GSMA

IoT Guide: Connected Environment

January 2024

Contents

01 Introduction

Introduction

The advent of the Internet of Things (IoT) has ushered in a transformative era in addressing critical aspects of environmental sustainability. This report delves into the extensive number of applications of IoT technologies across three pivotal domains – air, water, and food – each of which sit at the apex of Maslow's hierarchy of human need as the most critical things required for human life.

Beginning with air, IoT plays a crucial role in monitoring and managing air quality, essential for sustaining human life. From urban centres grappling with pollution to intelligent road traffic management and efficient public transport systems, IoT applications offer innovative solutions to mitigate environmental risks and enhance the overall well-being of communities.

In the realm of water, the deployment of smart meters, more carefully managed water distribution networks, and advanced irrigation systems are instrumental in optimizing water usage. This not only addresses the pressing issue of water scarcity but also recognizing the significance of water as a basic human necessity for survival and health.

The report extends its focus to food, encompassing diverse applications such as crop and livestock management, drone-assisted farming, and the optimization of food supply chains through IoT technologies.

By exploring the myriad applications of IoT in these critical domains, this report aims to underscore the pivotal role of technological innovation in addressing the most elemental requirements for human existence and environmental sustainability.

This report draws extensively on Transforma Insights' research on IoT use cases and their sustainability impact.

Matt Hatton - Founding Partner, Transforma Insights

02 Air

Air

According to the World Health Organization (WHO), ambient air pollution in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide per year in 2019. At the same time, illness, premature deaths, and the weakening of ecosystems, crops, and habitats caused by industrial pollution also has a significant impact on the world's economy. Major pollutants including Particulate Matter (PM), Carbon Monoxide (CO), Ozone (O_3), Nitrogen Dioxide (NO_2), and Sulphur Dioxide (SO_2) lead to fatal conditions suhc as ischaemic heart disease and stroke, chronic obstructive pulmonary disease, acute lower respiratory infections respectively, and cancer within the respiratory tract. There are several IoT use cases that can substantially help with monitoring and managing the volume of air pollution.

2.1

Air quality monitoring

IoT is extensively used for environmental monitoring, including sensors that are capable of monitoring temperature, humidity, NH_3, CO, CO_2, NO, NO_2, O_3, SO_2, volatile organic compounds (VOCs), various types of particulate matter (generally PM10 and PM2.5, consisting of particles less than 10 micrometres and 2.5 micrometres respectively) and other pollutants present in both water and air.

Environment monitoring devices can guide authorities and businesses (for instance, construction businesses) to take appropriate actions to lower pollution levels by helping users to identify pollutant sources and track historical data and trends. They can help automate the process of managing emissions by initiating various purification mechanisms when air pollutants exceed certain thresholds and notify authorities of any increase in emission levels.

Failing to comply with regulations can cost companies millions of dollars in civil penalties. For instance, in the US, Chevron Phillips Chemical Company had to spend USD118 million to upgrade and implement compliance mechanisms for violating the Clean Air Act by exceeding limits for the emission of VOCs. As part of this process, the company was required to install air quality monitoring devices at its facilities to monitor hazardous emissions.

The installation of smart environment monitoring devices offers many advantages when compared to conventional methods. Traditional monitoring systems often require manual readings, resulting in emissions often not being reported in a timely manner, making them inefficient and unreliable for companies and governments. Additionally, manual monitoring approaches tend to be labour-intensive, which makes it expensive for the stakeholders to gain real-time insights into the pollution status of locations such as industrial facilities. It is also polluting in itself, due to the associated manpower and travel requirements.

As an example, Yacimientos Petrolíferos Fiscales (YPF) installed multiple air monitoring stations in its refinery sites in Argentina. YRF was facing challenges with its pollutant monitoring at its refinery sites. In addition to this, the company was

also facing the local anger for neglecting the refinery's negative impact on air quality.
As a result of pressure from the government and the community, the company installed six air quality monitoring stations to measure ozone, carbon monoxide, nitrogen dioxide, sulphur dioxide, hydrogen sulphide, VOCs, PM10, and wind speed and direction. It then furnished real-time data on air quality via wireless medium to a publicly available website. Instant notifications are also displayed on operators' mobile phones whenever hazardous gases or particulate matter pollution cross the pre-defined levels.

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2.2

Road traffic management

One way to improve air quality is through more effective road traffic management. Increasingly, urban areas are turning to smart traffic management systems, including traffic monitoring, smart parking, and road tolling systems, together with corresponding control systems to mitigate traffic congestion problems. Additionally, many cities are introducing limits on the most polluting vehicles, such as the 'Ultra Low Emission Zone' deployed in London. These types of deployments also require systems such as automatic number plate recognition (ANPR).

According to the World Bank, globally, urban populations will grow from around 56% of the world's population currently to 70% in 2050. This has the potential to further intensify traffic congestion, generating additional greenhouse gases as well as localised pollution.

Idling in traffic congestion and at traffic signals leads to both productivity loss and unnecessary CO_2 emissions. As discussed in Transforma Insights recent 'Sustainability Enabled by Digital Transformation' report, road traffic management solutions can improve the efficiency with which vehicles traverse a city, often using AI. This can decrease fuel consumption while vehicles are idling at traffic signals by 40%, with an average overall reduction of fuel consumption, and therefore pollution, of 2%.

Drivers in urban areas can spend a lot of time looking for parking spaces, which leads to high congestion, more time spent driving vehicles, and more emissions. Looking for a parking space is sometimes reported to be responsible for almost 30% of all traffic congestion in urban areas and is estimated to be responsible for the emission of 28 million tonnes of CO_2 every year. Smart parking solutions are being introduced to address many problems associated with traditional parking. These solutions help drivers identify the nearest vacant parking space by deploying sensors throughout a designated area, or by deploying AI-enabled CCTV-based solutions to support similar monitoring.

