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Science, technology and innovation for sustainable urban development in a post-pandemic world

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Note

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This series of publications seeks to contribute to exploring current issues in science, technology, and innovation, with particular emphasis on their impact on developing countries.

The term “country” as used in this study also refers, as appropriate, to territories or areas. In addition, the designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgment about the stage of development reached by a particular country or area.

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1. Introduction

The world is far from attaining resource-efficient, safe and inclusive urban areas,[1] where anyone can benefit from environmentally friendly and prosperous economies and high-quality public goods and services. At its sixteenth session, in 2013, the United Nations Commission on Science and Technology for Development examined the theme of science, technology and innovation (STI) for sustainable cities and peri-urban communities, including environmental sustainability. Since then, accelerating technological change in renewable energy, artificial intelligence, machine learning and big data have opened new possibilities for addressing urban problems innovatively, at a lower cost and more sustainably.

The international landscape in which STI and urban development policies interact has also changed since 2013, with the adoption of the following: Sendai Framework for Disaster Risk Reduction 2015–2030; Addis Ababa Action Agenda of the Third International Conference on Financing for Development; 2030 Agenda for Sustainable Development, in particular Sustainable Development Goal 11; Paris Agreement under the United Nations Framework Convention on Climate Change; and New Urban Agenda adopted by the United Nations Conference on Housing and Sustainable Urban Development (Habitat III).[2] Sustainable urban development, as framed by Sustainable Development Goal 11, invites the international community to rethink urban development patterns and to make urban settlements more inclusive, productive and environmentally friendly.

In addition to accelerating technological change and a new international landscape, the coronavirus disease (COVID-19) pandemic and its effects on urban life provide a third strong reason for the Commission to take a fresh look at the issue of urban development and its social, economic, and environmental dimensions. Accounting for an estimated 90 per cent of all reported COVID-19 cases, urban areas have become the epicentre of the pandemic (United Nations, 2020a), and this can have significant negative effects along all dimensions of sustainable development.

On the other hand, the pandemic has shown the importance of STI systems in contributing to equipping society with the instruments and capabilities required to direct innovation efforts towards improving sustainable urban development and the resilience of urban systems. Scientific knowledge production processes, digital technology adoption and innovations in organizational and institutional settings have contributed to mitigating the impact of the pandemic, helping many urban socio-technical systems to continue to function during the crisis.

As a result, the world has gained access to a rich variety of STI solutions, both technological and non-technological, to urban sustainability issues. These innovative solutions help shape the evolutionary patterns of urban socio-technical systems and contribute to fixing unsustainable urban operations, including economic activities.

The publication is structured around four chapters. Chapter 2 presents the most pressing challenges to sustainable urban development in a post pandemic world. Chapter 3 discusses in depth the contribution that STI practices make towards mitigating these challenges. Chapter 4 presents conclusions and policy recommendations.

[1] Definitions of urban, peri-urban, and rural areas differ significantly in the literature and among countries. These differences usually relate to minimum population sizes and density, and they make it difficult to agree on universal definitions. In this paper, the terms urban area and its synonyms – such as urban environments, urban settlements, urban communities, urban systems, urban regions and urban territories – are used interchangeably, and they cover all degree of urbanization and types of urbanized territories, from the more densely populated urban areas of cities and towns to the intermediate and less dense urban areas that create the urban–rural continuum of peri-urban spaces. Peri-urban spaces are composed of both urban and rural areas; they form urban–rural interfaces and may gradually evolve into fully urban territories, but their growth is fragmented and involves relatively sparse and discontinuous land use patterns.

[2] See, respectively, United Nations General Assembly resolutions 69/283, annex; 69/313, annex; and 70/1, annex; United Nations Framework Convention on Climate Change, FCCC/CP/2015/10/Add.1, annex; and General Assembly resolution 71/256, annex.

2. Challenges of sustainable urban development

People live in a highly urbanized world. In 2017, urban areas were home to more than 4 billion people,[3] and this event has become an important milestone in the history of humanity; for the first time, the worldwide share of urban population has outnumbered the rural population (United Nations, Department of Economic and Social Affairs, 2019a). The urbanization process is considered as one of the main demographic trends, alongside with population growth, population aging and international migration.

During the last two centuries, an overall reduction in human fertility levels has been registered almost worldwide. As a result of this trend, the absolute size of the world's population is expected to grow continuously over the next decades, but at a slower pace compared to the pre-1950 scenario, moving from the 7.7 billion recorded in mid-2019 to 8.5 billion in 2030 and almost 10 billion in 2050 (United Nations, Department of Economic and Social Affairs, 2019b). Notwithstanding the reduced growth pace, urban areas will continue to expand and absorb most of this future population growth.

Two thirds of the worldwide population are expected to live in urban areas by 2050 (World Bank, 2021). In 2020, most of the population was still rural only in a few low-income and lower-middle-income countries – mainly located in Central Africa and South Asia. In many middle-income countries across Eastern Europe, East Asia, Africa and South America, between 50 per cent and 80 per cent of the population was already living in urban environments, and the percentage went above 80 per cent in most high-income countries across Australia, Japan, the Americas, the Middle East and Western Europe (Ritchie and Roser, 2019). Moreover, in addition to being among the most highly urbanized regions in the world, Asia and Africa are also expected to urbanize fastest in the coming decade and to accommodate the largest numbers of new urban dwellers (World Bank, 2021). As a result of these variations within and across regions, dissimilarities appear in urban sustainability implications, which expose the coexistence between local and global dimensions of sustainable urban development.

Moreover, while the populations of many urban areas continue to expand, other urban areas are affected by urban shrinkage, a phenomenon that has become global. However, because urban shrinkage and urban population growth are two very localized events, they can manifest together within the same town, city, or macro-region. For example, the most notable and rapid increase in urban population is expected in Africa and Asia, but cases of urban shrinkage have been spotted in some macro regions of China, India, Japan and the Republic of Korea (Pallagst et al., 2021; Richardson and Nam, 2014). Shrinking towns and cities – and sometimes neighbourhoods (Schenkel, 2015) – are also appearing in Europe and North America (Gao and Ryan, 2020; Richardson and Nam, 2014). For example, urban shrinkage has affected the structural configuration of cities such as Schwedt and Dresden in Germany, Glasgow in Scotland (United Kingdom), and Buffalo and Pittsburgh in the United States of America.

Regionally differentiated patterns also appear when observing the dynamics of population aging. The share of older population – individuals aged 65 years or more – has increased globally over the last three decades, and it is expected to double by 2050 (United Nations, Department of Economic and Social Affairs, 2019c). However, global aging remains a more local issue. The uneven distribution of elderly populations causes variations in this general prediction; more impact is forecasted in regions such as sub-Saharan Africa, whereas only relatively modest changes are expected in European cities (Sivaramakrishnan, 2018).

[3] In producing this estimate, the Department of Economic and Social Affairs of the United Nations examined urbanization trends in 1,900 urban settlements with 300,000 inhabitants or more.

The global scale and the pace of urbanization trends bring unprecedented challenges, whose implications deeply affect the configuration of urban systems and their functioning. The COVID-19 pandemic has also highlighted the challenges facing urban areas, which have become the locus of crucial urban sustainability lessons that country leaders, local authorities, and other urban development actors should take into consideration.

Box 1
The COVID-19 pandemic and sustainable urban development

Urban areas have become the epicentre of the COVID-19 pandemic, where the quality of life has been severely damaged by the devastating effects that the pandemic has caused. For many cities the COVID-19 pandemic has started as a health crisis but has subsequently expanded into "a crisis of urban access, urban equity, urban finance, safety, joblessness, public services, infrastructure and transport" (United Nations, 2020a). Urban areas have become the physical space in which COVID-19 has worsened existing deep-rooted inequalities caused by gender, age and place of residence. Meanwhile, social care systems have left older individuals and those affected by mobility issues isolated, with no opportunities for social interaction, and housing systems with informal settlements have left their residents exposed to a higher risk of virus transmission due to overcrowded and unhealthy leaving conditions.

The responses of government leaders to the pandemic have introduced drastic social distancing and lockdown measures, which have modified patterns of energy and transport demand worldwide. Although only temporarily, these measures have led to a significant reduction of greenhouse gas emissions (Le Quéré et al., 2020) and some air pollutants (Streiff, 2020) in many urban areas. These indirect effects of the COVID-19 pandemic have demonstrated that a greener urban future is possible. However, other pressing environmental challenges have been exacerbated, showing the need for more innovation in urban socio-technical systems. For example, the intense use of disposable plastics has led to a significant increase of urban plastic pollution and inappropriate waste management practices (Adyel, 2020).

The devastating impact of COVID-19 on economy has generated business closures and jobs losses worldwide, especially in least developed and developing countries. As a result, existing economic inequalities have been exacerbated and the level of poverty has increased, especially for families relying on informal economic activities. For example, the economic hardship has pushed millions of informal workers in developing countries out of urban areas due to their impossibility to afford the prevision of basic urban services, including housing (United Nations Human Settlements Programme (UN-Habitat), 2020). Moreover, populations who are affected by a higher incidence of extreme poverty will also be the most exposed to the long economic fallout of the pandemic.

The pandemic has exposed the incapability of many urban settings to deliver on the expectations of disaster and risk management for urban resilience and sustainability. Many urban socio-technical systems have fallen under the pressure, leaving people and places behind, and this result clashes with the core principles of inclusivity and social justice that urban sustainable development champion.

Source: UNCTAD.

The main global challenges facing urban socio-technical systems are summarized in table 1, which is complemented by a detailed overview of these challenges that takes into consideration the effects that the COVID-19 pandemic has brought on urban systems. The challenges cover key areas of the green–productive–inclusive triad of sustainable urban development. Health is not covered in this paper, as it has been extensively analysed in an issues paper prepared for the intersessional panel,[4] held in January 2021, ahead of the twenty-fourth session of the Commission on Science and Technology for Development, as well as in the United Nations Secretary-General's report presented to the Commission at its twenty-fourth session in May 2021.[5]

[4] For more information, see https://unctad.org/system/files/information-document/CSTD2020-2021_Issues01_Health_rev_en.pdf.

[5] For more information, see https://unctad.org/meeting/cstd-2020-2021-inter-sessional-panel.

Note: all websites in references were accessed in April 2022.

Table 1
Global urban sustainability challenges: A brief summary

Urban sustainability challenges	Urban sustainability dimensions		
	Green	Productive	Inclusive
Inefficient and polluting urban energy systems	■		■
Unsustainable urban production and consumption patterns	■		■
Urban water scarcity	■		■
Urban traffic congestion and vehicle emissions	■		■
Limited access to decent urban employment opportunities and growing inequalities		■	■
Unaffordable and poor-quality housing	■	■	■
Gender-based inequalities and violence against women and girls		■	■
Defective urban planning practices	■	■	■
Urban violence and insecurity			■
Vulnerability to natural disasters			■

Inefficient and polluting urban energy systems

Urban systems consume up to 75 per cent of the world's energy. They are responsible for producing over 50 per cent of the overall greenhouse gases, which increases to approximately 80 per cent when indirect greenhouse gas emissions are taken into account (UN-Habitat, 2021b). These harmful levels of emissions are correlated with urban energy production and consumption processes, which are highly dependent on fossil fuels. When coal, natural gas and oil are burned, they release carbon dioxide and other greenhouse gases, which are one of the prime causes of global warming and climate change.

It is important to note that public financial flows for renewable energy continue to be concentrated in a few countries, making it difficult for many developing countries and least developed countries to sustain urban energy transitions. Sub-Saharan Africa and Latin America have attracted most of the international investments since 2010. However, national-level data shows significant inequalities; between 2010 and 2018, developing countries such as Argentina, India, Nigeria, Pakistan and Türkiye received 30 per cent of the total investments, whereas only 20 per cent was directed to the 46 least developed countries (United Nations, 2021). In addition, the COVID-19 pandemic has caused substantial decline in renewable energy investments – a 34 per cent decrease in the first half of 2020 compared to 2019 (International Renewable Energy Agency (IRENA), 2020).

Unsustainable urban production and consumption patterns

In 2020, most of the global material footprint – which refers to the raw materials extracted to meet the existing consumption demand – is generated in urban areas, exceeded the growth in population and economic. Should the world continue to follow this consumption trend, by 2050, the equivalent of almost three planets will be required to provide the natural resources needed to sustain current lifestyles (United Nations Environment Programme (UNEP), 2019). In many Mediterranean countries, for instance, a few major urban systems are sufficient to consume the vast majority of the biocapacity of their nation – in some cases, even all of it. Examples of cities include Rome and Naples in Italy, Barcelona and Valencia in Spain, Tunis in Tunisia, Cairo in Egypt, and Athens and Thessaloniki in Greece (Global Footprint Network, 2015).

Excluding Australia, New Zealand, Europe and North America, all regions of the world experienced a significant rise in domestic material consumption rates over the past two decades, and the material consumption of urban systems is expected to grow from 40 billion tonnes in 2010 to 90

billion tonnes by 2050 (UNEP, 2018). In developing and least developed regions, this increase is mainly due to late industrialization processes and the outsourcing of material-intensive production. In developed countries, the rise is driven by unsustainable lifestyles (United Nations, 2021).

Plastic waste has been emphasized in urban-related material consumption debates. Cities are responsible for producing an estimated 60 per cent of the plastic that reaches marine waters. However, the global recycling rate remains between 14 and 18 per cent (Organization for Economic Co-operation and Development (OECD), 2018a). This recycling issue has also been exacerbated by the COVID-19 pandemic, which has caused a heavy use of plastic goods, especially single-use plastics, such as face masks, personal protective equipment kits and sanitizer bottles.

The food waste challenge is as critical as the issue of the accumulation of plastic waste. Food waste represents 44 per cent of the global waste and more than 17 per cent of the global food production may be lost annually (UNEP, 2021). Electronic waste is an additional challenge, which continues to expand. Despite highly hazardous substances, which contaminates soil and groundwater, less than 20 per cent of electronic waste is formally recycled and 80 per cent ends in landfill site or is informally recycled (World Economic Forum, 2019).

Urban water scarcity

Population growth and urbanization are increasing the demand for resources, amplifying levels of water stress. Poorest countries are suffering the most, as they also have a lower coverage of freshwater bodies: 1.4 per cent of land compared to the overall 3.5 per cent of developed countries (Favre and Oksen, 2020).

For example, more than 60 per cent of urban areas in sub-Saharan Africa do not have access to water and sanitation services (Mitlin et al., 2019). Moreover, most households connected to municipal piped networks receive water intermittently, and residents that cannot access public supply are forced to rely on costly alternative of self-provision or private vendors.

Recent studies estimate that the global urban population facing water scarcity will drastically increase. Hence, between 1.7 and 2.4 billion people will live in water-scarce regions by 2050 (He et al., 2021). Moreover, 292 out of 526 large cities worldwide and 19 megacities are expected to experience perennial or seasonal water scarcity issues by 2050.[6]

Droughts, climate change, and pollution are among the most critical events that influence the availability of water resources – and hence, it is giving impacts to the adequacy of the supply of clean water for drinking and sanitation purposes (European Environment Agency, 2011). Addressing urban water scarcity is a key societal challenge. The control and movement of water resources require several core activities to be conducted, which include the replenishment of water reserves, extraction, transport, distribution, and safely treatment and disposal of wastewater. Each activity involves a combination of technologies, management techniques, and human and financial resources whose absence threaten the sustainable and stable supply of clean and fresh water to urban populations (Favre and Oksen, 2020).

[6] In this study, large cities are urban areas with more than 1 million inhabitants, whereas megacities have a population of more than 10 million inhabitants. The megacities are located in Bangladesh, Brazil, China, Egypt, India, Indonesia, Mexico, Pakistan, Peru, the Philippines, the Russian Federation, Türkiye and the United States.

