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Fourth Industrial Revolution for the Earth Series

# Harnessing the Fourth Industrial Revolution for Sustainable Emerging Cities

In collaboration with PwC and Stanford Woods Institute for the Environment

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# Preface: The Fourth Industrial Revolution and the Earth

Industrialization has led to many of the world's current environmental problems. For example, climate change, unsafe levels of air pollution, the depletion of fishing stocks, toxins in rivers and soils, overflowing levels of waste on land and in the ocean, loss of biodiversity and deforestation can all be traced to industrialization.

As the Fourth Industrial Revolution gathers pace, innovations are becoming faster, more efficient and more widely accessible than before. Technology is also becoming increasingly connected; in particular, we are seeing a merging of digital, physical and biological realms. New technologies are enabling societal shifts by having an effect on economics, values, identities and possibilities for future generations.

We have a unique opportunity to harness this Fourth Industrial Revolution, and the societal shifts it triggers, to help address environmental issues and redesign how we manage our shared global environment. The Fourth Industrial Revolution could, however, also exacerbate existing threats to environmental security or create entirely new risks that will need to be considered and managed.

Harnessing these opportunities and proactively managing these risks will require a transformation of the "enabling environment", namely the governance frameworks and policy protocols, investment and financing models, the prevailing incentives for technology development, and the nature of societal engagement. This transformation will not happen automatically. It will require proactive collaboration between policy-makers, scientists, civil society, technology champions and investors.

If we get it right, it could create a sustainability revolution.

The "Fourth Industrial Revolution for the Earth" series is designed to illustrate the potential of Fourth Industrial Revolution innovations and their application to the world's most pressing environmental challenges. It offers insights into the emerging opportunities and risks, and highlights the roles various actors could play to ensure these technologies are harnessed and scaled effectively. It is not intended to be conclusive, but rather to stimulate discussion between diverse stakeholders to provide a foundation for further collaborative work. This paper, with special thanks to Nina Nasman and Dan Dowling from PwC UK, looks at the Fourth Industrial Revolution and sustainability in emerging cities.

# Foreword

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The world's emerging cities, if they intelligently harness the rapid and disruptive technological change of the Fourth Industrial Revolution, have the potential to offer a sustainable future.

Today's emerging economies attract more urban citizens than ever before. Cities in Asia and Africa are forecast to absorb 90% of the world's 2.5 billion new urbanites by 2050.[1] Cities have always been melting pots of innovation and economic activity, attracting increasing numbers of people and providing transformational economic opportunities. We have seen how urbanization has increased productivity, fostered innovation and raised incomes to create today's global metropolitan powerhouses of Dubai, London, New York, Seoul, Shanghai and Singapore.

It is in emerging cities like Bogotá (Colombia), Lagos (Nigeria) and Mumbai (India) that the battle for a sustainable future will likely be lost or won. Many developing countries see the challenge of sustainable urbanization as a defining one. Rapid and poorly managed urbanization often proceeds at the expense of both liveability and the environment. More often than not, cities have not been well planned, managed or funded and the supply of urban infrastructure and services has subsequently failed to keep up with the needs of people and the economy. The consequences have included alarming levels of poverty, disease, inequality and environmental damage. Urban dwellers in these emerging cities are hardest hit: 98% of large emerging cities do not meet the World Health Organization (WHO)'s air quality guidelines.[2] Negative environmental impacts also hit productivity and the economy, with these constraints being acutely felt in China, India and, increasingly, urban Africa.

Cities need to advance from incremental to transformative action on the environment to enable society to meet the Sustainable Development Goals (SDGs). Global efforts, including the UN's New Urban Agenda, the Paris Agreement on climate change and innovative peer-to-peer networks like C40 and the Coalition for Urban Transitions, are all helping cities to build strong policy agendas for environmental change. But while progress is being made, efforts need to accelerate sharply.

As the fastest-ever period of technological innovation, the Fourth Industrial Revolution presents great promise to leapfrog traditional development and accelerate the transition to a more sustainable urban future. Fourth Industrial Revolution technologies such as artificial intelligence (AI), autonomous vehicles and drones, the internet of things (IoT), advanced materials, 3D printing and biotechnology are particularly relevant. Many are already showing promise at reshaping urban sectors – including transport, energy, waste, water and buildings – and change will only accelerate. Cities can harness these pioneering technologies, combined with each other and with new business models, to not only enhance urban economic productivity but to reduce environmental impact and increase well-being. The Fourth Industrial Revolution, however, also presents its own set of risks. Emerging cities need to invest in the enabling technological infrastructure and skills to ensure they don't get left behind, and to minimize unintended harmful impacts of the Fourth Industrial Revolution.

This paper explores how the Fourth Industrial Revolution is changing environmental sustainability in emerging cities, shining a light on existing and future opportunities for these cities to harness innovation for sustainable outcomes.

# Fourth Industrial Revolution and the agenda for change

Balancing the impact of complex interactions between cities and the natural environment (from resource use and ecosystem services to pollution) will be vital for a sustainable future. In emerging cities, action to address the following key challenges will be particularly important for delivering environmental sustainability and could be supported by Fourth Industrial Revolution innovations:

- Smart planning and construction to make better use of the built environment
- Sustainable transport and logistics to increase mobility and connectivity
- Clean energy and utilities to improve efficiency of urban systems and the environment
- Urban health and resources to lower pollution and improve liveability and affordability
- Resilient urban systems to enable cities to prepare for, and withstand, environmental shocks and disasters

## Smart planning and construction

Based on a study of 50 global cities, inefficient urban sprawl is projected to directly contribute to nearly 60% of the expected rise in energy use.[3] One estimate puts the annual cost of sprawl in the US at $1 trillion per annum.[4] The trend of reducing densities and higher costs is spreading across emerging cities.[5]

While the co-location of people, jobs, services, entertainment and shops defines the built environment, uncoordinated development and sprawling single-use construction patterns characterize many of today's rapidly growing cities. Low capacity and ineffective urban policy, planning, regulation and incentives mean urban space is not used as well as it could be. This is costly, but also results in higher greenhouse gas (GHG) emissions and air pollution resulting from increased private transport share, inefficient services, fewer open spaces and extensive grey infrastructure. Socially, poorly planned cities are worse off too because people with lower incomes are typically marginalized, living in poorly constructed homes in disconnected, unserviced settlements.

Mixed-use development, which is compact and well-connected, offers a better model for the economy and environment. Solutions to make more out of scarce, valuable urban space include:

- Integrated, digital urban planning, transparent land-use planning, monitoring and management, and clear property rights that allow for the development of shared spaces
- Denser, integrated and mixed-use communities close to transport nodes, e.g. transit-oriented development
- Multifunctional buildings optimizing floor space 24/7
- Next generation building codes using digital design and nano-materials to radically reduce embodied carbon in production
- Just-in-time offsite, pre- and modular fabrication improving construction efficiency and flexible, reusable building parts
- Smart residential and commercial building management reducing costs of inefficient energy and water use

Technologies of the Fourth Industrial Revolution can offer new tools for city authorities, private developers and residents to properly plan, visualize and manage urban development and operations. Drones, sensors and big-data-powered simulations aided by AI can simplify these processes and improve engagement with citizens leveraging new ways of generating and using data. Advanced materials, 3D printing, blockchain and AI, can support intelligent-building design and streamline construction contracting.