With the initial goal of reducing the overall CO_2 emissions by efficiently using parking spaces, the city of Cologne adopted a smart parking guidance system, increasing the adoption and willingness to pay for the services by the citizens. The district of Nippes was equipped with overhead sensors to help provide information about the available and occupied parking slots, which were displayed directly on-site at 27 central intersections. This system has been active since June 2020. In 2021, the system was augmented with a dedicated mobile app called ParkPilot Cologne. This helped in providing information about the availability of parking spaces and e-charging terminals.

Smart tolling systems and road pricing schemes, both of which can act to reduce pollution, often use ANPR cameras to set, administer, and enforce a better-targeted payment structure when vehicles enter a relevant area. Camera-based schemes offer significant advantages over traditional systems which usually rely on the use of toll booths.

2.3

Public transport and integrated transport systems

Smart Public Transport includes a range of applications that monitor public and shared transportation and potentially optimise these in real time. This includes tracking and monitoring of buses, bikes, and scooters through an integrated public transportation schemes (including bus, metro, trains, shared bikes). Shared mobility is particularly important in the shift towards a low-carbon economy as 25% of energy related emissions come from transport.

Private cars cause 50% of the transport sector's greenhouse gas emissions, so making people shift from private transport to public transport is key to reducing pollution. Buses play a major role in this, since a typical full single deck bus equates to 40 cars off the road, while a double deck bus equates to 75. Real time route planning software can make sure that buses are not running empty or unnecessarily, while passenger counting solutions can support route optimisation. Furthermore, sensor devices attached to buses that capture air pollutants data support in city planning decisions and air quality improvement initiatives. utility, particularly for purposes of load balancing (see 'Load Balancing' section, below).

As an example, Baghirathi Transport Solutions provides transportation services to schools and businesses in India. To improve the operational efficiency of its fleet, it turned to Vodafone to provide IoT connectivity so it could track, monitor and geo-fence around 200 of its vehicles. As a result of deployment, it increased efficiency and frequency of services improving customer satisfaction. The company witnessed reduction in fuel and maintenance costs and enhanced its ability to direct vehicles towards approved routes more easily.

Another major initiative to reduce car usage is Bike and Scooter sharing schemes that have become quite prevalent in many cities in recent years. According to the Institute of Transportation & Development Policy (ITDP), if the mode share for e-bikes rises to 11%, a reduction of 7% in carbon emissions is expected from the urban transport sector by 2030, equivalent to a claimed 134 million cars off the road. To use one specific example, the city of Washington D.C. has 5,000 bikes in circulation. Transforma Insights estimates that this could save 139,815 kgs or 140 tonnes of carbon emissions in Washington D.C. in a year.

Beyond the individual benefits of the monitoring and management of public transport assets, Integrated Transport Systems (ITS) support multiple modes of transportation from a unified platform by combining mass transit, carsharing, bike sharing, and taxi services using a single interface. By so doing, they aim to reduce dependence on cars and increase use of less polluting forms of transport.

2.4

Using IoT to reduce CO_2 emissions in other sectors

As well as the examples quoted above, any IoT application that seeks to reduce the consumption of fuel has a knock-on effect on improving air quality. These include:

Road Fleet Management – Telematics devices retrieve information related to driver behaviour, location, and fuel consumption. Driver behaviour analysis examines harsh braking, speeding, acceleration, and over-idling, with the aim to reduce fuel costs, and pollution, as drivers then tend to drive more economically. After adopting fleet telematics, companies typically experience fuel savings, and therefore pollution reduction, of about 15%. Sub-applications such as tyre pressure monitoring can also be critical: an under-inflated tyre having pressure below 40% can result in an increase in fuel consumption by 8%.

Supply Chain – In addition to road transport, the wider use of IoT across the supply chain can significantly improve its efficiency and therefore reduce the environmental impact of products. Supply chain includes areas such as sourcing, production, packaging, distribution management, warehousing, inventory management, return, and disposal. All parts of supply chain have potential to produce waste and harmful emissions but also offer the opportunity for improvement through IoT. Apart from the carbon savings achieved by reduced electricity and fuel used there is also a positive effect on directly reducing pollution by reducing waste, particularly food waste. 1 kg of edible food wasted releases 2.5 kg equivalent of carbon dioxide (CO_2), and when this adds to landfill it generates methane. 6-8% of emissions can be cut down by reducing food wastage

Smart Buildings – Buildings account for nearly one-third of global energy consumption and 55% of global electricity demand. According to the International Energy Agency (IEA), digitalisation of buildings (including smart thermostats, controllers, smart lighting) could cut total energy use in residential and commercial buildings between 2017 and 2040 by as much as 10%. This topic is examined in detail in the IoT Guide to Connected Energy.

Smart Grid – Smart meters and smart grids are an integral part of a country's energy system, which is central to reducing carbon emissions and reliance on unsustainable energy sources. A smarter grid, with more balanced demand and supply constitutes the main mechanism to deliver low carbon electricity more efficiently and thereby reducing environmental impact. This topic is covered in detail in the IoT Guide to Connected Energy.