Urban traffic congestion and vehicle emissions

Although transport systems offer numerous benefits to societies, urban mobility has brought about some of the greatest obstacles to urban sustainable development. Air pollution, congestion, and limited access to public transport have become prominent challenges facing many urban areas in developing and developed countries. Among the most relevant causes are the presence of many transport vehicles that still heavily depend on fossil fuels; rising private ownership of polluting vehicles; road congestion due to limited urban space unable to accommodate growing levels of urban traffic; and access to public transport that is increasingly unaffordable for poorest groups of urban populations. Road congestion is particularly common in high-density urban systems, where the presence of vehicles on urban streets is increasing while the physical space to support their movement remains insufficient. This urban challenge influences the effectiveness and efficiency of transport systems and road usage; urban economies deteriorate due to limited accessibility, and it creates parking difficulties, longer commuting times, limited mobility of non-motorized transport modes and pedestrians, lower quality of public spaces, higher environmental degradation and higher levels of stress for drivers and urban residents.

Transport activities are responsible for generating approximately 25 per cent of energy-related carbon emissions from fuel combustion worldwide (International Energy Agency, 2019), and most of this pollution comes from urban areas. For example, in European cities, road transport is by far the biggest emitter accounting for more than 70 per cent of all greenhouse gas emissions from transport (European Commission, 2014). These high levels of harmful emissions have severe health implications on urban residents; they are directly associated with increasing mortality rates and respiratory and cardiovascular diseases (World Health Organization, 2005).

Limited access to decent urban employment opportunities and growing inequalities

Urbanization and economic development go hand in hand. Overall, countries with a higher per capita gross domestic product (GDP) tend to be more urbanized, especially in terms of metropolitan populations. The share of the population living in metropolitan areas of above 1 million people is roughly four times greater in high-income countries, at 47 per cent, than in low-income countries, at 12 per cent. In middle-income countries, GDP per capita in the most metropolitan regions is twice as great as per capita income in the least metropolitan regions (OECD/European Commission, 2020). As a result, urban areas contributed about 80 per cent of global GDP before the pandemic (Estrada et al., 2017). They are expected to become the main driving force of the post-pandemic economic recovery.

Due to substantial differences in the roll-out of vaccinations and in the distribution of State aid, urban areas in developed countries have tended to recover faster than those in developing countries and the least developed countries. Urban unemployment rates in Latin America and the Caribbean reached an average of 10 per cent in 2017, but in January 2021 the figure doubled in some countries.[7] In South Africa, the unemployment rate was at 46.3 per cent, a steep increase during the pandemic especially because of youth unemployment.[8]

The global decline in job opportunities in urban areas indicates a fragile economic system with a low level of resistance to exogenous shocks. One of the main causes of this weakness is the widespread presence of informal working conditions; 1.6 billion informal workers worldwide have little or no social protection (Codd and Ferguson, 2020). Informal economies have been significantly impacted during the pandemic. For example, millions of informal urban workers in India had to move back to rural settlements after losing their jobs. Similarly, in Peru, over 170,000 urban dwellers in poor conditions transferred to the countryside in 2020. While the global unemployment

[7] See https://www.cepal.org/en/publications/42251-employment-situation-latin-america-and-caribbean-transition-young people-school and https://www.bbvaresearch.com/en/publicaciones/colombia-effects-of-covid-19-on-employment-in-january-2021/.

[8] Contribution from the Government of South Africa.

rate has grown, existing gender and age discrepancies in job opportunities have worsened. In North America and Western Asian, for instance, approximately 11 per cent of the labour force was without a job in 2019, but the unemployment rate of female workers was 6 per cent higher than male workers.[9] Moreover, with a level of unemployment that was 18 per cent higher than adults (United Nations, 2020b), young people are required to confront higher degrees of uncertainty, as well as the likelihood of greater labour market disruption.

Forced labour, child labour, modern slavery, human trafficking and high numbers of workplace fatalities and injuries are additional challenges that prevent many urban areas from being places of inclusive and equitable economic growth. For example, over one million work-related fatalities are reported every year in rural and urban areas – which is equivalent to 5.7 per cent per 100,000 workers – and millions of workers suffer from occupational injuries (International Labour Organization, 2019).

Unaffordable and poor-quality housing

Because of existing poverty rates, around a billion urban dwellers are forced to live in informal settlements, which enhance peri-urbanization processes and are mainly located in regions of developing countries. Available statistics show that Eastern and South-Eastern, Central and Southern Asia, and sub-Saharan Africa account for 80 per cent of the worldwide population living in informal settlements, where residents experience overcrowded and low-quality housing conditions. Considering current urbanization trends, approximately 3 billion people may require quality and affordable housing by 2030 (United Nations, 2021), augmenting an existing housing deficit that the building sector is incapable to overcome.

However, this affordable housing crisis extends beyond developing countries. It also afflicts housing markets in developed countries. House prices are currently three times higher than the median family income in almost all international cities, and the most unaffordable housing markets worldwide are spread across all developed countries.

To increase infrastructure resilience and improve the sustainability and efficiency of industrial sector activities, including the housing sector, significant global investments have already been made in research and development – US$1.7 trillion in 2020. However, when comparing country-level financial capacity for research and development efforts, a significant gap emerges between developed and developing countries (UNCTAD, 2020).

Gender-based inequalities and violence against women and girls

Women and girls who live in urban areas are subject to inequalities and their economic position is significantly disadvantaged compared to men. Despite more substantial working effort, women are subject to occupational segregation, which prevent them for accessing many urban employment opportunities, including managerial jobs. For example, in 2019, only 28 per cent of managerial positions worldwide were occupied by women and, when compared with the situation in 2000, this figure only shows a 3 per cent increase in a 19-year time frame (United Nations, 2020b). In certain occupations predominated by women, wages are often lower than occupations predominated by men. Legal barriers and gaps are among the main cause of this economic inequality, and they are also instrumental in creating occupational segregation and preventing girls and women from having equal participation in decision-making processes within workplaces (Hyland et al., 2019; OECD, 2018b).

Urban areas are the spaces in which most technological advancements are produced and implemented. Gender inequality has also appeared in the form of a technology-related bias. This resulted from design processes that have failed to sufficiently incorporate the perspectives of women. For example, evidence that proves the presence of gender biases in artificial intelligence

[9] See https://unhabitat.org/World%20Cities%20Report%202020 and https://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_813449/lang--en/index.htm.

and emerging technologies is growing. Facial recognition technologies, web searches, and the speech recognition software enabling artificial intelligence bots and voice assistants are examples of technological solutions whose levels of performance have been evaluated as higher for men than women (Chin and Robison, 2020; Bajorek, 2019). This phenomenon is observed by the European Union Agency for Fundamental Rights, in a report that examines discrimination in data-supported decision-making. The report indicates that these different levels of performance could be the result of technology design processes that have been developed without giving equal representation to both genders (European Union Agency for Fundamental Rights, 2018).

Moreover, cases have been reported of gender biases in urban planning practices (Pojani et al., 2018), which tend to overlook how girls and women experience the urban environment. Consequently, their needs are not addressed. According to the Handbook for Gender-Inclusive Urban Planning and Design that the World Bank has recently released, most cities in the developed and developing world have been planned by and for men (World Bank, 2020a).

Finally, a strong correlation exists between urbanization and gender-based violence and abuse against women and girls. Moreover, the data collected after the COVID-19 outbreak confirms that, during the pandemic, all acts of violence against women and girls have intensified in many countries, especially domestic violence cases.

Inadequate urban planning practices

Urban planning practices have exposed difficulties in regulating the growing demand for land that a fast-urbanizing world is posing – a demand that creates urban sprawl and uncontrolled peri-urbanization processes. In developing and developed countries, many large urban areas have expanded their boundaries and economic activities by taking possession of surrounding rural areas, where unregulated patterns of informal settlements and small towns – some of which are newly developed – have rapidly densified. Fragmented around existing urban areas, these new urban entities are regulated by growth dynamics and generate peri-urban spaces that many local authorities have largely overlooked.

A common reaction among municipal governments has been the attempt to regulate peri-urban areas with traditional urban planning instruments. However, these tools have proven incapable of successfully dealing with the complexity due to fragmented space distribution processes, which in turn affected socioeconomic and environmental sustainability. The result is an uneven development between centrally located urban spaces and urban spaces positioned in peri-urban interfaces. Compared to populations living in urban centres, many peri-urban residents are exposed to higher levels of vulnerability and poverty. They have reduced accessibility to jobs, housing and other socioeconomic opportunities and services that central urban areas can offer.

Local planners and authorities struggle to cope with the complexity of peri-urbanization expansions, as documented in many studies. There is a need for alternative urban planning tools and strategies and innovative land use governance systems and policies.

Pursuing sustainable urban development also requires disability inclusion in urban planning practices. Estimates suggest that one billion people worldwide are living with a disability, however, planning processes often fail to consider the barriers – physical but also technical, environmental and social – that design choices create for urban residents with disabilities (United Nations, Department of Economic and Social Affairs, 2015 and 2016). As a result of this neglected perspective, the capability of persons with disabilities to access urban spaces, their services and their facilities is severely undermined. Poor planning poses a significant threat to the inclusion of people with disabilities in urban life, leading to increased inequalities, marginalization and an accentuated risk of poverty.

Urban violence and insecurity

About 83 million people in urban areas worldwide have to live with the consequences of armed conflicts, crime and violence (United Nations, 2020b). For example, murders related to armed conflicts in urban settings caused more than 20,000 deaths between 2015 and 2017 and they were more than tripled between 2018 and 2020 (United Nations, 2020b). In addition, in 2017, approximately 500,000 urban residents were murdered worldwide as a result of other types of crimes (United Nations, 2020c). Recent statistics show that approximately 54 per cent of urban resident's homicides are carried out with firearms, many of which are entering urban spaces due to illicit trafficking (United Nations Office on Drugs and Crime (UNODC), 2020a). Armed conflicts in cities generally are the consequence of social unrest and unstable political conditions, which pose a substantial threat to urban livelihood.

Over 150 million urban citizens are also confronted with forced evictions (Farha, 2020), involuntary removal from their homes or land without having access to legal and judicial processes. This problem has been amplified by COVID-19, during which significantly impoverished living conditions have left millions of urban households unable to escape their insecure housing arrangements.

Vulnerability to natural disasters

The sustainable development of many urban areas in developed and developing countries is also constantly threatened by natural disasters; not only pandemics, but also adverse events such as hurricanes, urban floods, earthquakes and landslides. The direct losses from natural disasters in urban spaces was $2.9 billion during the period between 1998 and 2017 (Wallemacq and House, 2018).

Beyond economic damages, natural disasters also wreak havoc with urban social stability and dramatically affect people livelihoods in urban areas. In China, for example, extreme seasonal weather displaced 744,000 people across 26 provinces and cities in 2020 (Lew, 2020). Meanwhile in Peru, people are displaced and lose their job in areas at risk of mudslides and flash floods caused by torrential rains occurring high in the Andean mountains.[10]

[10] Contribution from the Government of Peru.

3. Applying science, technology and innovation for sustainable urban development

STI solutions can mitigate the most pressing urban sustainability challenges, harnessing the value embedded in global population growth while facilitating sustainable urbanization processes. Both technological and non-technological innovations have been introduced in developed, developing and least developed countries to sustain positive change in urban socio-technical systems.[11] The COVID-19 pandemic has showcased the pivotal importance that STI systems play in contributing to equip society with the instruments and capabilities required to direct innovation efforts towards improving sustainable urban development and the resilience of urban systems. Scientific knowledge production processes, digital technology adoption, and innovations in organizational and institutional settings have contributed to mitigating the impact of COVID-19, helping many urban socio-technical systems to continue to function during the crisis.

Table 2
Summary of science, technology and innovation solutions to urban sustainability challenges

Urban sustainability challenges	Category	Science, technology and innovation solutions
Inefficient and polluting urban energy systems	**Energy**	Biomass energy systems; solar energy systems; hydropower energy system; geothermal energy systems; wind energy systems; green hydrogen technology; energy efficiency in the construction sector
Unsustainable urban production and consumption patterns	**Circularity**	Product-service systems; matchmaking platforms for exchanging resources; environmental labelling; food traceability systems; food sharing networks and technology; pay-as-you-throw pricing models; smart bin solutions; single-use plastic ban; circular economy for plastic; cup-as-a-service subscription models; data platforms for plastic waste mapping; digital systems for automatic hazardous waste detection; robotic systems for waste management; right-to-repair standards; urban mining techniques
Urban water scarcity	**Water**	Smart metering infrastructures; nanotechnological applications for desalination processes; sensor-based water protection systems; portable testing kits for real-time quality control; satellite technology; mobile applications for waste monitoring
Urban traffic congestion and vehicle emissions	**Mobility**	Low-emission vehicles; journey planner applications; real-time traffic management systems; mobile ticketing; mobility as a service; bike sharing systems; cycle-to-work schemes
Limited access to decent urban employment opportunities and growing inequalities	**Economic prosperity and financial stability**	Dedicated urban zones for STI development; digital finance; e-commerce platforms; ICT-related education and training programmes; innovative data management systems; cash transfer schemes and programmes; smart technologies to fight forced labour and modern slavery
Unaffordable and poor-quality housing	**Housing**	Digitalization of construction operations and manufacturing processes; digital twin technology in construction; predictive analytics; environmentally sound technologies; smart building solutions

[11] Please note that the analysis does not aim to cover all possible STI solutions to urban sustainability challenges. The objective is to select a comprehensive number of most notable technological and non-technological innovation cases whose collective examination is required to form a sufficiently robust and data-rich environment for supporting: (a) the identification of relevant lessons and practical implications; and (b) the subsequent formulation of policy measures that can maximize existing potentials. In the framework of this analysis, more than 100 STI-related initiatives have been examined. Moreover, these STI solutions need to be viewed as an interdependences effort to address challenges of sustainable urban development.

Urban sustainability challenges	Category	Science, technology and innovation solutions
Gender-based inequalities and violence against women and girls	**Gender empowerment and equality**	Gender-pay-gap regulations; compensation management platforms; anti-violence online services; awareness-raising measures and education
Defective urban planning practices	**Urban planning**	Spatial group model building; gamification for digital participation; digital twin technology for urban planning; online crowdsourcing platforms
Urban violence and insecurity	**Safety and security**	Crime prevention policy; gunshot detection technology; crime mapping tools; predictive profiling technology
Vulnerability to natural disasters	**Protection from natural disasters**	Disaster data infrastructure; nature-based solutions

3.1 Energy

Urban socio-technical systems for energy production and distribution are highly dependent on fossil fuel combustion. A transition to low carbon and sustainable renewable sources is urgently needed, especially considering the steep increase in urban energy demand that an expanding population will progressively cause. The use of renewable sources to produce energy gained momentum during the last two decades. However, their share in the energy mix has always remained limited in comparison to fossil fuels. This gap has triggered significant investments in research and development activities, which have resulted in notable technological and non-technological STI solutions to address the unsustainable urban energy system.

Solar photovoltaic systems

Technologies using solar photovoltaic systems to produce urban energy are used in many different application contexts, such as buildings and waste management systems. Moreover, ground mounted panels are among the most common applications, together with rooftop and floating installations.

Aside from most common ground mounted application, rooftop solar photovoltaic installations have increased significantly in recent years. These can easily sustain energy production in urbanized territories where energy is not available, or where power interruptions and outages occur regularly. For example, in Zambia and Zimbabwe, the United Nations Development Programme has worked with various stakeholders to install rooftop solar panels on national medical warehouses and health-care facilities, giving them the capability to autonomously produce green energy (Burton and Alers, 2019).

Compared to ground mounted and rooftop installations, floating solar photovoltaic power represents a more recent technology power industry. The implementation of floating solar photovoltaic systems emerged in 2008, mainly in response to increasing competition for land use due to an expanding population and a growing demand for agricultural and industrial services. For example, in the city of Suzhou, in the Anhui Province of China, the China Energy Conservation and Environment Protection Group has partnered with Ciel and Terre – a French company specialized in floating solar photovoltaic panels – to generate approximately 70,000 MWh of green electricity annually, equivalent to the power consumption of 21,000 households (Sustainable Water and Energy Solutions Network (SWESN), 2021a).

To eliminate gaps in electricity provision, solar photovoltaic systems have been extensively used in Africa. For example, as part of the sustainable energy strategy 2035 of the Government of Egypt, the Government is currently constructing 26 new electricity stations near the city of Aswan, with a total capacity of 26,000 MW. Electricity produced through solar energy increased from 0.529 billion kW to 1.465 billion kW between 2018 and 2019 (increasing by 177 per cent) as Egypt inaugurated the Benban Solar Park, the world's largest solar park.[12]

[12] Contribution from the Government of Egypt.

