Facchini, A. (2004). Developing the urban metabolism approach into a new urban metabolic model. In Marchettini, N., Brebbia, C., Tiezzi, E. and Wadhwa, C. *The Sustainable City III*. United Kingdom: WIT Press.

50 Girardet, H. (2004). *Cities People Planet – liveable cities for a sustainable world*. United Kingdom: Wiley Academy.

51 Ravetz, J. (2000). City Region 2020: *Integrated Planning for a Sustainable Environment*. London: Earthscan.

52 Ravetz, J. (2000). City Region 2020: Integrated Planning for a Sustainable Environment. London: Earthscan.

53 Girardet, H. (2004). Cities People Planet – liveable cities for a sustainable world. United Kingdom: Wiley Academy.

54 Costa, A., Marchettini, N. and Facchini, A. (2004). Developing the urban metabolism approach into a new urban metabolic model. In Marchettini, N., Brebbia, C., Tiezzi, E. and Wadhwa, C. The Sustainable City III. United Kingdom: WIT Press.

55 Hodson, M. and Marvin, S. (2009). 'Urban ecological security': a new urban paradigm? International Journal of Urban and Regional Research, 33(1). pp. 193-215.

56 Hodson, M. and Marvin, S. (2009). 'Urban ecological security': a new urban paradigm? International Journal of Urban and Regional Research, 33(1). pp. 193-215.

57 Hislop, H. and Hill, J. (2011). Reinventing the wheel: a circular economy for resource security. London: Green Alliance.

58 United Nations. (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

59 Satterthwaite, D. (2003). The links between poverty and the environment in urban areas of Africa, Asia and Latin America. Annals of the American Academy, 590. pp. 73-92.

60 Joassart-Marcelli, P. and Musso, J. (2005). Municipal Service Provision Choices within a Metropolitan Area. Urban Affairs Review, 40(4), pp. 492-519.

61 Graham, S. and Marvin, S. (2001). Splintering urbanism: Networked infrastructures, technological mobilities and the urban condition. United Kingdom: Routledge.

62 Swilling, M., Robinson, B., Hodson, M. and Marvin, S. (2011). Growing greener cities. In: UN-Habitat EGM on the green economy and sustainable urban development, 17-18 February 2011 Nairobi.

63 IEA (2009). Key World Energy Statistics. Paris: International Energy Agency.

64 Rode, P., Burdett, R. and Soares Gonçalves, J.C. (2011). Buildings:

investing in energy and resource efficiency. In Towards a Green Economy – Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme.

65 Rode, P., Burdett, R. and Soares Gonçalves, J.C. (2011). Buildings: investing in energy and resource efficiency. In Towards a Green Economy – Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme. p.70.

66 Rode, P., Burdett, R. and Soares Gonçalves, J.C. (2011). Buildings: investing in energy and resource efficiency. In Towards a Green Economy – Pathways to Sustainable Development and Poverty Eradication. United Nations Environment Programme. p. 353.

67 WBCSD (2000). Eco-efficiency – creating more value with less impact. Switzerland: World Business Council for Sustainable Development.

68 Hislop, H. and Hill, J. (2011). Reinventing the wheel: a circular economy for resource security. London: Green Alliance.

69 World Bank. 2010. Eco2Cities: Ecological Cities as Economic Cities. Washington D.C.: World Bank.

70 Addington, M. (2009). Energy sub-structure, supra-structure, infra-structure. In Ecological Urbanism (eds. M. Mostafavi and G. Doherty). Lars Müller, Switzerland.

71 Addington, M. (2009). Energy sub-structure, supra-structure, infra-structure. In Ecological Urbanism (eds. M. Mostafavi and G. Doherty). Lars Müller, Switzerland.

72 Lovins, A., Datta, E.K., Feiler, T., Rábago, K.R., Swisher, J.N., Lehmann, A, and Wicker, K. (2002). Small is profitable: the hidden economic benefits of making electrical resources the right size. United States: Rocky Mountain Institute.