## Sustainable transport and logistics

In Mexico City, traffic jams are estimated to cost 33 billion pesos ($1.8 billion) per year in lost time and productivity because 85% of road space is taken up by private cars, which only account for 30% of commutes.[6]

High connectivity and the smooth movement of people and goods define a well-functioning city. Yet, many cities have struggled to meet demands for existing transport and traffic systems, let alone improve connectivity within and between places. As well as the major, well-documented, impact on air quality and public health, the result is longer and costlier commutes and firms unable to take advantage of close markets for logistical efficiency gains.

Without technological change, the traditional, car-dominated cities of the 20th century will not survive rapid urbanization and increasingly stringent air pollution regulations. Solutions, some costlier than others to implement, include:

- Integrated intra- and inter-urban transport and logistics systems, reducing the need for private vehicles
- Real-time transport and traffic management and monitoring
- Cleaner vehicles and low-carbon mobility solutions that allow people to walk and bike more freely
- Platforms to better utilize existing and new forms of shared and ambient mobility, e.g. bikes, buses, and autonomous vehicles
- Mixed-use neighbourhoods and better use of home services improving access to goods and services

Exploiting Fourth Industrial Revolution technologies could transform not only the daily commute, but also delivery logistics, inclusion and productivity. Autonomous vehicles providing on-demand mobility services are one, much-debated, option. Deploying AI and sensors also offer options. These are based on IoT, for predictive and real-time traffic flow and pollution management, advanced materials for low-carbon and clean fuel options, drones for deliveries and virtual reality (VR) for remote meetings.

## Clean energy and utilities

India is already the world's third-largest user of energy, yet its urban population is still expected to grow by nearly half a billion people in coming decades. As a result, it is set to record the world's fastest growth in residential energy demand, at an average annual rate of 3.2% between 2012 and 2040.[7]

Cities are our biggest opportunity to mitigate climate change. They account for more than 70% of global energy use and GHG emissions to power their buildings, industry, utilities and infrastructure.[8] India has set an ambitious electric capacity target of 57% coming from renewable sources by 2027.[9] This requires huge investment in renewable, decentralized and controllable energy solutions. South Africa has already auctioned more than 5 gigawatts of renewable generating capacity to the private-sector, for nearly R200 billion ($15 billion) in just four years.[10]

Improvements to fossil-fuel generated power and heat include renewable energy generation coupled with energy efficiency measures. These key solutions include:

- Renewable, decentralized energy generation such as rooftop solar, city heat networks and peer-to-peer energy systems
- Temperature sensors, smart meters and occupant controls for efficiency and to control energy and water use
- Intelligent grid management helping utilities monitor assets, model use and ensure efficient and cost-effective operations
- Advanced batteries for energy storage and electric vehicles
- Waste-to-energy plants including associated district heat and cooling networks

The Fourth Industrial Revolution technologies can offer new efficiencies in generation through virtual power plants. These integrate various energy sources through IoT and cloud-based platforms for more reliable power supply, decentralized energy storage networks and quad generation. For transmission, sensor-based electric and water grids are used[11], while in distribution and consumption, the technologies include blockchain-enabled asset and contract management, and demand forecasting and AI-powered modelling.

## Urban health and resources

In China, health costs related to urban air pollution are estimated to exceed 10% of GDP.[12] In South Africa, domestic and municipal sectors could reduce water use by up to 30% just by addressing physical leaks and household water wastage.[13]

Degraded air quality, dirty water and unsustainable waste practices are contributing to deteriorating health and economic productivity in many emerging cities. In Kolkata (India), investing Rs13.1 billion ($204 million) to improve efficiency in the waste sector could reduce waste-related greenhouse gas emissions by 41% by 2025.[14] Planning new cities and retrofitting existing ones requires a paradigm shift given rapid urbanization and growing environmental pressures.

The urban "anatomy" of energy networks, green spaces, and water and waste systems must transform from their current wasteful linear ways into resource-efficient ones. Key solutions include:

- Sharing economy principles for developing smart solutions and efficient supply chains, which can help meet human needs within minimal footprints, improve the quality of life and reduce economic losses from waste
- Circular economy design for remanufacturing, refurbishing and recycling to keep components and materials circulating, reduce damage and manage negative environmental effects
- Integrated municipal and industrial waste management
- Life-cycle assessments of water quality, management and re-use
- Air pollution sequestration and purifiers, including biofilters
- "Living" building façades, green spaces and urban agriculture

Municipalities also have the difficult balancing task of ensuring that more stringent environmental quality controls and rules do not leave society's poorer members further marginalized. Fourth Industrial Revolution innovations will be integral to delivering a better environmental quality of life in cities. Opportunities include developing urban farms on rooftops and building walls, making underutilized spaces greener and less polluting through bioengineering, tracking water quality and waste types for recycling, creatively re-using waste, and educating people in the correct practices to minimize water use and waste with the help of IoT, blockchain and VR.

## Resilient urban systems

More than 95% of registered deaths from storms and floods between 2000 and 2013 were recorded in low- and middle-income countries.[15] If action isn't taken, sea level rises and flooding could cost coastal cities $1 trillion by 2050.[16] Cyberattacks on urban infrastructure could cost insurers billions of dollars.[17]

Emerging cities have to continually manage change, and often respond to natural hazards and human catastrophes like conflict and mass migration. Demographic, economic, political and cyber shocks can also have an impact on the city environment because reduced financing abilities, different priorities and compromised systems can divert scarce funds and focus from key sustainable infrastructure and low-carbon investments.

Climate change is increasing the frequency of extreme weather events, with underlying geopolitical unrest and social inequality exacerbating vulnerability to these shocks. Cities will need to be at the forefront of averting and tackling negative impacts, from damaged infrastructure to related infectious disease outbreaks. Solutions include:

- Real-time, integrated and adaptive urban management systems and change management to better adapt to, learn from and respond to shocks
- Integrated financial, procurement and governance systems
- Enhanced risk monitoring and prediction, combined with up-to-date cyber security measures, for flexible, reliable city and utility functions as well as insurance management
- Disaster-ready urban infrastructure and buildings, and smart emergency response systems for natural and manmade disaster prevention, mitigation and recovery

The Fourth Industrial Revolution technologies have immense potential to promote predictability and transparency in risk preparedness and responses: IoT and AI can predict and communicate potential shocks and disasters in real-time, while blockchain can enhance cybersecurity, drones can deliver urgent supplies to hard-to-reach areas, and 3D printing and advanced materials can better rebuild infrastructure making it more resilient and with a lower ecological footprint.