To address the energy affordability challenge facing many urban residents, the African company SolarWorks is providing solar home systems and energy services on a pay-as-you-go basis to urban populations in Malawi and Mozambique. The company operates using an innovative business model; customers pay small amounts every month using mobile money until they reach the necessary expenditure to own the appliance model (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2021).

Hydropower energy system

Hydropower is an old technological solution, but under the right conditions, it can still provide urban areas with cost-effective and green electricity. As of 2021, for example, Norway produces 99 per cent of electricity from hydropower, while China has the largest hydropower plant in the world, producing 80 to 100 terawatt-hours per year.

Examples from various countries show that cities can enhance their existing hydropower infrastructure to produce more emission-free energy. For example, the hydropower station on the River Danube in Pfaffenstein, Germany, produces about 40 million kilowatt-hours of green electricity for the City of Regensburg. This amount of energy is sufficient to serve 11,000 households and the electric buses of the city. In Australia, Melbourne is another city where the authority has been introducing mini plants in different parts of the city since 2008. These plants generate approximately 69,500 megawatt-hour of power per year, and they save about 75,800 tonnes of carbon emissions (Melbourne Water, 2017; SWESN, 2021b).

Small-scale micro-hydropower solutions have also spread, making a notable difference to urban and rural communities in remote locations. For instance, kinetic hydropower systems have been introduced in canals in Germany, India, South Africa and the United States.

Geothermal energy systems

Geothermal power plants produce electricity by converting heat sourced from geothermal fluid. High or medium temperature resources of better efficiency are located closely to regions, such as El Salvador, Iceland, Kenya, New Zealand and the Philippines. Leveraging the predisposition of their natural environments, all these regions are currently using geothermal energy to produce a share of the electricity demand generated by their urban and rural areas. For example, geothermal resources account for nearly 40 per cent of the power-generating capacity of Kenya (SWESN, 2021c).

Geothermal energy is also used in European cities. As part of the project Decarb City Pipes 2050, for example, the European cities of Bilbao (Spain), Bratislava, Dublin, Munich (Germany), Rotterdam (Netherlands), Vienna and Winterthur (Switzerland) are coordinating their work in this green energy domain by exchanging experiences and lessons on how geothermal energy can be used to decarbonize building heating systems.

Wind energy systems

Wind power is one of the most rapidly accelerating technologies amongst all renewable energy systems. In 20 years, the combination of onshore and offshore wind generation capacity has increased worldwide, from 7.5 gigawatts (GW) to some 564 GW. The United Kingdom was the third largest generator of wind powered electricity among OECD European countries in 2018, after Germany and Spain. Other pioneering countries in the use of wind power for energy production include China and the United States. In the meantime, France, the Republic of Korea and Viet Nam are increasing their investments (IRENA, 2020).

Land-based wind sites are often located in remote locations, but small wind turbines can also enter into urban areas, for example, on the roofs of residential and commercial buildings. However, the efficiency and environmental sustainability of these roof-mounted turbines is still highly debated. This is mainly due to the presence of multifaced technical challenges – for example, wind in urban areas is irregular and severely affected by the presence of buildings and other obstacles.

Green hydrogen technology

Green hydrogen is becoming a new alternative energy source to fossil fuel. Several countries have launched programmes to investigate how to benefit from green hydrogen production and to develop the technologies required to transform hydrogen into a source of clean power. Australia, Chile, Germany, Japan, Portugal, Saudi Arabia and Europe are some of the countries and areas that are planning extensive investments in green hydrogen technologies (European Commission, 2020).

Studies on green hydrogen show that it may enable the development of low- and zero-emission heavy vehicles including trains and hydrogen-powered aerial vehicles, as well as decarbonizing industries such as cement and steelmaking. Additionally, electricity can be converted into hydrogen by electrolysis, providing an innovative way to store and transport renewable energy generated by other means when batteries or other modes of storage and transport are not practical or competitive.

Biomass energy systems

Anaerobic digestion technologies or biomass that convert biodegradable waste into methane-rich biogas are commonly deployed worldwide. For example, urban areas in Guatemala use electricity generated from sugarcane biomass – also known as bagasse – which has been an established practice amongst sugarcane producers since 1990. During the 2017–2018 harvest season, bagasse made it possible to save approximately 4 million tons of carbon emissions (SWESN, 2021d).

In Manouba, a city in north-eastern Tunisia, a family-managed agricultural enterprise developed in 2015 an innovative form of biofuel, using pear and olive tree waste. In Brazil, Rio de Janeiro piloted the first biomethanization system in Latin America. This system processes the organic fraction of urban solid waste via anaerobic digestion to generate energy and to produce organic compost. The systems tested in Rio de Janeiro could provide meet the daily need for green energy of an urban area with 70,000 inhabitants (Yeung, 2020; Rajab, 2018).

Energy efficiency in the construction sector

In recent years, many developing and developed countries have introduced new regulatory systems or modified their existing schemes. For example, in Romania, new building energy codes have been introduced in 2017, which require new construction and renovations to comply with minimum energy performance standards. Similar restrictions have also been introduced in Brazil, where some types of incandescent bulbs have been banned, and the National Institute for Standardization of Brazil has made mandatory the certification of public lighting using LEDs and other efficient lamps (UNEP, 2017a).

Meanwhile, other countries are experimenting with solar thermal ordinances (STOs), which are applied as a part of municipal regulations regarding building technologies. STOs are legal provisions that require a building's minimum share of heating demand to be covered through the installation of solar thermal systems.

Energy efficient buildings also require investments in innovative materials that offer adequate thermal performance. On this matter, the Government of Ukraine launched a State Programme on Energy Efficiency in 2016. The programme provides loans to finance the costs for a variety of energy efficient materials and equipment. The total amount of loans issued as of the end of 2017 was over €150 million for 373,000 households, saving 6 billion m^3 of natural gas (United Nations Economic Commission for Europe, 2019).

Thermal insulation is key to attain energy-efficient buildings, as heating and cooling operations account for approximately 50–60 per cent of their total energy consumption (IRENA, 2021). Digital solutions can be used to track these inefficiencies, by monitoring the overall energy performance of buildings and evaluating the performance of single building component.

3.2 Circularity

Production and consumption patterns have become key priorities for many urban regions of the developed world because they are putting a serious strain on the limited natural resources that the world has to offer. In the last decade, local and national governments, consumers, and producers started to take conscious actions that attempt to integrate circularity and behavioural change into urban areas. The STI solutions resulting from these actions mainly focus on decreasing material footprint per capita, preventing excessive waste production, and increasing the recycling and reusing of different types of waste.

Box 2
Promoting urban policy as part of national development: Lesson from Romania

The Ministry of Development, Public Works and Administration is currently setting up the first Urban Policy of Romania. The Urban Policy represents an essential framework for establishing the connection between the dynamics of urbanization, demographic changes and the overall process of national development. A broad array of policy objectives and associated measures were identified for the effective attainment of (a) green and resilient, (b) competitive and productive, (c) just and inclusive, and (d) well-governed cities.

Building on the logic of the resilient recovery, the Urban Policy of Romania promotes the reconsideration of policy choices that address inequalities and local capacities while emphasizing a green, inclusive recovery. Key concepts, such as the "circular economy", the "localization of the Sustainable Development Goals", "tactical urbanism" and "the 15-minute city", are all taken into consideration in the first Urban Policy of Romania, to help achieve better quality of life by enhancing economic activity, providing quality living environments, improving job opportunities and having well-serviced business locations.

Source: Contribution from the Government of Romania.

Product-service systems to reduce footprints

To reduce the ecological footprint of urban environments and their residents, many companies are spending significant resources on the development of innovative business models. Product-service systems, for example, are circular business models that enable producers to retain the ownership of their products even as they are sold to customers for temporary use. Producers also remain responsible for undertaking maintenance service and repairs. For example, CECOLAB in Portugal is working to develop sustainable market solutions in a model of circular economy for strategic value chains on the national level.[13]

Matchmaking platforms for exchanging resources

In addition to product-service systems, companies are also adopting business-to-business matchmaking platforms for exchanging resources. These platforms allow companies to put their unused products, materials, and waste back into the market and help other companies to find resources while reducing waste. Excess Materials Exchange is an example of a business-to-business matchmaking platform that enables users to find reuse options for unused materials and waste. During the pilot study, the platform has circulated 18 different materials back to markets, enabling exchanges of excess resource flows between different industries and sectors, and saving significant amount of carbon emissions and energy (Excess Material Exchange, 2019).

Environmental labelling

Another way to decelerate the consumption of materials and goods in urban areas is to make customers aware of the environmental cost of their buying habits, by providing them with detailed information about this. This can be achieved with environmental labelling and information schemes, which are voluntary methods of environmental performance certification.

[13] Contribution from the Government of Portugal.

Eco-labels can be effective tools for communicating and marketing environmental credentials of products, and they are often used in sustainable public procurement to ensure that public organizations purchase best-standard products. Examples of where this has been done include Brazil, Colombia, India and Viet Nam (UNEP, 2017b). However, it is important to note that eco-labels may also be misused to convey inauthentic information about environmental impacts. This practice is known as greenwashing.

Food traceability systems

Food that should feed urban and rural population can easily become waste along its production and distribution journey. Digital traceability and tracking systems can enable earlier detection of inefficiencies along food supply chains. For example, the improvement of locally produced food safety and traceability measures is the core focus of the AMBROSIA project, whose main output is a digital system that helps municipalities tracks points of origin and shipping processes. It also records all transactions, the status of foods during transportation and environmental conditions (European Space Agency, 2018).

Food sharing networks and technology

Food waste is a growing concern on a global scale. In response to this challenge, innovative solutions have been introduced in urban areas not only to improve the food supply chain but also to convert the waste it produces in other products. Food waste from companies, supermarkets, and hospitality facilities, can be reintroduced as organic waste in other processes. For example, online food sharing services, such as Ollio and FoodCloudhelp, to collect food that can be redistributed among urban and rural residents in need. Moreover, unused food can also be managed through redistribution organizations. With the support of the United Kingdom Food Reduction Fund, eight redistribution organizations have been able to save 2500 tonnes of food and redirect it to people in need – food that would have ended up in landfills (Harvey et al., 2020; United Kingdom, Department for Environment, Food, and Rural Affairs, 2018).

Box 3
Bioeconomy, circular and green economy policy model in Thailand

The bioeconomy, circular and green economy policy model is an economic model towards sustainability that combines bioeconomy with circular economy and green economy.

- Bioeconomy focuses on efficient utilization of natural resources along with natural balance protection, by using technological advancement in various disciplinary to increase efficiency and innovation.
- Circular economy is an economic system that all resources can be restored and re-utilized to avoid resource scarcity.
- Green economy is an economic development model that concerned balanced development between economy, society, and environment.

This development model emphasizes inclusive and sustainable development focusing on food and agriculture, health and medicine, bioenergy, biomaterials and biochemicals, and tourism and the creative economy. The bioeconomy, circular and green economy policy model will help Thailand to overcome the middle-income trap and the effects of COVID-19 pandemic, to improve social inequality by linking knowledge on STI to biodiversity and cultural diversity to build the internal strength of the country and distribute benefits to community equally.

Source: Contribution from the Government of Thailand.

Pay-as-you-throw pricing models

The COVID-19 pandemic has caused increasing amount of mixed waste, a suspension of recycling activities and lack of proper equipment for waste collectors, including personal protective

equipment. In the Philippines, results of the survey conducted by the Technical Working Group on Anticipatory and Forward Planning, showed that in the first month of pandemic, 35 per cent of the respondents were not able to sell their product which led to wastage of produce and losses for the farmers. Although the Government is assuring the people that there is enough food supply, bringing them to the consumers becomes a problem during the early stage of the COVID-19 pandemic.[14]

In urban areas, to facilitate the process, some local authorities have introduced pay-as-you-throw pricing models. The objective is to improve municipal waste management by encouraging waste reduction and separation before disposal and making waste producers responsible for collection and treatment. In Bergen, Norway, the combination of the digital platform with data collection processes and new economic incentives has resulted in a 10 per cent reduction of the general waste level (Circit Norden, 2020).

Smart bin solutions

Municipal waste management can also be improved by introducing networks of compacting bins with built-in sensor solutions, which are connected through a digital platform. The bins automatically upload data on filling levels on the platform, which helps determine when and where waste collection services are needed.

For example, the Selçuklu Municipality of Konya in Türkiye, started to monitor the garbage containers instantly with the Waste Scada System. The system uses energy from the sun and does not need extra wiring. The technology can be easily installed on used containers, vehicles and other elements without the need to change the existing infrastructure.[15]

Circular economy for plastics

To accelerate the transition to zero-plastic waste, countries and industrial sectors have introduced changes in policy, regulatory, and business settings. These changes are helping urban areas to decrease plastic waste production by modifying the consumption patterns of single-use plastics and reducing their usage. For example, single-user plastic bags have been widely removed in small-scale markets and supermarket chains, where many retailers have introduced biodegradable bags. Plastic shrinks' wrappers have also been replaced with alternative options such as reusable pallet wrappers.

Other initiatives include deposit return schemes and reward mechanisms that encourage customers to bring back plastic containers, such as bottles and cans, and innovative cross-sector alliances which provide policy direction. The United Kingdom, for example, is advocating green production and consumption through the United Kingdom Plastics Pact initiative – a cross-sector alliance whose objective is to create a circular system that keeps plastic out of the natural environment.

Cup-as-a-service subscription models

Another stream of innovative solutions to plastic pollution includes technology-based platforms and new business models that are helping urban areas to establish stronger collaborations between actors along the supply chain, ranging from consumers, food retailers, utility companies, and recyclers. These solutions act as an intermediate agent between the public and private sector, and they facilitate the creation of sustainable waste management ecosystems for plastic products.

For example, cUPcircle is an award-winning circular economy service that has been piloted in the hospitality sector. cUPcircle introduces a cup-as-a-service subscription model for cafes and their customers, providing them continuously with reusable cups in place of disposable cups. The cups are equipped with barcodes. Customers who subscribe to this service receive their beverages in reusable cups in exchange for a deposit. After being used, the cups are collected in smart bins, which recognize the digital profile of customers and refund the deposit (UNLEASH, 2018).

[14] Contribution from the Government of the Philippines.

[15] Contribution from the Government of Türkiye.

Data platforms for plastic waste mapping

Moving to a more international level, in 2019, about 50 major global companies forged the Alliance to End Plastic Waste (AEPW), a non-profit organization whose objective is to reduce the pressure that plastic waste is creating on society. This commitment of tackling plastic pollution is bolstered by the implementation of a new data platform. Supported by a technological partner, research and development efforts are being made to establish a digital platform solution that can aggerate and scale the different streams of data that the actors operating in the plastics value chain possess.

Digital systems for automatic hazardous waste detection

STI solutions can also help detect and manage hazardous waste. The ARCtic Sea-ice and CleAN (ARC-SCAN system), for example, can automatically detect oil spills in open waters, enabling a prompt response. The system represents an advanced technological solution that combines nautical navigation systems, satellite imagery, and machine learning (European Space Agency, 2019).

Robotic systems for waste management

Additional advanced technologies are also entering into waste sorting operations, with robotics and artificial intelligence that can be used to support hazardous waste identification processes and to improve waste disposal operations.

For example, robot technology and recycling specialists in Denmark and Sweden have been experimenting with new robotic solutions that use vision systems and deep learning to identify items that contain batteries but may pass unnoticed when electronic waste is sorted. Research and development in robotics are also producing new generations of robotic systems for locating chemical leaks in industrial sites and cleaning machines powered with artificial intelligence.

Electronic waste recycle management

The recycling process of electronic waste is extremely complex and poses a serious threat to urban life. Electronic objects are composed of an untangled mix of different materials, which are difficult to separate for reuse purposes. Changes in international regulations, for example, have been introduced in Europe, where an eco-design law including right-to-repair standards has been recently enforced. This new legislation forces manufacturers to ensure the longer-lasting life of their appliances, so that the production of electronic waste can be reduced.

