UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

UNCTAD

SCIENCE, TECHNOLOGY AND INNOVATION FOR SUSTAINABLE URBANIZATION

UNCTAD Current Studies on Science, Technology and Innovation. N°10

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I. Introduction

The past two decades have witnessed the emergence of the new developmental phenomenon of urbanization. Cities are not only the engines of economic growth but also increasingly spaces of shared social, cultural and economic experiences (United Nations Human Settlements Programme (UN-Habitat), 2005). Urbanization is synonymous to most people in the developing world with job creation and poverty reduction. Yet while some cities across the world have managed to benefit from urbanization as a developmental tool by applying the right policies, others have merely moved poverty to urban areas. In addition, various examples from around the world demonstrate that being a developed country is not a prerequisite for sound urbanization that contributes to economic development.

Urbanization has accompanied large-scale improvements in some developing countries towards the Millennium Development Goals. The most important change has been the eradication of extreme poverty in rural areas, for instance in China. Such progress has depended primarily on the role of cities in employment generation and their ability to provide basic services such as water, health and sanitation for the masses at a lower cost than in rural areas.

The next wave of urbanization represents an opportunity to meet the Millennium Development Goals and raise people out of poverty. Moving to cities may provide employment, health and sanitation all at once to citizens of developing countries. Despite this, urbanization is a core concern that developing countries struggle with, with many common issues. Developing countries need to find ways to accommodate growing demands on their cities to ensure that the social, cultural and environmental needs of their citizens are met. Cities need to envisage policies that bridge growing urban divides that translate not only into unfair economic opportunities but also unfair access to services. Cities should aim to become shared spheres of prosperity.

Urbanization is a key environmental issue as well. The rapid pace at which urbanization is taking place in the developing world has an impact on climate change and other global environmental issues. Cities account for more than two-thirds of the global energy demand and result in up to 80 per cent of global greenhouse gas emissions. The urban planning and investment choices that a few large developing countries will make therefore represent one of the most important environmental issues of the twenty-first century. Entire new industries are forming with the aim of switching to clean and renewable energies and managing the world's resources in a more efficient manner, primarily in developed countries but also in the developing world.

In recent years, sustainable urbanization has become a very popular topic. Several conferences at international, regional and local levels have periodically discussed urbanization issues in detail. Debate on the topic has already reached a level of maturity whereby tools, resources and applications are abundant worldwide. Innovation on sustainable urbanization is happening everywhere, in both developed and developing countries.

This report aims to contribute to the sustainable urbanization discourse by addressing the specific role of science, technology and innovation. It is based on literature review and an analysis of cities in developed and developing countries that provide examples that can be reapplied elsewhere. The report provides a fresh perspective on the discussion on sustainable urbanization, drawing on current research and case studies from around the world. The report identifies key sectoral planning challenges posed by rapid urbanization, particularly in developing countries, and proposes practical guidelines to city planners and other decision makers for addressing these challenges through the use of science, technology and innovation.

The publication draws on lessons learned from panels organized by the United Nations Commission on Science and Technology for Development on the topic of science, technology and innovation for sustainable cities and peri-urban communities during its 2012–2013 intersessional panel, held in Lima, Peru in January 2013, and its sixteenth session, held in Geneva, Switzerland in June 2013.

Chapter II reviews global urbanization trends and the case for sustainable urban development. Chapter III proposes science, technology and innovation options with examples of policy considerations on the path towards sustainable urban planning. Chapter IV looks at ways in which science, technology and innovation can improve resource management in an urban setting. Finally, chapter V discusses policy implications with regard to increasing the diffusion and adoption of science, technology and innovation for sustainable urbanization in developing countries.

II. Urbanization and sustainability

This chapter discusses current urbanization trends, the relationship between urbanization and the attainment of the Millennium Development Goals and the need to foster sustainable urbanization for improved outcomes in developing countries.

II. a. Trends of urbanization

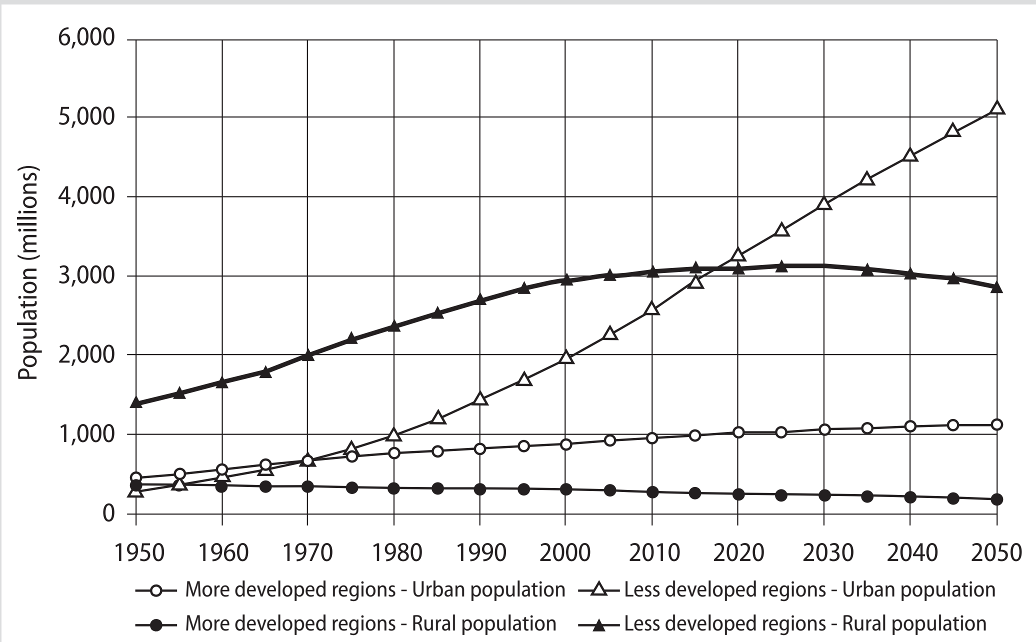
According to the world development indicators of the World Bank, people living in urban areas represented 52.6 per cent of the world's population in 2012. It is estimated that by 2050 the number of inhabitants of urban areas will increase from the current 3.5 billion to 6.2 billion, which will approximately constitute more than two-thirds of the global population. The unprecedented pace of urbanization in developing countries, where more than 90 per cent of urban population growth will occur over the next 30 years, is the main driver of this trend. Most of this growth will be attributed to mid-size towns.

Table 1 shows urbanization trends by development group. The growth of urban areas until 2050 will primarily take place in developing Asia, Africa and Latin America. Rural areas of both developed and developing regions will stagnate and urban populations of developed regions will incur a very small increase. It is expected that the urban population of sub-Saharan Africa will double, to reach almost 600 million by 2030.

Urbanization and the Millennium Development Goals

Urbanization is mainly stimulated by economic factors. People move to cities in search of jobs and a better quality of life.

Table 1. Urban and rural populations by development group



Source: Department of Economic and Social Affairs – Population Division, 2012.

Cities generate four-fifths of the global gross domestic product with just over half of the world's population, on 2 per cent of the earth's surface (Department of Economic and Social Affairs – Population Division, 2012). Most new jobs are created in cities; 60 per cent of the increase in the global gross domestic product between 2010 and 2025 is expected to come from 600 cities (Gapper, 2012).

Urbanization in the developing world has been a major contributor to progress towards attaining some of the Millennium Development Goals, such as those related to poverty, sanitation and health. This is to be expected, given that on average a 10 per cent increase in a country's urban population results in a 30 per cent increase in that country's per capita output. In addition, per capita incomes are almost four times higher in majority-urban countries in comparison to majority-rural countries (Glaeser, 2011).

In addition to their role in alleviating poverty through their economic dynamism, cities also make public services more accessible (World Bank and International Monetary Fund, 2013). Due to the economies of scale achieved through their higher density, it is less costly to provide piped water, sanitation, education and health care services in urban areas. The provision of such services is directly linked to the Millennium Development Goals. For instance, in sub-Saharan Africa, urbanization facilitated half of the decline in poverty. In addition, nearly 30 per cent of improvements on target 7.C[1] was achieved by urbanization (World Bank and International Monetary Fund, 2013).

Growing urban divides in all spheres

Urbanization has raised the standard of living for many by offering employment opportunities and better public services. However, it also comes with important challenges, particularly for developing countries. In many parts of the world, urbanization has not taken place in a socially inclusive manner. Many developing countries have not been able to predict and prepare for the rapid pace of urbanization that is in progress. Even where the trend is predictable, cities are unable to address the needs of growing populations and cope with surging requirements for housing, physical infrastructure, including roads and telecommunications technologies, and social services, such as health and education. The continuation of current urbanization patterns in the developing world could lead to urban decay and a low quality of life, adversely affecting the economic growth of developing countries.

Although urbanization itself is not the cause of poverty, unplanned urbanization is resulting in the shift of poverty to urban areas in developing countries. In 2012, urban poverty was already a serious issue: 525 million urban inhabitants lived on under $1 per day, while 1.2 billion citizens lived on under $2 per day. The growth of slums has been inevitable, representing 38 per cent of urban growth around the world and three-quarters of urban population growth in sub-Saharan Africa. The global slum population has been growing by more than 20 million additional slum dwellers per year and will reach a projected total of 1.4 billion in 2020. In Africa, more than half of urban citizens live in informal settlements, where the water supply and sanitation are severely inadequate. Climate change is exacerbating the risk of disasters for populations living in such inadequate shelters.

The growth of slums has a direct impact on the attainment of the Millennium Development Goals in cities. In 2007–2008, UN-Habitat, the United Nations Human Settlements Programme, measured indicators of progress towards the Millennium Development Goals in slums and other areas of 200 cities globally. The study indicated that slum dwellers die earlier, experience more hunger, are less educated, have fewer chances for employment and suffer more ill health than the rest of the urban population.

II. b. Sustainable urbanization

It is due to these trends that there is a need to focus on sustainable urbanization, in terms of what can be considered sustainable

[1] Target 7.C: Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation.

Box 1. New York City: Measuring sustainability

New York City has launched PlaNYC, a comprehensive agenda that includes long-term targets for enhancing infrastructure, the environment, quality of life and the economy to accommodate an additional 1 million people until 2030. PlaNYC measures 29 sustainability indicators in categories including housing, parks, public transport, water supply, energy efficiency and air quality through a dedicated office of long-term planning and sustainability.

Sources: Green Media, 2012; and PlaNYC, 2015.

or unsustainable in the future and how to address the issue. There is no generally agreed common definition of sustainability or sustainable urbanization. However, there is a growing set of areas and actions that together constitute the benchmarks for sustainable urbanization. The definition continues to evolve and higher standards are set.

The economic, social and environmental effects of uncontrolled rapid urbanization are increasing awareness of the need for sustainable practices. Large-scale events such as the Olympics are increasingly evaluated on whether they incorporate legacy projects that plan the reuse of facilities following the event. New ecological cities are planned and constructed that rely fully on sustainable technologies. In addition, cities are increasingly setting goals and measuring their sustainability by using indicators such as the availability of shelter and safe drinking water, urban density, public space as a percentage of urban area, energy efficiency of buildings, share of renewable energy sources, access and proximity to mass transit, wastewater treatment, number of road traffic fatalities, solid waste management and recycling (UN-Habitat, 2012c). box 1 presents an example of measuring sustainability in the United States of America.

The definition of sustainability in the urban context can be divided into the subsections of smart, environmentally friendly, prosperous and socially inclusive cities, as follows:

- Smart cities cover the needs of their citizens adequately. They offer high-quality services, including mobility, habitat and public space.
- Environmentally friendly cities manage their resources efficiently. They minimize waste and promote environmental awareness among citizens and environmentally friendly buildings and construction materials to reduce energy consumption.
- Prosperous cities maximize economic opportunities by tapping into the competitive advantages of their locations, not only at the city level but beyond, covering the region, in order to attract entrepreneurship and new economic activity.
- Socially inclusive cities strive to increase quality of life for all citizens regardless of income levels, through increasing safety by addressing crime, stimulating economic opportunities for the poor and integrating informal areas, and practising governance that involves the public in decision-making structures.

Sustainable urbanization can thus cover all actions that lead to a more efficient management of land and resources, improved mobility, economic dynamism, higher environmental quality, safety, security, access to urban services and social cohesion. Generally, the relevant literature accepts sustainable cities as those that have sound spatial plans that address the needs of their population, ensure the circulation of people through sound mobility systems and use their resources efficiently, and even manage to build a circular economy through means such as recycling. This definition may be seen as the narrow definition of sustainable urbanization. In the broader sense, sustainable urbanization also addresses social policies, including for reducing crime and ensuring social justice, funding models and governance structures. Since science, technology and innovation are more relevant to and have a stronger impact on sectors included in the narrow definition of sustainable urbanization, this report will cover their role accordingly.