**Figure 1:** Level of development of Fourth Industrial Revolution technology applications that address challenges for sustainability in emerging cities.

| Fourth Industrial Revolution technologies | Challenges for sustainability in emerging cities | | | | |
|---|---|---|---|---|---|
| | **Smart planning and construction** | **Sustainable transport and logistics** | **Clean energy and utilities** | **Urban health and resources** | **Resilient urban systems** |
| 3D printing | ■ | □ | □ | ■ | □ |
| Advanced materials | □ | ■ | ■ | □ | □ |
| Advanced sensor platforms | □ | | | □ | |
| Artificial intelligence | □ | ■ | ■ | □ | □ |
| Biotechnologies | □ | □ | □ | ■ | □ |
| Blockchain | ■ | □ | ■ | □ | □ |
| Drones and autonomous vehicles | ■ | ■ | ■ | □ | ■ |
| Energy capture, storage and transmission | ■ | ■ | ■ | | ■ |
| Geo-engineering | | □ | | □ | |
| Internet of things | ■ | ■ | ■ | ■ | ■ |
| Robots | ■ | ■ | ■ | ■ | □ |
| New computing technologies | | | | □ | |
| Virtual, augmented and mixed realities | | □ | □ | | ■ |

# Transforming business as usual in emerging cities

To accelerate sustainable urban development patterns in emerging economies, the following five key Fourth Industrial Revolution innovations are 'game-changers' that fuse a range of technologies and provide opportunities for emerging cities to tackle current and future environmental challenges.

## Adaptive cities: Making the most of multifunctional space

**Flexing and optimizing urban land, space and buildings to maximize their potential can be a game-changer for rapidly growing cities that want to foster better density and reduce costly, inefficient sprawl.**

Using Fourth Industrial Revolution technologies, existing buildings and spaces can be upgraded to become multi-use.

- IoT and bioengineering can be utilized to alter space and integrate operational systems to make lighting, heating, deliveries and waste collection more efficient based on real-time demand. For example, the Wooden Tower building redesign in Lagos represents smart, sustainable principles.[18]
- AI and data analytics alongside online and SMS engagement platforms can help cities and building managers monitor and adapt spaces based on local citizen and consumer demands at low cost. An example would be Google's Sidewalk Labs plans in Toronto (Canada) to pilot the Loft concept (a mixed-use building with a strong skeleton structure and adaptable interior for changing residential, commercial and other uses).[19] The environmental gains of adaptable space can be large through land conversion, less construction and better utilization of assets.

New buildings and spaces can be designed and built on the same mixed-use principles with the help of Fourth Industrial Revolution technologies.

- Mixed and augmented realities can be used to simulate and plan mixed-use, inclusive developments, where people can satisfy their everyday needs without the need to travel.
- Blockchain and AI technologies can help automate planning processes and property developments. Brazil's Real Estate Registry Office is piloting blockchain to improve accuracy of property ownership data with US start-up Ubitquity.[20] Use of blockchain for land ownership is also being trialled in Costa Rica.[21]
- Drones, 3D-printing and robots can be used to construct new multifunctional buildings in a more timely and resource-efficient manner, and to deliver pop-up development that can generate economic activity on unutilized land.
- Advanced materials such as graphene can be very light and 200 times stronger than steel, ensuring that new building shapes and public spaces could be constructed with a far lower environmental footprint.

## Seamless cities: Connecting people and places

**Integrated public transport systems, on-demand mobility and intelligent traffic management will be crucial for improving air quality and connectivity in gridlocked emerging cities.**

Fourth Industrial Revolution innovations can improve current traffic flow and management.

- IoT and AI, coupled with big data and low-tech solutions including mobile phones and GPS navigation systems, can automate traffic monitoring and communicate congestion to vehicles on the road. This can help to optimize route planning, cut travel time and reduce GHG emissions. WhereIsMyTransport, a start-up in Cape Town (South Africa), has already started aggregating formal and informal public transport data into an open platform,[22] while Ninja Van uses algorithms and real-time tracking to enhance last-mile logistics across South-East Asia.[23]
- Blockchain technology, combined with real-time pattern recognition data, can help cities price and trigger incentives for transport network companies to provide services during off-peak times and to complement public transport.

Technological advances can also help reduce traffic volumes.

- Autonomous vehicles (cars, buses and trucks), especially when low or zero-emission and deployed for shared transport and logistics services, can reduce energy use, emissions and the numbers of vehicles on the road.
- Virtual, augmented and mixed reality meeting services in shared spaces could also reduce the need to travel for meetings, boosting broader connectivity and the competitiveness of smaller companies in emerging cities.

## Empowered cities: Optimizing urban energy systems

**Smart grid management combined with decentralized, renewable energy distribution systems will empower cities and urbanites with more frugal and flexible clean energy systems.**

Fourth Industrial Revolution innovations can help improve efficiency and reliability of existing grid-based power distribution.

- IoT, drones and robots, harnessed for sensor-based grid and network management, can help utilities (and cities) monitor and inspect the health of the power system in real-time to reduce losses and improve reliability.
- AI and smart meters, combined with the above, can also help forecast and optimize energy generation and demand. Smart grids are being piloted from cities in Brazil to the Philippines.
- Advanced materials, emerging battery and biotechnologies offer new ways to generate, store and consume renewable energy in cities by raising capacity (e.g. by harnessing photosynthesis in plants) and by managing peak demand (especially for solar energy on cloudy days).
- Quad generation technologies can optimize the heat - or in particularly hot climates the 'coolth' - provided to industry and homes through central provision and district energy centres, which measure and manage demand by cooperating with heat generation, distribution, use and reuse.

Fourth Industrial Revolution innovations can also help raise access to clean energy.

- Blockchain offers some of the most promising opportunities for expanding power access. Such technologies are showing decentralized, renewable power systems are possible with micro- and smart grids and peer-to-peer systems, as developed by Wattcoin in Ghana.[24]
- IoT, blockchain and pay-as-you-go systems also combine to increase accessibility to power in underserved markets. The Sun Exchange leases solar cells to firms and communities in southern Africa enabled by quick, secure and low cost payments to global investors using bitcoin.[25]

## Living cities: Advancing circular resource management

**Intelligent reduction and optimized reuse of waste and materials over their life-cycle will be crucial to preserve natural resources, avoid disease outbreaks, contaminated soils and waters, and local environmental degradation in emerging cities.**

By harnessing Fourth Industrial Revolution technologies, waste reduction and disposal could be done cost-effectively and quickly, particularly where political will, city-industry-citizen cooperation and budgets align. Reducing the waste burden should be a primary goal.

- IoT, AI and blockchain can help companies and industries monitor, analyse and automate their purchasing patterns. This will help them become smarter in their inventory and supply chain management, in turn minimizing deliveries of wasted products.
- Advanced materials used for intelligent packaging can limit waste creation. Concrete that contains graphene could clean itself and the air around it, creating a catalytic environment that breaks down larger harmful molecules into harmless compounds to lower pollution.[26] Cities can behave more like nature, mimicking the anatomy and metabolism of living structures that reuse, repurpose, regenerate and reprocess resources producing very little actual waste.
- Bioengineering can be used to create living building façades, and urban and vertical farms that can reduce the need to transport food great distances. It can also help to clean the air and create more green space in cities. One form of urban agriculture that promises significant environmental benefits is aquaponics; an efficient closed-loop system combining plant growing with fish farming, which has already been trialled in Brazil.