Responsible production principles for extending the lifespan of electronic products can also be complemented with new recycling techniques. These include urban mining, the extraction of the nanometals embedded in discarded electronic applications – largely found in urban settlements – which are in turn reused in manufacturing processes of new products. China has been experimenting with urban mining techniques and technologies for many years, where the volume of material recovered and reused has been growing significantly since 2006. Moreover, the practice is becoming significantly cost efficient (Zeng et al., 2018).

To monitor this electronic waste, the International Telecommunication Union published the Global E-waste Monitor 2020, which assessed the quantitative, flows and the circular economy potential of e-waste. The International Telecommunication Union has also published a toolkit on policy practices for e-waste management which presents tools for fair and economically viable and extended producer responsibility in the management of e-waste.[16]

3.3 Water

Access to clean water in urban areas is hindered by multiple factors, such as the lack of adequate infrastructure, limited water resources, global warming, pollution in water sources, high-water stress due to excessive extraction, and wasteful behaviour. Many technologies and innovative practices are currently available that can help tackle urban water scarcity challenges. In addition to manual

[16] Contributions from the International Telecommunication Union.

drilling, more advanced solutions include smart water infrastructures, nanotechnological applications, sensor-based water protection systems, portable testing kits for real-time quality control, satellite technology and mobile applications.

Smart metering infrastructures

Improving water-use efficiency, demand management, and leakage control is one of the most urgent actions in urban contexts. Smart technologies can provide the necessary support. They can trigger behavioural change of urban households by providing them with real-time information and customized feedback. For example, Smarter Homes is a company that produces smart metering and automated leakage prevention systems. Their devices have been installed in 40,000 households in India, and they have helped save approximately 35 per cent of water consumption on average (Viola et al., 2020).

Nanotechnological applications for desalination processes

In response to growing demands for clean water in urban system, several countries are producing additional drinking water by using desalination technologies, the process of removing salt from seawater and then filtering it to obtain drinking quality water. As of 2018, there were 16,000 desalination plants in 177 countries.

Nanotechnological applications have been introduced. These have proved to be more sustainable than reverse osmosis, one of the most common methods used in water desalination that results in pollution of sea waters. For example, the European project NAWADES has developed since 2016 nanotechnology-based, self-cleaning membranes for water desalination at a plant located in the metropolitan areas of Barcelona, Spain (European Commission, 2017).

Sensor-based water protection systems

Digital solutions for water protection can help increase the efficiency and effectiveness of water treatments, enabling real-time water monitoring and the more rapid detection of possible pollutants. The project Fiware4Water, for example, has been developing a smart solution platform in European cities. It builds upon distributed intelligence and combines different types of sensing devices, such as smart meters and water quality sensors, to monitor water quality parameters and enable real-time monitoring (European Commission, 2022).

Box 4

Sensing technology for ensuring ground and surface water quality

Keeping the quality of ground and surface waters under control by using sensing technology is the primary purpose of GEMStat. Included in the GEMS/Water Programme of UNEP, GEMStat is a free, global water quality information system that contains millions of data entries sourced from water stations worldwide. The system relies on a voluntary submission scheme that invites countries and their local organizations to share the data that they capture with monitoring networks. GEMStat is currently combining data from water stations positioned in more than 80 countries and covers a timeframe of 93 years, from 1906 to 2020. In addition to storing the data in the same database, GEMStat produces statistical and graphical analysis of water quality data at different levels of aggregation.

However, for crowdsourcing platforms such as GEMStat to be functional and maximize the potential benefits they can produce, innovative training and supportive policy frameworks are required to build capacity. Not all countries can access these online services, mainly due to the lack of adequate systems for gathering water quality data and lack of appropriate knowledge and skills.

Source: UNEP, The global water quality database GEMStat (see https://gemstat.org/about/).

Portable testing kits for real-time quality control

To address water contamination issues, the British Geological Survey has developed an innovative approach to the assessment of microbial risks in drinking water. Their methodology introduces a real-time assessment that works faster than traditional methods based on faecal indicator organisms. The British Geological Survey implements on-site testing using portable tryptophan-like fluorescence sensors, which provide instantaneous readings. In 2020, this new assessment was tested in Africa. The results of the test show that tryptophan-like fluorescence has proved to be a more stable and precautionary indicator of microbial risk than faecal indicator organisms (Sorensen, 2020).

Satellite technology

When visible, pollution and contamination in water sources can also be detected by using satellite technology and drones. This approach might constitute an economically feasible solution for obtaining high-resolution images. Sentinel-2, for example, is an Earth observation mission launched by the European Space Agency. Its objective is to monitor variability in land surface conditions using two polar-orbiting satellites. Due to its public-domain nature, Sentinel-2 is an open-data project, and its satellites can provide free images (Favre and Oksen, 2020).

Mobile applications for waste monitoring

Images are also the main medium for protecting land and water from pollution in the form of free, easily accessible, and user-friendly mobile services that are emerging in many countries. For example, a project of the Environmental Protection Agency has resulted in a new application that can be downloaded on mobile phones. The service enables citizens to report water and land pollution when they spot it; by taking and sending a photo of the polluted area, citizens can make authorities aware of environmental problems. The application also uses an embedded Global Positioning System that helps authorities locate and investigate the reported areas (European Commission, 2021a).

3.4 Mobility

Congestion and air pollution are some of most significant mobility-related problems in urban areas globally, where state- and municipal-level interventions are urgently needed. STI solutions to these urban sustainability challenges can be grouped in three main categories: low-emission vehicles; policy, regulations, and financial schemes to incentivize the use of more sustainable transport solutions, and intelligent transportation systems.

Low-emission vehicles

Electric cars are among the most common examples of low-emission vehicles. The electrification of urban transportation system is growing in both developed and developing countries as a result of combined forces, such as more favourable policy settings, financial incentives, and continuous research and development efforts that are increasing the performance of vehicles while reducing their overall costs.

For example, Basel Agency for Sustainable Energy (BASE), has supported an effort to electrify the transport system in helping Bogota, Colombia to gain access to nearly 1,500 hybrid busses. This is in line with government strategies to cap the surge of fossil-fuel-based vehicles since hybrid buses were found to save 35 per cent fuel vis-à-vis diesel buses. Since 2013, BASE has supported similar initiatives in Argentina, Costa Rica and Peru for technical, financial and operational analysis and modelling.[17]

[17] For more information, see https://energy-base.org/news/paving-the-way-for-e-mobility-in-latin-america/.

Box 5
An electric scooter sharing service for sustainable urban mobility

Vehicle sharing services benefit from Global Navigation Satellite System information in order to track the vehicles, which are widely distributed across the city. In the case of "floating sharing", where vehicles are not parked in specific stations, the Global Navigation Satellite System is the main source of information for users to locate the vehicle. It also enhances security of the system by alerting about unexpected movements and tracking a vehicle in the event of theft.

Adopting this technology, G-MOTIT is a European-funded project that has developed an electric scooter sharing service in order to solve urban mobility problems potentially in major metropolitan areas in Europe.[a] It allows users to reserve a scooter with their smartphone, receive a notification with the position of the assigned vehicle, drive it and drop it off wherever they want. The service aims to enhance vehicle positioning performance by developing and integrating Global Navigation Satellite System-based location technology, which is key for the success of the service.

Source: Contribution from the United Nations Office for Outer Space Affairs.

[a] For more information, see http://gmotit.pildo.com/.

In Belarus, the National Academy of Sciences, together with other stakeholders, has developed a comprehensive programme for the expansion of electric transport between 2021 and 2025. It includes more than 40 interrelated activities that range from research and development to work on the development of charging infrastructure. Under the Electromobility Europe Programme, the National Academy of Sciences also supports planning processes and tools for the step-by-step conversion of the conventional or mixed bus fleet to a hundred percent electric bus fleet.[18]

Intelligent fast-charging solutions are emerging in cities to tackle the issues of congestion in recharging stations and slow charging rates. For example, in the Netherlands, Amsterdam has been equipped with Flexpower, the largest public smart charging network for electric vehicles in the city.[19] This technology combines faster charging with the use of locally generated renewable electricity and ensures a more efficient use of the electric grid capacity. A total of approximately 500 charging stations have been upgraded and connected to the Flexpower network – approximately 30 per cent of all charging stations for electric cars in the urban area (Bons et al., 2020).

Journey planner applications

Journey planner applications enhance urban mobility by providing real-time information. Urban mobility users can use these mobile applications to plan their journey, receiving continuous up-to-date information and advice about the level of traffic in different areas of the city and availability of public transport options at specific times.

Aberdeen City Council, in Scotland (United Kingdom), launched a journey planner application called GoAbz in late 2020. GoAbz assists citizens and tourists in planning their journeys around the city Aberdeen. The application provides information on journey times and costs, and it also enables users to receive suggestions on alternative transport modes – cycling, walking, buses and trains (Aberdeen City Council, 2020).

Real-time traffic management systems

In Bengaluru, India, the Electronics City Township Authority (ELCITA) and Siemens have developed and tested a real-time traffic management solution that fully automates traffic control and monitoring operations. The system automates operations such as vehicle detection,

[18] Contributions from the Government of Belarus.

[19] See https://www.elaad.nl/projects/flexpower-amsterdam/.

traffic density estimation, identification of traffic accidents and traffic light control (Chandran, 2018). In the Philippines, the government has developed Local Traffic Simulator (LOCALSIM), a microscopic traffic simulation software, designed to be used by road and traffic engineers as a decision support system for traffic management.[20]

Mobile ticketing

Mobile e-ticketing solutions have the potential to boost active travel – cycling – and public transport usage. For example, Oyster is a pay-as-you card developed by Transport for London. Citizens and tourists can top up their cards at kiosks and online. The cards can be used to travel on buses, subway, trams, and many other transport solutions. Moreover, as part of their pay-as-you-go scheme, Transport for London also allows city users to pay tickets with contactless credit and debit cards or mobile devices on all transport services in London (Transport for London, 2021).

Similarly, in 1997, Hong Kong (China) has introduced the Octopus smart card system, the first integrated contactless ticketing system for public transport in the world. The Octopus card can be used for travelling and shopping and on electronic government platforms. The card has achieved wide circulation within the city and can also be linked to other devices, such as smartphones and smart watches.[21]

Finally, an e-ticketing system has also been introduced in Amsterdam. The service is called iAmsterdam and provides visitors with the access to public transports, bike sharing schemes, and the main attractions in the city. The iAmsterdam card is also available as a mobile application, which provides information on activities and touristic attractions (Puhe et al., 2014).

Mobility as a Service

The multimodal approach to urban mobility is called Mobility as a Service (MaaS), a system which helps users pay for tickets for a wide range of public and private transport options and obtain real-time information on their functioning. MaaS Madrid is one of the earlier examples of integrated digital transport service platforms, and it was launched by Madrid City Council. This technology combines bus services, cableways, and BiciMAD – the bike-share system of the city – in a dedicated mobile application (Arias-Molinares and García-Palomares, 2020).

A similar MaaS platform, which is called Whim, is also used in Finland by the city of Helsinki. Whim integrates information on bike sharing systems, taxis, car sharing services and conventional rental cars, together with public transport data. The MaaS solution of Helsinki also allows payments to be processed through the mobile application (Centre for Studies on Risks, the Environment, Mobility and Urban Planning, 2019).

Bike sharing systems

Bike sharing systems generally combine the use of smart cards, mobile applications, automatic docks and stations, and platforms for sourcing real-time information on where bikes can be borrowed or left after being used. As of 2019, 18 million bikes have been shared in urban areas worldwide through 1600 bike sharing systems (Hyatt, 2019), which are becoming increasingly popular.

Cities such as Edinburgh (United Kingdom), Bogota, Mexico City, Berlin, Lille (France), Prague have been using bike sharing schemes for many years and have achieved notable benefits. For example, the bike sharing system in Mexico City has reduced taxi use and private car use of 8 and 5 per cent, respectively, and it has made it possible to save approximately 500 tons of carbon emissions, while helping users to save more than 2,000 days in aggregated travel time (Figueres, 2017).

[20] Contributions from the Government of the Philippines.

[21] For more information, see: https://www.octopus.com.hk/en/consumer/octopus-cards/about/index.html

Cycle-to-work schemes

During the COVID-19 pandemic, many Governments have incentivized cycling to reduce infection rates in urban areas, where bikes have become one of the preferred urban transport solutions. Meanwhile, many municipal governments, such as in Peru that of Lima, have started to redesign their urban infrastructure by expanding routes for cyclists to improve urban mobility,[22] an approach that, in many cases, has been largely overlooked for years.

In many countries, national Governments have activated Cycle-to-Work schemes. In the United Kingdom, for example, this scheme allows employees to buy commuter bikes and cycling equipment through their employers, by means of an advantageous loan. After making their purchase, employees repay all costs in small instalments, which are automatically deducted from their monthly salaries. After 12 months the employer will have recovered their costs, while the employee will maintain the ownership of the bike and equipment (United Kingdom, Department for Transport, 2019).

Another example is that of World Bicycle Relief, an international non-profit organization which has introduced Employee Purchase Programmes in developing regions, allowing their essential workers to buy a bicycle over a few months. Employee Purchase Programmes have helped purchase more than 600 bikes in Colombia, about 150 in Kenya, and almost 800 for employees located in the peri-urban areas around major cities in Zimbabwe (World Bicycle Relief, 2020).

3.5 Economic prosperity and decent job

Limited access to decent work opportunities, growing economic-related inequalities, financial instability among urban populations, forced labour, and modern slavery are pervasive issues facing urban economies across the globe. Implementing solutions through science, technology, and innovation could help policymakers to foster entrepreneurship, promote economic prosperity, and support financial stability for urban residents. Under the influence of COVID-19, these solutions have become imperatives for the recovery of urban economies, where an urgent call for smart, sustainable and human-centric economic prosperity has been raised worldwide.

Dedicated urban zones for STI development

Dedicated zones or areas have been developed in the urban areas of several countries to nurture the sustainable development of science, technology, and innovation that promote job creation and advance industrialization. These are an effort from the government to support the local urban innovation ecosystem in facilitating ease of business, providing access in financing and tax support, and to create more demand for new job opportunities.

In Türkiye, the Government established Technology Development Zones to provide job opportunities and accelerate the entry of foreign capital into the country that makes advanced technology investments. They accomplish this goal by increasing the competitiveness of the industry, providing significant contributions to the development of the cities.[23] Furthermore, many support and tax incentives are provided to entrepreneurs in Technology Development Zones, which make significant contributions to sustainable urban development.

In the Dominican Republic, another example is from the city of Santo Domingo, with the establishment of Technological Hub Value Proposition.[24] The hub is pivotal to support capacity-building, as well as guided spaces that facilitate the creation, incubation and acceleration of technology-based ventures that make intensive use of knowledge. This hub also incubates companies pursuing cutting edge products in 3D printing, virtual reality, drones, blockchain and biotechnology, among others.

[22] Contribution from the Government of Peru.

[23] Contribution from the Government of Türkiye.

[24] Contribution from the Government of Dominican Republic.

A similar concept has been developed in the city of Nyeri, Kenya with the establishment of a Science and Technology Park, in collaboration with Dedan Kimathi University. The STP encourage cooperation and synergies between universities, research institutions and the private sectors to create a favourable environment for innovation, renovation and training.[25]

In Latvia, the Government has established three innovation zones in Riga. The creation of these innovation zones aims to help companies, researchers as well as start-ups to test their innovative smart city products in real-life settings and to cut unnecessary steps in approval procedures necessary for implementation of new products.[26]

Another example is the creation of hubs of innovation and entrepreneurship for the transformation of historic urban areas in Lisbon.[27] The Hub is part of a European Commission programme that aims to promote the urban transformation and regeneration of historic urban areas, using as the main catalyst innovation and entrepreneurship, while preserving their unique social and cultural identity and the environment.