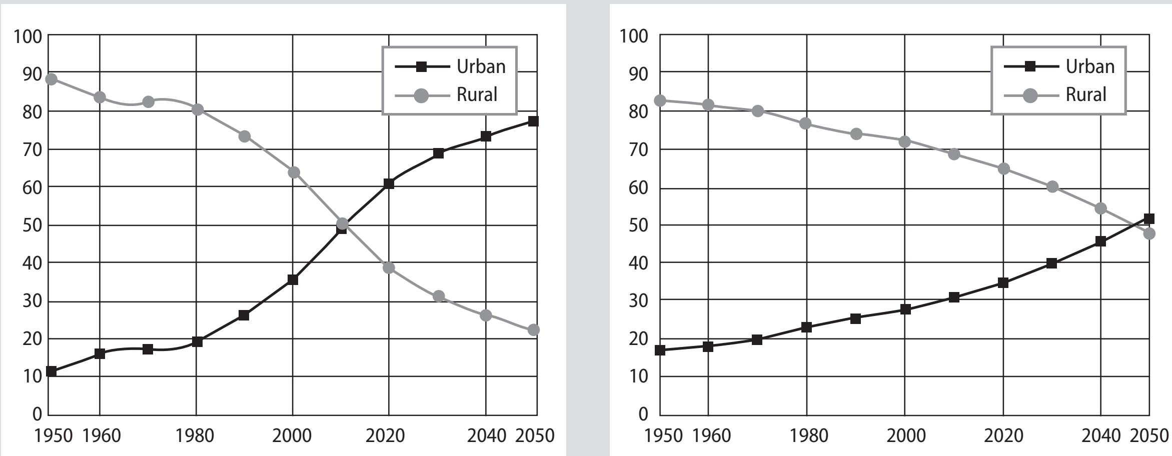
Sustainable urbanization comes at a cost. In the next 10 years, more than $10 trillion will need to be invested in urban infrastructure in Asia and Latin America (Economic and Social Commission for Asia and the Pacific et al., 2011). In the period until 2030, twenty times the infrastructure capacity added during the past decade is needed for roads and public transport across the world. The estimated rate of urbanization in China and India until 2050, outlined in box 2, attests to the scale of investments required to address the needs of growing urban populations in terms of jobs, housing, basic services and infrastructure. Furthermore, urban population growth and steadily rising incomes result in higher resource consumption. Cities around the world, especially rapidly growing cities in Asia, Africa and Latin America, need to find ways to delink urban economic growth from resource consumption. Urbanization is creating cross-sectoral governance challenges, including imbalances in quality of life and other social issues that need to be addressed through integrated multi-stakeholder mechanisms.

Urbanization is a multidimensional and complex process. Due to the wide scope of the topic, sustainable urbanization is addressed by several international organizations, such as UN-Habitat. It encompasses several dimensions, some of which are addressed through policies that are beyond the realm of science, technology and innovation. For example, addressing the topic of housing versus habitat concerns not only construction but several other departments, since habitat includes the provision of access to jobs as well as housing. Science, technology and innovation are key enablers of sustainable urbanization, yet not the only ones, and have prerequisites such as local regulations, capacity-building and accountability. Science, technology and innovation are part of comprehensive initiatives to improve

Box 2. Urbanization in China and India

Proportion of urban and rural populations

China **India**



Urbanization in the developing world is led by China and India. The urban population of China is expected to increase from just above 10 per cent in 1950 to almost 80 per cent in 2050. In India, urbanization has been slower but will accelerate after 2020 to pass the 50 per cent threshold in 2050. Urbanization will continue to drive increases in national income in both countries. For instance, 70 per cent of all new jobs in India will be created in urban areas, with twice the productivity level of equivalent jobs in rural areas. Cities will drive social inclusion as well since public infrastructure, such as for water and sanitation, is more affordable in urban areas than in sparsely populated areas.

Sources: Department of Economic and Social Affairs – Population Division, 2014; Dobbs et al., 2011; and Sankhe et al., 2010.

cities, along with other components such as leadership, urban governance, regulation and financing.

This report, which is part of the UNCTAD series on current studies on science, technology and innovation, focuses on their specific role in bringing about sustainable urbanization in developing countries and how to strengthen this role. Therefore, for the purposes of this report, sustainability refers to all practices based on science, technology and innovation that lead to an improved quality of life for urban citizens.

II. c. Role of science, technology and innovation in the urban context

Science, technology and innovation are key elements of sustainable urbanization and will play a growing role as such. Their use may not solve all urbanization problems, yet can provide a multitude of solutions that can be leveraged by cities. The use of science, technology and innovation in the urban context implies the application of both high and low technology and innovative approaches to urban planning and institutional innovation. Science, technology and innovation approaches are widely available for cities to draw upon, yet cities are complex structures that require integrated responses to their problems and there are sometimes difficulties related to such integration.

Although this report separately analyses the various sectors that are important for sustainable urbanization, it is necessary for urban planners and managers to address issues with an intersectoral mindset. Urban systems need to be designed with multiple uses in mind. Science, technology and innovation offer a range of related options, including high technology, low technology and innovative governance. Combining science, technology and innovation to solve urban problems is often contextual, although there are several good practices to draw upon from cities across the globe.

Science, technology and innovation contribute to sustainable urbanization in a variety of ways, including with regard to new capabilities in spatial planning, socioeconomic research, enhancing cooperation between urban departments, optimizing mobility and enabling sustainable resource management. A science, technology and innovation-oriented mindset also brings about innovative models of thinking in urban governance, such as for participatory budgeting and regional urban planning. Finally, science, technology and innovation contribute to social inclusion by improving the tools available to urban planners to respond to the needs of excluded groups and to increase sensitivity to gender equality.

Each urban setting faces different challenges and has different technology needs. In some cases, inexpensive and readily available technologies may be the best solution to urban problems. For example, intermodal transport services can be designed without necessarily requiring expensive high-technology means of transport. Promoting bicycles, an affordable, healthy, clean and energy-efficient technology, may be the best option to improve mobility in many cities, for both younger and older citizens.

Furthermore, innovation, which in the urban context may refer to any new method, business model, policy, institutional design or regulation, could meet the needs of urban populations in a more efficient, effective and sustainable way. For instance, improved rules or legislation, as well as improved institutions, stakeholder participation models and new means of delivering services, can contribute to sustainable urbanization. As a final point, high technology, low technology and urban innovation can also be integrated to address a specific urban issue in harmony.

II. d. Cities as systems

A sociotechnical system is the way humans and technologies work together to produce outcomes. The answers to societal challenges cannot be expected to come from technologies alone but rather from how technologies are developed and used in the overall development process. For example, a transportation system is not only vehicles and roadways but also how people drive, ride, build and maintain them. The city itself can be viewed as a complex sociotechnical system that addresses the needs of densely settled communities. Science, technology and innovation approaches may therefore be seen not merely as technologies but within the context of the urban sociotechnical system. Cities are ultimately places where humans live and must therefore address human needs and aspirations. When envisaging science, technology and innovation for cities, it is necessary to ensure harmony between engineered systems and design and architectural concerns. For example, when planning roads with a technocratic mindset, one might achieve perfection in terms of engineering, yet actually destroy the fabric of a city as a place where people enjoy living, as is often true in the use of elevated highways. Cities provide science, technology and innovation with an opportunity to produce benefits for large populations, if the related solutions are applied to address human needs.

Science, technology and innovation are key ingredients for sustainable urbanization in developing countries, yet not the only ones, and have prerequisites to be effective, such as institutional and regulatory reform, socially inclusive policymaking, the availability of funds and the establishment of partnerships. Cities need to be viewed as complete sociotechnical systems in order for science, technology and innovation-related solutions to be effective, and such solutions will be ineffective if other policies do not complement them. Science, technology and innovation drive sociotechnical change, yet city leaders need to increase the awareness of citizens to the urgency of sociotechnical change for their own well-being and quality of life. Such solutions also need to be accompanied by leadership, a supportive regulatory environment, education and citizen participation. One simple way to explain the positioning of science, technology and innovation as part of a comprehensive framework of policies leading to sustainable urbanization is through the example of bicycle-sharing programmes. Such initiatives cannot succeed without dedicated lanes, laws that clarify priorities in traffic and, most importantly, education and awareness-raising so that citizens no longer rely on their automobiles for all travel.

Within an urban sociotechnical system, more positive outcomes may be achieved if cities are designed with an intersectoral mindset, for instance when addressing energy, water and public health in an integrated manner. In some cases, the best application of science, technology and innovation may be a combination of low and high technology in one package and it is necessary for city management to find an appropriate balance. For example, building design, energy consumption and mobility are closely interlinked; taller buildings may negatively affect exposure to sunlight, reducing the potential for the use of solar panels, and street width affects the capacity to accommodate multiple modes of transport, as well as the architecture of buildings.

III. Sustainable urban planning

This chapter addresses how science, technology and innovation can contribute to sustainable urban planning in order to address issues such as urban sprawl, traffic congestion and natural hazards. The chapter presents several important uses of science, technology and innovation in areas such as spatial planning, mobility and disaster resilience. This is not an exhaustive list but rather a selection of highly relevant uses, to draw attention to the potential of science, technology and innovation. Several cities around the world are already using innovative planning, technology and governance models in sectors such as spatial planning and mobility to address these complex challenges.

III. a. Density, land use and spatial planning

This report first considers spatial planning in its sectoral analysis of sustainable urban development as it is a cross-cutting theme that affects all other sectors. Urbanization in developing countries takes place with little long-term spatial planning and is driven by the short-term profitability expectations of the real-estate sector. Even planned development strategies sometimes underestimate the pace of urbanization. For example, the 1995 plan for Shanghai, China estimated a population of 15 million by 2020, yet the city had already reached 16 million inhabitants in 2000.

Current research in urban planning promotes more compact and dense spatial planning for cities. There are several ways in which increasing density may be beneficial for cities with growing populations. The following section discusses alternatives for how to achieve this.

Urban sprawl and its effects

Unplanned urbanization often results in urban sprawl, which is commonly defined as single-use low-density urbanization and has several negative dimensions. Whereas urban sprawl was previously associated with North American cities, it is rapidly extending to cities across the developing world (Economic and Social Commission for Asia and the Pacific et al., 2011). The density of urban areas in terms of number of people per hectare is decreasing across the world due to uncontrolled urban sprawl. Lower density makes it more challenging and expensive to provide adequate public services such as transport and utilities (UN-Habitat, 2012c). Unplanned urbanization results in investments that dictate future urban land and resource consumption patterns. It is costly to replace such investments with more sustainable infrastructure later on since they lock in the options of urban planners (UN-Habitat, 2012c).

As a result of unplanned urbanization, millions of people live in informal settlements on the periphery of cities without access to basic services, water and sanitation due to the lack of funds to carry out important infrastructure projects. For example, large shortfalls in water supply have increasingly been experienced in Lagos, Nigeria, where official supplies barely meet half the level of demand due to population growth, insufficient infrastructure, illegal connections, poor maintenance and inadequate access to limited supplies (Worldwatch Institute, 2007).

Urban sprawl is also damaging the environment and affecting the livelihood of communities located in the immediate vicinity of cities by covering land that could otherwise be utilized for agriculture, tourism or recreational activities. For example, significant damage has been caused to environmentally sensitive areas around the following cities: São Paulo, Brazil; San José, Costa Rica; Panama City, Panama; and Caracas, the Bolivarian Republic of Venezuela (Economic and Social Commission for Asia and the Pacific et al., 2011).

Science, technology and innovation for spatial planning

Cities can accommodate growing populations in accordance with their land use, spatial design and density plans by combining several regulatory instruments. Table 2 provides examples of regulatory instruments for land use and spatial planning that can contribute to sustainable growth in cities.

Information and communications technologies play a key role in enabling and enforcing regulatory measures such as the above for the spatial planning of urban areas. For example, city planners can use simulation, modelling and visualization technologies to aid long-term planning and investment decisions (Dodgson and Gann, 2011). Geospatial tools can identify infill zones such as abandoned land or buildings that are suitable for redevel-

Table 2. Regulatory instruments for land use and spatial planning

Urban growth boundaries	Establishing clear limits to any form of building development around cities to limit urban sprawl; creating green corridors that protect existing ecosystems.
Land-use regulation	Introducing zoning regulation that prioritizes the development of previously developed – brownfield – land in the inner city over greenfield development at a citywide level. Closely linked to infill development, which refers to new construction within existing urban areas as opposed to urban expansion.
Promotion of mixed-use settlements	Designing neighbourhoods that include residential, service and local employment elements and are adequately covered in terms of basic services and infrastructure.
Density regulation	Providing minimum rather than maximum density standards; establishing clear density standards at a citywide level, such as floor area ratios,[2] in support of compact city development with a hierarchy of higher-density mixed-use clusters around public transport nodes.
Density bonus	Providing development bonuses that allow increased development rights, for example extra floor area with respect to standard planning regulations, for green projects that support citywide and local sustainability.
Special planning powers	Establishing urban development corporations or urban regeneration companies to promote and enable green projects.
Vehicle and traffic regulation	Introducing regulation for vehicle types, emission standards, speed limits and road space allocation that favours green transport, especially green public transport.
Parking standards	Providing maximum rather than minimum parking standards; reducing private automobile parking standards to a minimum, for example less than one automobile per household, especially in areas of high public transport accessibility.
Car-free developments	Providing planning incentives for car-free developments in higher-density areas with high public transport accessibility.
Minimum emission standards	Regulating minimum carbon-emission and energy-efficiency standards at the local level for buildings and vehicles.

Sources: United Nations Environment Programme, 2011; and Wheeler, 2008.

2 The floor area ratio is the most common density measure for planning purposes and is calculated by adding all the area of residential and business floor spaces and dividing it by the entire area of the development site (United Nations Environment Programme, 2011).

Box 3. Oman: Use of information and communications technologies for spatial planning

Information and communications technologies are increasingly being used in the form of geospatial applications in urban areas. Oman, in partnership with the International Society of City and Regional Planners, is developing a planning information system as part of its national spatial strategy. The system will become the central hub for all types of spatial data in the country, supplied by data from multiple national institutions. It will be complemented by a capacity-building programme in order that the system may be managed locally. Data will be linked to a map and the system will help access information on serviced land in Oman, such as with regard to utility networks, by overlaying different types of data.

Source: Suri, 2013.

opment and plan for their reallocation. Geospatial data can be used for scenario planning to envision future urban development that is consistent with a city's historic and current development path. Geospatial tools can also combine statistical information with satellite maps to run analyses such as on poverty targeting, urban infrastructure and transport planning and socioeconomic analyses such as crime statistics and the tracking of illegal settlements (UNCTAD, 2012a). In Bangkok, Thailand spatial data is used to analyse flood risks and improve the security of tenure in informal settlements. box 3 provides an example of the use of information and communications technologies for spatial planning in Oman.