73 Lovins, A., Datta, E.K., Feiler, T., Rábago, K.R., Swisher, J.N., Lehmann, A, and Wicker, K. (2002). Small is profitable: the hidden economic benefits of making electrical resources the right size. United States: Rocky Mountain Institute.

74 Bieker, S., Cornel, P. And Wagner, M. (2010). Semicentralised supply and treatment systems: integrated infrastructure solutions for fast growing urban areas. Water Science & Technology, 61(11), pp. 2905-2913.

75 Bieker, S., Cornel, P. And Wagner, M. (2010). Semicentralised supply and treatment systems: integrated infrastructure solutions for fast growing urban areas. Water Science & Technology, 61(11), pp. 2905-2913.

76 RUAF (2011). What is urban agriculture? Resource Centres on Urban Agriculture & Food Security. http://www.ruaf.org/node/512 [Accessed 12 December 2011]

77 Smit, J. and Nasr, J. (1992). Urban agriculture for sustainable cities: using wastes and idle land and water bodies as resources. Environment & Urbanisation, 4(2), 142

78 Smit, J. and Nasr, J. (1992). Urban agriculture for sustainable cities: using wastes and idle land and water bodies as resources. Environment & Urbanisation, 4(2), p. 142.

79 Von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos,

P. (2009). Factor Five: Transforming the global economy through 80% improvements in resource productivity. London: Earthscan. p.34.

80 Birkeland, J. (2002). Design for sustainability. A sourcebook of integrated eco-logical solutions. London: Earthscan, p.13.

81 Hartshorn, J., Maher, M., Crooks, J., Stahl, R. and Bond, Z. (2005). Creative destruction: building toward sustainability. Canadian Journal of Civil Engineering, 32, pp. 170–180.

82 WBCSD (2000). Eco-efficiency – creating more value with less impact. Switzerland: World Business Council for Sustainable Development.

83 Guy, S., Marvin, S. and Moss, T. (2001). Urban infrastructure in transition. United Kingdom and United States: Earthscan, pp. 202-203.

84 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: lung Wicha Press, p.58.

85 Guy, S., Marvin, S. and Moss, T. (2001). Urban infrastructure in transition. United Kingdom and United States: Earthscan pp. 202-203.

86 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

87 Guy, S., Marvin, S. and Moss, T. (2001). Urban infrastructure in transition. United Kingdom and United States: Earthscan, pp. 202-203.

88 Guy, S., Marvin, S. and Moss, T. (2001). Urban infrastructure in transition. United Kingdom and United States: Earthscan, pp. 202-203.

89 Graham, S. and Marvin, S. (2001). Splintering urbanism: Networked infrastructures, technological mobilities and the urban condition. United Kingdom: Routledge.

90 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press,

91 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand Clung Wicha Press.

92 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

93 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

94 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Thailand: Clung Wicha Press.

95 United Nations (2011). Are we building competitive and liveable cities? Guidelines for developing eco-efficient and socially inclusive infrastructure. Clung Wicha Press, Thailand

96 Winn, R. (2008). Mariannhill Landfill Conservancy: History. http://www.landfillconservancies.com/mlc_history.htm [Accessed 15 July 2011].

97 Parkin, J. (2011). Personal communications.

98 Parkin, J. (2011). Personal communications.

99 Parkin, J. (2011). Personal communications.

100 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

101 Havard Kennedy School. (2006). Mariannhill Landfill Conservancy. http://www.innovations.harvard.edu/awards.html?id=42981 [Accessed 12 July 2011].

102 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

103 SA Good News. (2007). Durban launches Africa's first landfill gas to electricity project.

http://www.sagoodnews.co.za/environment/durban_launches_africas_first_landfill_gas_to_electricity_project.html [Accessed 12 July 2011].

104 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

105 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

106 Taylor, Y. (2009) Toxic Landfill sites! Perhaps not... http://www.earthorganization.org/articles/Library/Toxic_landfill_sites_perhaps_not/default.aspx [Accessed 12 July 2011].

107 Kadalie, R. (2011). Mariannhill – a dump with a massive difference. The New Age. http://thenewage.co.za/blogdetail.aspx?mid=186&blog_id=961 [Accessed 22 July 2011].