A different approach under the dedicated zone concept has also been developed in Russia through their single industry cities or monocity. Togliatti (or Tolyatti) is a prime example of a monocity, where innovative activities have received active support. It is the place where one of the Russia's largest high technology parks (technopark) is located, the Zhiguly Valley. Technopark's residents enjoy support at all stages of their innovative activities – from idea generation and prototype development through to the commercialization of the product. The cities of Cherepovets, Norilsk and Magnitogorsk provide further examples of successful dedicated zones or areas that bring forward comprehensive plans for socio-technical development to facilitate industry and promote job creation for their citizens.[28]

Digital finance

Digital finance has emerged as a financial initiative to support urban lifestyle in providing electronic financial products and services, ranging from digital banking, peer-to-peer lending, e-trading platform, and digital payment services. Local authorities can leverage digital finance to overcome barriers to economic productivity, entrepreneurship, and employment, and support the financial inclusion of low-income groups that experience financial instability. This technology can enable the distribution of critical financial flows and targeted funds to local companies, supporting stabilization and recovery in emergency situations such as the COVID-19 pandemic.

Another good example is demonstrated by the CloQ application, targeting the unbanked population which has access to mobile platforms in urban areas. Launched in 2018, CloQ is a microcredit mobile application for people whose income is below minimum wage. The application has started by focusing its operations on Brazilian territories and, in the first two years of activity, it has provided access to credit for urban entrepreneurs (United Nations, Department of Economic and Social Affairs, 2021).

E-commerce platforms

E-commerce platform is a technology that has been proved important for business in boosting sustainable development urban area. In particular, e-commerce platforms have been helping micro, small and medium-sized enterprises by providing online spaces to sell products or services, expanding their market opportunities beyond their geographic boundaries. Additionally, given that demand traffic in e-commerce platforms come from urban areas, labour force absorption occurs to support the logistics sector to cope with the surging demand. This relation was amplified during the COVID-19 pandemic era when people switched to e-platform in buying their daily needs due to public health-related mobility restrictions.

[25] Contribution from the Government of Kenya

[26] Contribution from the Government of Latvia.

[27] Contribution from the Government of Portugal.

[28] Contribution from the Government of Russian Federation.

For example, in Uganda, UNCDF is collaborating with the main ride-hailing company in Kampala, to launch a digital platform called SafeBoda (United Nations Capital Development Fund, 2020). The e-commerce platform for home deliveries has, during the lockdown, helped 18,000 people to keep their jobs, 800 vendors to maintain their revenue streams, and thousands of customers to continue to receive deliveries of food and other essential goods.

ICT-related education and training programmes

In addition to data-driven decision-making and predictive analytics, which are becoming increasingly common, industrial sectors have also been experimenting with technological advancements that are leading to higher degrees of automation, such as robotic technologies. Although in certain sectors automation processes may cause a reduction of workers, this technology unleashes productivity gains and can help reduce occupational injuries and fatalities in dangerous urban occupations – for example, construction jobs.

In response to risk of displacing humans with machines in some professions, many national and local authorities have reacted by promoting innovative education and training programmes that target young people and aim to increase their ICT skills. These upskilling opportunities are offered to ensure a better alignment between growing markets and education systems: an alignment which is indispensable to leave no one behind and drive sustainability-oriented system change in urban areas.

For example, European countries can rely on the Digital Opportunity traineeships, a training initiative funded by the European Commission. Between 2018 and 2020, this initiative provided more than 6,000 students with the opportunity to boost their digital skills in fields with high market demand. Examples of knowledge areas include cybersecurity, big data, quantum technology, machine learning, web design, digital marketing, and software development (European Commission, 2021b).

Similarly, in South Africa, the Oliver Tambo Research Chairs initiative builds on existing continental frameworks and interventions geared towards the development of high-end skills, the recruitment and retention of excellent researchers and the provision of incentives to support research that contributes to socioeconomic and transformative development in Africa.[29]

Innovative data management systems

Providing financial support and access to job market to people in need requires scoring and assessment tools that ensure financial inclusion. However, many local authorities are experiencing difficulties in developing effective systems. To overcome this challenge, urban areas can benefit from the use of data management solutions, which can help eliminate silos effects and lack of interoperability while providing advanced data visualization tools, the use of artificial intelligence for predictive analysis, big data analytics capability and more transparent and accountable reporting systems.

In Costa Rica, for example, the national government has developed a data-integrated, cross-agency platform that contains data of potential beneficiaries of all social protection programmes financed by the state – more than 3.5 million individuals and approximately 1.2 million households (United Nations Development Programme, 2021). To develop the platform, information modules and data infrastructures have been standardized to facilitate data integration after collection processes, which are undertaken simultaneously in different public agencies in rural and urban settings.

In the Islamic Republic of Iran, STI policymakers have developed an innovative platform to help match private sectors with the city administration to provide services and products for people in urban areas. The aim of this platform is to disentangle the complexity of agreement and provide incentives for the private sector in supporting the transition toward urban sustainable development. For example, the platform has been implemented as part of Smart Waste Management Systems

[29] Contribution from the Government of Kenya.

in the Islamic Republic of Iran, to make the outsourcing process more transparent and encourage start-ups and entrepreneurs to cooperate with the municipality administration.[30]

Another example is artificial intelligence-powered Jobs Factory of the World Tourism Organization, a platform that supports and improves competitiveness regarding job creation and helps to leverage human capital development in cities that rely on the tourism sectors. The joint initiative between the World Tourism Organization and Hosco, the professional network specially designed for the hospitality industry, allows monitoring current and future skills development, facilitating intelligent labour market data collection, insights and forecasting to access jobs opportunities.[31]

Cash transfer schemes and programmes

Many national and local authorities are also supporting the financial inclusion of urban populations by means of innovative cash transfer schemes that do not leverage technological solutions but still ease the financial burden of poorer workers and help them access secure financial services, limiting the widespread adoption of informal loans.

To nudge behavioural change in low-income populations and improve the sustainability of their financial situation, local authorities can also initiate conditional cash transfer programmes. These programmes help provide poor people with money in return for fulfilling specific behavioural conditions. For example, compulsory attendance of children to school, mandatory visits to health centres, and up-to-date vaccination are among the conditions in the Brazilian experience of Bolsa Família (World Bank, 2020), a conditional cash transfer programme activated in Brazilian municipalities.

Another example comes from the city of Sabang, in Indonesia which piloted a similar locally funded cash transfer program called Geunaseh. The objective of this social protection program is to provide poor households with the monthly-based cash assistance they need to meet the health and nutritional needs of children. The program has been written in law, defining provision and governance mechanisms and the role of the local stakeholders involved in the delivery (United Nations Children's Fund (UNICEF), 2021).

Smart technologies to fight forced labour and modern slavery

STI solutions also offer effective technological means to fight against child labour – whose rate has increased from 8.4 million in 2016 to 160 million in 2021 – but also modern slavery, human trafficking and migrant smuggling, which are crucial urban-related phenomena. Remote monitoring tools addressing forced and child labour, for example, use mobile-phone-based technologies, real-time tracking systems, and other networked technologies to determine the presence of illegal working conditions in a workplace. Some of these real-time monitoring tools also use satellite imagery to oversee the movements and loads of boats and web scraping to search for child abuse data that can lead law enforcement agencies to children in need for help. This technology can also be used to stop human trafficking operations (UNICEF, 2020).

Smart technologies for preventing forced labour can also leverage predictive profiling, facial recognition, and blockchain technology. Predictive profiling via natural language processing and artificial intelligence can be used to evaluate the probability of having messages associated with forced labour that travel across the Internet. Facial recognition algorithms are adopted by law enforcement authorities during web crawling operations, to scan online advertisements and attempt to prevent or stop forced labour crimes. Finally, blockchain technology enables the constant monitoring of global supply chains to identify the presence of illegal operations involving illicit traffic of goods and modern slavery. Nevertheless, the application of these technologies requires strong cross-sector coordination, revised institutional arrangements, and new regulatory frameworks that ensure privacy and data are firmly protected (Inter-agency Coordination Group Against Trafficking in Persons, 2019).

[30] Contribution from the Government of the Islamic Republic of Iran.

[31] Contribution from the World Tourism Organization. For more information on Job Factory, see: https://www.unwto.org/jobs-factory.

3.6 Housing

The housing construction sector is responsible for the development of one of the most crucial urban infrastructure assets, but it is severely lagging behind. The "Industry 4.0" vision is crucial to ensuring the improved efficiency and sustainability of the sector and the development of more affordable and quality housing solutions. The progress of this vision is highly dependent on STI efforts. Many countries have positioned the framing of cross-sector partnerships and industrial alliances for research and development at the centre of their national development agenda for the housing construction sector, alongside establishing international standards to facilitate collaborations.

Digitalization of construction operations and manufacturing processes

STI solutions for supporting sustainable development in the housing construction sector strongly focus on the digitalization of operations and manufacturing processes. A wider use of digital fabrication techniques, which rely on IT-controlled production environments, can help improve efficiency while increasing production rates. For example, by capitalizing on digital fabrication technologies and offsite manufacturing techniques, a 30-storey hotel and a 57-floor skyscraper have been built in China in less than 20 days. The use of traditional building techniques would have required more than one-year of on-site construction activities to deliver the same building (Chang et al., 2018).

A growing number of factories have been equipped with additive manufacturing technologies – 3D printing. This technology is used frequently during prototype phases, but it can also help build new houses. This is the case of the non-profit organization New Story, which is introducing 3D-printed homes in the slum areas of the Plurinational State of Bolivia, Haiti and Mexico. Using 3D-printing technology, New Story can produce a 600-square-feet (about 56 square meters) home in only one day, and with an overall cost of $4,000 (Altman and Pompei, 2018).

The digitalization of the housing construction sector and actualization of the "Industry 4.0" vision can truly push sustainable urban development. However, it also exposes digital skills gaps that may prevent these technological developments from taking place and being effective. For example, approximately 70 per cent of the population living in lower-income economies do not possess basic digital skills (UN-Habitat, 2021a). The COVID-19 pandemic has clearly exposed this skills gap and showcased the magnitude of the effects that they have on sustainable urban development, especially in a moment of crisis.

Digital twin technology in construction

By using digital twin technology, virtual models can be created to predict the functioning of an object. This insight can be used to inform decision-making processes in the housing construction sector (Arup, 2019). Engineers and designers across manufacturing industries are increasingly using this technology to experiment with different design solutions, whereas civil engineers are using digital twins as a supporting tool during the design, construction, and monitoring processes of transport infrastructure assets (OECD, 2020). Moreover, in housing construction, digital twins allow the collection of information during the entire life cycle of a building and help improve maintenance operations, while facilitating data sharing operations.

Predictive analytics

Big data analytics makes it possible to obtain a greater level of product differentiation, which is driven by intelligence, and can better align productive systems with the request of users. For example, in South Africa, under the Innovation and Transformative Technologies Framework, the Government is working to enable big data in analysing areas of urgent housing needs; areas that need subsidized housing; areas requiring improved access to infrastructure, amenities and services, and areas that support the integration of different housing typologies, land uses and economic development.[32]

[32] Contribution from the Government of South Africa.

Offering a diverse housing stock requires governments and stakeholders in the construction and real estate sectors to better understand the varied housing needs of heterogeneous residents, using such a knowledge to design affordable housing solutions which are tailored to meet their expectations (Pimentel Walker, 2016). Affordable housing provision should be diversified in terms of types and tenure, hence providing accommodation options to a broader number of residents while creating diverse and vital neighbourhoods.

Machine learning models that transform big data in predictive analytics are already in use in the construction sector. For example, they are used to forecast the potential demand for new homes or fluctuations in market values, and the deployment of this technology can be extended to cover additional functions (Grybauskas et al., 2021).

Environmentally sound technologies and smart building solutions

Housing construction actors in developing and developed countries are increasingly harnessing environmentally sound technologies and smart technologies in new-built and retrofitting operations. In many cases, environmentally sound technologies measures and smart technologies have been adopted to address climate and environmental issues by increasing the use of renewable energy and recycled materials, reducing waste productions and implementing water-efficiency schemes. One example is the creation of EcoSUN Green Village, a pilot project in South Africa which implements environmentally sound technologies and smart technologies to address challenges in human settlement (see box 5).

Box 6
EcoSUN Green Village, a village for the future

The EcoSUN Green Village, located in the Eastern Cape province of South Africa, is a collaborative pilot project between the Department of Science and Innovation, Ndlambe Local Municipality, Nelson Mandela University, Eastern Cape Department of Human Settlement and the Ministry of Education and Research of Germany.

The objective of the project is to implement innovative technologies to address challenges faced by the human settlement sector, such as water and energy resource scarcity as well as unemployment. The innovative technologies include the application of water recycling (grey water technology), water filtration, renewable energy (solar technology), innovative building materials and sustainable water drainage.

The 1-hectare village includes 10 houses, Multi-purpose Centre, landscaping for recreational activities, a vegetable garden and a waste management facility. The intention is to make a village that operates independently of the municipal services, a village that supports the community and generates jobs.

The EcoSUN Green Village to date has created employment for 22 youth from the area, in the construction of the Multi-purpose Centre, and has attracted donors eager to support local economic development. Further collaborations are to be forged with in the upcoming construction of a sustainable urban drainage system and landscaping for the village.

This pilot project has proven that innovative building materials and technology can be implemented within a limited time and accepted by communities, even under the challenging conditions brought about by COVID-19.

Source: Contribution from the Government of South Africa.

As another example, the World Bank Group has developed a knowledge platform on eco-friendly infrastructure construction to help govern infrastructure projects across countries in Latin America and the Caribbean (Montgomery, 2015). The idea behind the initiative is to have a one-stop shop that calls up technical specialists with different types of expertise to design and plan for sustainable buildings, roads, bridges, ports, power plants and water supply systems.

3.7 Gender-related empowerment and equality

The value of sustainable urbanization cannot be realized without introducing safeguards against the existing gender-based gaps, prejudice and discrimination that have spread in urban environments worldwide. STI solutions in this application area range from new digital tools to non-technological interventions which aim to support awareness-raising activities, community mobilization actions, educational programmes, legal and policy reforms, and changes in institutional settings.

Gender-pay-gap regulations

Wage disparities differ across countries and strongly depend upon local circumstances. No disaggregated data is currently available to determine the global urban–rural spatial variation in the gender wage gap. However, many cities worldwide remain plagued by gender-unequal economies. The relevance of the problem has been recently underscored by a recent joint initiative in London, Los Angeles (United States), Barcelona (Spain), Freetown, Mexico City and Tokyo, where the municipal administrations have decided to launch the first-of-its-kind network of cities in support of gender equity.[33]

Recognizing the relevance of gender-based economics issues, to ensure that men and women receive equal pay for equal work, some Governments have implemented innovative adjustments to their existing policy and regulatory frameworks which impact urban workplaces. For example, a legislative framework – the Equality Act 2010, amended in 2017 – has been introduced, in the United Kingdom, in England and Scotland to improve the transparency of wages. The act requires public, private and voluntary-sector organizations with 250 or more employees to annually publish a series of pay gap metrics on their own websites and on a dedicated reporting service website created by the central government (Equal Pay Portal, 2019).[34]

However, when examining the effectiveness of these new regulatory reforms, the scientific community offers inconclusive evidence of their effectiveness. For example, on the one hand, the pay transparency laws in Denmark, the United Kingdom and United States have been correlated with a reduction of the gender pay gap (Kim, 2015; United Nations Entity for Gender Equality and the Empowerment of Women (UN-Women), 2017a). On the other hand, statistical analyses of the impact of the Austrian Pay Transparency Law on individual salaries and the gender pay gap have not evidenced discernible effects (Böheim and Gust, 2021).

Compensation management platforms

Making information on gender-friendliness more accessible requires companies that manage urban workplaces to discover pay gaps and find possible solutions. This discovery process depends upon the capability to aggregate the statistics needed for complying with transparency laws. To facilitate this analytical process, digital services have been developed. These include artificial intelligence-powered budgeting and forecasting tools that provide estimates of gender-based gaps in remuneration processes, and the voluntarily tracking of salaries across demographic characteristics.

Anti-violence online services

In many cities around the world, women and girls do not have the required level of safety. Violence makes up at least 25 to 30 per cent of urban crime and women, especially in developing countries, are twice as likely to be victims of violent aggression (including domestic violence) as men (UN-Habitat, 2007).