Policy considerations

Developing spatial plans in the early phases of urbanization based on the political consensus of stakeholders, support from the private sector and outside assistance or investment can prevent the later waste of financial resources. Spatial plans are the strategic decisions of cities on spatial design and density that take into account population growth estimates, topographic characteristics and the capacity to implement related changes (UN-Habitat, 2012c).

The main spatial design options to accommodate population growth are as follows:

- Increasing density
- Extending the city
- Multiplying nodes by building satellite towns

Spatial planning can optimize the density of cities according to urban development goals and enable public services that achieve economies of scale. Increasing urban density can save costs arising from the provision of basic services to scarcely inhabited and extended city outskirts. It can also be beneficial in terms of encouraging public transport. For example, high density in central Hong Kong (China) allows 85 per cent of all trips to be made by using public transport (UN-Habitat, 2012c).

Increasing density can be a solution for physical limitations on urban growth, as is often seen in city-States such as Singapore or cities of small island developing States. Academic research has shown that higher population density in cities leads to more face-to-face interactions between citizens, which results in a superlinear acceleration of innovation, wealth creation and productivity. At the same time, too much density is also not advisable since it can result in the overuse of public infrastructure that will depreciate early. Research in 247 large counties in the United States identified that public spending first decreases with higher density but can increase after a tipping point (UN-Habitat, 2012c).

Densification policies can be coupled with innovative models of urban development. On high-value public land that is covered by slums, local governments can implement

Box 4. Innovative spatial design strategies in practice

Portland, United States, is a city that experiences relatively stable population growth and its spatial design was therefore based on increasing density. The city established an urban growth boundary and prioritized infill development by regenerating brownfield areas and replacing degraded buildings with new ones that had a higher capacity.

Cape Town, South Africa, adopted a densification policy in February 2012 in order to address challenges of rapid low-density development such as long travel distances, loss of agricultural land and operational inefficiencies (City of Cape Town, 2012). The policy supports the increase of average gross density through the subdivision or consolidation of plots, in order to make room for redevelopment at higher densities. Objectives include the efficient use of infrastructure, development of public transport, protection of the environment, revitalization of city life through mixed land uses and the development of attractive and safe urban environments.

If a city grows faster than 1 to 2 per cent per year, infill development may not be sufficient and extending the city at its fringes may be required. The Commissioners' Plan of 1811, the original design plan for the streets of Manhattan, was a far-sighted extension plan that foresaw such gradual expansion.

For cities with even higher growth rates, establishing satellite towns in the vicinity of major cities may be an appropriate solution, as envisaged in the Comprehensive Plan 1999–2010 of Shanghai, which includes nine satellite towns that will receive migration from rural areas. Moreover, building strong links between cities within a region, as occurs in Seoul, Republic of Korea, can lead to new possibilities for cooperation such as joint financing, sharing infrastructure with other towns and joint regional governance mechanisms to manage transport, waste and water resources.

Sources: Gill and Bhide, 2012; and UN-Habitat, 2012c.

slum-upgrading programmes for the benefit of all stakeholders. They can propose improved housing for occupants of slums in higher modern buildings on parts of the same land. The private sector can construct these buildings free of cost in return for development rights in other zones of the city. As a result, the city can upgrade infrastructure at no cost, optimize land use and create open space on valuable land with the help of vertical resettlement (Gill and Bhide, 2012).

Spatial plans can include regional integration aspects. Cities are located in regions and should undertake metropolitan strategic planning for integration with their regions and not only in the jurisdiction area of the metropolitan zone to which they belong. Various spatial design strategies can be implemented depending on the needs of the specific urban area. box 4 provides examples of cities that have implemented innovative spatial design strategies.

Spatial planning that includes public transport networks from the very beginning is a key factor in helping to prioritize public transport. Cities can be designed by locating mixed-use developments and jobs near intermodal public transport connections, thereby minimizing dependence on automobiles and reducing the distance that people need to travel. Spatial design should plan for integrating the incoming population into the public transport system. Each mode of public transport requires a minimum density to be economical, and the choice between buses, trams and light rail may be identified accordingly. For example, a density of 20 persons per hectare generally makes urban zones dependent on automobiles. As of 60 persons per hectare public transport starts to be economical and as of 150 persons per hectare walking and bicycling may be considered practical transport modes.

III. b. Mobility

Automobile travel as an inefficient mode of transport

Population growth and rapid migration to cities make it harder to predict and plan potential public transport routes that can answer the needs of inhabitants. As mentioned in the previous section, in low-density cities it is more difficult to introduce cost-efficient public transport due to increased distances and a decreased number of people per trip. It takes years to reverse transport strategies that do not answer the needs of citizens, due to the cost and scale of underlying investments. Investing in automobile infrastructure causes lock-in that multiplies investment needs for a later shift to means of public transport. Moreover, low population density results in higher per capita transport energy consumption.

Mobility based on fossil fuel-powered automobiles is increasingly becoming a liability for the world's cities. In many cities, automobile ownership is too costly for the majority of inhabitants, for example in Nairobi, Kenya, where only 1 in 7 inhabitants has an automobile (UN-Habitat, 2012c). Prioritizing automobile travel excludes most of the population from adequate means of transport. Automobiles are the most spatially inefficient transport mode, as they can carry only 2,000 people per hour on a 3.5 metre-wide lane in the city, in comparison with 20,000 people via a single-lane bus rapid transit system (Asian Development Bank and German Agency for International Cooperation, 2011).

Traffic congestion causes economic damage to cities. For example, Bangkok is losing 6 per cent of its gross domestic product to congestion, a percentage comparable to the tourism sector of the city, which produces 7 per cent of the gross domestic product. In Mexico City, Mexico the average daily commute time is 2.5 hours, creating a loss of 2.6 per cent of gross domestic product (Glaeser, 2011). The cost of traffic congestion is 10 per cent of the gross domestic product of Lima, Peru and 3.4 per cent of the gross domestic product of Buenos Aires, Argentina (Economic and Social Commission for Asia and the Pacific et al., 2011). Most of this economic loss comes from the value of the time lost by drivers and passengers. Moreover, congestion worsens carbon emissions and air pollution, resulting in negative effects on health.

Automobile travel requires vast land for roads and parking areas. New sprawling suburbs have high infrastructure costs and cause the loss of productive agricultural land as well as the loss of urban land to asphalt. Due to their hard surfaces, roads also make the absorption of storm-water more difficult.

While fossil-fuel powered automobile travel is increasingly becoming less sustainable, public transport is also facing the challenge of lack of interest. In particular, public transport projects that are undertaken without sufficient public consultation are likely to misinterpret local demand on transit routes. At the same time, despite its drawbacks, automobile ownership is continuously increasing. The global private automobile fleet is expected to grow from 1 billion in 2002 to 2 billion in 2022, mainly driven by motorization in Asia. In Delhi, India, it is estimated that the number of vehicles in 2030 will be five times that of 1990 levels (Asian Development Bank and German Agency for International Cooperation, 2011). Automobiles are seen as a status symbol that ensures convenience and personal freedom of travel and citizens are biased towards using this mode of transport.

Science, technology and innovation for avoiding congestion and improving urban mobility

Mobility solutions should not only focus on supplying infrastructure but on answering the demand for infrastructure. They should be centred on the movement of people and goods instead of the movement of vehicles and deal with the causes of mobility issues rather than merely the symptoms. They are thus directly linked to spatial planning, as spatial plans dictate mobility options and whether or not cities may be walkable. Spatial planning that takes the needs of urban transport into consideration from the beginning is a key factor in helping to prioritize public transport. Cities can make streets more walkable for pedestrians through the provision of dedicated lanes and suitable street crossings and by minimizing pedestrian bridges. In addition, bicycling may be encouraged through the provision of dedicated lanes and low-velocity streets. Ultimately, mobility issues cannot be solved only by science, technology and innovation. Social aspects and driver education need to be combined with technological solutions.

Cities can make use of technology to switch to cleaner fuels in transport vehicles, implement various public transport systems and enable regulatory measures that control and improve the flow of traffic. Although there are a large variety of science, technology and innovation solutions that can address congestion and high levels of fuel consumption, many are not feasible for implementation in developing countries due to their cost. It is therefore imperative for cities in developing countries to integrate high and low technology to provide mobility solutions for citizens.

Bus rapid transit has lately emerged as a popular urban transit solution and is being introduced across the world, including in cities of least developed countries, with successful results in reducing congestion, air pollution and travel time, as shown by the examples in box 5. Bus rapid transit is a dedicated-lane bus system with signal priority at intersections, prepaid fares and fast-boarding platforms. While bus rapid transit is a relatively low-cost method of providing public transport, it needs to be viewed in the larger context of urban mobility, ensuring the development of infrastructure for bicycles and pedestrians, as well as integration with other means of public transport.

Science, technology and innovation, especially information and communications technologies, enable innovative regulations to improve mobility in growing urban areas. Information and communications technologies can inform citizens with regard to mobility choices they are about to make through algorithms that predict traffic flow one hour ahead of time with up to 80 per cent accuracy. Providing data on the impact of journeys to urban citizens allows them to adjust their mobility choices. In addition, information and communications technologies can analyse route patterns in new ways so that bottlenecks can be addressed through the most efficient investments in public transport. For example, information and communications technologies are key to understanding the reasons behind phantom traffic jams, through which a small disturbance in the flow of vehicles during heavy traffic leads to a traffic standstill. Information and communications technologies models are being developed to explain the reasons for such traffic jams so that roads can be designed to prevent them.

Box 5. Bus rapid transit in developing countries

The city of Curitiba, Brazil, pioneered public-transport oriented spatial design based on bus rapid transit, with a system that uses dedicated lanes, allowing it to function as a low-cost subway. The system also has a special design for stops that facilitates quick payments and easy transfers. Starting at 25,000 daily passengers in 1974, the bus rapid transit system grew to serve 2.2 million passengers in 2007. Although the city's population grew from 400,000 to 2 million in 50 years, it did not suffer from additional pollution or congestion.

Curitiba's system was the first of its kind in the world and similar systems were later introduced in more than 83 cities globally. The sharing of knowledge between cities has greatly contributed to the increase in the number of such systems. For example, a presentation in 2004 by the mayor of Bogota, Colombia, describing the success of the bus rapid transit system in the city motivated the conceptualization of a similar project in Ahmedabad, India.

Since its launch in 2009, the system in Ahmedabad has been expanded to cover a distance of 67 kilometres, with 136 buses transporting 130,000 passengers per day. An additional 21 kilometres is expected to be completed by 2015 in phase two of the project and a further 27 kilometres is planned for phase three. The system in Ahmedabad is India's most extensive and successful bus rapid transit system. It gives priority to buses at junctions and uses segregated lanes, level passenger boarding, external ticketing and real-time arrivals information to reduce traveling times and ensure better service compared with conventional bus services. As a result of factors such as higher efficiency and increased ridership, it is estimated to have increased the travel speeds of buses by 20 to 60 per cent and achieved carbon dioxide emissions savings of 92,000 tons in 2010.

Sources: UN-Habitat, 2012c; and Worldwatch Institute, 2007.

Box 6. Information and communications technologies tools for mobility

The city of Dublin, Ireland, is cooperating with International Business Machines to identify and solve the root causes of traffic congestion along its public bus network. Information-sharing between partnering local governments and universities is resulting in the use of 3,000 data sets to identify new ways for Dublin's transport, energy and water systems to work in an integrated manner. Such data is also being made available to the local community, which is encouraging the development of innovative information and communications technologies tools. Data from a citywide network of sensors is being integrated with geospatial data so that city officials can monitor and manage the bus fleet in real time.

The same business model is being piloted in Abidjan, Côte d'Ivoire, where the analysis of global positioning system data to understand mobility patterns has helped identify four new bus routes and optimize several others. As a result, citywide travel time has decreased by 10 per cent and there is less need for informal bus services.

Singapore is using geospatial data and information collected from transport tickets to plan future transport services and recommend routes and to provide additional services such as the location of taxicabs during rain. Singapore also uses mobile telephone data to map current traffic situations and propose alternate travel routes to drivers, in order to reduce congestion.

In cooperation with the World Bank, the non-profit organization OpenPlans has developed a real-time traffic crowdsourcing application for Cebu City, the Philippines. Once deployed, the application will collect real-time traffic data from 500 telephones deployed in taxicabs. This data will provide citizens with up-to-date information about traffic conditions and the historical archive will help inform planners and transport engineers.

Sources: Robinson, 2012; OpenPlans, 2012; and Worldwatch Institute, 2012.

There are various applications for information and communications technologies, such as traffic management systems, open access and multimodal trip planning services. Several cities including New York City and San Francisco in the United States and London, United Kingdom of Great Britain and Northern Ireland, are providing open access to core city data and enabling the development of applications that help citizens make more informed travel decisions, such as finding the closest bicycle-share or car-share station (Worldwatch Institute, 2012). Information and communications technologies may also be used by citizens to plan a door-to-door journey by integrating walking and different modes of public transport such as bicycles, buses, trains and automobile-sharing. If citizens are informed that it is less economical for them to drive, for example via applications they can access from their mobile telephones, they will be more inclined to use public transport. Online commercial tools that provide multimodal routing services, such as Open Trip Planner (www.opentripplanner.org) and Moovel (www.moovel.com), are already available in the United States. Finally, as shown in the examples in box 6, information and communications technologies-related tools that combine geospatial mapping with crowdsourced data from mobile telephones or transport tickets can play a role in relieving traffic and optimizing transport efficiency.

Policy considerations

Avoid, shift, improve

Mobility in cities can be improved through the combination of three strategies, namely avoid, shift and improve, which can transform behaviour and influence technology choices (Asian Development Bank and German Agency for International Cooperation, 2011 and United Nations Environment Programme, 2011). The avoid strategy is for reducing journeys and avoiding the need to travel. Shift represents a move to more environmentally friendly modes of transport. Improve refers to the improvement of energy efficiency in the transport vehicles used. The avoid–shift–improve model is based on a combination of incentives and disincentives and the use of technology. For example, regulators can aim to overcome automobile dependence through a combination of measures such as the following (Wheeler, 2008):

- Traffic-calming techniques to slow automobile traffic and create more humane urban environments better suited to other transportation modes.