Healthcare – The health sector is responsible for a significant portion of a country's carbon footprint owing to the intensive nature of its work and 24/7 operating hours. Healthcare is estimated to account for 4.5% of the world's carbon footprint. Major contributors to emissions are building energy, travel (patient, staff, visitor travel) and medical equipment and gases. The use of IoT for remote monitoring, asset monitoring and more efficient operations creates a big opportunity to reduce pollution. The American Telemedicine Association and University of California in 2017 studied found out home treatment, rather than as an in patient, saved 5 million miles of travel (by patients and clinicians) over 18 years, removing nearly 2,000 metric tons of CO_2, 50 metric tons of CO, 3.7 metric tons of nitrogen oxides and 5.5 metric tons of volatile organic compounds. IoT solutions can also improve the efficiency with which patients are treated in hospitals. What's even more apparent is that focusing on disease prevention and chronic disease management can reduce emergency admissions which results in lowering environmental impacts. According to the UK's NHS, the carbon footprint of an average general physician appointment is 6kg CO_2e (which jumps to 18kg if the physician makes a prescription), and each elective inpatient stay is estimated at 708kg CO_2e (not including patient, visitor, and staff travel).

03 Water

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Water

In 2016 the United Nations Environment Programme (UNEP) estimated that nearly half of the world's population would be suffering the effects of extreme water stress in 2030, and demand for water would exceed supply by 40%. Water losses can also be considerable, even in developed countries; Brazil lost 39.2% of its treated water in 2019, compared to 14% in the US, and 23% in the UK in 2020. Water loss leads to contamination risk i.e. when the water pressure drops due to a leak, there's a possibility that contaminants in the ground can enter the pipe and travel through the pipe network. Contaminants can include bacteria and viruses, making the water unsafe for consumption. IoT solutions are being widely used to monitoring distribution and consumption of this scarce resource.

3.1

Water smart meters

Water loss is a significant issue in many countries. According to the US Environment Protection Agency (EPA), household leaks waste 4 trillion litres of water annually in the United States. Nearly 10% of homes have leaks that waste 400 litres or more per day in the US. The most common types of leaks found in the home are dripping taps, worn toilet valves, showerheads and outdoor leaks.

Detecting water leakage or loss is one of the key water saving measures for a utility. Smart water meters are equipped with sensors for leakage detection based on the water flow rate at any given point of time. This in turn helps the local utility track the water consumption per user and detect any losses or changes in the level of consumption. These meters are also able to detect unexpected drops in pressure within the water grid, allowing for the identification of leaks before the metering point. A study by Telefonica Tech in 2022 estimated that since the deployment of smart meters, water leaks have been reduced by 40% through quick detection, and operation and maintenance costs could fall by 20%. The firm also estimates that customer satisfaction rates are 60% higher with connected meters when compared to traditional meters. Smart water meters benefits are not only limited to reducing losses but also make consumers more aware of their habits, encouraging them to reduce their consumption of water. For instance, A research study by Sydney Water in Australia has demonstrated a 6% decline in the water use over a period of two years in residential areas with the deployment of smart water meters. Just like leaks, poor usage habits

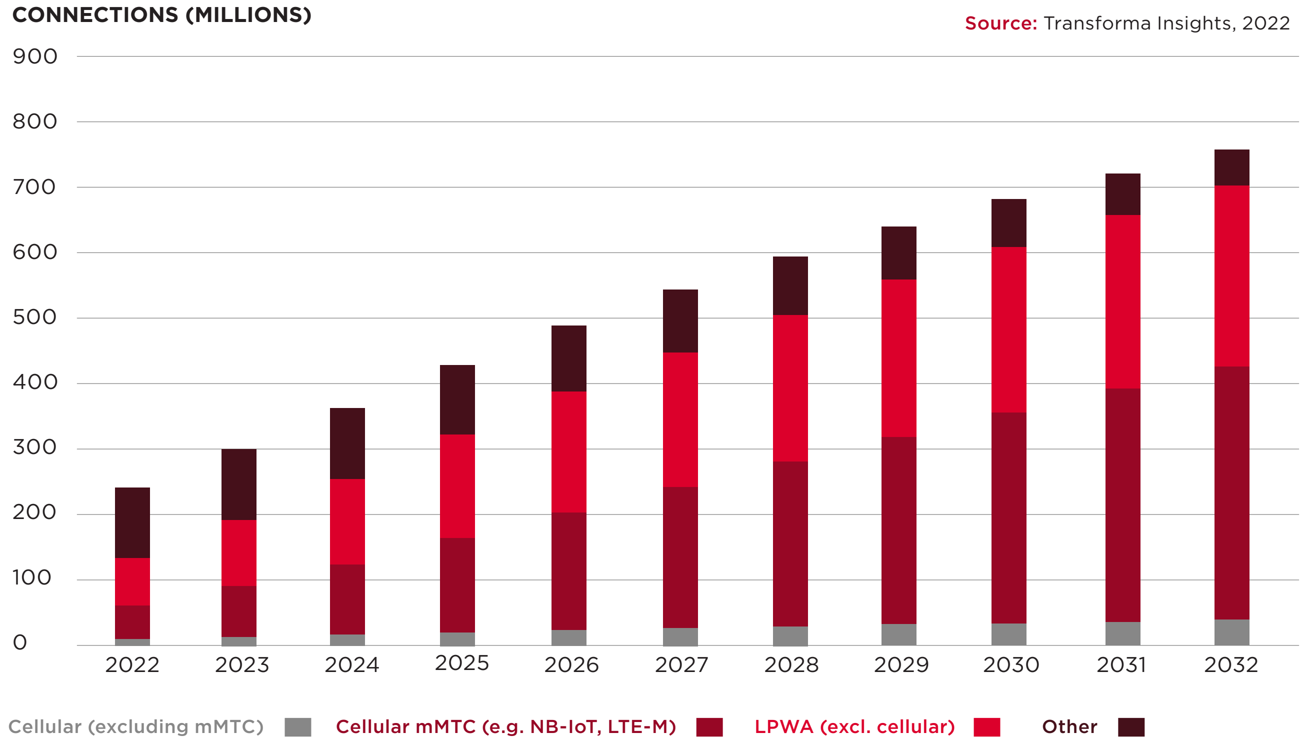
Smart Meter deployment

40% ↓↓
Reduction in leaks

20% ↓↓
Lower maintenance costs

Figure 1

Global smart water meters 2022-32



have a substantial impact on overall loss, and it's in the water utilities interest to influence consumer behaviour and provide customers with the necessary tools to use water more efficiently.