In response to this lack of safety in public and private urban spaces, technological-related grassroots innovations are spreading, some of which aim to enhance the capability of women, girls, and other city users to report abuses and help ignite the reaction of public authorities and the

[33] See https://www.london.gov.uk/press-releases/mayoral/global-cities-unite-to-tackle-gender-inequality.

[34] Gender pay gap reporting system (see https://www.equalpayportal.co.uk/gender-pay-gap-reporting/).

public. For example, by leveraging online messaging systems and social media, the crisis-mapping platform designed by the Nairobi-based company Ushahidi has helped to monitor election-related violence in Kenya and many other reports of gender-based violence across the world. Ushahidi collects reports of violence submitted by eyewitnesses and, after checking their validity, it maps them out, making all data publicly available.[35]

Awareness-raising measures and education

Innovative gender-equality measures are also urgently needed to rethink urban safety, whose improvement can drastically change the lives of women and girls and their relationship with urban environments. For example, with sexual harassment in Moroccan public transports and streets not yet legally recognized, introducing a training module on prevention methods for ALSA Marrakech drivers – a large network of buses which serve the entire city – has created a possible safeguard. The training has informed more than 1,500 bus drivers about the procedures that can be adopted to take action against sexual harassment episodes, should they witness abuses in buses and around bus stops. Similarly, taxi drivers have been made aware about sexual harassment and mobilized to take action (UN-Women, 2017a).

Similarly, in Rwanda, a citywide campaign has been launched to prevent sexual harassment on public transportation, and actions have been taken to enhance the capacities of public transport workers to prevent sexual harassment in public spaces. Meanwhile, in Ecuador, education material on gender discrimination and stereotypes has been piloted in some schools of Quito, whereas public service announcements in Indian metro lines and open discussions have been introduced to raise awareness. Finally, Papua New Guinea has launched a multi-channel campaign that has reached thousands of urban residents by combining social media and television networks, radios and social interactions in schools, churches and public spaces (UN-Women, 2017b).[36]

3.8 Urban planning

To ensure that central urban areas and their peri-urban interfaces provide all residents with equal access to urban services, facilities, and opportunities, local authorities and urban planners can rely on different STI solutions that upgrade urban planning procedures. Their adoption leads to a more detailed understanding of sustainable development issues and more efficient and inclusive decision-making processes. These technologies help leverage collective intelligence and create the open, inclusive, and highly collaborative environments that are required to ensure that urban planning processes take control of peri-urbanization processes and make urban spaces accessible to all people, regardless of gender, age, disability, or any other factors.

Spatial Group Model Building

To ensure the synergetic growth of interconnected urban, peri-urban, and rural areas, some local authorities are replacing siloed approaches to urban planning with more integrated practices that use system thinking to better address the spatial complexity of urban–rural linkages and maximize existing interdependences. Achieving this objective, however, requires urban analysts and planners to trigger processes of co-design and participatory decision-making that ensure vertical and horizontal coordination, ensuring that excepted benefits reach all parties and resource conflicts are minimized.

Studies on peri-urban planning and management have led to the definition of new approaches that respond to the specific needs of peri-urban interfaces. For example, the city of Christchurch, New Zealand, has contributed to piloting an innovative participatory process called Spatial Group Model Building (SGMB). SGMB helps combine the expectations and knowledge of a wide range of

[35] See https://journals.openedition.org/factsreports/4316

[36] UN-Women, 2017b. Buy from Women, United Nations Entity for Gender Equality and the Empowerment of Women, New York. See https://www.unwomen.org/-/media/headquarters/attachments/sections/library/publications/2017/buy-from-women.pdf?la=enandvs=231.

actors into a peri-urban planning processes by inviting them to co-design a group model building – a model that connects the flows, processes, and collaborative relationships among actors within a complex system.

The participatory process is supported with Geographic Information System (GIS) technology, which helps stakeholders visualize the physical space and connect the information of the group model building on digital maps. The towns of Lundazi and Monze, Zambia, have adopted SGMB to investigate how East Coast Fever – a disease of cattle and buffalo – oscillate over time and determine context-specific interventions that can mitigate the impact on the local economy (Mumba et al., 2017). SGMB has also been applied in the Indian state of Bihar, the district of Jessore in Bangladesh, and the Tanintharyi region, in Myanmar (Rich et al., 2018).

Box 7
CITInova project to improve national capacities for sustainable urban development

The CITinova project is a good example of a project aimed at improving national capacities in urban planning for the sustainable development of Brazilian cities. The specific objectives of the project are to: (a) accelerate the transition of cities towards sustainable urbanization; (b) use technology and innovation to improve the quality of life and well-being of citizens; and (c) avoid the direct emission of 3.8 million tons of CO_2.

Funded by Global Environment Facility, implemented by UNEP and executed by the Ministry of Science and Innovation of Brazil in partnership with the Brazilian cities of Brasilia and Recife, the project brings many success stories in developing innovative technological solutions and offers methodologies and tools for integrated urban planning and more sustainable cities. One success story is the public and free District Environmental Information System Platform, which provides climate projections for the Federal District and Integrated Development Region of the Federal District and Surroundings.

Another success story is the revitalization and urbanization of Capibaribe Park in the city of Recife. The project covers 30 km of the riverbanks, focusing on public spaces for people on cycle paths and pavements, leisure and contemplation areas. This is helpful to Recife, which aims at increasing the public green area index from 1.2 m^2 per inhabitant to 20 m^2 by 2037.

Source: Contribution from the Government of Brazil.

Gamification for digital participation

Different digital support tools that local authorities, urban planners, and other participants of collaborative urban planning processes can use to jointly develop and assess alternative sustainable development strategies are currently available. For example, as part of the Block-by-Block initiative, UN-Habitat has introduced Minecraft in the framework of public space planning, where the videogame has become a participatory tool for simulating the co-production of regeneration projects for neglected public spaces. This Minecraft-based methodology is freely available to all and provide residents of urban areas with access to a virtual environment in which they can collaboratively design, build, and discuss virtual urban landscapes and architectural models that have the potential to improve the quality of existing urban spaces.

After being piloted in Nairobi and Mumbai, the Block by Block methodology for co-created public spaces have been used extensively in urban areas across the world, in particular developing regions, where it has shown a good capability to mobilize community engagement (Imam and Lahoud, 2021). A few years after starting the initiative, in an effort to improve the current methodology, UN-Habitat introduced a mixed-reality tool which has been tested in Stockholm and Johannesburg (South Africa). This enhanced version of the Block by Block methodology uses virtual reality to provide users with a lifelike experience (UN-Habitat, 2019).

Digital twin technology for urban planning

Virtual reality can also be used to create urban digital twins – virtual models of entire urban systems – as in the case of Herrenberg, a small city in Germany. The digital twin has been used to collect data describing the emotional responses of citizens that local authorities are collecting to inform decision-making (Dembski et al., 2020). Similarly, Buildmedia – a company specialized in 3D visualizations of urban infrastructure – has created a digital twin of Wellington City. The digital twin builds on a combination of smart city technologies that connects streams of urban mobility data. This data describes the real-time functioning of the urban infrastructure and provides different types of urban mobility and transportation statistics, including air traffic data. By using the digital twin, local authorities can acquire data for supporting decision marking and collaboratively work on unbuilt developments, which can be integrated as virtual models in the existing built environment of the city (Frearson, 2021).

Online crowdsourcing platforms

Local authorities and planners can also use a low-tech apparatus, such as social media channels and online platforms, which can help stimulate inclusive discussions on planning ideas and better understand the preferences of key actors that are affected by urban planning decisions, including citizens (Afzalan and Muller, 2018). Online platforms that pool crowd-generated data can help generate collective knowledge and awareness around urban planning challenges, and they can also be used to increase the accessibility of urban spaces.

For example, the German non-profit organization Sozialhelden has developed Wheelmap, an online map for wheelchair accessible places identification. Wheelmap provides information that is generated with a Wikipedia-approach; anyone can access the online map – which is generated by using OpenStreetMap data – and share knowledge on the wheelchair accessibility of the locations they have visited. Users can pick any public place around the world, rate their level of accessibility for individuals with mobility impairments, and upload photographs. As of today, Wheelmap provides data on more than 1.5 million public places and is available in 33 languages. This data helps people with reduced mobility to make informed travel plans and contributes to making owners of wheelchair-inaccessible public places and local authorities aware of existing barriers (Mobasheri et al., 2017).

3.9 Safety and security

Worldwide efforts have been made to sustain urban safety and security, which are primarily based on the use of innovative policy interventions and research and development efforts that are increasing the availability and performance of technological STI solutions. Examples of technologies for urban safety and security enhancement include gunshot detection systems, crime mapping tools and predictive profiling technology.

Crime prevention policy

To reduce youth homicide, a key issue in Doha, Qatar, the local government launched the policy program ‘Line Up, Live Up’, in collaboration with UNODC and sports organizations (UNODC, 2020b) . This program aimed to break the chain of violence by inducing behavioural change in new generations. Sports were promoted among at-risk youths to provide them with a means to learn tolerance and respect and to develop the positive behaviour that can help them avoid criminal activates and violence in the future.

Gunshot detection technology

Technological solutions for crime prevention have also been implemented. For example, different variations of gunshot detection technology – an audio-based analytical tool – are sprouting up. gunshot detection technology offers automated analyses of urban soundscapes and build upon a network of acoustic sensors to identify the sound of urban gunshots. Data generated from gunshot detection technologies becomes a source of information on firearm-related crimes, and this information can be relayed to context-aware emergency services (Irvin-Erickson et al., 2017).

Moreover, this knowledge can also support police forces to determine the position of gunshots in real-time. Gunshot detection technology uses algorithms that identify particular acoustic frequencies at different points of public transport networks (such as underground routes or bus lanes). This differentiation helps to timely distinguish gunshots from other noises and to compute the spatial coordinates of the location where the crime is taking place (ACOEM, 2020).[37]

Crime mapping tools

To enhance the capacity of gunshot detection technology in crime prevention, visualization of crimes is also required. Technologies that are used for spatial identification of crime hotspots have been implemented in cities worldwide. Crime mapping via GIS analysis, for instance, is an effective measure that local police forces can adopt in urban areas to develop timelines and map locations of crime events.

In central London, police forces use crime mapping to analyse vehicle crime patterns, understand routines and behaviours of criminals, and determine the most probable location where these crimes take place and could happen in the future (Braga et al., 2019). Similar practices are also implemented in cities of the Global South, such as Mexico City wherein heat maps are created by local authorities to identify hotspots prone to violence against women (Garfias Royo et al., 2020).

Moreover, researchers at University of Pretoria have showcased the usefulness of crime mapping in the context of African cities by developing a robbery risk model for the city of Tshwane, South Africa. The model is based on a geospatial analysis in which commuter nodes and urban public facilities become points of interest (Kemp et al., 2021).

Predictive profiling technology

Some innovative solutions for addressing forced evictions in urban areas rely on predictive profiling techniques, in which machine learning algorithms are a key component. A variety of machine learning models can be used to identify city buildings in which tenants are at risk of landlord harassment. New York City is an example of good practice wherein data scientists have developed an-hoc machine learning model. Their model analyses historical canvass data to predict landlord harassment and create risk scores. Local government agencies harness this intelligence to prioritize inspections to high-risk buildings and better organize outreach activates to vulnerable tenants (Ye et al., 2019).

Protection from natural disasters

STI solutions contribute to protecting urban areas and their populations from natural disasters by empowering and giving a voice to people, including the most vulnerable; extending access to education services, making possible the monitoring of environmental risks, connecting people, and enabling the development of early warning systems.[38]

Disaster data infrastructure

Data analytics capability is also of the utmost importance for urban regions that are facing natural disasters. To develop this capability, many national and local governments are increasing efforts towards building integrated data management systems that pool critical information on urban infrastructure assets. For example, after experiencing a series of natural disasters, Latin America and Caribbean cities have decided to invest in developing the capacity for building a data management platform for supporting disaster management, by conducting activities that are helping to connect heterogeneous data on critical infrastructures. This integration process is already helping local

[37] ACOEM, 2020. Brochure: Gunshot and Acoustic Threat Detection: Hear Danger before you See Danger, ACOEM, Richmond, Virginia, United States. https://www.acoem.com/wp-content/uploads/2020/03/Brochure.-ACOEM-Gunshot-Acoustic-Threat-Detection-brochure-2020.pdf.

[38] To obtain a more comprehensive understanding of this theme, please see the UNCTAD issues paper on "The role of science, technology and innovation in building resilient communities, including through the contribution of citizen science". https://unctad.org/system/files/official-document/CSTD2019_Issues02_STI_Build.Res.Comm_en.pdf.

governments to model risk in infrastructures such as mobility and transportation (Jorisch et al., 2018). In Türkiye, the Disaster Management and Decision Support System was developed in order to monitor and manage disaster and emergency processes electronically and to provide decision support to managers.[39]

Examples of integrated disaster data management systems are also emerging from private sector organizations. For instance, the Portuguese company Tecmic and the private non-profit association INOV – Instituto de Novas Tecnologias – have developed the 4Forces platform, which has been tested by using data from the city of Lisbon. The 4Forces platform simulation process aims at ensuring rapid decision-making on resource allocation in case of disasters.

Nature-based solutions

When developing disaster risk reduction schemes and practices, city governments can also implement nature-based solutions. "Nature-based solution" is an umbrella term that groups different types of ecology-based technical solutions, innovative actions, and policies whose objective is to help protect, govern, and recover urban ecosystems, build up their resilience to natural disasters, and protect biodiversity (United Nations Office for Disaster Risk Reduction, 2020).

For example, the uMngeni Infrastructure Partnership in KwaZulu-Natal province, South Africa, has utilized nature-based solutions to rehabilitate natural ecosystems, such as river areas and the Midmar Dam, which serve the urban population in the province (Youth4Nature, 2021). In Switzerland, the Government spent 0.6 per cent of its GDP on protection against natural hazards, including the construction of elaborate protective structures to prevent damage. Knowledge regarding the continual intensification of land use is a key prerequisite for minimizing risk, which is why work on analysing land use risk is currently ongoing.[40]

A similar practice in Lahore, Pakistan shows the Government that is committed to remedying to the challenges that high-rate air pollution and heat. An urban forest named Liberty Market was planted in the city in 2019. Acting as a nature-based solution, the forest combined ecological engineering and active policymaking to ensure the exclusive use of native species of vegetation for restoring urban forested areas (Arif, 2021).

[39] Contribution from the Government of Türkiye.

[40] Contribution from the Government of Switzerland.

4. Conclusions and policy recommendations

The COVID-19 pandemic has enabled many new forms of innovation for sustainable cities and communities. It has also triggered a level of research, development and experimentation that countries had previously struggled to implement during non-crisis conditions. The pace at which local and national leaders and stakeholders have reorganized urban socio-technical systems in many regions, by introducing innovative STI solutions to the challenges imposed by the crisis, has been significant. It is now necessary to seize this innovation momentum, using its transformative power, to ensure that urban areas can deliver on their commitment to sustainable urban development.

The following recommendations are therefore presented, making a distinction between the considerations that apply to national Governments and those that would be more pertinent for international action.

Adjust pre-COVID priorities and resource allocation strategies

The uncertain investment climate and fragile financial situation of public and private organizations could severely undermine the capability of countries to sustain the innovation momentum and the scope and scale of STI actions for uplifting urban sustainability. Considering only the period between 2020 and 2030, it is estimated that more than $40 trillion will be required to provide funding for the urban infrastructure developments that are needed to enhance the sustainability of cities and towns worldwide and harness the value of sustainable urbanization (UN-Habitat, 2020c).

The negative economic effects of the COVID-19 pandemic have reached public sector organizations; the overall revenue of local authorities is expected to decline between 15 per cent and 25 per cent in 2021, with more drastic effects on developing countries. For example, the revenue losses of African local governments could go up to 60 per cent (United Nations, 2020d). With such a massive shortfall in public and private budgets, fewer funds will be available for STI activities oriented towards enhancing urban sustainability.

Considerations for Governments:

- Redefine sustainable urban development priorities in the aftermath of the pandemic – in particular, the urgent need to invest in STI solutions that can alleviate unemployment and the financial issues of low-income households and smaller firms.
- Ensure that priority is given to the STI actions that can create value for money and more efficient spending, with a particular focus on activities that can boost urban resilience.