Fourth Industrial Revolution innovations also offer better ways to handle waste once created.

- IoT, advanced sensor platforms, AI and shared data can help cities predict and track municipal and industrial waste generation and collection, analyse types of waste and optimize disposal and recycling. India's I Got Garbage cloud-based platform has helped recycle more than 5,000 tonnes of waste and supported more than 8,000 informal waste pickers since 2013 through predictive, structured solid waste management.[27]
- Automated 3D-printing robots can process different forms of waste into building materials; primary structures and temporary scaffolds made out of organic compounds and metal scrap are being trialled by the likes of Terreform ONE.[28]

## Regenerative cities: Intelligently responding to catastrophic risk

**Smarter risk forecasting, response simulations and regenerative materials will be game-changers for protecting lives and the urban environment in emerging cities at risk of, or prone to, climate shocks and natural disasters.**

Helping cities and communities plan, prepare and collaborate with each other, with business and government is critical.

- IoT, blockchain and advanced sensor platforms, together with predictive AI analytics, can help cities monitor tremors, sea level changes and other possible natural hazards in real-time, with thresholds for automated triggers enabling early evacuation when needed. PetaBencana.id in Indonesia combines multiple open-source sensors, AI and people's social media reports for real-time flood mapping in the capital Jakarta.[29]

Mitigating the impacts of natural disasters is another area of Fourth Industrial Revolution innovation.

- Advanced materials such as self-healing concrete and biomimicry can help buildings withstand earthquakes and restore after such shocks. Companies such as Flextegrity have developed building materials that could reduce earthquake-related damage through ductility, energy absorption and bio-sensitive pipe support.[30]
- VR offers opportunities for cities to simulate disasters and prepare response strategies, as trialled by the Singapore Defence Force,[31] while game-based platforms could also be used to train citizens how to react in an emergency.

Fourth Industrial Revolution innovations are also transforming approaches for responding to natural disasters, which often hit poorer communities the hardest.

- Drones have been deployed to deliver emergency supplies and assess damage after disasters. Following the devastating hurricanes Harvey and Irma in 2017, utilities and insurance companies contracted drone firms to inspect and estimate pay-outs in the south-east of the US and the Caribbean. The Government of Bosnia and Herzegovina used drones to identify displaced land mines after severe flooding in 2014.[32]
- Portable 3D printers, powered by renewable energy to reduce reliance on possibly destroyed electricity lines, have the potential to save lives in the aftermath of disasters, both with printing urgently needed medical supplies and through the construction of temporary shelters.

Figure 2: The Fourth Industrial Revolution's game-changers for emerging cities


## Longer horizon game-changers: hyper-connected clean cities

Many of the Fourth Industrial Revolution innovations identified in this paper relate to their application within the city boundary. Cities do not exist in isolation, however, and their future prosperity and sustainability will depend on mutually beneficial relationships with other cities. Currently, there are several Fourth Industrial Revolution-related innovations in the connectivity space, which could prompt the next big shift of humanity's settlement patterns. Described below are future Fourth Industrial Revolution innovations, which will help cities to connect.

While transformational innovations in this space are often early stage, emerging cities with large infrastructure deficits can seize opportunities to leapfrog and test nascent technologies that unlock new possibilities for inter-city connectivity. Emerging cities (with strong leadership and more flexible regulatory frameworks) could be prime partners for global companies and investors looking to demonstrate more pioneering connectivity solutions. Designers and planners will, however, need to ensure that any solutions are inclusive, and benefit, rather than further isolate, the poorest communities.

Innovations that are likely to evolve in coming decades and that could fundamentally transform city-to-city public and private transport solutions, helping our future cities become clean and hyper-connected, include:

- Ultra-high speed surface solutions. A number of companies are in the early stages of prototyping a super-high-speed, vacuum-based transportation system called Hyperloop. It is projected to be fully self-powered using solar panels along the tunnel surface. Advanced materials are planned for the tunnel, the vehicle and for next-generation rechargeable battery storage devices. The vehicle itself will be highly automated using AI. Potential travel speeds above 500 miles per hour (805 kilometers per hour) between cities means that Hyperloop could provide a cheaper and cleaner alternative to air travel and long-haul road transport, particularly for those cities within one to two hour flight times. Feasibility studies under way in China, India, Netherlands, Scandinavia, the UAE, and the US represent collaborative and healthily competitive development efforts. Companies that are in the early test phases for such technology include Space X, and two specialized start-ups, Hyperloop One and Hyperloop Transportation Technologies. China Aerospace Science and Industrial Corporation (CASIC) is a recent newcomer to the project, announcing plans for an intercontinental supersonic T Flight "flying train" based on Hyperloop technologies.[33]
- Underground transport solutions. Although traditionally challenged both by physics and financial feasibility, further potential could be drawn from underground space. For example, The Boring Company, led by Tesla entrepreneur Elon Musk, is in the early stages of designing high-speed transport tunnels for short- and long-distance travel. The tunnels would be equipped with high-speed automated electric "skates" for short-haul vehicle transport, or used as a long-haul Hyperloop vacuum-tube supersonic transport system. If this could be done efficiently, and enhanced by Fourth Industrial Revolution technology, these enterprises could play a role in tackling congestion, reducing air and noise pollution, lowering GHG emissions, and cutting travel time for passenger transport and logistics across and between cities. Many significant engineering and regulatory hurdles must, however, be overcome for this concept to become commercially viable, and serious questions exist about upfront capital and maintenance costs, seismic risk, lifecycle energy needs and the quality, safety and affordability of the passenger experience.
- Mid- and long-distance drones. Mega-drones could provide public transport solutions that avoid the traffic jams and air pollution that accompany many surface transport solutions today. The drones would combine composite advanced materials vehicles and next-generation batteries with AI-powered autonomous driving and drone technology. Multi-passenger unmanned aerial vehicles are yet to be developed, but similar innovations are already happening on a smaller scale. Current specialized start-ups include German company Lilium, and China's Ehang, which is developing a one-person Autonomous Aerial Vehicle prototype for Dubai. Airbus also has a two-person autonomous aerial taxi, which it hopes to have ready by 2020. Google, Tesla and Uber are also exploring "flying car" technologies.
- Advanced aircraft solutions. Since Solar Impulse 2 circumnavigated the world, the broader potential and application of electric aircraft is starting to be realized. Airbus' E-Fan X is another early two-seat example, while Zunum Aero and DARPA are also developing airplanes for short-haul travel. For dense, highly-populated urban centres noise and air quality are growing problems. Fourth Industrial Revolution-enabled aircraft using advanced materials and next-generation batteries could enable electric aircraft for narrow-body short-haul flights. Were these to become feasible in coming decades, they could dramatically improve the urban environment and engender better connectivity between cities at a time when airport capacity and flight paths become less controversial because of fewer noise and pollution concerns in, and around, airports.
- Harnessing space connectivity. Advanced and nano satellites, among other technologies, are a growing frontier for city development and connectivity. Enabled by the Fourth Industrial Revolution, satellite functionality could be transformed with advanced materials, AI and blockchain. In China, researchers are trialling quantum cryptography technologies, which use space to send information and communicate securely between cities. A $100 million satellite, called Quantum Experiments at Space Scale, was launched from the Gobi Desert in 2016,[34] with plans to create a network of satellites and ground stations in cities to transmit quantum particles of data. Currently in its infancy, such technologies could revolutionize how cities avoid, mitigate and respond to environmental risks and catastrophes by improving detection mechanisms and reducing response times. Surrey Satellite Technologies Ltd is also creating a range of small, yet increasingly high-tech, satellite products and services, which could be better harnessed by cities. According to Nanosats.eu, there were 535 nanosatellites in orbit, as of July 2017.