According to Transforma Insights, by 2032 there will be over 760 million smart water meters deployed globally, of which around 90% will be residential and 10% businesses.

Smart water meters have witnessed significant demand in regions such as the Middle East and Africa that face water crisis either due to climatic conditions (including erratic weather patterns) or countries that have a higher population density. Many countries or regions are implementing legislation to require that smart water meters are deployed. California state law, for instance, requires that smart water meters be deployed in all cities by 2025; San Francisco has spent USD60 million to install 178,000 smart water meters. There are hundreds of examples of smart water meter deployments worldwide. For instance, Gandia City, Spain, has over 200,000 inhabitants during the summer with increased tourism, and faces issues related to water scarcity and leakage. The local utility company focused on transforming its water networks by deploying new smart meters using NB-IoT provided by Vodafone Spain. These smart meters would directly send data through to a data analytics platform to which all consumption information is uploaded and integrated. Using the technology, the firm has detected 700 leaks and saved over 300,000 m3 of water per year.

3.2

Water distribution network

As well as home losses many water utilities are focused on careful management of the distribution network. 'Non-revenue water' (NRW), or water lost through the distribution network, creates a significant cost for many water utilities. In 2018, it was estimated that NRW costs governments and utilities approximately USD39 billion annually, much of which was in developing countries.

Smart water grids are useful in leak detection and monitoring the quality of water. These grids monitor the physical infrastructure through sensors, capturing information such as volume, pressure, temperature, chemicals, leak detection, and supply levels. Data management software can then be used to analyse the water flow pattern, enabling predictive modelling and decision making, enabling better assessment of energy use, leaking assets, water supply, pricing, capex, and labour. Further efficiencies can be gained through improved fault detection, where issues can be detected quickly or pre-empted with predictive maintenance.

This reduces maintenance costs and improves the reliability of service for end users. Smart Grids are also useful in case of a catastrophe, such as floods and droughts by dynamically adapting water distribution.

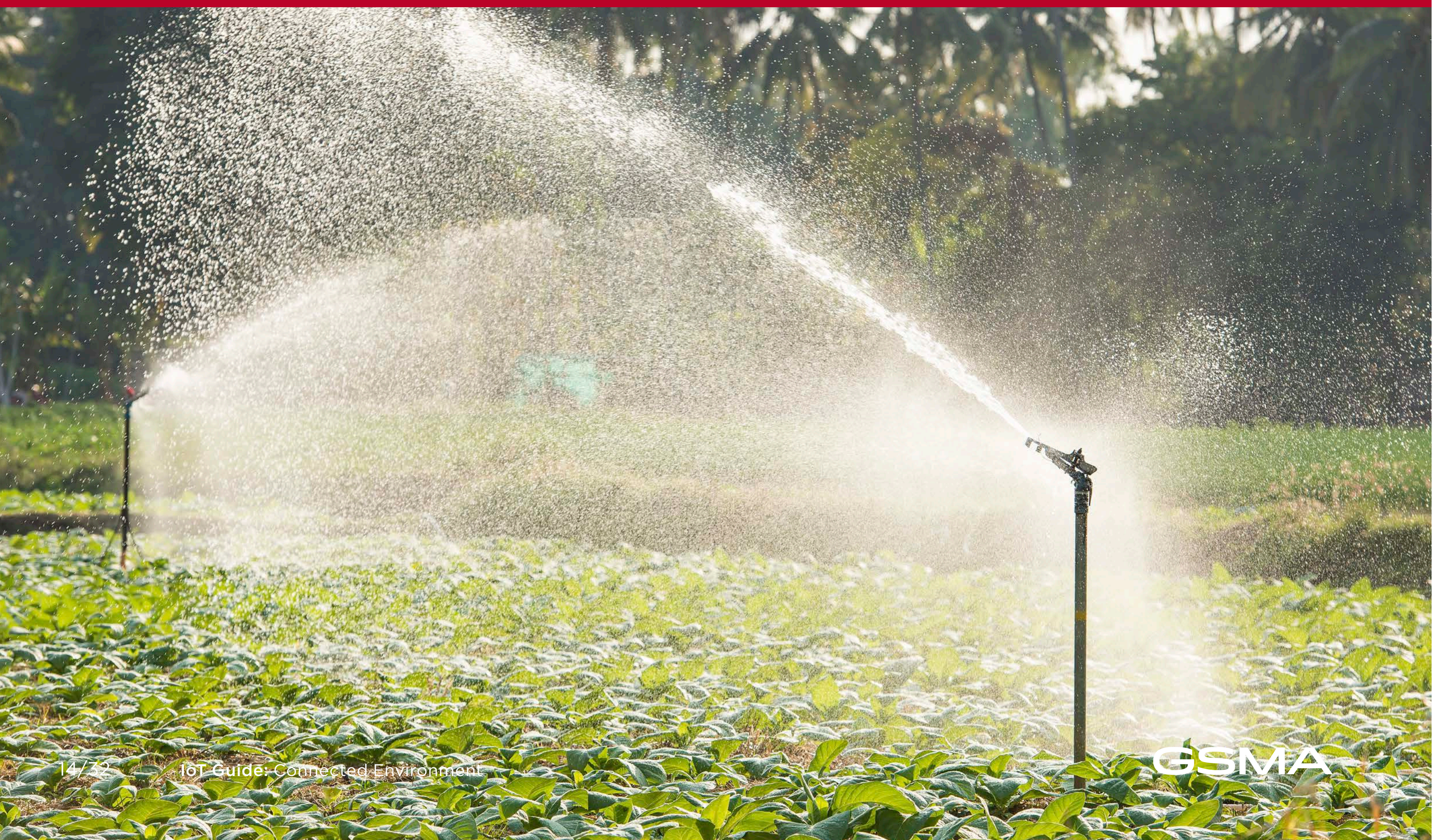
As an example, Australian regions such as Wivenhoe, Somerset, and North Pine face significant drought issues, having seen the combined water level drop to less than 17% capacity during the period 2007-2008. Since then, the SEQ water grid uses bi-directional water pipelines to change the course of the water according to need, along with the introduction of purified recycled water to the system at several points. After the deployment of a smart water grid, SEQ's rainfall dependency dropped from 95% to 75% in four years. The water grid includes: 12 connected dams, ten connected drinking water treatment plants, three advanced water treatment plants (purified recycled water), a desalination plant, 28 water reservoirs, and 22 bulk water pumping stations. With the deployment of the grid, there has been greater ease in moving treated drinking water around the three regions.