Considerations for the international community:

- Introduce financial measures that can help reinstate the financial stability of private- and public-sector organizations, especially in developing economies.

Find and share STI solutions for sustainable urban environments

The analysis has uncovered an incredibly data-rich but fragmented knowledge environment. The application of STI in urban contexts has led to the development of many experiences, solutions and practical knowledge whose potential for innovation is not fully enacted. Cross-country collaborative research efforts are needed to pool and formalize this knowledge and to ensure knowledge transfer. In addition, the sharing of STI practices will also help to raise awareness of the many innovations which are already available and to forge new local and international collaborations, strengthening urban innovation ecosystems worldwide.

Consideration for Governments:

- Capture, formalize, and share positive and negative practices at different stages of development and experience on the use of STI solutions for urban sustainability enhancement.

Considerations for the international community:

- Support cross-country collaborative research efforts by establishing common strategies for data collection and analysis that can facilitate benchmarking
- Establish a virtual environment to facilitate international knowledge transfer and ensure that an international basis of experience is available for all

Cultivate and empower local ecosystems for urban innovation

Developing, testing and scaling STI solution to urban sustainability challenges requires a cross-sector and multi-stakeholder effort, with strong collaboration among heterogeneous actors and across scales – national Governments, local public sector organizations, businesses, third sector organizations, financial institutions, universities and research centres, and civil society. When all these actors operate in concert, urban innovation can flourish.

Governance frameworks supporting local innovation ecosystems for urban innovation are also required to facilitate open innovation processes, international cooperation, and the scaling up of collaborative dynamics, the three elements whose combination has proven indispensable in the fight against COVID-19 (Klingler-Vidra et al., 2021; Park et al., 2021). In this instance, local governments need to adapt swiftly to digital solutions, particularly to step up their efforts and develop new ways to communicate with their citizens in supporting the ecosystem for urban innovation, for example by facilitating citizen participation through online platforms.[41]

Considerations for Governments:

- Frame an enabling institutional, policy, and regulatory environment that promotes the development of an open innovation culture in urban spaces and facilitates cross-sector and multi-stakeholder collaboration.
- Expand incubation services to facilitate the transformation of business-sector research in science, technology, and innovation that actively contribute to solving urban development challenges (e.g. housing, job creation, waste management, etc.)

Considerations for the international community:

- Assist countries, especially in developing regions, in structuring long-term collaborative efforts that extend beyond single projects and look at multi-year developments.
- Enhance capacity-building support to increase the availability of resources for scaling up research development capacity in response to emergency condition.

[41] Contribution from the Government of Belgium.

Protect against the unperceived complexity of urban digital transformations

In building capacity for local urban innovation, actions should also be taken to raise the awareness of the challenges that the unperceived complexity of technology-related development can generate in urban sustainability actions. For example, in leveraging smart cities technologies to improve urban service delivery, a wrongful conceptualization of smart city development processes has led to faulty implementation in both developed countries (Martin et al., 2019) and emerging economies (Fromhold-Eisebith and Eisebith, 2019).

As a result, urban digital transformations can be erroneously conceived of as ready-to-implement technological upgrades, rather than an ongoing socio-technical change process that is firmly anchored to spatial and temporal dimensions and existing socio-technical arrangements. In this context, preliminary work through feasibility studies to analyse citizen security, mobility flows, risk management, and allocating economic resources would be important before developing the smart city processes.[42] To enhance urban sustainability, technological solutions are more effective when they are conceived taking into account local conditions and supported with complementary changes in existing institutional settings and a people-centred focus. Otherwise, negative externalities and inefficacies may appear.

Considerations for Governments:

- Provide local actors with the knowledge resources necessary to familiarize them with sustainable urban digital transformations and help them develop policy and governance capacity.
- Raise awareness among municipal governments and other local stakeholders on the unperceived complexity of technology-related urban development strategies (e.g. smart city) and the importance of integrating local context conditions with a people-centred focus in urban sustainability actions.

Consideration for the international community:

- Mobilize resources for supporting more research exploring the non-technological change dimensions of urban digital transformations for urban sustainability.
- Develop operational tools that consider the place-based and socio-technical nature component of technology-related sustainability transitions, to stop the spread of one-size-fits-all mentalities.

Introduce new and more equitable financing mechanisms

More efficient spending is necessary but insufficient in ensuring that the research and development efforts for sustainable urban development receive adequate financial support. The size of the investments requires countries to establish new international mechanisms to support the financing of STI solutions for urban sustainability challenges. These mechanisms are required to overcome existing inequalities in funding provision and ensure the activation of collaborative ventures with heterogenous actors. Without cross-sector collaborative efforts, financing urban development initiatives involving STI solutions has proven complex, especially when they are technology-related. In addition, to optimize revenue mobilization, countries should strengthen their institutional settings to ensure that public investment management in cities and communities is supported by policy coherence across multiple levels of governance.

[42] For example, the feasibility study of a smart city in Piura, Peru.

Considerations for Governments:

- Facilitate cross-sector collaborative ventures with heterogenous actors to increase the financial capacity of cities and urban communities to support the research and development actions required to embrace STI solutions.
- Optimize revenue mobilization by prioritizing STI measures that can ensure value for money and more efficient spending.
- Strengthen institutional settings to ensure that public investment management in cities and communities is supported by policy coherence across multiple levels of governance.

Considerations for the international community:

- Enhance international support by mobilizing additional financial resources for developing countries from multiple sources.
- Ensure that research and development efforts for sustainable urban development receive adequate financial support in all regions, especially those with the highest need.

Rethink urban areas as data infrastructures

The COVID-19 pandemic has put significant attention on the value of data and the important role this resource plays in fostering urban sustainability. Lessons from the pandemic have led to important considerations for future STI policy and practice. First, the pandemic has exposed a critical gap in urban disaggregated data, whose elaboration is crucial to obtain localized knowledge on the functioning of urban socio-technical systems and prepare appropriate STI solutions. Second, the pandemic has further demonstrated that data fuel STI and, if correctly deployed, data can help increase urban resilience.

In this regard, the rapid and widespread diffusion of smart city technologies and other digital solutions has augmented this potential, by facilitating the continuous creation of massive amounts of new data at unprecedented speed. This data can be used to create fertile environments for STI activities oriented towards delivering sustainable value for cities and urban communities.

Considerations for Governments:

- Transform existing data governance structures to ensure a more systemic, human-centric, cross-collaborative and privacy-preserving approach to the management and development of urban data infrastructures.
- Ensure that data governance structures are supported by cross-sector and multi-stakeholder collaborative ecosystems.

Considerations for the international community:

- Mobilize the resources required to increase the international availability of urban disaggregated data to obtain localized knowledge on the functioning of urban socio-technical systems and prepare appropriate STI solutions.
- Provide countries with guidance on how to best develop effective local and national regulatory frameworks.

Integrate policy settings for sustainable urban development

The complexity of urban sustainability challenges requires multi-sector and multi-level investments and efforts, which build the foundations of the integrated approach to urban sustainability enhancement that the 2030 Agenda for Sustainable Development and the New Urban Agenda champion. STI measures have proved effective in supporting integrated sustainable urban development; many solutions can address multiple sustainable urban development goals simultaneously, and they impact on multiple policy sectors. However, to maximize synergies and minimize trade-offs, coordination is needed among policy settings. When sustainable urban development policy is fragmented among policy areas, their functional logics and actors lack the coordination that is required to acquire a comprehensive understanding of urban sustainability issues – for example, technological upgrades that lack interoperability.

Considerations for Governments:

- Help local development actors to embrace the integrated approach to urban sustainability enhancement that the 2030 Agenda for Sustainable Development and the New Urban Agenda champion.
- Adjust institutional frameworks to integrate urban sustainability policy settings, horizontally and vertically, and ensure the coordination needed to maximize synergies among STI actions and minimize fragmentation and trade-offs.

Considerations for the international community:

- Ensure a cross-sectoral harmonization of urban sustainability policies across governmental levels, from local to global.

Boost scale-up and spreading of operations

The COVID-19 pandemic has demonstrated that organizations need to accelerate the digitalization of urban socio-technical systems, especially where the delivery of basic services require more resilient operational modes. Cities and urban communities have been experimenting with a growing number of STI measures for increasing this resiliency, to the extent that many urban areas have become living laboratories for the testing and experimentation of urban innovations.

Despite the progress, in many cases, government leaders and other stakeholders struggle to move beyond local pilot phases and ensure that the benefits of a solution – together with the lessons learned during the testing – can be scaled to reach a wider audience. STI studies can help overcome this critical challenge. More research efforts and resources should be allocated to determine the barriers that are inhibiting scale-up, to develop viable strategies that can ensure the mobility of solutions and, when needed, to achieve the necessary economies of scale and return of investments.

Considerations for Governments:

- Assess the socio-technical factors that hinder or accelerate local scale-up and spreading operations.
- Develop evidence-based strategies that can help ensure the mobility of STI solutions within national boundaries.
- Encourage local actors to join national and international networks of cooperation in which they can develop deeper insight into how to manage scale-up and spreading of operations.

Considerations for the international community:

- Compile and disseminate good practice on the framing of business models that support the scaling up and replicability of STI measures with potential for urban sustainability enhancement.
- Introduce measures that can help ensure the mobility of STI solutions across regions.

Building capacity around digital mindsets, skills and technology acceptance

During the COVID-19 pandemic, many have been left behind because existing inequalities have been entrenched and amplified. Among these inequalities are digital divides – especially skills and digital literacy – which have prevented many individuals from accessing the digital services that have replaced ordinary delivery methods. Digital divides also hinder the engagement of citizens who are not connected (e.g. older generations, deprived communities, etc.), as these people are not sure of what the benefits are for them in engaging with these technologies.[43]

Closing these digital skills and knowledge gaps should be a central theme in all efforts to foster truly inclusive sustainable urban development. Measures to increase digital literacy and human skills development are equally important as those to boost access to infrastructure or the Internet.

Considerations for Governments:

- Build consensus and strengthen collaboration in the field of digital education strategies, including by developing national strategic plans.
- Increase innovation and investment in digital technology for learning and teaching.
- Introduce the training measures required to provide all children, young adults and adults with a sufficient level of digital literacy and vital digital skills.
- Enhance the digital skills of educators by providing them with the knowledge required to effectively introduce digital technologies in learning environments.
- Increase access to digital devices and infrastructure for all teaching staff and learners, while ensuring that the use of this technology is embedded in their teaching and learning activities.

Consideration for the international community:

- Strengthen scientific cooperation in the field of digitally enhanced teaching and learning, to provide government leaders and local authorities with more guidance.
- Encourage the reframing of national education systems to ensure that digital literacy and digital technologies become a central component of existing and future school curricula, at all levels, from pre-primary schools to universities.

[43] Contribution from the Government of the United Kingdom.

References

Aberdeen City Council (2020). New journey planning app launched. Available at https://news.aberdeencity.gov.uk/new-journey-planning-app-launched/.

ACOEM (2020). Brochure: Gunshot and Acoustic Threat Detection: Hear Danger before you See Danger. ACOEM. Virginia.

Adyel TM (2020). Accumulation of plastic waste during COVID-19. *Science*. 369(6509):1314–1315.

Afzalan N and Muller B (2018). Online Participatory Technologies: Opportunities and Challenges for Enriching Participatory Planning. *Journal of the American Planning Association*. 84(2):162–177.

Altman M and Pompei A (2018). 3D Printing For Good: How One Nonprofit Is "Printing" Homes For Families In Need. Available at https://unfoundation.org/blog/post/3d-printing-for-good-how-one-nonprofit-is-printing-homes-for-families-in-need/.

Arias-Molinares D and García-Palomares JC (2020). Shared mobility development as key for prompting mobility as a service (MaaS) in urban areas: The case of Madrid. *Case Studies on Transport Policy*. 8(3):846–859.

Arif Y (2021). Liberty Market forest: an urban forest in Pakistan: Nature-Based Solutions Initiative. Available at https://www.naturebasedsolutionsinitiative.org/news/liberty-market-forest-an-urban-forest-in-pakistan/.

Arup (2019). *Digital Twin: towards a meaningful framework*. Arup. London.

Bajorek JP (2019). Voice Recognition Still Has Significant Race and Gender Biases. Available at https://hbr.org/2019/05/voice-recognition-still-has-significant-race-and-gender-biases.

Böheim R and Gust S (2021). *The Austrian Pay Transparency Law and the Gender Wage Gap*. IZA DP No. 14206. IZA Institute of Labor Economics. Bonn.

Bons P, Buatois A, Ligthart G, Hoed RVD, Warmerdam J (2020). *Final report – Amsterdam Flexpower Operational Pilot: a detailed analysis of the effects of applying a static smart charging profile for public charging infrastructure.* Amsterdam University of Applied Sciences. Amsterdam.

Braga AA, Turchan B, Papachristos AV and Hureau DM (2019). Hot spots policing of small geographic areas effects on crime. *Campbell Systematic Reviews*.

Burton T and Alers M (2019). Solar for Health: Five Ways Solar Power Can Make Universal Healthcare a Reality. Available at https://www.un.org/en/un-chronicle/solar-health-five-ways-solar-power-can-make-universal-healthcare-reality.

Centre for Studies on Risks, the Environment, Mobility and Urban Planning (2019). *MaaS in Europe: Lessons from the Helsinki, Vienna and Hanover experiments*.

Chandran T (2018). Smart Cities: Reducing Congestion with Deep Learning. Available at https://new.siemens.com/global/en/company/stories/research-technologies/archive.html.

Chang Y et al. (2018). Unlocking the green opportunity for prefabricated buildings and construction in China. *Resources, Conservation and Recycling*. 139:259–261.

Chin C and Robison M (2020). *How [Artificial Intelligence] AI Bots and Voice Assistants Reinforce Gender Bias*. Brookings Institution. Washington, D.C.

Circit Norden (2020). WasteIQ - Smart waste management by pay-as-you-throw. Available at https://circitnord.com/inspiration-cases/cecase-49/.

Codd F and Ferguson D (2020). The covid-19 outbreak and employment rights. Debate Pack No. CDP-2020-0140. The House of Commons Library. London.

Dembski F, Wössner U, Letzgus M, Ruddat M and Yamu C (2020). Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. *Sustainability*. 12(6):2307.

Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (2021). *Reaching last-mile communities with tailored solar solutions: UpOwa*. Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ).

Equal Pay Portal (2019). Gender pay gap reporting. Available at https://www.equalpayportal.co.uk/gender-pay-gap-reporting/.

Estrada F, Botzen WJW and Tol RSJ (2017). A global economic assessment of city policies to reduce climate change impacts. *Nature Climate Change*. 7(6):403–406.

European Commission (2014). Transport emissions. Available at https://ec.europa.eu/clima/eu-action/transport-emissions_en.

European Commission (2017). European Commission. Available at https://cordis.europa.eu/article/id/157580-improving-desalination-with-nanotechnology.

European Commission (2020). Questions and answers: A Hydrogen Strategy for a climate neutral Europe. Available at https://ec.europa.eu/commission/presscorner/home/en.

European Commission (2021a). Digital Opportunity Traineeships initiative exceeds original targets. Available at https://digital-strategy.ec.europa.eu/en/news/digital-opportunity-traineeships-initiative-exceeds-original-targets.

European Commission (2021b). *Digital Solutions for Zero Pollution*. European Commission.

European Commission (2022). FIWARE for the Next Generation Internet Services for the WATER sector. Available at https://cordis.europa.eu/project/id/821036.

European Environment Agency (2011). *Safe water and healthy water services in a changing environment*. European Environment Agency.

European Space Agency (2018). AMBROSIA | ESA Business Applications. Available at https://business.esa.int/projects/ambrosia.

European Space Agency (2019). ARCtic Sea-ice and CleAN monitoring. Available at https://business.esa.int/projects/arctic-sea-ice-and-clean-monitoring.

European Union Agency for Fundamental Rights (2018). *Big Data: Discrimination in data-supported decision making*. European Union Agency for Fundamental Rights. Vienna.

Excess Material Exchange (2019). *EME Pilot Report*. Excess Materials Exchange. Amsterdam.