108 Taylor, Y. (2009) Toxic Landfill sites! Perhaps not... http://www.earthorganization.org/articles/Library/Toxic_landfill_sites_perhaps_not/default.aspx [Accessed 12 July 2011].

109 Moodley, S. (2007). Turning a landfill into an asset. Delivery. 11, pp. 70-71.

110 Wright, M. (2011) Personal communications.

111 Wright, M. (2011) Personal communications.

112 Strachan, L. and Pass, J. (2010). Ch. 18: Energy from waste: An overview of Africa's first landfill gas to energy Clean Development Mechanism projects. In The Waste Revolution Handbook. Waste Revolution South Africa, Durban, pp. 130-135.

113 Wright, M. (2011) Personal communications.

114 Wright, M. (2011) Personal communications.

115 SA Good News. (2007). Durban launches Africa's first landfill gas to electricity project.http://www.sagoodnews.co.za/environment/durban_launches_africas_first_landfill_gas_to_electricity_project.html [Accessed 12 July 2011].

116 Wright, M. (2012) Personal communications.

117 Havard Kennedy School. (2006). Mariannhill Landfill Conservancy. http://www.innovations.harvard.edu/awards.html?id=42981 [Accessed 12 July 2011].

118 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

119 Kadalie, R. (2011) Mariannhill – a dump with a massive difference. The New Age. http://thenewage.co.za/blogdetail.aspx?mid=186&blog_id=961 [Accessed 22 July 2011].

120 Winn, R. (2008). Mariannhill Landfill Conservancy: History. http://www.landfillconservancies.com/mlc_history.htm [Accessed 15 July 2011].

121 Strachan, L. (2007). Mariannhill Landfill Conservancy – A 'Closed Loop' Design. http://www.durban.gov.za/durban/services/cleansing/gastoelec/fill [Accessed 12 July 2011].

122 Moodley, S. (2007). Turning a landfill into an asset. Delivery. 11, pp. 70-71.

123 Parkin, J. (2011). Personal communications.

124 Strachan, L. and Pass, J. (2010). Ch. 18: Energy from waste: An overview of Africa's first landfill gas to energy Clean Development Mechanism projects. In The Waste Revolution Handbook. Waste Revolution South Africa, Durban, pp. 130-135.

125 Wright, M. (2011) Personal communications.

126 Wright, M. (2011) Personal communications.

127 Garner, E. (2009). An Assessment of Waste Management Practices in South Africa: A eThekwini Municipality. Master's thesis. South Africa: University of KwaZulu-Natal.

128 Parkin, J. (2011). Personal communications.

129 Wright, M. (2011) Personal communications.

130 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

131 Martin, M. (2009). The "Biogasification" of Linköping: A Large Technical Systems Perspective. Environmental Technology and Management, Linköping Universitet. http://www.iei.liu.se/envtech/forskning/forskningsprojekt/synergibiodrivmedel/1.187129/BiogasificationofLinkopingLTSFINAL.pdf [Accessed 30 July 2011]

132 Martin, M. (2009). The "Biogasification" of Linköping: A Large Technical Systems Perspective. Environmental Technology and Management, Linköping Universitet. http://www.iei.liu.se/envtech/forskning/forskningsprojekt/

synergibiodrivmedel/1.187129/BiogasificationofLinkopingLTSFINAL.pdf [Accessed 30 July 2011].

133 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

134 Martin, M. (2009). The "Biogasification" of Linköping: A Large Technical Systems Perspective. Environmental Technology and Management, Linköping Universitet. http://www.iei.liu.se/envtech/forskning/forskningsprojekt/synergibiodrivmedel/1.187129/BiogasificationofLinkopingLTSFINAL.pdf [Accessed 30 July 2011].

135 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

136 Ericson, J. and Grahn, M. (2010). Biogas as fuel for transport in Linköping (Sweden). Eltis. http://www.eltis.org/index.php?id=13&study_id=2733 [Accessed 30 July 2011].