3.3

Irrigation systems

Water scarcity has long been a concern for farmers in many areas around the world. Around 50% of water used in irrigation is wasted due to evaporation and runoff caused by inefficient irrigation techniques. This not only causes water wastage, but the excess runoff water often seeps into the ground causing waterlogging, salinity imbalances, and transporting nutrients, pesticides and heavy metals leading to incidents of water-borne diseases, in some situations resulting in human suffering and health cost. Using the exact amount of water also prevents fertilizer overuse and leaching, which is one of the most widespread problems in the US. IoT-controlled irrigation systems have the potential to save this water wastage by 20-40%. In pilot tests run by the International Center for Water Technology, smart irrigation controllers saved 20% more water than traditional irrigation controllers.

One example of smart water irrigation system is KisanRaja, a motor-controller device that allows farmers to operate their water pumps using a smartphone. Over 30,000 farmers in India have adopted KisanRaja. The water pumps are cellular-enabled. To control the pump, the farmer sends an SMS or calls the mobile number of the SIM inserted in the device. Farmers receive voice alerts in case of faulty power supply, motors not starting, lack of water in a connected well, and on any attempt of motor or device theft. There are other sensors that can be connected to make the process more efficient which include soil sensors and weather sensors. For example, based on weather forecasts, KisanRaja alerts the farmer to not irrigate their fields when rain is predicted. The solution has helped farmers save time and fuel used in irrigating the fields. It has also reduced repair costs as it reduces the damages that can occur in failure states (for instance, when the pump is kept running in absence of groundwater). In West Bengal, the technology has helped farmers reduce water usage by 18 to 25%.



A more sophisticated system for water management can be created by monitoring water sources (such as tanks and reservoirs) for better coordination between water source, pumps and irrigation activities. For example, Farmbot, in collaboration with Inmarsat and Pivotel (an Australian supplier of satellite services), is deploying satellite-controlled pumps, enabling farmers to remotely control pumped water supplies, tanks and reservoirs in real time leading to better coordination between tank levels and water sources and a reduction in unnecessary travel associated with checking water storage and operation.

Satellite-controlled pumps, enable farmers to remotely control pumped water supplies, tanks and reservoirs in real time.

04 Food

Food

The Agriculture industry is facing an uphill task of feeding a growing global population at the same time as marshalling depleting resources, most notably water. To meet increasing food demand, the industry as a whole needs to increase production by 70%, compared with 2009, to feed over 10 billion people by 2050. Throughout the food supply chain, across the proverbial 'farm-to-fork', there are numerous ways in which IoT is being deployed to optimise food production, distribution and storage.

4.1

Crop management

Crop Management refers to monitoring of crop conditions via in-field sensors to monitor soil, crops, and plants by collecting data such as temperature, moisture, salinity and fertility. They can also detect weed growth, water levels and pest/animal invasion. Data collected can be used to recommend doses of fertiliser, targeted irrigation and early identification of diseases or substandard conditions.

The most common way to monitor soil is through wirelessly connected soil sensors that transfer data related to moisture, salinity and irrigation pressure to enable farmers to make better irrigation decisions resulting in increased yield. The overall benefits of Crop Management are much more than reduction of water usage; it also minimises site-specific applications of inputs (such as fertilizers, nitrogen and pesticides). Fertilizer usage is critical for improvement of soil yield, but excessive fertilisation can degrade land health. The EU's LIFE GAIA Sense project estimates that smart farming practices can result in energy reduction of up to 25%, reduced nitrogen use of up to 30%, reduced pesticide usage of between 11 and 25%, and 25% lower water consumption. These technologies can reduce production costs by around 15% on average while increasing yields by 15-20%.

Château Kefraya is a winery with 300 hectares of vineyards in Beqaa Valley, Lebanon. It deployed a Libelium sensor network to monitor soil and climate data to better understand their impact on grape production. The sensors measure, for example, altitude, soil temperature, atmospheric pressure, humidity, air temperature, solar radiation and luminosity. Data is transmitted locally via LoRaWAN to Actility's cloud platform via 3G enabled remote monitoring and data analytics. The result was production of higher quality wine.

Smart Farming

15-20% ↑↑

Increase in crop yields

15% ↓↓

reduction of production costs

4.2

Livestock management

Livestock is one of the fastest growing sub-sectors of agriculture, contributing around 40% of the global value of agricultural output and supporting livelihoods of almost 1.3 billion people around the world. Along with the growing demand for livestock products, concerns about greenhouse emissions, limited land and water resources, and limited labour are also growing. About 50-60% of the operating costs in dairy farming are due to animal feeding and related labour activity. By automating specific processes, such as feeding schedules and water distribution, farmers reduce the time and money spent on these tasks significantly while ensuring that their animals are properly cared for. Livestock Management uses IoT for automated real-time monitoring of livestock health and welfare, location, production/ reproduction status and environmental impacts on livestock.