Box 7. Intermodal transport planning

In developing countries, intermodal transport services are contributing to social inclusion. Several cities in Latin America – including La Paz, the Plurinational State of Bolivia; Rio de Janeiro, Brazil; and Medellín, Colombia – are implementing cable car and escalator projects to integrate poorer outskirts, located on steep landscapes, with city centres. The cable car, also known as a gondola lift, is a transport system that travels up and down a mountainside in which cabins are suspended on a continuously moving cable driven by a motor at one end of the route. Cable cars dramatically reduce daily commutes for citizens living in areas that are difficult and costly to access with traditional public transport services.

Free cable cars and escalators were installed in Medellín in order to provide access to the city centre from the most isolated neighbourhoods. Before, inhabitants in these neighbourhoods had to commute 2.5 hours to reach the city centre. The cable cars now provide access to more than half a million citizens. In addition, a network of escalators has reduced the time needed to access one of the poorest sections of the city by half an hour.

Sources: Danish Architecture Centre, 2013; and Vuchic, 2008.

- Improved transit, such as by prioritizing walking and bicycling as genuine options to automobile use.
- Improved land use, for example by establishing urban villages that are self-sufficient in terms of employment and recreational activities and thereby reduce the need to travel by automobile.
- Growth management to prevent sprawl and redirect development into urban villages.
- Economic incentives, such as better taxation of transportation.

Traffic-calming techniques include altering road layout and design such as by narrowing entries to streets, planting trees and employing variable street surfaces, speed-restricting devices and visual signs for cautious driving. On busier roads, traffic calming may be achieved by reclaiming road space for other uses and reducing the speed of traffic. Traffic-calming measures can reduce congestion, thereby saving fuel wasted in traffic jams and preventing the loss of time.

Intermodal transport

Traffic calming should be implemented in coordination with schemes that make public transport more attractive in the same areas by combining land use and intermodal transport strategies. Cities can reclaim road space in parallel to improving intermodal public transport networks such as rail links. Modern light-rail systems that accompany pedestrian zones in city centres reduce the need for automobiles. Intermodal transport networks include mass rapid-transit systems surrounded by high-density land-use developments. Science, technology and innovation can help in the process of planning the integration of modes of transport such as walking, public transport, bicycles, taxicabs and automobiles, for example through park-and-ride systems. A transit-oriented development approach concentrates residential and commercial developments within walking distance of public transport stations to maximize the number of passengers. Intermodal transport services can contribute to social inclusion by combining a wide variety of science, technology and innovation-related solutions, as shown by the examples in box 7.

Regulatory mechanisms and incentives

Cities can accompany public transport infrastructure investments with innovative regulatory mechanisms and incentives. Optimizing urban mobility entails achieving the best balance between different modes of transportation (Vuchic, 2008). Regulations such as incentives for public transport use and disincentives for automobile use can be introduced in order to reach a compromise between personal freedom to choose transport modes, social optimum modes that minimize travel costs and the time for travellers in the urban area and environmental concerns such as the need to reduce air pollution. Measures can include both soft incentives and hard regulation (Banister, 2008 and Vuchic, 2008).

Traffic demand management regulation more suited to higher-income countries includes low-emission zones in city centres and increased fuel taxes, road pricing and parking-zone charges. Road pricing may be a solution for traffic calming in larger cities, as shown in box 8, but the investment in the technical infrastructure necessary to operate it, such as cameras that take photographs of license plates, road signalling and sensors that automatically deduct tolls from units inside vehicles, may not be worthwhile in smaller cities as the scheme may not raise enough funds to cover operational infrastructure costs. Political acceptance by the public may be a more significant issue and road pricing also requires privacy and data protection measures.

Possible measures and incentives vary across countries and include traffic calming, the promotion of walking, bicycling and automobile-sharing programmes and the reallocation of open space to public transport. One important element of success for such schemes is to gather public support by engaging stakeholders and communicating and sharing information.

When launching bicycling incentives such as electric-bicycle promotion campaigns, it is just as important to establish a legal framework on the status of such vehicles within city traffic as it is to make the vehicles available and establish the physical infrastructure. For example, bicycle-sharing programmes, already available in around 200 cities worldwide, require infrastructure such as parking spaces and tracks and a legal framework that protects the rights of cyclists. Otherwise, users may not feel safe when bicycling in the city.

III. c. Resilience against natural hazards

High exposure of urban areas to natural disasters

Cities in developing countries undergoing unplanned urbanization are facing the risk of high human and economic losses from natural

Box 8. Regulatory measures to avoid congestion

Road pricing in Singapore and London

Singapore was one of the first cities to apply physical, regulatory and pricing measures to coordinate the use of different modes in a balanced intermodal transport system. The city pioneered road pricing in the city centre to reduce congestion. In parallel, it built a state-of-the art subway system and optimized its bus system with many transfer points and major terminals at subway stations. The Land Transport Authority comprehensively plans and coordinates all modes of mobility in Singapore.

London has also implemented congestion pricing in the city centre. While the scheme faced resistance at the beginning, it gained more public acceptance after reducing traffic levels by 15 to 20 per cent and congestion by over 20 per cent in the first three years of operation. Milan, Italy and Stockholm, Sweden have also implemented similar measures in their city centres.

Regulation and programmes that encourage walking and bicycling

London has recently introduced a rewards system through which users can accumulate points as they walk or bicycle and redeem them to obtain different kinds of services such as haircuts and shopping. A mobile telephone application uses the telephone's global positioning system signal to track movement (see www.recyclebank.com). In Switzerland, a bicycle-to-work initiative encourages participants to commute up to 50 per cent of the time by bicycling and gain the chance to win prizes such as holiday weekends.

Combination of measures

Cheonggyecheon, a river running through downtown Seoul, was used as a sewer in the 1950s and then covered by an elevated motorway in the 1970s. The motorway became very congested in the 1980s and at the same time created an urban fault line hampering the livelihood of the middle of the city. In 2003, the metropolitan government removed the motorway, restored the river and turned the area into a tourist attraction, creating 300,000 jobs and also providing environmental benefits. The project was accompanied by improvements to the city's public transportation system, which was made possible through a consensus-based decision-making model that promoted intermodal transit, incorporating dedicated bus lanes and a unified fare system. The key to success was the formation of a consultative group, the Citizens Collaborative Council, which ensured that no party would be disadvantaged by the proposed transport solutions.

Sources: Banister, 2008; UN-Habitat, 2012c; and Vuchic, 2008.

hazards. The effects of climate change are exacerbating the issue by instigating more frequent urban climate-related hazards. On the one hand, more and more people are moving into vibrant metropolises that are situated on or close to the coast. On the other hand, such cities are increasingly at risk due to climate-change induced natural disasters, especially informal settlements on city fringes and lower-quality buildings that are the products of rapid unplanned urbanization and represent a resilience issue for developing countries, although they play an important role in terms of meeting the shelter needs of the urban poor. Low construction standards and poor drainage result in serious vulnerability to natural risks.

Hurricane Sandy, which made landfall in the United States in October 2012, only one year after Hurricane Irene, served as a reminder of the dangers that cities face. New York City is one of several global cities at risk due to the fact that it is surrounded by water, and the precautions such cities can take against risks such as rising sea levels are limited. In developing countries, urban areas with large populations situated along coastlines and exposed to climate-related hazards include Guangzhou and Shanghai in China, Alexandria in Egypt, Kolkata and Mumbai in India and Ho Chi Minh City in Viet Nam.

In the past 20 years, floods have become the most frequent natural disaster. The average annual number of floods has increased at a higher rate than any other natural hazard (Green Media, 2012). The most important hazards that will become more frequent and affect urban zones due to increased climate variability include rising sea levels, storm surges, extreme rain, heat waves and the heat-island effect, water scarcity and air pollution.

City managements in lower and middle-income countries face challenges in developing and maintaining disaster risk management strategies. They lack an understanding of risk and methodologies to assess risk, particularly with regard to urban growth areas and informal settlements. Disaster and climate-change risk is not a priority due to the lack of financial resources and institutional capacity. Finally, few have procedures to mainstream disaster risk management and climate change adaptation into urban planning or monitoring of a city's risk reduction performance (Thapa et al., 2010 and Dickson et al., 2012).

Science, technology and innovation for monitoring and managing natural hazards

A resilient city is one that can predict and react to natural disasters in order to minimize the loss of lives and disruption to city utilities and services. The use of technology plays an important role in improving city resilience against natural hazards. Several cities in developing countries are already using science, technology and innovation for this purpose in various forms and combinations. The most common applications are hazard monitoring and surveillance, information and communications technology-based city operations centres, geospatial tools and large-scale infrastructure such as storm-water tunnels and barriers.

Some of the benefits of designing cities that are compact and dense were noted in chapter III. a. Higher density also requires stronger infrastructure that is resilient to natural disasters. Otherwise, increasing density will only exacerbate the exposure of cities to such risks. Science, technology and innovation play a key role in informing urban planners of where to build cities to prevent risks brought about by climate change or proximity to a coast.

Hazard monitoring and surveillance techniques can be beneficial for early warning and land-use planning. For example, Mumbai has 35 automatic weather stations that measure real-time rainfall intensity and flow gauges on the Mithi River to monitor water flow. Chacao, a subdivision of Caracas, has a wireless early-warning system that connects civil protection and environmental institutions with cameras that monitor four river channels crossing the city. The city also provides online real-time hazard information to citizens (United Nations Office for Disaster Risk Reduction, 2012).

Information and communications technologies that combine data from different departments can enable cities to monitor risks in an integrated manner. Rio de Janeiro established an operations centre by partnering with International Business Machines that provides real-time integrated data from 30 agencies on transport, energy, weather and emergency services. The centre has improved reaction times and coordination between agencies. For example, when a 20-storey building collapsed in January 2012, the centre employees alerted the fire and civil defence departments, asked the gas and electric companies to shut down service in the area, closed the subway stop, blocked the street, dispatched ambulances, alerted hospitals, sent equipment to clear the rubble and deployed civil guards to secure the site. The centre also kept citizens informed over the Internet via Twitter (Singer, 2012).

Information and communications technologies in the form of geospatial tools may be beneficial for assessing disaster risk and disaster recovery. For example, such tools were used by the International Organization for Migration in Haiti after the January 2010 earthquake to identify appropriate buildings and sites that could be used as shelters (UNCTAD, 2012b).

In Malaysia, a multi-use tunnel was constructed for storm-water management and road traffic in Kuala Lumpur in response to a serious problem of flooding and a need to divert large quantities of water from the city. The high-technology tunnel has two layers that can be used in three modes depending on the intensity of water flow, as shown in box 9. In the first mode, the tunnel is used for road traffic on an everyday basis. In the second mode, when there is a moderate storm, one layer is used for road traffic, while the other layer diverts storm-water. In the third mode, in the event of heavy flooding, the tunnel is closed to traffic and both layers are used to divert water to holding reservoirs. In some cities, lower-technology solutions such as insulating subway entrances to prevent storm-water from flowing in may also be useful in improving resilience.

Policy considerations

Cities need to invest proactively in infrastructure in order to adapt to natural hazards. As oceans grow warmer and sea levels rise due to the effects of climate change, cities will have to continuously revise their risk assessments and adapt their infrastructure. Many of the policies mentioned in previous sections can help increase resilience. For example, improved buildings can reduce human losses and spatial plans can take into account the risk of natural disasters. In addition to the necessity to save lives when disasters occur,

Box 9. Malaysia: Storm-water management and road tunnel

Source: Suri, 2013.

adaptation has a financial dimension. Investing into adaptation earlier can reduce the scale of economic losses and the financing required to repair damage. Considering that the economic damage that New York City suffered due to Hurricane Sandy is estimated at $20 billion, the human and economic costs of inaction in less-prepared cities in developing countries can be enormous. The cost of repairing damage from climate change-related flooding is estimated at 2 to 6 per cent of regional gross domestic product in Bangkok, Ho Chi Minh City and Manila, the Philippines (UN-Habitat, 2012c).

Cities can mainstream adaptation into urban planning. Possible measures include building new developments outside of risk areas, upgrading informal settlements and addressing the lack of infrastructure and the degradation of the environment (UN-Habitat, 2012c).

Box 10. Mainstreaming adaptation into urban planning and urban risk assessments

The eThekwini Metropolitan Municipality, South Africa, integrated adaptation planning into its general urban planning and development framework, including adaptation at both municipal and community levels. In 2006, a climate change-related impact assessment was prepared, following which a climate change adaptation strategy was put together to identify key interventions for such situations as an urban heat-island effect or a rise in sea level. The strategy is constantly being extended, to include reforestation projects and water, health and disaster management. An assessment tool was also developed to evaluate and compare policies and mainstreaming initiatives were undertaken, such as the creation of a climate protection branch within the municipality.

Sorsogon City, the Philippines, is a city with 152,000 inhabitants that is open to the Pacific Ocean to both the east and west. The city faces an average of five tropical storms each year. In cooperation with UN-Habitat, the city conducted a vulnerability and adaptation assessment, as a result of which it directed urban development plans to safer inland areas. Settlements in high-risk coastal zones will be incrementally relocated through local shelter relocation projects or voluntary resettlement. Inland areas will be incentivized through infrastructure investments and the construction of new residential units and new industrial sites for employment.

Sources: United Nations Environment Programme, 2012b; and UN-Habitat, 2012c.

Integrating spatial planning with infrastructure can also improve resilience. Risk assessments are tools that can mainstream resilience and preparedness into spatial planning. The tools map the areas that are most vulnerable to hazards and help adjust land use and development strategies. Some cities or city areas are more vulnerable than others and risk assessments make it possible to demarcate and provide extra safety for these areas. Regulatory measures based on risk assessments can help city planners forecast and guard against future developments to avoid the risk of disaster.