137 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809

138 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809

139 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

140 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809.

141 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809.

142 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

143 Martin, M. (2009). The "Biogasification" of Linköping: A Large Technical Systems Perspective. Environmental Technology and Management, Linköping Universitet. http://www.iei.liu.se/envtech/forskning/forskningsprojekt/synergibiodrivmedel/1.187129/BiogasificationofLinkopingLTSFINAL.pdf [Accessed 30 July 2011].

144 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

145 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

146 IEA (2005). 100% Biogas for urban transport in Linkoping, Sweden.

International Energy Agency. http://www.iea-biogas.net/_download/linkoping_final.pdf. [Accessed 28 July 2011].

147 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

148 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

149 IEA (2005). 100% Biogas for urban transport in Linkoping, Sweden. International Energy Agency. http://www.iea-biogas.net/_download/linkoping_final.pdf. [Accessed 28 July 2011].

150 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809.

151 Svensk Biogas (2011). Biogas – for a sustainable society. http://www.svenskbiogas.se/sb/Biogas-Sustainable-society_eng_webb.pdf [Accessed 30 July 2011]

152 IEA (2005). 100% Biogas for urban transport in Linkoping, Sweden. International Energy Agency. http://www.iea-biogas.net/_download/linkoping_final.pdf. [Accessed 28 July 2011].

153 IEA (2005). 100% Biogas for urban transport in Linkoping, Sweden. International Energy Agency. http://www.iea-biogas.net/_download/linkoping_final.pdf. [Accessed 28 July 2011]

154 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

155 Svensk Biogas (2011). Biogas – for a sustainable society. http://www.svenskbiogas.se/sb/Biogas-Sustainable-society_eng_webb.pdf [Accessed 30 July 2011].

156 Svensk Biogas (2011). Biogas – for a sustainable society. http://www.svenskbiogas.se/sb/Biogas-Sustainable-society_eng_webb.pdf [Accessed 30 July 2011].

157 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

158 Ericson, J. (2005). Svensk Biogas AB in Linköping (Sweden). Osmose. http://www.osmose-os.org/documents/5/CaseStudyBiogasLinkoping(SE)2.pdf. [Accessed 3 August 2011].

159 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

160 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809

161 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809

162 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

163 Berglund, B., Ersson, C., Ekland, M. and Martin, M. (2011). Challenges for developing a system for biogas as vehicle fuel – lessons from Linkoping, Sweden. In: World Renewable Energy Congress 2011 – Sweden Bioenergy Technology (BE), 8-11 May 2011, Linköping.

164 Barbero, S. (2011). Systemic Design in Energy Sector: Theory and Case Studies. Acta Technica Corviniensis. Bulletin of Engineering. Tome IV. ISSN 2067-3809.

165 Martin, M. (2009). The "Biogasification" of Linköping: A Large Technical Systems Perspective. Environmental Technology and Management, Linköping Universitet. http://www.iei.liu.se/envtech/forskning/forskningsprojekt/synergibiodrivmedel/1.187129/BiogasificationofLinkopingLTSFINAL.pdf [Accessed 30 July 2011].

166 Integrated Transport Planning Ltd and IBIS Transport Consultants Ltd. (2009). BRT-Lite Evaluation Final Report for the Lagos Metropolitan Area Transport Authority. In print .

167 LAMATA (2008). Lagos Bus Rapid Transit Scheme (BRT). Lagos: Lagos Metropolitan Area Transport Authority.

168 LAMATA (2009). Lagos BRT-Lite: Africa's first bus rapid transit scheme, Lagos BRT-Lite Summary Evaluation Report. Lagos Metropolitan Area Transport Authority, Nigeria

169 LAMATA (2007). Lagos Metropolitan Area Transport Authority (LAMATA) Brochure. In print.

170 Manda, M.A.Z. (2009). *Water and Sanitation in Urban Malawi: Can they meet the Millennium Development Goals? A study of informal settlements in three cities*. Human Settlements Working Paper, International Institute for Environment and Development, London, p.2.