One example of livestock management is Dairy Dreams, which partnered with Nedap to track and monitor the activities of the cows at its farm. Dairy Dreams has 3,000 cows at the farm that are milked three times a day in a milking parlour. The farm now uses Alta Cow WATCH smart tags, powered by Nedap technology to continuously monitor their eating, rumination, and inactive behaviour. Using the monitoring solutions, Dairy Dreams was able to increase the pregnancy rate from 60% to 70%, increase the service rate by 8-10%, and achieve 100% palpated pregnancy rate among heifers (cows that have never had a calf).

4.3

Vertical farming and greenhousing

The use of IoT in indoor farming, including vertical farming and greenhouses, is similar to outdoor uses, but the environment is more closely controllable as the temperature, air humidity and lighting can be adjusted rather than just monitored. Crop growers to maintain optimal growing environments by adjusting HVAC, lighting, irrigation, chemical spraying and other activities.

An interesting case to depict the importance of IoT in greenhouses is the Getlini EKO greenhouse case. The greenhouse was not able to meet yield expectations because operators weren't able to find the right balance between temperature and air humidity for plants' transpiration. By deploying Aranet's IoT solution, they had more visibility into plant behaviour, which helped them identify the ideal time for lighting, irrigation and fertilisation, increasing their yield by 18% during the first two years.

Indoor vertical farms give even more control to a producer, as most of the indoor farms now use artificial lighting, aeroponic and hydroponic technologies to grow plants. These farms heavily depend on the use of AI, IoT and robotic process automation for operation. For example, AI-based lighting systems can adjust lighting based on plant conditions, as plants require different light intensities at different growth stage. AeroFarms, one of the leading indoor farming companies, in collaboration with Nokia Bell Labs private 5G, is using custom light algorithms for each plant to give them the exact intensity, frequency and spectrum required for photosynthesis.

4.4

Drone farming

Drones are bringing about big changes in agriculture by improving the efficiency of a range of different agricultural operations. They are being used for crop monitoring, soil analysis, planting, soil and field analysis, irrigation, fertilizer and chemical spraying, and livestock monitoring amongst other activities. As such, this use case overlaps with a number of the other application areas discussed in this document. For instance, airborne drones can be used to collect information that can be incorporated into crop management.

The benefits to farmers include less labour effort, higher productivity and more efficient use of resources including water, chemicals, fertilizers and land. Drones have the potential to improve crop yield, increase efficiency and reduce costs by reducing manual labour and costs of water and fertilizers. For instance, a Basque winemaker used drone data to maximise its yield and increased the production of his vineyards from 65,000 bottles (the previous harvest) to 76,000, a 17% increase. Drones have an additional impact on yield as they maximise the utilisation of land through optimised seed placement and mapping. The American Farm Bureau Federation estimates that farmers in the US can save around USD1.3 billion every year by using drones in their operations. It is estimated that in India, drone led farming can reduce input costs by 18-20% while enhancing yield by 30-100%.

4.5 Farm automation and robotics

One of the most significant challenges the agriculture industry faces today is the shortage of skilled labour to perform time-sensitive tasks. Automation offers a reliable and productive solution to alleviate the labour shortage challenge by automating repetitive labour-intensive tasks.

Farm Automation and Robots includes a range of technologies used to automate repetitive labour-intensive tasks performed by farmers in the field. This solution area particularly focuses on smart agriculture vehicles and autonomous/semi-autonomous robots replacing manual labour work such as harvesting, seeding and weeding.

Harvesting and weed control use AI and computer vision to locate and pluck out weeds accurately during weeding and identify and pick quality produce during harvesting. This harvesting is still an emerging area and most of the companies (such a Ripe Robotics and KUKA CropBot) are doing early commercial trials with plans to expand in the upcoming years.

Similar to other applications, using farm automation and robots farmers can reduce operational costs and increase yields while promoting sustainable farming practices. Robots can bring down the harvesting cost by 20-25% , resulting in 12%-18% reduction in total production costs, and increase the yield. Robotic harvesters are more efficient than human labour. In the case of weeding, it is estimated that weeding constitutes about 16% of the total cost of cultivation and weed control robots can reduce annual weed control costs by 50-80%, bringing down total cost of cultivation by 8-13%.

4.6 Produce monitoring

Produce Monitoring includes technologies used in post-harvesting operations, especially in quality control and sorting and storage. It includes monitoring of silos to transmit information related to grain stock levels, temperatures inside the silo and moisture content, and other condition information. Spoilage of food is a major obstacle for many farmers around the world and the amount of food loss varies by crop type (as much as 50% of cereal grains, vegetables and fruits can be spoiled during the storage and transportation stage due to the lack of technical inefficiency such as non-maintenance of appropriate moisture levels).

One major example of a product in this area is Bin-Sense. IntraGrain collaborated with SaskTel and Ericsson to support its grain monitoring product. IntraGrain wanted to develop a solution to monitor grain storage conditions to prevent spoilage so that more products can reach consumers in good condition. The company created Bin-Sense and collaborated with SaskTel and Ericsson for connectivity. Bin-Sense collects silo conditions data and sends it over the cellular network to IntraGrain's servers where it is then provided to the end users via their web or mobile user interface. This prevents spoilage and ensures that more of their product reaches buyers, maximising revenues.