For example, Dhaka, Bangladesh, accompanied infrastructure measures such as reinforcing river and canal embankments with efforts to prevent the encroachment of buildings on the vicinity of canals for improved protection against major floods. Similarly, regulatory measures based on risk assessments can guide future developments to avoid disaster risk. For example, Singapore requires new land reclamations to be at least 2.25 metres above the highest level of recorded tides (UN-Habitat, 2012c).

The United Nations Environment Programme, UN-Habitat and the World Bank, with the support of Cities Alliance, a global partnership for urban poverty reduction and the promotion of the role of cities in sustainable development, have developed a standardized risk assessment tool to assess urban risk and identify areas and populations that are most vulnerable, typically those living in informal settlements. The tool provides a framework for both qualitative and quantitative assessments that enhance a local government's capacity to identify hazards that may arise from disaster and climate change-related risks. The tool assesses the exposure and vulnerability of specific assets and populations, analyses institutional capacities and data availability and quantifies city vulnerabilities through the application of a baseline-benchmarking approach to assess progress over time and space (UN-Habitat, 2012c). box 10 provides examples of the use of urban risk assessments to improve disaster resilience.

IV. Sustainable urban resource management

Energy, water and food consumption in urban areas in developing countries is rapidly rising in parallel with growing incomes, putting pressure on limited resources. At the same time, higher consumption leads to higher amounts of waste. Long-term urban sustainability depends on technologies that conserve resources and minimize waste. Fortunately, science, technology and innovation options are abundant to respond to the needs of cities, and this chapter looks at ways in which they can help improve resource management in an urban setting. Applications include replacing public urban infrastructure with more efficient options such as lighting with light-emitting diodes, tracking public and private resource consumption and detecting resource leakages and theft, as well as the smart management of resources.

IV. a. Energy for cities

Heavy energy consumption in cities

Cities are major consumers of energy and therefore vulnerable to energy scarcity and energy price increases. Adequate energy supply to growing urban zones is increasingly becoming a challenge. It is largely expected that in cities of emerging countries, demand will continue to exceed capacity in the coming years. This raises questions on how to improve energy efficiency, regulate the electricity market, involve the private sector and revise the mechanism of subsidized energy pricing, among others (GlobeScan and McCormick Rankin Corporation McLean Hazel, 2007).

Large centralized energy production facilities require costly distribution systems that are vulnerable to misuse and natural disasters. In rapid-growth urban environments, low-density sprawl leads to a rapid increase in per capita distribution and line-maintenance costs. In many countries, distribution lines are also subject to siphoning. Moreover, centralized energy production follows a supply-driven approach, prioritizing selling energy over saving energy, creating no incentives for energy-efficiency practices that can reduce consumption. With rapid urbanization, providing access to electricity in a centralized manner for growing cities will grow more challenging.

Science, technology and innovation for urban energy conservation

Various clean low-carbon energy technologies compatible with use in cities are available to improve energy efficiency and enable the transition to renewable energy sources in cities. Table 3 gives examples of innovative energy technologies that may be considered for densely populated urban areas (UN-Habitat, 2012b). Each technology has market-related, technical, institutional, political, social and environmental challenges on the way to mainstream use. Cost competitiveness with fossil-fuel energy sources is a major issue. The technical limitations of clean energy technologies such as the battery efficiency of solar photovoltaic technology and issues such as the lack of infrastructure or trained workers and the lack of public acceptance also need to be overcome (Organization for Economic Cooperation and Development, 2012).

Table 3. Energy technology options

Solar	Solar thermal storage	Solar thermal power plants gather heat from the sun and boil water into steam to generate electricity by running a turbine. The energy can be temporarily stored and used when needed during peak hours.
Hydro	Micro hydropower systems	Micro hydropower systems can complement intermittent wind or solar energy by pumping water to an upper reservoir when excess energy is produced and letting it down when more energy is needed.
Kinetic	Converting kinetic energy from walking	Purpose-made slabs installed on pavements can harvest renewable energy from footsteps. The technology, developed by Pavegen, converts kinetic energy to electricity that can be stored and used for powering off-grid applications such as pedestrian lighting, wayfinding solutions and advertising signage (see www.pavegen.com).
Heating	District heating	District heating systems can distribute heat and power from a centralized location. The heat often comes from combined heat and power plants and can therefore achieve higher efficiencies and lower emissions than separated heat and power production.
Electric grids	Smart grids	Smart grids are intelligent electric systems that have the following three major components: demand management; distributed energy generation; and transmission and distribution grid management.
	Vehicle-to-grid	Once the number of electric vehicles in urban traffic reaches a critical mass, it will be possible to benefit from bidirectional connections between the batteries of such vehicles and smart electricity grids. At peak times for the grid, if a vehicle is not in use, it can feed energy from its battery back into the grid.
Lighting	Light-emitting diodes	Partnerships between information and communications technologies networking and lighting companies are making smart, networked information and communications technologies-based lighting with light-emitting diodes possible. Light-emitting diode technologies can generate relatively effortless and immediate savings in electricity.
Information and communications technologies	Carbon-footprint applications	Information and communications technologies-related applications can help encourage more sustainable energy consumption patterns by individuals, for example by proactively tracking and distributing information on personal carbon footprints and consumption patterns.

Sources: Mitchell and Casalegno, 2008; Robinson, 2012; Totty, 2011; United Nations Environment Programme, 2011; UN-Habitat, 2012b; and Villa and Mitchell, 2010.

Information and communications technologies play a critical role in many of the options listed in table 3. They enable the automated, or smart, management of electricity generation and distribution, leading to lower consumption and reductions in carbon emissions (Souter and MacLean, 2012). The large-scale use of information and communications technologies for energy management in urban areas in the medium to long term will have a profound impact on consumption patterns. The possibility for households to be informed of patterns of consumption and to compare them is likely to induce behaviour that conserves energy.

Policy considerations

Although energy policy is a national issue, cities in developing countries can lead the way in leapfrogging to advanced renewable energy sources and efficient transmission

Box 11. Regulatory support for renewable energy

The Government of India formulated a solar cities programme in order to reduce demand for fossil-fuel energy sources by at least 10 per cent in sixty cities between 2007 and 2012. The programme allocates financial assistance to local governments that show commitment to implementing renewable energy projects through master plans, governance structures and project proposals.

The authorities of the city of Rizhao, China, provided strong political and financial support for the development of a local solar panel industry. As a result, solar technology became widespread, with 99 per cent of Rizhao's households in the central districts using solar water heaters and almost all traffic signals, street lights and park illuminations powered by solar energy. In addition, solar cooking facilities are common in households and solar panels are used to heat greenhouses, reducing overhead costs for farmers.

Shanghai envisages a total of 13 wind farms with an installed capacity of 2.1 gigawatts by 2020, which will provide electricity to more than 4 million households. The plan includes China's first offshore wind farm, which is also the world's first major wind farm outside of Europe. It will provide around 1 per cent of the city's total power production.

In several cities across Eastern Europe that had older district heating infrastructure, modernization efforts driven by European Union directives as well as national energy programmes are taking place that could generate 15 to 30 per cent savings in heating energy. Since district heating can use renewable energy sources such as biomass, geothermal and solar energy with biomass, it harbours great potential for countries that already have infrastructure for this technology in place.

Sources: United Nations Economic Commission for Europe, 2011; UN-Habitat, 2012b; and UN-Habitat et al. 2009.

technologies through local regulations, incentives or subsidies, as shown in the examples in box 11. Cities can pioneer the transition to renewable energy by making use of national incentives as well.

The use of new technologies in cities can reduce the burden of rapidly increasing energy demand, as shown in the examples in box 12. For instance, implementing smart grids increases the flexibility of energy production and distribution by making it possible for decentralized individual energy producers, for example households with solar panels on their roofs, to feed surplus energy back into the electricity grid (Cosgrave, 2012). Smart grids provide real-time information to utility companies with the help of sensors, enabling them to respond to changes in power supply, demand, costs and emissions and to prevent major power outages. Smart grids can drive cross-sectoral cooperation, enable decentralized energy generation and encourage more efficient energy consumption patterns.

Smart grid investment should be prioritized in large cities that face frequent peaks in electricity demand and also have a high potential for decentralized generation capacity, such as suitable weather conditions for installing solar panels on buildings. Local governments can establish regulatory frameworks for local energy marketplaces that make use of smart-grid technology. These marketplaces would make it possible for individuals to trade excess power generated by their private facilities, such as micro wind turbines or solar energy panels located in homes (Robinson, 2012). The deployment of smart grids could generate up to $4 trillion worth of savings until 2050 in Europe, mainly due to the reduced need to invest in new electricity generation capacity (Organization for Economic Cooperation and Development, 2012).

Off-grid energy production based on renewable sources can also reduce the need to invest in new centralized production and distribution systems. Cities can provide incentives to companies that specialize in off-grid solutions. Finally, designing integrated energy and waste management infrastructure can optimize energy efficiency and generate significant savings.

Box 12. Technologies for energy generation and conservation in practice

Information and communications technologies tools for optimizing energy management

The following cities are partnering with Cisco to provide integrated city data for use in improving traffic, public transportation, energy efficiency and the self-management of carbon footprints by residents: Hamburg, Germany; Amsterdam, the Netherlands; Lisbon, Portugal; Seoul; Madrid, Spain; Birmingham, United Kingdom; and San Francisco.

Kinetic energy

Purpose-made slabs installed on pavements can convert kinetic energy from footsteps to electricity. The technology, developed by Pavegen, is best suited to high-footfall urban environments and represents a good example of how clean technologies can also be enjoyable, which is an important aspect for general public awareness and adoption. The technology was installed in 2012 at a subway station in London near the Olympics facilities.

Off-grid energy generation

Sunlabob, a company in the Lao People's Democratic Republic, started operations by providing solar electrification to homes on a rental basis. It established an innovative public–private partnership business model whereby local public authorities covered part of the investment cost through ownership of solar lamps that were rented out to households, while Sunlabob owned the charging stations. The company created a national network of franchises and provided training on marketing, installation and maintenance. Following its initial success, Sunlabob diversified to offer a full range of renewable energy solutions, such as solar water pumps and heaters, water purification systems, street lighting solutions, cooling units for health posts and solar lanterns.

Another off-grid solution provider is M-Kopa, a start-up in Kenya that has designed a solar lamp consisting of a base station with a solar panel, three lamps and a charging kit for use with telephones. Users can pay for part of the system upfront and the rest via minimal instalments that they transfer by using mobile telephones. The lamps can replace kerosene lamps that are not only expensive but also dangerous to health.

Integrated energy and waste management

The Hammarby Sjöstad district of Stockholm is an ecological district that has used brownfield industry space for development, referred to as the Hammarby Model in urban planning. The district minimizes energy use while optimizing water use and waste management with the help of recycling, energy and waste treatment plants. Buildings send waste and wastewater to combined heat and power plants and wastewater treatment plants that then produce heating, biogas and electricity for the buildings. The district plans to produce 50 per cent of its energy requirements locally.

Sources: Bolay and Kern, 2011; Danish Architecture Centre, 2010; The Economist, 2012; and Villa and Mitchell, 2010.

IV. b. Solid waste management

Exponential growth in urban waste

Uncontrolled solid waste is growing faster than urbanization and represents a serious issue for the sustainability of cities. Growing cities generate higher amounts of waste per inhabitant. Rates of solid waste growth are fastest in China, other countries in East Asia, parts of Eastern Europe and the Middle East (Hoornweg and Perinaz, 2012). The amount of solid waste generated in rapidly growing cities in developing countries is a serious health risk for their populations. Using landfills reduces the attractiveness of cities. Landfills do not decompose easily, and produce methane, which heavily contributes to greenhouse gas emissions. The incineration of solid waste is also not preferable as it can cause air pollution. Although waste is an energy source that could be reused, it is not seen as such in many countries.

The cost of solid waste management can be very high, reaching up to half of the total municipal budget of medium-sized cities in lower-income countries. Global solid waste generation is due to increase from 1.3 billion tons per year to 2.2 billion tons by 2025. It is an urgent priority, especially in lower-income

Box 13. Integrated solid waste management in practice

In Kalundborg, Denmark, companies located in an industrial zone started selling waste products as raw materials to each other in 1961. The network later grew to include more than 30 exchange pipes. Surplus heat, steam and other residue generated from a 1,500 megawatt coal-fired power plant are all reutilized by nearby businesses, reducing the ecological footprint of the plant and involved companies.

São Paulo implemented a landfill emissions control programme that renovated two solid waste landfills. Methane-rich biogas from decaying waste was used to generate electric power on site. The programme both reduced the amount of methane released into the atmosphere and supplied energy to 7 per cent of households in São Paulo. The programme was approved as a Clean Development Mechanism project of the United Nations Framework Convention on Climate Change. In 2008, the programme was generating a number of carbon credits that was close to the sum of all other certified projects in Brazil. The city used the proceeds of these credits to fund urban and environmental improvement projects in surrounding areas.

Sources: Goldenstein, 2008; Jastrup and Drique, 2012; and UN-Habitat, 2012b.

countries, where serious increases in solid waste management costs are expected (Hoornweg and Perinaz, 2012).

Science, technology and innovation for waste management

Integrated solid waste management is a waste management approach that refers to a shift from less-preferred waste treatment and disposal methods such as incineration and different forms of landfilling towards the reduce, reuse and recycle, or three Rs, model, as shown in the examples in box 13.

Activities under integrated solid waste management can include the following:

- Resource conservation, which avoids excessive resource consumption.
- Waste reduction through resource-use optimization.
- Waste collection and segregation, ensuring appropriate waste treatment.
- Waste reuse, which circulates waste and avoids the use of new resources.
- Waste recycling, which converts waste into useful products.
- Energy recovery, which harnesses residual energy from waste. For example, waste and wastewater can be used for producing biogas, synthetic gas and synthetic construction materials.
- Landfill avoidance, which conserves land and avoids the risks of contamination.
- Construction and maintenance of infrastructure for waste collection, recovery of materials from waste streams through collection, segregation and the application of technologies related to the three Rs and associated activities.