171 Manda, M.A.Z. (2009). *Water and Sanitation in Urban Malawi: Can they meet the Millennium Development Goals? A study of informal settlements in three cities*. Human Settlements Working Paper, International Institute for Environment and Development, London, p.2.

172 Nkhoma, S. (2011). Personal Communications

173 Morgen, P. (2007).Lessons from a Low Cost Ecological Approach to Sanitation in Malawi, Water and Sanitation Programme. Field Note, Nairobi, p. 3

174 Nkhoma, S. (2011). Personal Communications

175 Morgen, P. (2007).Lessons from a Low Cost Ecological Approach to Sanitation in Malawi, Water and Sanitation Programme. Field Note, Nairobi, p.12.

176 Nkhoma, S. (2011). Personal Communications.

167 LAMATA (2008). Lagos Bus Rapid Transit Scheme (BRT). Lagos: Lagos Metropolitan Area Transport Authority.

168 LAMATA (2009). Lagos BRT-Lite: Africa's first bus rapid transit scheme, Lagos BRT-Lite Summary Evaluation Report. Lagos Metropolitan Area Transport Authority, Nigeria

169 LAMATA (2007). Lagos Metropolitan Area Transport Authority (LAMATA) Brochure. In print.

170 Manda, M.A.Z. (2009). *Water and Sanitation in Urban Malawi: Can they meet the Millennium Development Goals? A study of informal settlements in three cities*. Human Settlements Working Paper, International Institute for Environment and Development, London, p.2.

171 Manda, M.A.Z. (2009). *Water and Sanitation in Urban Malawi: Can they meet the Millennium Development Goals? A study of informal settlements in three cities*. Human Settlements Working Paper, International Institute for Environment and Development, London, p.2.

172 Nkhoma, S. (2011). Personal Communications

173 Morgen, P. (2007).Lessons from a Low Cost Ecological Approach to Sanitation in Malawi, Water and Sanitation Programme. Field Note, Nairobi, p. 3

174 Nkhoma, S. (2011). Personal Communications

175 Morgen, P. (2007).Lessons from a Low Cost Ecological Approach to Sanitation in Malawi, Water and Sanitation Programme. Field Note, Nairobi, p.12.

176 Nkhoma, S. (2011). Personal Communications.

177 Nkhoma, S. (2011). Personal Communications.

178 Manda, M.A.Z., Nkhoma, S. and Mitlin, D. (2011). Understanding pro-poor housing finance in Malawi. Human Settlements Working Paper No. 32. International Institute for Environment and Development, London, p. 5.

179 Nkhoma, S. (2011). Personal Communications.

180 Nkhoma, S. (2011). Personal Communications.

181 Manda, M.A.Z. (2009). *Water and Sanitation in Urban Malawi: Can they meet the Millennium Development Goals? A study of informal settlements in three cities*. Human Settlements Working Paper, International Institute for Environment and Development, London, p. 6.

182 CCODE (2011) Use of Ecosan Products in Malawi: Experiences from Users in Peri-Urban Areas, WIN-SA Fieldnote September 2011, Water Information Network South Africa, Pretoria, South Africa.

183 Austin, L.M., Duncker, L.C., Matsebe, G.N., Phasha, M.C. and Cloete, T.E. (2005) Ecological Sanitation- Literature Review, Water Research Commission Report No. 246/05, Gezina, p.11.

184 Nkhoma, S. (2011). Personal Communications

185 Bunda College of Agriculture (2011) Evaluating Ecosan Technology, Draft Report May 2011, Bunda College of Agriculture

186 Nkhoma, S. (2011). Personal Communications

187 Nkhoma, S. (2011).Personal Communications

188 Demonstration Project for the Renovation of Multifamily Buildings (2011). About the project. project. http://www.obnovendom.com [Accessed November 2011].

199 Demonstration Project for the Renovation of Multifamily Buildings (2011). About the project. http://www.obnovendom.com [Accessed November 2011].