Taken together, a range of Fourth Industrial Revolution-related innovations and breakthroughs that are anticipated in coming decades will change how cities are connected and communicate with one another. These developments are expected to change city-to-city transport fundamentally while delivering sustainable outcomes through new connectivity solutions underground, on the surface and in the air.

# Challenges and risks of the Fourth Industrial Revolution transition

The way cities look, feel and work will inevitably change with the advent of Fourth Industrial Revolution technologies. The speed of innovation is unparalleled, but the scale and effectiveness of harnessing Fourth Industrial Revolution innovations in rapidly growing cities will depend on factors such as the city's cultural or economic context, the quality of enabling infrastructure, skills development and urban ambitions. All cities, however, will need to resolve and mitigate the broader risks and challenges associated with adopting new technologies generally, and some technologies specifically, to ensure the Fourth Industrial Revolution is a sustainable revolution.

## Climate and environment

**Energy intensity of Fourth Industrial Revolution technologies:** Fourth Industrial Revolution technologies can help to increase energy efficiency, but their underlying use of energy is a cause for concern (e.g. the power required for blockchain and AV if they run on fossil-fuel-based energy). Government-led standards and incentives are needed to limit and, over time, reduce energy consumption from devices, sensors and appliances, and promote renewable energy sources.

**The butterfly effect:** Individual cities face particular climate threats and experience differing urban heat island effects, but addressing these with Fourth Industrial Revolution innovations (including geo-engineering), can have wide-ranging unintended consequences in other parts of the world. Early research suggests that bringing up deep cold waters or managing solar radiation may have damaging side effects.[35] A proliferation of AV could inadvertently increase urban sprawl because commuting time becomes converted into productive time. Technological advances can be encouraging, but further testing and development are necessary to ensuring safe and sustainable applications.

**Increased rural-urban migration:** Efficiency and competitiveness gains from Fourth Industrial Revolution deployment may attract more people to cities for economic opportunities, placing the urban environment under greater pressure, and posing a risk to rural areas that are already behind in development. Measures to mitigate negative effects involve ensuring adequate urban and infrastructure plans. For example, central government support for smarter villages helps to ensure openings for business, and provides those living in villages and rural areas with fast digital access, in turn, lessening the need for people to travel or move to urban areas.

## People and society

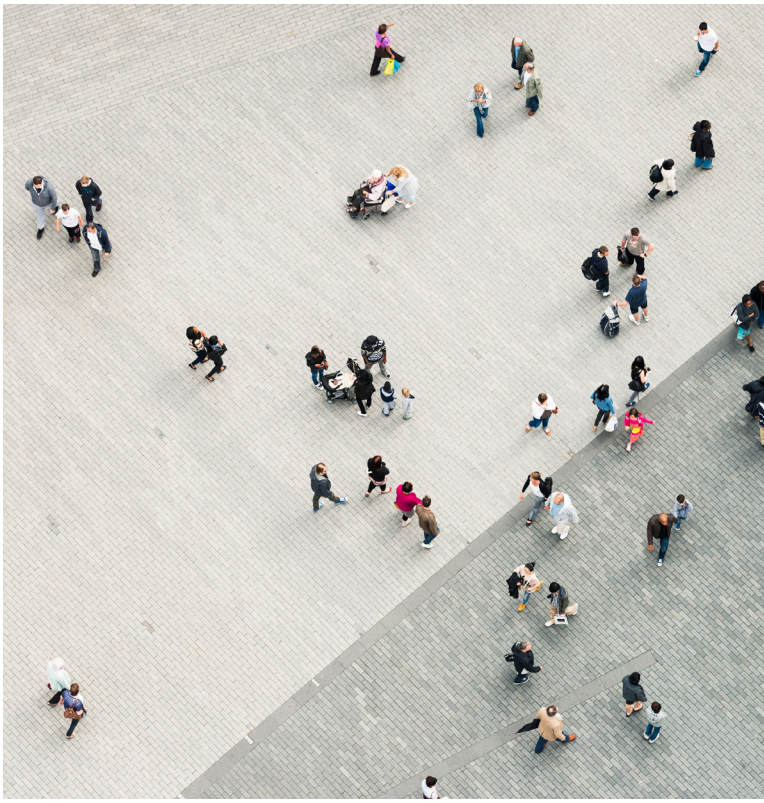
**Jobs and inequality:** The search for better livelihoods remains a driver of rapid urbanization, but the world of work is changing and increased automation is inevitable as technology use rises. Governments need to ensure that the opportunities and benefits of the Fourth Industrial Revolution are widely shared within, and between cities, and that the vulnerable and marginalized are not left further behind. This is particularly true in low- and middle-income countries where unemployment is high, especially for youth. Reforms should focus on restructuring economies for a new, sustainable Fourth Industrial Revolution age, retraining those whose jobs become automated and re-evaluating the tax system and social protection schemes if there are fewer jobs available. Not doing so could exacerbate the negative environmental effects of inefficient resource and land use brought on by economic inequality.

**Skills to implement and use new technologies:** Fourth Industrial Revolution technologies and their applications often require specialist skills, beyond basic digital literacy. In an index of 10 global cities' readiness to implement new technologies and current initiatives, Singapore came first, but according to research by PwC Russia, only 42% of its residents surveyed felt ready to use them.[36] To harness Fourth Industrial Revolution technologies for environmental sustainability in emerging cities, digital and Fourth Industrial Revolution awareness and skills need to be taught from an early age, and tailored higher education curriculums are required to equip school leavers and graduates with practical tools for work. Alongside this, older generations should not be left behind.

**Human-centred design:** The opportunities for operational and environmental improvements through Fourth Industrial Revolution technologies are often clearly laid out, but end-users can be forgotten. Ensuring that innovations are human-centred through user-testing and that their deployment is well-communicated can ensure that Fourth Industrial Revolution technologies are adopted more quickly and can achieve their desired environmental effects.

## Economy and governance

**Terms of public-private partnerships:** Greater data-sharing and collaborative solutions will be required between the private-sector and governments to ensure new technologies in the likes of waste, water and transport, are piloted and adopted. The terms of PPP engagements need to be aligned with the new wave of technologies, ensuring



that there are incentives related to transparency and revenue. Efforts are required to ensure that locations that are behind the digital curve and require upfront investment in infrastructure and skills, are not forgotten.