The long-term vision under integrated solid waste management is to establish a circular economy in which the use of materials and the generation of waste are minimized, any unavoidable waste is recycled or remanufactured and any remaining waste is treated in a way that causes the least damage to health and the environment or even creates value by recovering energy (Totty, 2011 and United Nations Environment Programme, 2011).

Policy considerations

Following the Hammarby Sjöstad and Kalundborg examples, cities can make use of technologies to convert certain types of waste into energy. Many Governments in Europe are promoting ecological industrial parks, also referred to as industrial symbiosis systems. Emerging economy cities are also implementing projects based on integrated solid waste management and the three Rs.

Public–private partnerships, as well as joint initiatives of local communities and non-governmental organizations, can be effective in launching waste management initiatives. In several countries, public–private partnerships between municipalities and the private sector, as well as organized initiatives by citizens, are already actively participating in solid waste management, as shown by the examples in box 14.

Managing solid waste in combination with spatial planning can help optimize energy consumption and reduce waste in cities (UN-Habitat, 2012c). For example, the location of landfills can minimize negative effects and providing sorting and recycling space close to locations where waste is generated can help reduce the size of disposal sites.

IV. c. Resource-efficient buildings

High energy consumption in buildings

The built environment poses a challenge for resource efficiency. Buildings account for 40 per cent of global energy use, 38 per cent of global greenhouse gas emissions, 12 per cent of global potable water use and 40 per cent of solid waste streams in developed countries (United Nations Environment Programme, 2012a). The lack of resource efficiency measures for existing or new buildings results in a missed opportunity and carries the resource burden, environmental damage and social inequality into the future. Since new buildings are long-term investments and the housing stock of cities is gradually replaced, policies requiring resource efficiency standards can combine affordability with sustainability in the long term.

Especially in cities in developing countries, the built environment is a cause of concern in terms of current and forthcoming housing shortages. There is high demand for affordable housing in the cities of rapidly urbanizing countries in Asia, Africa and Latin America and a lack of space for newcomers. In China, it is estimated that as much new building floor space will be built until 2030 as the entire existing building stock of the United States (UN-Habitat, 2012a). Due to the fact that the supply of affordable housing, infrastructure and services is not able to catch up with the rate of urbanization in developing countries, informal shelters are built with no infrastructure, little sanitation and no compliance with planning or building regulations.

Box 14. Public–private partnerships and community initiatives for solid waste management

In developing countries, public–private partnerships and innovative community initiatives are contributing to the management of urban waste.

For example, in 1998 in Dhaka, a city of 12 million inhabitants where the municipality cannot process more than 30 to 40 per cent of generated solid waste, Waste Concern, a local non-governmental organization, launched a public–private partnership for waste collection with logistical support and programme coordination by public authorities. Local communities collected waste that complied with the minimum quality benchmarks of Waste Concern and sold it to private fertilizer companies. The initiative reduced greenhouse gas emissions, saved landfill area in the city and provided employment for women.

The public–private partnership model of Waste Concern was replicated in several other cities and towns in Bangladesh, servicing a total population of 130,000 in 15 cities. The collection of waste helped avoid the production of methane gas that is released when organic waste is deposited at a landfill. The project was registered with the Clean Development Mechanism.

The Waste Concern model was extended to three composting models and four financial models, following which it was applied in other countries. The city of Matale in Sri Lanka established an integrated centre to treat organic waste and produce high-quality compost with assistance from Waste Concern and the United Nations Economic and Social Commission for Asia and the Pacific. The project is now being replicated by the Commission in 10 cities in Asia.

Sources: Economic and Social Commission for Asia and the Pacific et al., 2011; Municipal Government of Shanghai et al., 2011; and Suri, 2013.

Science, technology and innovation for resource-efficient buildings

Resource-consuming buildings harbour the greatest potential for resource and emissions reductions. Sustainable houses can be built by using a range of techniques and practices that improve resource efficiency and contribute to healthy indoor living conditions at a reasonable cost. Solutions differ according to the type of house, the climate zone and the available infrastructure around the building, such as whether there is access to district heating. Using sustainable technologies in new buildings could achieve a 30 to 50 per cent reduction in energy use, a 35 per cent reduction in greenhouse gas emissions, a 40 per cent reduction in water use and a 70 per cent reduction in waste outputs (United Nations Environment Programme, 2012a).

The vast majority of cities evolve gradually and retrofitting is therefore a key science, technology and innovation-related approach on which they need to rely. Retrofitting existing buildings can bring about significant efficiencies, both in terms of the building itself and the city in general. It is cheaper to build and retrofit in an urban zone that already benefits from connections to utilities and transport networks. Many cities are implementing retrofitting programmes such as the transformation of industrial riverfronts or the replacement of obsolete structures, for example in the Cheonggyecheon project in Seoul, as noted in box 8. Table 4 lists examples of technology options for sustainable buildings.

Buildings can employ either passive or active environmental design strategies. Passive design techniques such as improved insulation, natural ventilation and daylighting take advantage of the building's site or climatic characteristics to improve resource efficiency. According to energy consumption guidelines in the United Kingdom, the introduction of natural ventilation can save 55 to 60 per cent of the energy used in fully air-conditioned and glazed office buildings (United Nations Environment Programme, 2011). The potential use of passive strategies is greater in tropical regions due to the priority of blocking heat rather than generating it efficiently (Municipal Government of Shanghai et al., 2011). However, active systems employ technologies such as solar panels or energy-efficient appliances to improve efficiency (United Nations Environment Programme, 2012a). A study in the United States of more than 5,000 commercial buildings showed that in new buildings, employing energy-efficient lighting, heating, ventilation, air conditioning and shading can achieve a 64 per cent reduction in energy use (United Nations Environment Programme, 2012a).

While the operational phase of a building represents the most significant opportunity for resource efficiency, using innovative construction technology can also save costs and resources, as demonstrated in the examples in box 15. New prefabricated and modular building techniques, making use of local building materials and local know-how, can optimize the resource efficiency of construction (Kaye, 2012). Using building materials without harmful chemicals has a highly positive impact on the health of users. In addition, recycling building materials can dramatically reduce the environmental impact of the building process.

Table 4. Technology options for sustainable buildings

Design: Designing for sustainability can dramatically reduce energy consumption and create settings that encourage inhabitants to be more physically active.	Windows	Windows provide views and daylight, passive solar energy and natural ventilation to buildings. Through their optimal orientation and use, windows can provide net energy to buildings. Automated shading is essential in warmer climates to limit heat from the sun. Natural light is beneficial to productivity, well-being and health.
	Orientation towards the sun	Homes may be placed with large facades facing east and west, letting in morning and evening sunlight. Offices may have large facades facing north and south, letting in high quality daylight, with shielding from direct sunlight to avoid overheating.
	Green roofs and walls	Adding plants to rooftops, walls and balconies offers many benefits, as follows: added insulation; reduced runoff of water during heavy rain; aesthetic qualities; noise reduction; and a reduced heat-island effect.
Energy generation	Solar power	Photovoltaic cells can deliver clean energy to a building on site, eliminating transmission losses. Combined with a heat pump, solar power can also generate heating. The falling prices of photovoltaic cells have rendered their use more feasible in many parts of the world.
	Solar window blinds	Solar window blinds keep buildings cool by blocking sunlight and at the same time produce electricity via photovoltaic technology.
	Solar shingles	Similar to solar panels, solar shingles are based on photovoltaic technology. However, shingles can absorb more light and their durability makes it possible to use them as roofing material.
	Micro wind turbines	Generating energy from wind by placing turbines on top of commercial or residential buildings can cover a large percentage of the structure's energy needs.
Heating and cooling	Solar heating	Solar heating systems can provide heat and hot water and can be combined with heat pumps to create heat depots in hot periods for use in cooler weather.
	Insulation	Insulation materials, from mineral wool to aerogel, are essential in every climate for keeping heat either in or out of a building.
Heating and cooling	Natural ventilation	Techniques which use natural convection currents within air flow to direct air into and out of buildings in order to replace rising warm air with cooler air can function with minimal or no mechanical parts or energy consumption. For example, air ducts can be designed to allow air to enter low in the building via underground ducts, while simultaneously allowing air to escape from higher up the building, and provide for natural ventilation.
	Heat pumps	Earth-to-water or air-to-water heat pumps can draw thermal energy from the surroundings into buildings, multiplying the energy used, whereby 1 kilowatt-hour of electricity can deliver 2 to 4 kilowatt-hours of heat.
	Ambiators	Ambiators can cool interiors by using thermodynamic technology based on evaporation at a fraction of the energy consumption of conventional air conditioning. Ambiators process air through a pump that recuperates heat and reduces temperature. The pre-cooled air then passes through an evaporative cooling module that uses limited amounts of water to cool the air further (see www.hmx.co.in). Ambiators are more suitable for low-humidity locations.
Water	Reuse of water	Reusing water from washbasins or showers for water closets can reduce water consumption.
	Rainwater retention and collection	Rainwater can be held in fascines or tanks, reducing runoff during heavy rain. The water can then be reused in water closets.
	Reduction of covered ground	Reducing the amount of ground covered by buildings, pavements, roads, parking lots, etc. reduces both the local heat-island effect and pressure on sewage and drainage, as the earth can absorb more water during heavy rain.
Information and communications technologies	Smart homes	Monitoring and controlling energy demand in buildings can reduce energy consumption by 5 to 10 per cent.

Sources: Jastrup and Drique, 2012; UN-Habitat, 2012b; and UN-Habitat, 2011.

Box 15. Innovative construction technologies in practice

In Harare, Zimbabwe, the Eastgate shopping centre and office block was designed and built with an innovative passive cooling system that stores heat in daytime. The warm air rises in the evening, replaced by denser cool air low in the building. The shopping centre has avoided the need for artificial air conditioning and saved $3.5 million.

Broad Sustainable Building, a company in China, uses pre-manufactured structures for more sustainable building construction. This technique was implemented in the construction of the Tower Hotel in Yueyang. The building has several features, such as resilience to earthquakes of up to 9.0 on the Richter scale, thermal insulation and the ability to produce biogas from sewage and use hot wastewater for heating purposes. Broad Sustainable Building produced 93 per cent of the building parts in its factory and then shipped them to the construction site, where the building was assembled in only 15 days by bolting the pre-constructed modules together. The construction process required no water, welding or scaffolding, caused minimal dust and created only 1 per cent of the waste that is common in similar construction sites.

In Cuba, which has a programme for low energy and material consumption for housing, more than fifty thousand homes have been built in the last 20 years by using alternative building techniques with ecological materials that use recycled waste products and special types of tile, cement and concrete blocks. The materials require less energy and fewer resources. Biological wastes are used as fuel and bamboo is used in the construction process.

Sources: Kaye, 2012; UN-Habitat, 2012b; and UN-Habitat et al., 2009.

Policy considerations

Public support and regulation can speed up the adoption of green building practices in the construction sector. Innovative building regulation can also help improve resilience and environmental quality in cities, as shown in the examples in box 16.

Standard measurement and reporting requirements for building performance in terms of energy efficiency and greenhouse gas emissions can increase the use of sustainable construction in the real estate sector. They can also make it easier to embed the environmental performance of buildings into calculations of their financial value. Towards this end, the United Nations Environment Programme is piloting a common carbon metric that will measure emissions from buildings based on energy use, such as in heating, cooling, ventilation, lighting and appliances (see **www.unep.org/sbci/Activities/CCM_Pilot.asp**). This metric will allow data-driven comparisons between buildings. In addition, the Bonn Centre for Local Climate Action and Reporting, which was established in December 2009 as an initiative of the United Nations Environment Programme and the International Council for Local Environmental Initiatives–Local Governments for Sustainability, facilitates the voluntary publication of city commitments, actions and performance in terms of emission reductions (see **www.carbonn.org**). The centre also provides guidance for emissions reporting. A notable example of voluntary reporting initiatives is the Greenprint Performance Report, which measures the energy consumption and greenhouse gas emissions of assets owned by members of the Greenprint Foundation, a worldwide alliance of real-estate investors.

Establishing multi-tier building rating systems can guide the real estate sector in adopting comprehensive green building standards. Green building rating systems that certify environmental building design strategies are starting to be implemented globally. Notable examples are the Green Rating for Integrated Habitat Assessment in India, the Green Mark initiative in Singapore, which aims to shift Singapore's construction industry towards more environmentally friendly buildings, the Building Research Establishment Environmental Assessment Methodology in the United Kingdom and the Leadership in Energy and Environmental Design certification in the United States. The latter is provided to buildings that are generally designed to be healthier and safer for residents and to operate at a lower cost and higher asset value, reduce waste, conserve energy and water and reduce greenhouse gas emissions. Green building rating systems should be promoted

Box 16. Innovative building regulations in practice

Local governments may lead by example and implement energy-efficiency measures in new public buildings. For example, the new city hall of Seoul uses a combination of photovoltaic, solar and geothermal energy for power generation.

Vienna, Austria has an energy-efficiency policy that subsidizes new housing projects based on a competitive selection process that includes energy efficiency among its criteria. The city also partially subsidizes the refurbishment of existing buildings.

Stuttgart, Germany has analysed weather patterns to develop an urban climatic map and identify wind paths that transport clean air into the city and improve air quality by reducing the heat-island effect. As a result, constructing new buildings that would prevent air flow through these wind paths is prohibited.

As of 2016, new residences in England will be required comply with higher energy-efficiency standards, with heating energy demand levels corresponding to one-fifth of current buildings and on-or-off-site renewable energy generation for all building-related energy demands such as lighting and ventilation. By 2030, 2 to 3 million new homes will be built according to these zero carbon standards.