4.7

Fishing vessels

Commercial fishing boats are now equipped with sensors that can track weather conditions, wave height, and water temperature in real time. This information is then transmitted to a central database where fishery managers can analyse it and make decisions about where and when to deploy their fleet. IoT-enabled fish finders are also becoming increasingly common on commercial fishing boats. These devices use sonar to detect fish beneath the water's surface and provide information to the fishers in real time, thus helping identify areas where the catch can be increased. Sensors are also installed to measure the weight and number of passengers on board using weight and IR Sensors and notify the same data to the ship captains. Sensors are also being used to monitor the status of the fishing vessel.

Dobroflot, a Russian fishing fleet operator has deployed an IoT-based solution for monitoring fuel that has been developed by Orange Business Services. The satellite-based solution is expected to optimise fuel consumption, analyse weather and vessel position, save up to 10% on fuel costs, and prevent unauthorised usage of fuel at any time.

4.8

Fish farming

The aquaculture sector is looking to embrace IoT technology in operations to optimise and digitise their fishing processes including fish feeding, monitoring of water temperature, and assessment of water quality. IoT helps in better and efficient management of fish feeding via real-time monitoring of water conditions. These connected devices help in tracking fish appetite, fish health, fish size and biomass, and various other parameters such as dissolved oxygen, temperature, humidity, pH, salinity, and total dissolved solids.

Fish farming also poses a negative environmental impact. Farmed fish are often fed with antibiotics, and they build resistance to antibiotics, which can be passed to humans. IoT sensors can offer an alert system to identify waterborne problems such as algal blooms and pollutants, which could damage the local environment.

The Office for Forests of Basel deployed Endress+Hauser's Netilion Smart System for Aquaculture to provide continuous monitoring of water quality at its fish farm in Giebenach municipality. Sensors measure, for example, dissolved oxygen, nitrate, and ammonium levels in the water with the data transmitted into the Netilion Cloud. The Endress+Hauser Netilion Smart System for Aquaculture platform helped in lowering fish mortality while supporting the growth in fish stock and better replenishment of salmon stocks in the Rhine.

4.9

Transport and storage

In addition to production, food transport and storage are ripe opportunities for using IoT to ensure that produce is efficiently delivered, reducing the amount of food waste and therefore pollution associated with the whole process. Roughly one-third of the food produced in the world gets wasted or lost every year and a significant amount of this wastage happens in the post-harvest agricultural supply chain, especially in transportation, storage, and processing units.

There has recently been an increasing regulatory push for the monitoring of goods, particularly in the pharmaceutical and food industry, whilst in transit. For instance, the US FDA's Food Safety Modernization Act (FSMA) ensures the safety of refrigerated foods in transit, particularly those that present a risk of food poisoning.

Peloris Global Sourcing put in place an end-to-end solution for monitoring of Australian dairy farm milk while in transit so that it could be exported to the

Chinese market. Previously, clearing Chinese import quarantine checks would have taken 21 days – longer than the milk's 20-day shelf life – making its export to China unviable. By enabling Peloris and China Inspection & Quarantine Bureau officials to monitor the milk's temperature, location, and other variables in real-time using Sendum asset tracking devices connecting to Telstra network, it can now pass through quarantine checks in 36 hours – opening up the Chinese market to Australian dairy farmers.

There are also various IoT use cases at the final point of consumption, for instance in restaurants and commercial kitchens to allow end users to remotely manage kitchen equipment such as commercial refrigerators. Sensors deployed on the refrigerators can constantly monitor the status of the items inside the fridge and can accordingly inform users if anything is about to be spoiled or needs to be checked.

ShelfX partners with OptConnect to simplify their mobile self-checkout and inventory management solution for commercial refrigeration at retail stores. ShelfX has chosen OptConnect's Neo2 router to provide high speed connectivity to its refrigeration systems. The ShelfX system can be incorporated into any existing fridge or freezer and provides alerts for food safety, theft, and real-time customer support via its mobile app.

05 Connectivity requirements

Connectivity requirements

Decisions over which technology to use to connect IoT devices will be first and foremost dictated by the demands of the application. There are nine key sensitivities identified by Transforma Insights which will vary greatly, depending on the nature of the IoT deployment and will dictate connectivity/networking choices.

- **Cost -** This is always going to be consideration and a limitation. There are almost no applications that are completely price insensitive, meaning there is always an incentive to keep prices low. It's important to distinguish between the cost of the device and the cost of the connectivity.
- **Power –** Access – or lack of it – to mains power, is a key determinant of how an IoT application is architected. The use of battery power necessitates numerous compromises in terms of connectivity technology used, communications protocols, processing, and more. All those choices have implications for the power usage and require some sort of trade off. Most of the use cases profiled in this report will need to rely on battery power, being highly geographically distributed.
- **Speed -** The requirement for high-speed connectivity will be largely determined by the type of use case. Most environmental use cases are focused on relatively low bandwidth monitoring and control. Even those that rely on video and still image processing will tend to do a lot of processing on the device rather than sending a data stream.
- **Latency -** For some use cases, the key thing will not necessarily be the volume of data to be sent, but the round-trip time of the interaction between the IoT device and the server. Drones or some forms of farm automation, for instance, benefit tremendously from real-time connectivity. Some communications protocols are better for reducing latency, for instance those that do not require complex handshakes between client and server.
- **Availability –** A few environmental applications demand high availability, whereby access to the devices is provided with very reliable, robust connectivity technologies. Device location is a constraint when it limits access to specific networks (and power) and/or the ability of people to access the device. Geo graphically remote devices may have very limited options of how to be connected, often being limited to technologies that are low bandwidth or costly, or both. Also being located inside buildings, often in basements, will create challenges for some connectivity technologies. Many use cases demand high availability, necessitating the use of particular types of technology.
- **Mobility -** Some IoT use cases are mobile, whereas others are static. This has implications for the choice of technology. For instance, a connected vehicle requires a cellular technology capable of handing over between cells at high speed. Static devices, in contrast, may need a technology with superior propagation characteristics to ensure coverage within a building or in a remote location. Most use cases considered in this report are static, but with some exceptions, such as drones or farm automation.
- **Durability -** Turning predominantly to the hardware aspect, some IoT deployments will require ruggedised devices, potentially able to withstand extremes of temperature and vibration. This will have some implications for other connectivity-related choices. For instance, more ruggedised devices will often favour MFF2 soldered SIMs, or iSIMs, rather than removable SIM cards, with potential implications for how connectivity is delivered. This applies to most of the environment use cases considered here.