**Shape of urban governance:** As Fourth Industrial Revolution technologies enable more decentralized and automatically allocated and distributed services, the way urban governments govern and manage city systems will change. Are they ready? Having a coherent and coordinated urban Fourth Industrial Revolution strategy is necessary to manage this change and ensure its sustainability. Also required is collaboration on, and the co-creation of, new service delivery solutions with the private-sector to secure support from local government officials.

**Cyber security and privacy:** As more data on city operations, service providers, businesses and citizens are generated and shared digitally, balancing security and privacy concerns is already a key risk. Shared economy models function only if there is trust and transparency among and between parties. Assessing vulnerabilities and rapidly countering threats is crucial. Ensuring continuity and response planning is important to avoid funds and focus being diverted from environmental objectives.

# Ensuring that the Fourth Industrial Revolution is a sustainable revolution

Partnerships and a spirit of collaboration across many stakeholders will define new governance models for the Fourth Industrial Revolution and will be necessary to ensure it is a sustainable revolution.

Technological advances of the Fourth Industrial Revolution have huge potential, but can be hard to grasp fully. The applications are vast – and some may arrive faster than expected – but it can be hard to know where to start. Early successes and pilot testing of technologies in global cities can indicate the opportunities, which will resonate more broadly across the global economy and society.

Many emerging cities already have foundations for greater technology adoption, including ICT infrastructure and skilled workers. Still, cities facing rapid urban change will need different steps, new ways of working and tailored solutions if they are to leapfrog 20th century patterns of urban development, engender change and meet overarching SDGs.

Outlined below are non-exhaustive and broad recommendations to speed up innovation, minimize environmental risks and increase the positive environmental impact of Fourth Industrial Revolution technologies for different, but intertwined, urban stakeholders.

**Public-sector** (national and local governments, supported by international organizations)

- City development strategies for the Fourth Industrial Revolution: build on Third Industrial Revolution-based strategies, identify "quick-wins" that demonstrate environmental value and applicability, and also enable planning delivery of further Fourth Industrial Revolution projects. Strategies need to be clear, tailored to cities' contexts, and integrated with a city-region strategy, which engages with, and enjoys the support of, the private-sector and citizens.
- Create urban and national government innovation units: to nurture and pursue innovation and context-specific Fourth Industrial Revolution applications. Cities need to show leadership and a willingness to act on an agenda of change, balancing visionary ambitions with pragmatism about risks and costs.[37]
- Policy and regulatory environment to enable scaling of Fourth Industrial Revolution technologies and ensure these are developed and applied in a way that takes into account climate and the environment, business incentives and citizen needs. Governments need to set transparent, adaptable and enforceable policies, regulations and standards.

- Innovative finance mechanisms: to align the incentives as well as the risks of private-sector delivery of city-level Fourth Industrial Revolution projects and support early-stage commercialization. Urban and national governments need to provide innovative PPP solutions, blended and risk finance, e.g. challenge funds and viability gap funding, to enable financing for the public good and technology development.
- Information and engagement platforms: to ensure collection, sharing and public availability of data, cities need to lead in setting up platforms for collaboration. Exemplified by subnational Open Government Partnership[38] members or the Smart Hong Kong plan.[39]
- Skills and retraining: to build digital awareness (and use) among citizens, as well as to counter the negative effects from automation on jobs. Urban and national governments must promote new Fourth Industrial Revolution skills and retraining with a sustainability lens.

## **Private-sector** (businesses, entrepreneurs, investors and funders)

- Leadership on responsible business: to ensure the Fourth Industrial Revolution is a sustainable revolution. The private-sector, in association with governments, needs to take the lead on improving its own operations by embedding sustainability principles into Fourth Industrial Revolution technology design and investment decisions. Firms are key parts of the city economy and affect the environment locally and internationally via supply chains, often in emerging markets.
- Urban innovation pilots: to solve the problems that matter for emerging cities, start-ups and big tech firms ought to invest in continued innovation, as well as devising pilots for specific cities to develop truly "smart" sustainable solutions.
- Co-creation and collaboration: to reach agreement and formulate the necessary governance for setting standards, sharing data and other areas of Fourth Industrial Revolution engagement. Locally, the private-sector needs to collaborate broadly with government entities, utilities and citizens.
- Innovation ecosystems: to capitalize on the creative energy already found in many cities and develop local solutions. Businesses and investors can play a big role in the creation of city-based innovation hubs, incubators and accelerators supporting them to foster technology in the public interest, including those with environmental applications.
- City investment portfolios: to build the momentum and funding available for promising, sustainable city-focused innovations. Accelerators, angel, venture capital and impact investors can build and support portfolios of Fourth Industrial Revolution technology companies for urban environmental solutions.

## **Civil society** (civil society and non-governmental organizations, academia, research organizations and citizens)

- Educational partnerships: to ensure vocational and university graduates are ready to enter the job market with practical tools integrating digital and sustainability. Academia, governments and the private-sector could partner in education for the Fourth Industrial Revolution.
- Community participation: to ensure urbanites benefit from the Fourth Industrial Revolution and that smart city designs are human-centred. Civil society groups and citizens should actively take part in local and national discussions on the form and direction of urban development in the Fourth Industrial Revolution.
- Community finance: to speed up innovation and investment in local communities. Civil society organizations and savings groups can develop business plans, carry out pre-feasibility studies and blend private-sector finance for local Fourth Industrial Revolution pilots.