Rooftops cover one-fifth of urban surface areas. Green roofs can be used to provide insulation and thereby reduce heating and cooling costs for buildings, while at the same time absorbing rainwater and filtering pollutants so that the cleaned water may be reused. Some countries such as Austria, Canada, Germany, Switzerland and the United States are introducing regulation that makes it compulsory to construct green roofs on all new buildings or allocating subsidies for converting existing roofs. Toronto, Canada, is the first city in North America to require green roofs on new buildings. Several cities are also investing in rooftop gardens and trees that are designed to hold water. In Seattle, United States, households are reimbursed for putting in place such rain gardens. Rainwater harvesting from roofs was made mandatory in Bangalore, India, through a water supply and sewerage bill in 2009. Existing buildings that do not install rainwater harvesting structures are penalized.

Sources: United Nations Economic Commission for Europe, 2011; UN-Habitat, 2012b; Robbins, 2012; and Totty, 2011.

first and foremost at the level of municipalities and other local governance structures. Local authorities should also provide transparent information to the real estate sector on green building construction costs, which are normally lower than perceived by the public and can easily be recuperated in the long term owing to lower operating costs.

However, green buildings require higher start-up costs. Local authorities can provide construction companies with incentives such as cash payments, loans or lower taxes, in order that they may benefit from some of the long-term savings resulting from the lower resource use of ecological construction. If the business model of green regulation passes resource efficiency savings only to building owners, construction companies may not be willing to invest. Therefore, the introduction of green building regulation should be accompanied by information campaigns that educate builders on the technical aspects of new standards and by potential financial incentives such as favourable tax policies or interest rates that may compensate for the extra start-up costs of green construction (Municipal Government of Shanghai et al., 2011).

Green buildings need not be confined to cities in high-income countries. Local governments in developing countries can address housing shortages through construction initiatives for affordable, sustainable housing and the upgrading of informal settlements. box 17 provides examples of such programmes in developing countries.

IV. d. Water and agriculture

The damage of urban sprawl on peri-urban areas

Peri-urbanization, sometimes referred to as spillover growth, refers to urban growth into zones that lie between a city and rural zones, usually without spatial planning and the provision of basic services. Development of city fringes that undergo peri-urbanization is most often triggered by a real-estate boom that accompanies rapid urban growth. Populations that were previously rural benefit from new economic dynamism in manufacturing and services brought by urbanization, yet they do not always enjoy improvements in quality of life.

People living in peri-urban areas suffer the consequences of unplanned urban growth most intensely, as they face environmental pollution, rapid social transformation and poverty. Peri-urbanization also results in conflicts in basic needs and resources such as water. Although peri-urban zones in developing countries are often neglected in the process of urban growth and lack basic services such as water and sanitation, they have a key role to play in supplying cities with food, energy, water, building materials and critical ecosystem services. Their success or failure has implications beyond their vicinity. Since there is no return from urbanization and no future in rural poverty, the key question is in how to undertake the right urbanization for peri-urban zones.

The rules for the administrative governance of peri-urban areas are often unclear. Rapid urbanization causes peri-urban zones to undergo rapid transformations in land, social structure and economic activity. The extension of cities into peri-urban areas in developing countries is often uncontrolled, and such expansion can occur along a river or highway, as well as around a single metropolitan area. Due to a lack of regulation or planning, peri-urban areas face severe environmental, economic and property-related challenges. For instance, due to a lack of regulation, some cities release waste into peri-urban areas without facing any legal consequences. Insufficient regulation can result in peri-urban agriculture not being recognized as legal. Urban sprawl causes property speculation to increase land prices to unaffordable levels for peri-urban residents (United Nations Population Fund, 2008).

Many cities in developing countries expand with little focus on protecting peri-urban water systems or agricultural areas. Since the peri-urban area is not incorporated in city development plans, the effects of urbanization on city fringes are not properly assessed. For example, many of the households in peri-urban zones are involved in agriculture. A lack of understanding of the way peri-urban agriculture is sustained is a key issue affecting peri-urban farmers. Land acquisition and the fragmentation of land caused by urbanization disrupt the livelihood of farmers. Their vulnerability is also increased by industrial pollution and the lack of prioritization of agricultural programmes. In addition, opportunities for greater economic return by selling or leasing land decrease the attractiveness of future peri-urban agricultural prospects (Marshall et al., 2009).

Peri-urban zones on city fringes compete with urban residential and industrial demands for

Box 17. Sustainable housing programmes in practice

The United Nations Environment Programme is implementing a sustainable social housing initiative that was piloted in São Paulo and Bangkok in order to build social housing units that are both energy-efficient and low-cost.

Brazil and Mexico have housing programmes that aim to cover their housing shortages. Brazil's My House My Life programme provides incentives and subsidies to enable mortgages for low-income households and includes solar water heaters in housing design. Mexico's national housing programme subsidizes households for buying homes with pre-approved ecological technologies. In addition, the National Workers' Housing Fund Institute provides green mortgages of up to $1,250 to cover the cost of ecological technologies for low-income housing. The programme finances 22 technologies related to electricity, gas, water and health. The programme benefited over 3 million people between 2007 and 2012 and is being expanded to the retrofitting of existing housing stock.

There are also successful examples of the upgrading of informal settlements. For example, settlements in Manaus, Brazil were upgraded through the construction of parks, transport infrastructure and sewage pipes, as well as the provision of basic services such as water, sanitation and electricity.

Sources: UN-Habitat, 2012a; UN-Habitat, 2012c; and World Habitat Awards, 2012.

water. Growing urban zones endanger water resources that are critical for agriculture. A study conducted of Chennai, India, by the Social, Technological and Environmental Pathways to Sustainability Centre based at the University of Sussex demonstrated that after a water-use agreement was signed between the urban water management authority and rural farmers for the use of groundwater, peri-urban farmers were vulnerable to increased urban and rural demand and resulting price increases. Moreover, the water-use agreement had counterproductive effects on all parties. As urban water use increased, excessive groundwater extraction led to longer droughts, thereby also negatively impacting urban citizens due to reduced food production (Thapa et al., 2010).

Water scarcity can turn into a serious health issue for both rapidly growing cities and peri-urban zones. The lack of water negatively affects access to sanitation. The number of inhabitants in cities of sub-Saharan Africa without access to adequate sanitation more than doubled between 1990 and 2010, reaching 180 million (Food and Agriculture Organization of the United Nations, 2012). In Maputo, Mozambique, 20 per cent of the population lacked access to potable water in 2003. Half of the 10 million citizens of Jakarta, Indonesia had no access to potable water in 2007 (UN-Habitat, 2012c). Water consumption is already excessive according to World Health Organization norms and is likely to increase further in cities such as the following: Porto Alegre, Brazil; Nanjing, China; Johannesburg, South Africa; Bangkok; Tunis, Tunisia; and Montevideo, Uruguay. Water leakages and abuse are severe problems in many countries. The lack of water can thus be an inhibiting factor to sound urban growth and peri-urban livelihood.

The lack of healthy nutrition remains an important issue in growing urban areas in developing countries. More than half of the urban residents in Africa live in slums, are undernourished and have scarce employment opportunities. Commercial horticultural production of fresh fruits and vegetables, widely practiced in peri-urban zones especially in Africa, risks becoming unsustainable due to the lack of means and support. Horticulture and food production are sources of nutrition and employment for millions of urban Africans, yet they receive little recognition, regulation or support from their Governments. As a result, an important opportunity for the healthy nutrition of urban populations and a source of employment, especially for women workers, remains underutilized (Food and Agriculture Organization of the United Nations, 2012).

Science, technology and innovation for water and agriculture

Urban farming and market gardening

Science, technology and innovation increase the options for urban areas to become more self-sufficient in terms of nutrition. In Asia, Africa and Latin America, urban farming is already a livelihood and survival strategy for populations. Urban farming can also be critical to supply food for disaster-struck urban zones. Technologies and innovative models are available to promote urban farming. For example, school gardens represent an innovative means to promote horticultural production, while simultaneously improving the quality of meals at schools, providing practical nutrition education and increasing household consumption. In addition, family gardens may be established with links to markets through cooperatives.

Integrating urban farming into urban and peri-urban planning can produce multiple benefits. As the spread of urban zones results in a lack of space for food production, small-scale peri-urban market gardening can make up for shortages in healthy, fresh food and generate employment. Peri-urban farms can reuse urban wastewater for irrigation purposes. The production of fruit and vegetables in small private farms close to cities can be less costly than bringing supplies from rural areas, due to lower transport costs. Such production can also help contain urban sprawl by creating urban green belts. box 18 presents an example of the implementation of market gardening in Mozambique.

Box 18. Mozambique: Market gardening

Mozambique demonstrates a good example of policy-making for successful market gardening in Africa. The Government created green zones by organizing horticultural cooperatives in the capital city of Maputo and other major cities after the civil war of the 1980s, which disrupted food supplies and increased urban unemployment. These green zones produce a critical supply of fresh vegetables such as cabbage, lettuce, tomatoes, onions, eggplants, beans and pumpkins. Despite exponential growth that occurred without planning or administrative control, most of the green zones have been protected by the city council, sustaining the livelihood of predominantly women farmers. Membership in farmers' associations, which are affiliated with the General Union of Cooperatives, made it possible to protect the land of small-scale farmers from takeover by more wealthy farmers. The cooperative-based structure also supports farmers with financing, technical assistance and market access. The green zones play a key economic role through the production of healthy food on a small scale, the creation of employment opportunities and the use of urban wastewater for irrigation purposes.

Source: Food and Agriculture Organization of the United Nations, 2012.

Water technologies

Since peri-urban communities in developing countries largely depend on agriculture, water is a key resource for their economic well-being. Water storage, irrigation and water-lifting technologies can help tackle water shortages. For example, Grundfos, a Danish pump manufacturer, developed and implemented a solution to the challenge of providing sustainable access to water for rural and peri-urban communities in the developing world. The system, as implemented in Kenya, uses solar energy to activate a pump that extracts groundwater and distributes it through a payment system that is managed locally. The revenue from the pump is used for maintaining the system. Grundfos is working on introducing the system to other countries (World Business Council for Sustainable Development, 2012).

Phyto-remediation

Another innovative method for reusing urban wastewater is phyto-remediation, that is, the use of trees and plants to clean water, whereby a drainage system channels wastewater into a catchment that is filled with trees, which capture the water and hold the waste. The cleaned water is then reused for irrigation purposes.

Policy considerations

Peri-urbanization should take place as a planned, managed transition. Regional governance entities may be set up to establish a framework of equitable regulation that protects the environment, provides basic services to the poor and resolves land disputes that may arise from urban sprawl. It may even be to the benefit of a region as a whole to set city land-expansion limits, as set for example by Portland, and to encourage more concentrated development. Peri-urban areas can benefit from social inclusion programmes that upgrade existing informal settlements and prevent the formation of new informal settlements through adequate spatial planning. Peri-urban areas can be integrated into the urban transport network as well. Soweto, a township in South Africa that was part of greater Johannesburg as a separate municipality, was successfully integrated into Johannesburg as a result of a planning and investment effort that improved infrastructure, accessibility, safety and public spaces and provided new economic opportunities (UN-Habitat, 2012c).

Formal means of public participation in decision-making can play a key role in preventing resource conflicts between urban, peri-urban and rural stakeholders during the process of urbanization. Some countries have already established successful forms of participation in urban decision-making. For example, in Brazil, more than 70 cities have a participatory budget system that allows citizen participation in decisions of resource allocation (Marshall et al., 2009). The Coalition to Fight Poverty (Mesa de Concertación para la Lucha Contra la Pobreza) in Peru is a council of Government, non-governmental organization, church and community organization members that formulates short, medium and long-term priorities for community development in areas of infrastructure, health, education, security, recreation and employment (Marshall et al., 2009).

Horticulture may be supported through policies for urban zoning, building irrigation systems and the establishment of cooperatives that protect small-scale farming. Agricultural cooperatives can sustain agricultural production and the livelihood of the peri-urban farming community and industry in the face of urbanization. Cooperative structures improve the accessibility of markets and provide logistical support for individual farmers. Furthermore, Governments can support peri-urban farming through regulation. Tax policies can help sustain peri-urban food production for cities, thereby reducing the need to transport food from other areas, which would potentially increase food costs.

Water governance by a single unified authority can help resolve water-related conflicts in urban and peri-urban zones. For example, in 1963 Singapore centralized its water management through a public utilities board. Within 40 years of centralization, two-thirds of Singapore's land surface became a water catchment area that stored water in 17 reservoirs. Singapore also collects wastewater to produce drinking water and thereby covers 30 per cent of the city's needs (Tan, 2012).

Peri-urban communities may benefit from regional ecosystem assessments that map their composition, interlinkages and changes induced by urbanization, as shown in the examples in box 19. Assessments can document the vulnerabilities of peri-urban zones with quantifiable data so that policies may be developed to maintain landscapes and ecosystems that are important for food production, maintaining biodiversity and tourism.

Box 19. Ecosystem assessments in practice

Following up on the millennium ecosystem assessment released in 2005, the satoyama–satoumi assessment, a land and marine ecosystem assessment, was conducted in Japan by the Institute of Advanced Studies of the United Nations University. The assessment was divided into five major regional clusters and identified the root causes of decline in both land and marine ecosystems and the possible courses of action to reverse this trend. The most important root causes were land use transformation, largely due to urbanization, and demographic changes such as ageing that made it harder to sustain the landscapes, while the decline of these ecosystems negatively affected health and well-being in Japan. The assessment established that the two key challenges for the future were attracting participation by citizens and non-governmental organizations in re-establishing land and marine ecosystem services and formulating economic incentives to protect non-economic values in the landscapes.