200 Atasanov, D. (2012). Personal Communications.

201 World Bank (2008). http://data.worldbank.org/indicator/EN.ATM.CO2E.PC [Accessed February 2012].

202 Demonstration Project for the Renovation of Multifamily Buildings (2011). About the project. http://www.obnovendom.com [Accessed November 2011].

203 Demonstration Project for the Renovation of Multifamily Buildings (2011). About the project. http://www.obnovendom.com [Accessed November 2011].

204 Atasanov, D. (2011). Personal Communications.

205 Demonstration Project for the Renovation of Multifamily Buildings (2011). About the project. http://www.obnovendom.com [Accessed November 2011]

206 Atasanov, D. (2011). Personal Communications

207 Demonstration Project for the Renovation of Multifamily Buildings (2010). Phase 3 Survey. In print.

208 Atasanov, D. (2011). Personal Communications

209 Anastácio, A. and Schmeiske, O. (2001). Identificação e Avaliação de Canais de Logística Reversa. Institutode Pesquisa e Planejamento Urbano de Curitiba. http://www.abepro.org.br/biblioteca/ENEGEP2001_TR11_0014.pdf [Accessed August 2011].

210 Braga, M. and Bonetto, E. (1993). Solid waste management in Curitiba, Brazil – alternative solutions. Journal of Resource Management and Technology, 21(1), pp. 11-14.

211 IPPUC (2011). Curitiba em Dados. Instituto de Pesquisa e Planejamento Urbano de Curitiba. http://www.ippuc.org.br [Accessed August 2011].

212 Oliveira, M. (2001). A Trajetória do discurso Ambiental em Curitiba. http://www.scielo.br/pdf/rsocp/n16/a06n16.pdf [Accessed August 2011].

213 Prefeitura Municipal de Curitiba (1999). Pesquisa Sobre os Depósitos e Coletores Informais de Materiais Recicláveis do Município de Curitiba. In print.

214 Prefeitura Municipal de Curitiba/ Secretaria Municipal do Meio Ambiente. (2000). Gerenciamento dos Resíduos Sólidos Urbanos no Município de Curitiba. In print.

215 Rohn, T. (2007). Improvements to Curitiba´s waste disposal system: A comparative study between Curitiba and Germany solution. http://www.design.ufpr.br/issd/papers/ISSD1101.pdf [Accessed August 2011].

216 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

217 Hoglund, M. (2011). Portland Planning and Sustainability Commission Briefing May 24, 2011. http://www.portlandonline.com/bps/index.cfm?c=41664 [Accessed August 2011].

218 OGWC (2011). Report to the Legislature 2011. Oregon Global Warming Commission. http://www.keeporegoncool.org/content/oregon-global-warming-commission-report-legislature-recommends-40-key-actions [Accessed August 2011].

219 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

220 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

221 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

222 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

223 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

224 City of Portland and Portland Development Commission (2009). Portland Economic Development Strategy: A Five-Year Plan for promoting Job Creation and Economic Growth. http://pdxeconomicdevelopment.com/docs/EDS_Brochure.pdf [Accessed August 2011].

225 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress

Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

226 OGWC (2011). Report to the Legislature 2011. Oregon Global Warming Commission.http://www.keeporegoncool.org/content/oregon-global-warming-commission-report-legislature-recommends-40-key-actions [Accessed August 2011]

227 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

228 PPR (2009) Community Gardens Business Plan Fiscal Years 2008-09 through 2010-11. Portland Parks & Recreation. http://www.portlandonline.com/parks/index.cfm?a=246846&c=38306 [Accessed February 2012].

229 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

230 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

231 CAP (2010). City of Portland and Multnomah County Climate Action Plan 2009 Year 1 Progress Report. Climate Action Plan. http://www.ci.portland.or.us/bps/index.cfm?a=327050&c=49989. [Accessed August 2011].

232 Tortajada, C. (2006). Singapore: an exemplary case for urban water management. Paper prepared for the 2006 Human Development Report. http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1270074782769/Eco2_Cities_Book.pdf [Accessed October 2011]

233 MEWR (2009). *A Lively and Liveable Singapore:* Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/data/ImgCont/1292/sustainableblueprint_forweb.pdf. [Accessed October 2011].