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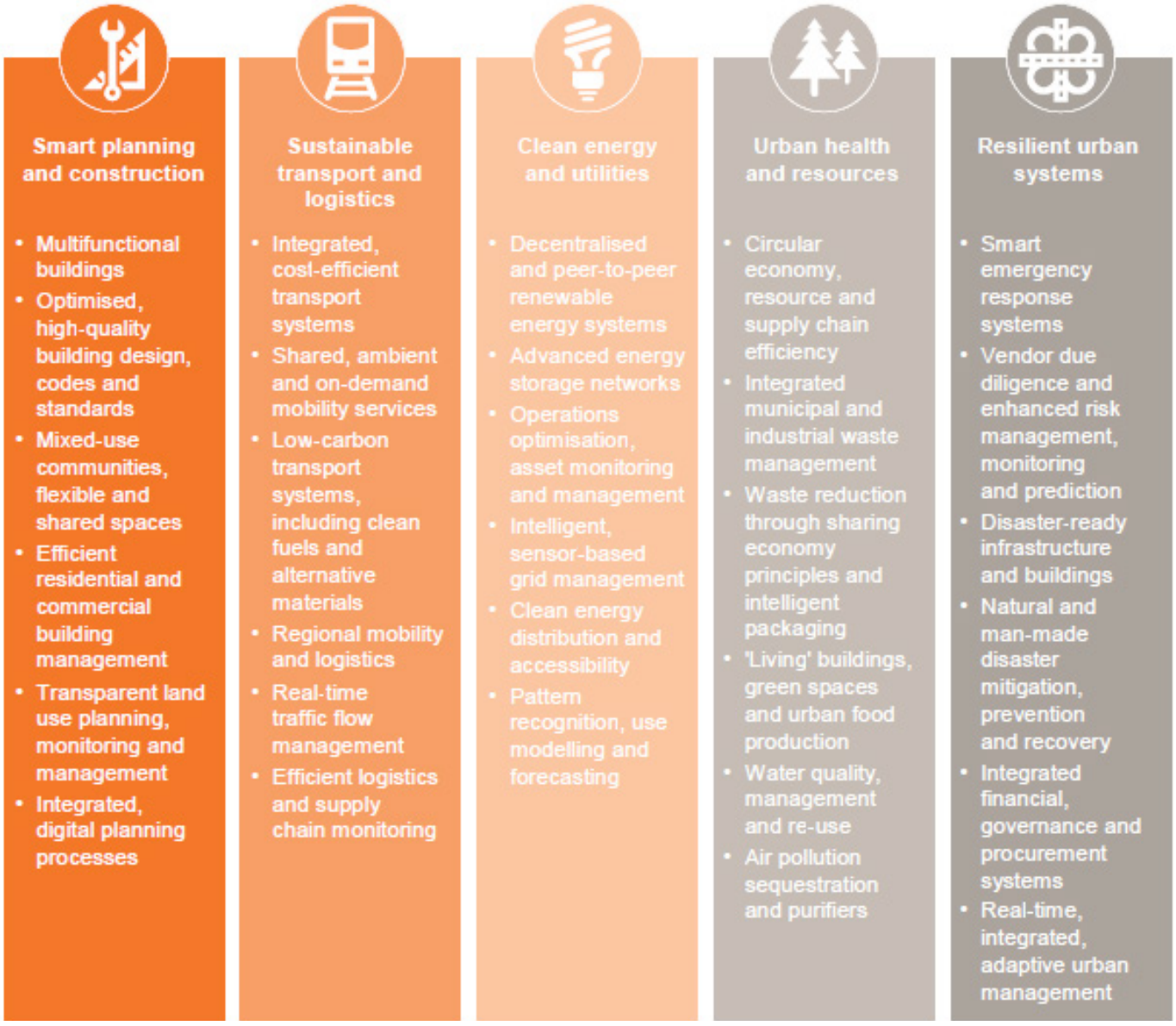
**About the Fourth Industrial Revolution for the Earth initiative**
The World Economic Forum is collaborating with PwC (as official project adviser) and the Stanford Woods Institute for the Environment on a major global initiative on the Fourth Industrial Revolution for the Earth. Working closely with leading issue experts and industry innovators convened through the World Economic Forum's Global Future Council on the Environment and Natural Resource Security, and with support from the MAVA Foundation, this initiative combines the platforms, networks and convening power of the World Economic Forum and its new Center for the Fourth Industrial Revolution in San Francisco. It also brings Stanford University's cutting edge research departments and connections with the Silicon Valley technology community together with the global insight and strategic analysis on business, investment and public-sector issues that PwC offers. Together with other interested stakeholders, this partnership is exploring how Fourth Industrial Revolution innovations could help drive a systems transformation across the environment and natural resource security agenda.

# Annex I

# Investment landscape overview of Fourth Industrial Revolution innovations and sustainability in emerging cities



# Annex II
# List and description of Fourth Industrial Revolution technology clusters most relevant for environmental applications

**Fourth Industrial Revolution technology clusters**

The following descriptions are provided as background and are not intended to be exhaustive.[40]

- **3D printing**. Additive manufacturing techniques used to create three-dimensional objects based on "printing" successive layers of materials.
- **Advanced materials** (including nanomaterials). A set of nanotechnologies and other material science technologies, which can produce materials with significantly improved or completely new functionality, including lighter weight, stronger, more conductive materials, higher electrical storage (e.g. nanomaterials, biological materials or hybrids).
- **Artificial intelligence**. Computer science learning algorithms capable of performing tasks that normally require human intelligence and beyond (e.g. visual perception, speech recognition and decision-making).
- **Robotics**. Electro-mechanical, biological and hybrid machines enabled by AI that automate, augment or assist human activities, autonomously or according to set instructions.
- **Drones & autonomous vehicles**. Enabled by robots, autonomous vehicles can operate and navigate with little or no human control. Drones fly or move in water without a pilot and can operate autonomously or be controlled remotely.
- **Biotechnologies**. Encompassing bioengineering, biomedical engineering, genomics, gene editing, and proteomics, biomimicry, and synthetic biology this technology set has applications in areas like energy, material, chemical, pharmaceutical, agricultural and medical industries.
- **Energy capture, storage, and transmission**. New energy technologies range from advanced battery technologies through to intelligent virtual grids, organic solar cells, spray-on solar, liquid biofuels for electricity generation and transport, and nuclear fusion.
- **Blockchain** (and distributed ledger). Distributed electronic ledger that uses cryptographic software algorithms to record and confirm immutable transactions and/or assets with reliability and anonymity. It has no central authority and allows for automated contracts that relate to those assets and transactions (smart contracts).
- **Geo-engineering**. Large-scale, deliberate interventions in the Earth's natural systems to, for example, shift rainfall patterns, create artificial sunshine or alter biospheres.
- **Internet of things**. A network of advanced sensors and actuators in land, air, oceans and space embedded with software, network connectivity and computer capability, which can collect and exchange data over the internet and enable automated solutions to multiple problem sets.
- **Neurotechnologies**. Technologies that enable humans to influence consciousness and thought through decoding what they are thinking in fine levels of detail through new chemicals that influence brains for enhanced functionality and enable interaction with the world in new ways.
- **New computing technologies**. This includes technologies such as quantum computing, DNA-based solid state hard drives and the combining of Third Industrial Revolution technologies (e.g. big data, cloud) with the other technologies (e.g. IoT, advanced sensor platforms). Quantum computers make direct use of quantum-mechanical phenomena such as entanglement to perform large-scale computation of a particular class of currently impossible tasks by traditional computing approaches.
- **Advanced sensor platforms** (including satellites). Advanced fixed and mobile physical, chemical and biological sensors for direct and indirect (remote sensing) of myriad environmental, natural resource and biological asset variables from fixed locations or in autonomous or semi-autonomous vehicles in land, machines, air, oceans and space.
- **Virtual, augmented and mixed reality**. Computer-generated simulation of a three-dimensional space overlaid to the physical world (AR) or a complete environment (VR).