Suncheon, a city on the south coast of the Republic of Korea, is a good example of an urban zone that has managed to protect its surrounding ecosystems. Despite being surrounded by cities prioritizing heavy industry, the city has invested in its ecosystems as of the late 1990s and turned Suncheon Bay into an award-winning ecotourism centre that attracts more than 2.3 million visitors per year. Although businesses and landowners disagreed with the plan at the beginning, it was implemented with the mayor's leadership and a clear vision of how the ecosystem approach would bring economic growth.

Sources: Duraiappah et al., 2012; and Economic and Social Commission for Asia and the Pacific et al., 2011.

V. Recommendations and conclusion

This report provides guidance on science, technology and innovation-related policies and practices that can lead to sustainable urbanization by producing wider economic, social and environmental benefits for cities. The report details how cities that prioritize sustainable growth patterns can improve employment and competitiveness, enhance social cohesion and create a healthy and liveable urban environment. As seen in the examples provided, many cities have achieved success on a partial basis by implementing some of the related technologies, yet the same cities may have failed in other areas.

The best way to achieve sustainable urbanization is for a city to implement integrated comprehensive policies that take into account all aspects such as spatial planning, mobility and buildings, among others. Cities need to embed sustainability in their urban plans and urban development policies. If a sustainability mindset is included in all sectors, there is a higher likelihood of achieving success. Mobilizing citizens to support this mindset is critical, since without the participation of citizens, policymakers cannot achieve objectives such as sustainable resource management. Ultimately, citizens are the ones who make decisions on consumption patterns.

In order for science, technology and innovation to be effective in bringing about positive responses in cities in developing countries, there is a need for strong diffusion mechanisms. Science, technology and innovation are widely available for sustainable urbanization and the related tools are constantly improving. Most significant for developing countries is the need to ensure that diffusion takes place where needed. Solutions need to travel quickly from creators to beneficiaries. However, as with the adoption of science, technology and innovation-related solutions, diffusion requires action on multiple fronts. Diffusion models should include capital accumulation and the local capacity development of beneficiaries.

Urban infrastructure in a number of developing countries, particularly least developed countries, is inadequate and insufficient to meet the needs of rapidly growing populations and economies. The lack of affordable housing furnished with basic services such as water, sanitation and electricity, especially for lower-income groups, results in informal shelters being built with no infrastructure, little sanitation and no compliance with planning or building regulations. Least developed countries have particularly high urban growth rates and require special consideration with regard to meeting shelter, sanitation and other infrastructure needs. Most least developed countries are located in sub-Saharan Africa and South-East Asia, where natural disasters pose constant risks.

Science, technology and innovation-related choices in developing country contexts differ from those in developed countries due to limitations in human resources, know-how and financing, among others. Constraints are particularly acute in least developed countries, limiting their ability to cope with the challenges of rapid urbanization and to ensure even the bare minimum – food, water and electricity – needed to sustain the livelihoods of their citizens. Nevertheless, science, technology and innovation have a key role to play in fostering sustainable urbanization in the developing world. The particular nature of urbanization in least developed countries requires customized models of delivering science, technology and innovation-related solutions, not least by tapping into indigenous knowledge.

As demonstrated in this report, many of the technologies that are useful in the urban context in developing countries can be low technology and therefore may not necessarily require high financial resources or investments. This report demonstrates that science, technology and innovation for sustainable urbanization often originate in developing countries, including least developed countries. Several successful innovations such as bus rapid transit systems, public–private partnerships for waste management, urban agriculture, models for public participation in decision-making, disaster risk management and sustainable housing programmes already have been or have the potential to be applied across the world.

Developing countries have also successfully demonstrated examples of creatively combining low and high technology according to local needs, as with some of the technologies used for disaster resilience. This report provides examples of how local knowledge may be leveraged to implement the construction of resource-efficient buildings that are not necessarily expensive. Many innovations originate in developing countries, yet there is a need for mechanisms to implement them more widely. In least developed countries, urbanization rates are still relatively low compared to other countries. Making innovative ideas on urbanization available to least developed countries can help their cities follow the best path from the start and minimize the cost of correcting unhealthy urban practices later on.

The examples given in this report illustrate the benefits of establishing strong links between national policies on science, technology and innovation, particularly research and development, and specific urbanization issues, in order to develop local solutions that address local needs. The report shows how developed countries are taking the lead with regard to innovative regulation in the urban context. This may therefore be an area for increased cooperation among cities in the future. Developing countries and least developed countries may need assistance in putting in place beneficial business models and urban governance structures that can popularize science, technology and innovation in high technology, low technology or innovation forms. For instance, while bicycling is a technology that has been available for over a century, encouraging the wide-scale adoption of bicycling in a city through bicycle-sharing systems integrated with information and communications technologies, which are accessible via smart telephones and the Internet, requires advanced technical know-how (Atlantic Council, 2013). Technical cooperation on innovative regulations may therefore speed up the process of implementing sustainable practices on a much wider scale in growing cities in developing countries.

Policy implications that may be derived from this report to address the specific urbanization needs of developing countries and least developed countries are further detailed in the following sections.

V. a. Urbanization as a key consideration in national innovation systems

Cities are one of the greatest innovation tools developed by humans. They encourage innovation through contact between people, which may be either planned or serendipitous. Creative inhabitants of cities constantly design novel solutions. The same applies to inhabitants of informal settlements, where people must embody an entrepreneurial spirit for their daily survival. It is important for developing countries to harness this innovative spirit and scale frugal innovation for the benefit of the larger population. Increasing the possibilities of public participation in urban decision-making may enable this, as seen in some of the examples provided in this report. Urban citizens are best placed to work with municipalities and identify science, technology and innovation-related requirements. Fostering cooperation between national councils on science, technology and innovation and local governments to solve urban problems is also beneficial.

Furthermore, if the national innovation system of a country prioritizes urbanization issues, this may be a great benefit for its development as, more often than not, urbanization and development occur in parallel. Mainstreaming sustainability into urban development plans from the start can help to avoid costly and difficult policy adjustments later on. While developing accurate long-term plans is more challenging in rapidly growing urban environments than in areas with constant populations, new technologies can empower urban planners by providing a greater capability and capacity to plan ahead.

V. b. Mobilizing the private sector and civil society

This report demonstrates the different areas in which public–private partnerships, particularly in developing countries, can have a lasting impact on sustainable urbanization. Such business models are valuable in terms of scaling the innovation generated by small organizations with the means available to large organizations. Local governments can also make public resources, such as open data, available to private-sector enterprises and community innovators. When local communities work together with businesses, they can steer innovation more effectively towards answering their requirements. For example, in Africa, the development of electronic payment systems based on mobile telephones led to the creation of new marketplaces at a relatively low cost and with low infrastructure requirements.

Sustainability examples from several cities show that applying technology in highly populated urban environments requires a sound business model in order to succeed. Popular adoption of new urban technologies depends on whether they can replace current habits and practices without disruption or economic disadvantages. City managements can increase the potential for entrepreneurs to establish sound business models through regulation, economic incentives and information and awareness campaigns.

Local governments should also put in place a comprehensive regulatory environment and provide incentives to encourage the private sector to participate in urban infrastructure and technology projects. Public–private partnerships can attract investment in sustainability projects. International organizations and business associations can assist in matching the sustainability needs of cities with possible solutions from the private sector. Municipalities can also receive support from national Governments and international organizations to create more favourable conditions so that sustainable practices do not remain expensive subsidy-dependent options but are turned into real business opportunities (Economic and Social Commission for Asia and the Pacific et al., 2011 and United Nations Environment Programme, 2011).

Particularly in the context of least developed countries, the social inclusion of slum areas is a necessity. Social entrepreneurship is an emerging business model that addresses societal needs by bringing together community innovators with private sector entrepreneurs to fund social innovation as a financially viable business. For example, open-data initiatives can help populations map their neighbourhoods. Cooperation initiatives that include non-governmental organizations can map slums and survey households to integrate slums into future urban development plans.

International organizations can contribute to standard setting and technical cooperation for sustainable urbanization. They can raise awareness among urban policymakers of the role of science, technology and innovation for sustainable urban development in developing countries, with a special focus on least developed countries, by serving as a forum for the sharing of good practices and experiences. In particular, international organizations can share and analyse evidence of successful examples of local innovation models that provide solutions to pressing urban challenges based on science, technology and innovation, including serving as incubators,. They can also share and analyse evidence of business models that scale innovative interdisciplinary solutions to city management and provide them to beneficiaries. Formal cooperation and technology transfer mechanisms can be established within relevant international organizations, such as the Clean Development Mechanism of the United Nations Framework Convention on Climate Change.

V. c. Innovative governance and financing models

The highlighted case studies from around the world demonstrate the need for cities to form a coalition of public, private and civil society actors and multilevel governance models in their transition to sustainability. Since policy changes related to prioritizing public transport, saving energy and efficient buildings, among others, affect all stakeholders that take part in urban life, they require consensus-based decision-making to succeed. Cities need to envisage and put in place legal participation mechanisms. Broad public participation can help gather input and promote consensus on urban projects, leading to cities that are more socially inclusive.

Sectors of urban management are interlinked. The absence of cross-sectoral policies can lead to fragmented governance, which is counterproductive and can lead to unexpected and unwanted outcomes. For example, rebound effects can occur in cases where the introduction of energy-saving technologies actually leads to an increase in per capita energy consumption (United Nations Environment Programme, 2011). Local governments in developing countries can launch cross-sectoral sustainability goals covering mobility, energy, buildings, water and waste. Science, technology and innovation have an essential role to play in addressing cross-sectoral sustainability challenges. For instance, information and communications technologies can be used to bring together data from different city departments and enable coordinated simultaneous responses to challenges.

Science, technology and innovation are important for urban economic dynamism and employment. Urban economies need to innovate and take a regional approach in order to provide employment for incoming populations. Assessing the advantages of the region and ensuring the integration of a city with its region are necessary to generate new employment. Formal governance mechanisms that enhance cooperation between national, regional and local governments can assist spatial planning at the regional level. Such governance models may even be developed across countries. An overall view of the regional economic landscape can help in forming a vibrant economic cluster. Science, technology and innovation make it possible to undertake regional work and exchange ideas more easily. Examples include regional planning and governance models that are being practiced in different urban hubs in Asia, including the Malacca Straits Diagonal, the Pearl River Delta and Metropolitan Manila (International Society of City and Regional Planners, 2012).

Public financial support for science, technology and innovation-related initiatives and start-ups oriented towards sustainable urbanization solutions is important. New forms of financial services are emerging, driven by the opportunities created by information and communications technologies (Robinson, 2012). For example, crowdfunding, peer-to-peer lending, sustainable investment funds and local and electronic currencies are all innovations that can be used to finance projects related to sustainable urbanization. In addition, new sources of investment capital, such as retirement and sovereign wealth funds, can finance science, technology and innovation-based solutions, in particular at a smaller scale, for sustainable urbanization.

V. d. Inter-city learning as an opportunity area

Cities of the world learn from one another. City-to-city knowledge exchanges on science, technology and innovation facilitate both North-South and South-South collaboration in sharing experiences on issues such as urban planning and design, mobility and efficient urban resource management. For example, since the European Union–Latin America and Caribbean summit in Madrid on 18 May 2010, the two regions have been undertaking joint efforts on smart cities, among other topics. A mapping exercise is being conducted to identify priorities on new biregional cooperation possibilities for smart cities. The objective is to constitute a database of biregional projects related to information and communications technologies, as well as applications and technologies deployed in thematic areas including smart cities to allow for the identification of twinning projects, funding instruments and collaborating institutions. It is based on an exploratory survey of cooperation on information and communications technologies through contact with national funding agencies in both regions.

At the level of mayors and municipalities, barriers between North and South are less significant, since solutions to urban problems can originate from anywhere. Cities help break barriers to learning among countries and regions. For example, the bus rapid transit system in Curitiba has been reapplied in many parts of the world, including in developed countries. Accelerating inter-city learning is a key opportunity for diffusing science, technology and innovation on a much wider scale towards sustainable urbanization in developing countries.

Multilateral and bilateral technology banks can be established to speed up the transfer of knowledge and experience on projects that are implemented in cities with similar problems. International local government networks such as Cities Alliance, the C40 Cities Climate Leadership Group, the International Council for Local Environmental Initiatives–Local Governments for Sustainability, United Cities and Local Governments and the World Urban Campaign coordinated by UN-Habitat are already playing an important role in increasing awareness of sustainability, circulating best practices and providing a platform for joint projects. Action at a mayoral level is effective since mayors regulate, operate or even own infrastructure such as roads, buildings and street lights, as well as public transport, land use planning and waste collection.

V. e. Cities undergoing a process of perpetual urbanization

Urbanization is not a one-time phenomenon and therefore not only a consideration for developing countries. It is perpetual. Cities continuously undergo a process of transformation by reimagining their existing infrastructure in the context of what becomes possible through science, technology and innovation. In many cities of developed countries, urbanization is occurring in the form of reurbanization, for instance to deindustrialize, to accommodate for ageing citizens and to improve resource management.

The nature of urbanization may change, yet it remains a continuously evolving process. In order to make this continuous process sustainable, cities need to consider science, technology and innovation options whenever they embark on new infrastructure investments and plans. They should continuously benefit from ecological solutions as they emerge, perpetually replacing obsolete and old infrastructure with more efficient and environmentally friendly infrastructure. They need to have mechanisms that assess the evolution of new technologies and innovative means of urban governance, in order to gradually integrate these into their domain.

Cities are already thinking of ways to repurpose their obsolete infrastructure. For example, New York City is piloting the use of its 12,500 public telephone booths as information nodes. A similar pilot that reuses public telephone booths as electric automobile-charging facilities is being run by Telekom Austria (Burnham, 2013). Such examples are encouraging proof that there is potential for cities at any stage of development to innovate and learn from other cities.

Since urbanization is a perpetual phenomenon, there needs to be a constant evolutionary transformation of infrastructure to adapt to the current requirements of citizens.

Cities should implement sustainable policies first and foremost because they improve the lives of their inhabitants. Ultimately, cities should be constructed so that they serve their citizens and not the other way around.

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