Farha L (2020). Covid-19 guidance note: Prohibitions of evictions. Available at https://www.ohchr.org/sites/default/files/Documents/Issues/Housing/SR_housing_COVID-19_guidance_evictions.pdf.

Favre L and Oksen P (2020*). Innovative Technology in the Water, Sanitation and Hygiene (WASH) Sector*. World Intellectual Property Organization. Geneva.

Figueres N von R (2017). What can other cities learn from Mexico City's bike-sharing scheme? Available at https://blogs.lse.ac.uk/internationaldevelopment/2017/12/08/what-can-other-cities-learn-from-mexico-citys-bike-sharing-scheme/.

Frearson A (2021). Digital twins offer "a very powerful way of developing our cities" say experts. Available at https://www.dezeen.com/2021/07/09/digital-twins-develop-cities-digital-design-architecture/.

Gao S and Ryan BD (2020). Can Neighborhood Planning in Shrinking Cities Achieve Demolition Goals? A Conformance and Performance Evaluation of Neighborhood Action Plans in Youngstown, Ohio. *Journal of Planning Education and Research*.

Garfias Royo M, Parikh P and Belur J (2020). Using heat maps to identify areas prone to violence against women in the public sphere. *Crime Science*. 9(1):1-15.

Global Footprint Network (2015). *How can Mediterranean societies thrive in an era of decreasing resources?* Global Footprint Network. Geneva.

Grybauskas A, Pilinkienė V and Stundžienė A (2021). Predictive analytics using Big Data for the real estate market during the COVID-19 pandemic. *Journal of Big Data*. 8(105).

Harvey J, Smith A, Goulding J and Branco Illodo I (2020). Food sharing, redistribution, and waste reduction via mobile applications: A social network analysis. *Industrial Marketing Management*. 88:437–448.

He C et al. (2021). Future global urban water scarcity and potential solutions. *Nature Communications*. 12(4667):1-11.

Hyatt A (2019). Real-time bikeshare information in Google Maps rolls out to 24 cities. Available at https://blog.google/products/maps/real-time-bikeshare-information-google-map/.

Hyland M, Djankov S and Goldberg PK (2019). *Gendered laws.* Policy Research Working Paper No. 9080. World Bank. Washington, D.C.

Imam A and Lahoud C (2021). The Block by Block playbook: Using Minecraft as a participatory design tool in urban design and governance. UN-Habitat. Nairobi.

Inter-Agency Coordination Group Against Trafficking in Persons (2019). *Human Trafficking and Technology: Trends, Challenges and Opportunities*. ICAT. Vienna.

International Energy Agency (2019). *CO_2 emissions from fuel combustion: Highlights.* International Energy Agency. Paris.

International Labour Organization (2019). *World Employment and Social Outlook – Trends 2019.* International Labour Organization. Geneva.

International Labour Organization (2021). Child labour rises to 160 million – first increase in two decades. Available at http://www.ilo.org/global/about-the-ilo/newsroom/news/WCMS_800090/lang--en/index.html.

International Renewable Energy Agency (2020). *Global Landscape of Renewable Energy Finance 2020.* International Renewable Energy Agency. Abu Dhabi.

International Renewable Energy Agency (2021). *Renewable Energy Policies for Cities: Buildings.* International Renewable Energy Agency. Abu Dhabi.

Irvin-Erickson Y, La Vigne N, Levine N, Tiry E and Bieler S (2017). What does Gunshot Detection Technology tell us about gun violence? *Applied Geography*. 86:262–273.

Jorisch D, Mallin C, Accurso M, Zaballos AG and Rodríguez EI (2018). *Technology for Climate Action in Latin America and the Carribean.* Inter-American Development Bank. Washington, D.C.

Kemp N, Breetzke GD and Cooper A (2021). Modeling the risk of robbery in the city of Tshwane, South Africa. *Cartography and Geographic Information Science*. 48(1):29–42.

Kim M (2015). Pay Secrecy and the Gender Wage Gap in the United States. *Industrial Relations: A Journal of Economy and Society*. 54(4):648–667.

Le Quéré C et al. (2020). Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*. 10:647–653.

Lew L (2020). Flooding hits southern China with 14 million affected. Available at https://www.scmp.com/news/china/society/article/3090854/after-coronavirus-flooding-hits-southern-china-14-million.

Melbourne Water (2017). Melbourne Water's mini hydro-electricity program. Available at https://www.melbournewater.com.au/media/2366.

Mitlin D, Beard VA, Satterthwaite, D and Du J (2019). *Unaffordable and Undrinkable: Rethinking Urban Water Access in the Global South*. Working Paper. World Resource Institute. Washington, D.C.

Mobasheri A, Deister J and Dieterich H (2017). *Wheelmap: The Wheelchair Accessibility Crowdsourcing Platform*. Springer International Publishing.

Montgomery R (2015). How can we promote sustainable infrastructure? Available at https://www.weforum.org/agenda/2015/11/how-can-we-promote-sustainable-infrastructure/.

Mumba C, Skjerve E, Rich M and Rich KM (2017). Application of system dynamics and participatory spatial group model building in animal health: A case study of East Coast Fever interventions in Lundazi and Monze districts of Zambia. *PLOS ONE*. 12(12):e0189878.

OECD (2018a). *Improving Plastics Management: Trends, policy responses, and the role of international co-operation and trade.* OECD Environment Policy Paper No. 12. The Organization for Economic Cooperation and Development. Paris.

OECD (2018b). *The impact of legal frameworks on women's economic empowerment around the world: Event highlights*. The Organization for Economic Cooperation and Development. Paris.

OECD (2020). *The Digitalisation of Science, Technology and Innovation: Key Developments and Policies.* The Organization for Economic Cooperation and Development. Paris.

OECD/European Commission (2020). *Cities in the World: A New Perspective on Urbanisation.* OECD Urban Studies. Paris.

Pallagst K, Fleschurz R, Nothof S and Uemura T (2021). Shrinking cities: Implications for planning cultures. *Urban Studies*. 58(1):164–181.

Pimentel Walker AP (2016). Self-help or public housing? Lessons from co-managed slum upgrading via participatory budget. *Habitat International*. 55:58–66.

Pojani D, Wardale D and Brown K (2018). Sexism and the city: how urban planning has failed women. Available at https://theconversation.com/sexism-and-the-city-how-urban-planning-has-failed-women-93854.

Puhe M, Edelmann M, and Reichenbach M (2014). Integrated urban e-ticketing for public transport and touristic sites. Science and Technology Options Assessment. European Parliamentary Research Service.

Rajab S (2018). Chanouf Farm Biofire. Available at https://www.un.org/sustainabledevelopment/blog/2018/07/chanouf-farm-biofire/.

Rich KM, Rich M and Dizyee K (2018). Participatory systems approaches for urban and peri-urban agriculture planning: The role of system dynamics and spatial group model building. *Agricultural Systems*. 160:110–123.

Richardson HW and Nam CW, eds. (2014). *Shrinking Cities: A Global Perspective*. Routledge.

Ritchie H and Roser M (2019). Urbanization. Available at https://ourworldindata.org/urbanization.

Schenkel W (2015). Regeneration Strategies in Shrinking Urban Neighbourhoods—Dimensions of Interventions in Theory and Practice. *Political Communication*. 23(1):69–86.

Sivaramakrishnan K (2018). *As the World Ages: Rethinking a Demographic Crisis*. Harvard University Press.

Sorensen J (2020). British Geological Survey. Available at https://www.bgs.ac.uk/news/real-time-detection-of-faecally-contaminated-drinking-water/.

Streiff L (2020). NASA Model Reveals How Much COVID-related Pollution Levels Deviated from the Norm. Available at https://www.nasa.gov/feature/goddard/2020/nasa-model-reveals-how-much-covid-related-pollution-levels-deviated-from-the-norm.

Sustainable Water and Energy Solutions Network (2021a). Power Generation from Solar Photovoltaic Panels Floating on Water Reservoirs. Sustainable Water and Energy Solutions Network.

Sustainable Water and Energy Solutions Network (2021b). Hydropower for CO_2-free Electric Buses in Old Town of Regensburg, Germany. Sustainable Water and Energy Solutions Network.

Sustainable Water and Energy Solutions Network (2021c). Sustainable Geothermal Power Generation and Heating of Greenhouses and Spas in Kenya's Rift Valley. Sustainable Water and Energy Solutions Network.

Sustainable Water and Energy Solutions Network (2021d). Water, Biomass and Energy Nexus: Electricity Generation from Sugarcane Biomass in Guatemala. Sustainable Water and Energy Solutions Network.

Transport for London (2021). Contactless and mobile pay as you go. Available at https://www.tfl.gov.uk/fares/how-to-pay-and-where-to-buy-tickets-and-oyster/pay-as-you-go/contactless-and-mobile-pay-as-you-go.

UN-Women (2017a). Buy from Women. Available at https://www.unwomen.org/sites/default/files/Headquarters/Attachments/Sections/Library/Publications/2017/Buy-from-women.pdf.

UN-Women (2017b). Making stepping out of home safer for women and girls in Marrakech. Available at https://www.unwomen.org/en/news/stories/2017/11/feature-marrakech-safe-cities.

UNCTAD (2020). *World Investment Report 2020*. United Nations Conference on Trade and Development. Geneva.

UNDP (2021). Comprehensive cooperation to Costa Rica´s National Information System and Unique Registry of Beneficiaries (SINIRUBE). Available at https://sdgs.un.org/partnerships/comprehensive-cooperation-costa-ricas-national-information-system-and-unique-registry.

UNEP (2017a). *Towards a zero-emission, efficient, and resilient buildings and construction sector*. United Nations Environment Programme.

UNEP (2017b). Consumer Information, including Ecolabeling. Available at http://www.unep.org/es/node/1509.

UNEP (2018). *The weight of cities: Resource requirements of future urbanization*. United Nations Environment Programme. Nairobi, Kenya.

UNEP (2019). Time to seize opportunity, tackle challenge of e-waste. Available at https://www.unep.org/news-and-stories/press-release/un-report-time-seize-opportunity-tackle-challenge-e-waste.

UNEP (2021). *Food Waste Index Report*. United Nations Environment Programme. Nairobi.

UN-Habitat (2007). Women's Safety and Security in Cities. Available at https://mirror.unhabitat.org/content.asp?typeid=19&catid=303&cid=6849.

UN-Habitat (2019). Using mixed reality technology for inclusive and participatory planning. Available at https://unhabitat.org/using-mixed-reality-technology-for-inclusive-and-participatory-planning.

UN-Habitat (2020). *World Cities Report 2020: The Value of Sustainable Urbanization*. UN-Habitat.

UN-Habitat (2021a). Energy. Available at https://unhabitat.org/topic/energy.

UN-Habitat (2021b). *Cities and Pandemics: Towards a More Just, Green and Healthy Future*. UN-Habitat. Nairobi.

UNICEF (2020). Accelerating results for children with technology and digital innovation. Available at https://www.unicef.org/reports/accelerating-results-children-technology-and-digital-innovation-2020.

UNICEF (2021). Better Parents, Healthier Children. Available at https://www.unicef.org/indonesia/social-policy/stories/better-parents-healthier-children.

United Kingdom, Department for Environment, Food, and Rural Affairs (2018). *Our Waste, Our Resources: A Strategy for England*. London.

United Kingdom, Department for Transport (2019). *Cycle to work scheme guidance for employers*. London.

UNLEASH (2018). Winners of SDG 12: Responsible Supply Chain and Consumption. Available at https://unleash.org/news/winners-sdg-12-responsible-supply-chain-consumption/.

United Nations (2020a). *COVID-19 in an urban world*. Policy Brief. United Nations. New York.

United Nations (2020b). *The Sustainable Development Goals Report 2020*. United Nations. New York.

United Nations (2020c). *A New Era of Conflict and Violence*. United Nations. New York.

United Nations (2021). *The Sustainable Development Goals Report 2021*. United Nations. New York.

United Nations Capital Development Fund (2020). United Nations Capital Development Fund. Available at https://www.uncdf.org/article/5577/uncdf-and-safeboda-with-support-from-sida-launch-an-e-commerce-platform-for-home-delivery-amid-covid-19.

United Nations, Department of Economic and Social Affairs (2015). *Accessibility and Disability Inclusion in Urban Development*. United Nations, Department of Economic and Social Affairs. New York.

United Nations, Department of Economic and Social Affairs (2016). *Good Practices of Accessible Urban Development*. United Nations, Department of Economic and Social Affairs. New York.

United Nations, Department of Economic and Social Affairs (2019a). *World Urbanization Prospects: The 2018 Revision*. United Nations, Department of Economic and Social Affairs, Population Division. New York.

United Nations, Department of Economic and Social Affairs (2019b). *World Population Prospects 2019: Highlights*. United Nations, Department of Economic and Social Affairs, Population Division. New York.

United Nations, Department of Economic and Social Affairs (2019c). *World Population Ageing 2019: Highlights*. United Nations, Department of Economic and Social Affairs, Population Division. New York.

United Nations, Department of Economic and Social Affairs (2021). CloQ - Simplifying Financial Inclusion. Available at https://sdgs.un.org/partnerships/cloq-simplifying-financial-inclusion.

United Nations Economic Commission for Europe (2019). Mapping of Existing Technologies to Enhance Energy Efficiency in Buildings in the UNECE Region. United Nations Economic Commission for Europe. Geneva.

United Nations Office for Disaster Risk Reduction (2020). Making Cities Resilient by Integrating Nature-Based Solutions into Urban Planning in Africa. Available at https://www.undrr.org/event/making-cities-resilient-integrating-nature-based-solutions-urban-planning-africa.

United Nations Office on Drugs and Crime (2020a). Firearms. Available at https://www.unodc.org/unodc/en/firearms-protocol/index.html.

United Nations Office on Drugs and Crime (2020b). Line UP, Live Up: Youth crime prevention through sports. Available at https://www.unodc.org.

Viola C, Modak N and Ferguson T (2020). The future of water: How innovations will advance water sustainability and resilience worldwide. Available at https://blogs.worldbank.org/water/future-water-how-innovations-will-advance-water-sustainability-and-resilience-worldwide.

Wallemacq P and House R (2018). *Economic losses, poverty & disasters: 1998-2017*. United Nations Office for Disaster Risk Reduction. Geneva.

World Bank (2020a). Gender-Inclusive Cities: Can Urban Planning Take into Account Women and Minorities? Available at https://www.worldbank.org/en/news/feature/2020/03/07/ciudades-feministas-diseno-urbano-para-mujeres-y-minorias.

World Bank (2020b). Strengthening Conditional Cash Transfers and the Single Registry in Brazil: A Second-Generation Platform for Service Delivery for the Poor. Available at https://www.worldbank.org/en/results/2020/04/22/strengthening-conditional-cash-transfers-and-the-single-registry-in-brazil.

World Bank (2021). *Demographic Trends and Urbanization*. World Bank. Washington, D.C.

World Bicycle Relief (2020). *2020 Impact Report*. World Bicycle Relief. Chicago.

World Economic Forum (2019). *A New Circular Vision for Electronics: Time for a Global Reboot*. World Economic Forum. Geneva.

World Health Organization (2005). Air pollution and climate change. Available at https://www.euro.who.int/en/health-topics/environment-and-health/Transport-and-health/data-and-statistics/air-pollution-and-climate-change2.

Ye T et al. (2019). Using machine learning to help vulnerable tenants in New York city. *Proceedings of the 2nd ACM SIGCAS Conference on Computing and Sustainable Societies*. COMPASS '19Association for Computing Machinery. New York: 248–258.

Yeung P (2020). The Brazilian megacity experimenting with eco-friendly waste disposal. Available at https://www.dw.com/en/the-brazilian-megacity-experimenting-with-eco-friendly-waste-disposal/a-51469344.

Youth4nature (2021). Nature-based Solutions: Cases in African cities. Available at https://www.youth4nature.org/blog/nature-based-solutions-cases-in-african-cities.

Zeng X, Mathews JA and Li J (2018). Urban Mining of E-Waste is Becoming More Cost-Effective Than Virgin Mining. *Environmental Science & Technology*. 52(8):4835–4841.

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