234 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

235 MEWR (2009). *A Lively and Liveable Singapore*: Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/data/ImgCont/1292/sustainableblueprint_forweb.pdf. [Accessed October 2011].

236 MEWR (2009). *A Lively and Liveable Singapore*: Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/

data/ImgCont/1292/sustainbleblueprint_forweb.pdf. [Accessed October 2011].

237 MEWR (2009). *A Lively and Liveable Singapore:* Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/data/ImgCont/1292/sustainbleblueprint_forweb.pdf. [Accessed October 2011].

238 MEWR (2009). *A Lively and Liveable Singapore:* Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/data/ImgCont/1292/sustainbleblueprint_forweb.pdf. [Accessed October 2011].

239 MEWR (2009). *A Lively and Liveable Singapore:* Strategies for Sustainable Growth. Ministry of the Environment and Water Resources and Ministry of National Development. http://app.mewr.gov.sg/data/ImgCont/1292/sustainbleblueprint_forweb.pdf. [Accessed October 2011].

240 NCCS (2010). Transcript of Minister for the Environment and Water Resources Dr Yaacob Ibrahim's reply to Parliamentary question on the Singapore Sustainable Blueprint on 11 January 2010. http://app.nccs.gov.sg/news_details.aspx?nid=98. [Accessed October 2011].

241 EDB (2009). S$1 billion environmental blueprint to make Singapore a clean technology and urban solutions hub. Economic Development Board Singapore. http://www.edb.gov.sg/edb/sg/en_uk/index/news/articles/s_1_billion_environmental.html [Accessed October 2011].

242 NCCS (2010). Transcript of Minister for the Environment and Water Resources Dr Yaacob Ibrahim's reply to Parliamentary question on the Singapore Sustainable Blueprint on 11 January 2010. http://app.nccs.gov.sg/news_details.aspx?nid=98. [Accessed October 2011].

243 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

244 Tortajada, C. (2006). Singapore: an exemplary case for urban water management. Paper prepared for the 2006 Human Development Report. http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1270074782769/Eco2_Cities_Book.pdf [Accessed October 2011]

245 PUB (2011). *Go with more ticks to save water*. Public Utility Board Singapore. http://www.pub.gov.sg/mpublications/Pages/PressReleases.aspx?ItemId=323 [Accessed October 2011].

246 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

247 PUB (2011). *Go with more ticks to save water.* Public Utility Board Singapore. http://www.pub.gov.sg/mpublications/Pages/PressReleases.aspx?ItemId=323 [Accessed October 2011].

248 SSNC (2010). Singapore's Second National Communication under the

United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

249 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

250 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].

251 PUB (2011). *Go with more ticks to save water.* Public Utility Board Singapore. http://www.pub.gov.sg/mpublications/Pages/PressReleases.aspx?ItemId=323 [Accessed October 2011].

252 PUB (2011). *Go with more ticks to save water*. Public Utility Board Singapore. http://www.pub.gov.sg/mpublications/Pages/PressReleases.aspx?ItemId=323 [Accessed October 2011].

253 MEWR (2011). Water Resource Management. Ministry of the Environment and Water Resources. http://app.mewr.gov.sg/web/Contents/Contents.aspx?ContId=682 [Accessed October 2011].

254 PUB (2011). *Go with more ticks to save water*. Public Utility Board Singapore. http://www.pub.gov.sg/mpublications/Pages/PressReleases.aspx?ItemId=323 [Accessed October 2011].

255 MEWR (2011). Water Resource Management. Ministry of the Environment and Water Resources. http://app.mewr.gov.sg/web/Contents/Contents.aspx?ContId=682 [Accessed October 2011].

256 Chew, V. (2009). Singapore-Malaysia Water Agreements. www.infopedia.nl.sg [Accessed October 2011].

257 SSNC (2010). Singapore's Second National Communication under the United Nations Framework Convention on Climate Change November 2010. National Environment Agency. http://app.mewr.gov.sg/data/imgCont/1439/singapore_snc2010.pdf [Accessed October 2011].