# Annex III
# The Fourth Industrial Revolution for the Earth initiative

The Fourth Industrial Revolution for the Earth initiative is designed to raise awareness and accelerate progress across this agenda for the benefit of society. In the first phase of the project, specific environmental focus areas will be considered in depth, exploring in detail how to harness Fourth Industrial Revolution innovations to better manage the world's most pressing environmental challenges. Initial focus areas will include:

- Air pollution
- Biodiversity
- Cities
- Climate change and greenhouse gas monitoring
- Food systems
- Oceans
- Water resources and sanitation

Working from these thematic areas the Forum, supported by Stanford University and PwC (as project adviser), and advised by the members of the Global Future Councils on the Future of Environment and Natural Resource Security and specific Fourth Industrial Revolution clusters, will seek to leverage their various networks and platforms to:

- **Develop a set of insight papers,** taking a deep dive into the possibilities of the Fourth Industrial Revolution and each of these issues.
- **Build new networks of practitioners** and support them to co-design and innovate for action on the environment in each of these issue areas, leveraging the latest technologies and research that the Fourth Industrial Revolution offers.
- Design a **public-private accelerator for action**, enabling both government, foundational, research, organization and commercial funds to be pooled and deployed into scaling innovative Fourth Industrial Revolution solutions for the environment.
- Help government stakeholders to **develop and trial the requisite policy protocols** that will help Fourth Industrial Revolution solutions for the environment take hold and develop.

The Fourth Industrial Revolution for the Earth initiative will be driven jointly out of the World Economic Forum Center for the Fourth Industrial Revolution in San Francisco and other Forum offices in New York, Geneva and Beijing.

# Endnotes


[1] UN, 2015, World Urbanization Prospects: The 2014 Revision, available at: https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf

[2] World Health Organisation, 2017, WHO Global Urban Ambient Air Pollution Database (update 2016), available at: http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

[3] Bourdic, L., Salat, S. and Nowacki, C., Assessing cities: a new system of cross-scale spatial indicators. Building Research & Information. 40(5). 592-605. 2012, available at: http://dx.doi.org/10.1080/09613218.2012.703488.

[4] The New Climate Economy, Release: urban sprawl costs US economy more than $1 trillion per year, March 2015, available at: http://newclimateeconomy.net/content/release-urban-sprawl-costs-us-economy-more-1-trillion-year

[5] UN-Habitat, 2016, World Cities Report 2016, available at http://wcr.unhabitat.org/

[6] Kramer, Arnoldo Matus, Mexico, 2017, available at: http://www.100resilientcities.org/strategies/mexico-city/

[7] U.S. Energy Information Administration, International Energy Outlook 2016, May 2016, available at: https://www.eia.gov/outlooks/ieo/buildings.php

[8] UN-Habitat, 2011, Hot Cities: Battle-Ground for Climate Change, available at: http://mirror.unhabitat.org/downloads/docs/E_Hot_Cities.pdf

[9] Central Electricity Authority of India, 2016, Draft National Electricity Plan, available at: http://www.cea.nic.in/reports/committee/nep/nep_dec.pdf

[10] Energy Intelligence, REIPPP: All you need to know, March 2016, available at: http://www.energyintelligence.co.za/reippp-all-you-need-to-know/

[11] World Economic Forum, Top Ten Urban Innovations, October 2015, available at: http://www3.weforum.org/docs/Top_10_Emerging_Urban_Innovations_report_2010_20.10.pdf

[12] The New Climate Economy, Economic growth and climate change, August 2014, available at: http://newclimateeconomy.report/2014/overview/

[13] Changing Markets, Running on Empty, April 2016, available at: http://www.actionaid.org/sites/files/actionaid/running_on_empty_-_water_efficiency_report.pdf

[14] The New Climate Economy, Better Growth Better Climate, August 2014, available at: http://newclimateeconomy.report/2014/wp-content/uploads/sites/2/2014/08/NCE-cities-web.pdf

[15] Revi, Aromar et al, Climate Change 2014: Impacts, Adaptation, and Vulnerability, October 2013, available at: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap8_FINAL.pdf

[16] OECD, Future Flood Losses in Major Coastal Cities, August 2013, available at: http://www.oecd.org/newsroom/future-flood-losses-in-major-coastal-cities.htm

[17] Orcut, M., 2017, Business Impact Insurers Scramble to Put a Price on a Cyber Catastrophe, MIT Technology Review, available at: https://www.technologyreview.com/s/603937/insurers-scramble-to-put-a-price-on-a-cyber-catastrophe/

[18] http://www.re-thinkingthefuture.com/rtfa2017-residence-concept/lagoss-wooden-tower-hka-hermann-kamte-associates/

[19] Sidewalk Labs, October 2017, available at: https://sidewalktoronto.ca/wp-content/uploads/2017/10/Sidewalk-Labs-Vision-Sections-of-RFP-Submission.pdf

[20] Allison, I., 2017, Blockchain-based Ubitquity pilots with Brazil's land records bureau, International Business Times, available at: http://www.ibtimes.co.uk/blockchain-based-ubitquity-pilots-brazils-land-records-bureau-1615518

[21] Avalon Life, 2017, available at: https://bitcoinist.com/avalon-life-puts-land-ownership-blockchain-launches-green-earth-zero-service-nem-technology/

[22] https://www.whereismytransport.com/

[23] https://www.ninjavan.co/

[24] https://wattcoin.com/

[25] https://thesunexchange.com/

[26] Al-Tabbaa, A., December 2016, The concrete that heals its own cracks, https://www.weforum.org/agenda/2016/01/the-concrete-that-heals-its-own-cracks/

[27] http://www.igotgarbage.com/

[28] http://www.terreform.org/projects_urbanity_rapid_refuse.html

[29] OECD, February 2017, Embracing Innovation in Government: Global Trends – Case Study PetaBencana.id, available at: https://www.oecd.org/gov/innovative-government/embracing-innovation-in-government-indonesia.pdf

[30] http://www.flextegrity.com/

[31] https://www.eonreality.com/portfolio-items/virtual-disaster-preparedness/

[32] Yakowicz, W., September 2017, Drone Companies Are Doing More Storm Damage Assessment in the Wake of Hurricanes Harvey and Irma, available at: https://www.inc.com/will-yakowicz/storm-damage-irma-harvey-drones.html

[33] Coffey, H., August 2017, China Announces Plans for 'Flying Train' that can Travel up to 2,500mph, available at: http://www.independent.co.uk/travel/news-and-advice/china-flying-train-2500mph-aerospace-science-and-technology-corporation-elon-musk-hyperloop-a7921541.html

[34] Chen, S., June 2017, Chinese Satellite Relays a Quantum Signal Between Cities, Wired, available at: https://www.wired.com/story/chinese-satellite-relays-a-quantum-signal-between-cities/

[35] Vidal, John, Geoengineering side effects could be potentially disastrous, research shows, February 2014, available at: https://www.theguardian.com/environment/2014/feb/25/geoengineering-side-effects-potentially-disastrous-scientists

[36] PwC, The Future is Coming: Index of Cities' Readiness, July 2017, available at: https://www.pwc.ru/ru/assets/the-future-is-coming-english.pdf

[37] PwC and World Economic Forum, Inspiring Future Cities & Urban Services, April 2016, available at: https://www.pwc.com/gx/en/industries/government-public-services/public-sector-research-centre/publications/assets/pwc-wef-urban-services.pdf

[38] Open Government Partnership, What's in the OGP Subnational Action Plans (2017), June 2017, available at:

[39] https://www.smartcity.gov.hk/

[40] Descriptions are provided in the context of the Fourth Industrial Revolution for the Earth initiative and were compiled by project partners from commonly available sources.

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