- **Space -** This relates to the dimensions of the device and the inherent limitations that come from that. An air quality monitoring device can probably be of any size, within reason, but in other cases, such as drones, it will want to be small and lightweight. Most use cases considered in this report are not particularly limited in this respect.
- **Security –** Some use cases have a greater inherent requirement for security than others, for instance those involving handling financial transactions, those involving personal or household data, those where there is a risk to life, or those relating to critical national infrastructure. Some environmental use cases have requirements for a relatively high level of security, being critical national infrastructure.
  This particularly applies to those involving drinking water but also extends to considerations of food security.

In the chart below we map the requirements of each of the major environment use cases onto the characteristics listed above.

Figure 2

Environment IoT application sensitivities

The twin overriding requirements for supporting IoT connectivity across these environmental use cases is that it be cheap and durable. Price is a critical factor for several reasons. The first is that deployments in these use cases tend to involve large numbers of devices, meaning that device costs, and potentially connectivity costs, spiral quite rapidly. In some cases the costs do not have associated revenue and/or they are shouldered by central or local government, meaning that careful consideration will be given to how to address them in as cost-effective a manner as possible. This includes air quality monitoring and public transport. In other cases, particularly those involving agriculture such as irrigation or crop management, margins on production are already quite tight and having a positive return on investment from the deployment depends on keeping the costs as low as possible.

Turning to questions of durability, this is quite intuitive in this sector. It tends to focus on applications deployed in harsh outdoor conditions and in some cases the conditions may be very harsh indeed, as with fishing vessels and fish farms. In many cases devices will be expected to be deployed for many years without replacement. In contrast, very few applications have much of a constraint over space, although weight does come into play for drones and livestock monitoring.

In tandem with the requirement for durability is the need for devices to operate with low power. Many of the use cases considered here are deployed in locations without ready access to mains electricity, or otherwise supported such as when connected to a road vehicle. Water smart meters are an excellent example, where they will need to rely on battery power for, ideally, decades of operation. Many of the agriculture applications, such as livestock management or irrigation will be similarly limited, although perhaps with some greater capacity for recharging devices.

In terms of requirements for performance in data speed and latency, these environmental use cases have quite limited demands. It is only really drones, traffic management and public transport that have anything approaching a requirement for high bandwidth connectivity. Demand for low latency is limited to control of drones and farm automation and robotics, where devices will often be controlled in real time. In most cases the amount of data being sent is tiny and there is little time sensitivity, certainly if the delay involved is in the order of a few seconds.

There is also relatively little requirement for mobility, and where there is it will often involve relatively slow movement within a well-defined geographical area, for instance for farm machinery or livestock. Produce monitoring through the supply chain, drones, public transport vehicles and fishing vessels are the exceptions.

Security considerations permeate across all of the use cases since these are applications dealing in many cases with food security or the supply of drinking water. As such they are potential vulnerabilities. The most pronounced of these relate to the water distribution network and to drones.

Demand for low latency is limited to control of drones and farm automation and robotics, where devices will often be controlled in real time. In most cases the amount of data being sent is tiny and there is little time sensitivity, certainly if the delay involved is in the order of a few seconds.

06 Key technologies

Key technologies

Having established the diversity of characteristics that any particular application might have, it's now worth considering the diverse set of connectivity technologies that might be considered for an IoT deployment, their strengths and their weaknesses. There is a dizzying array of potential technologies that might be appropriate for connecting different use case.

Figure 4
IoT connectivity technologies for Environmental use cases

TECHNOLOGY	WHAT IS IT?	STRENGTHS	WEAKNESSES	OPTIMUM FOR
2G/3G	A public network cellular standard.	Cheap (2G) and mature network technology.	In many parts of the world these networks have been switched off or will be shortly. Low bandwidth.	Inadvisable to use for any use cases due to the shut-down or imminent shut down of networks around the world.
LTE Cat 1	A public network cellular standard. IoT-oriented LTE technology, available on all LTE networks.	Very widely deployed, giving the most universal coverage of LTE globally. Moderately high data rates and good latency.	Power consumption is comparatively high. Performance not as strong as 5G. Higher cost than LTE-M/NB-IoT. Will only be supported for as long as there are LTE networks.	Use cases where trade off is required between cost and moderately high data rates, for instance in farming automation.
LTE Cat 1 bis	A public network cellular standard. Has capabilities very similar to LTE Cat 1, but using only a single antenna.	Mid-range data speeds and latency at low cost and decent power consumption. Supported everywhere with LTE networks.	Not good for in-building coverage, or areas of marginal cellular coverage. Will only be supported for as long as there are LTE networks.	All use cases where LTE Cat 1 is appropriate but not in hard-to-reach locations such as deep in-building or very remote.
LTE Cat 4 (and above)	A public network cellular standard. Not specifically IoT-oriented. Available on all LTE networks.	Very widely deployed, giving the most universal coverage of LTE globally. High data rates and good latency.	Power consumption is comparatively high. Performance not as strong as 5G. Higher cost than LTE-M/NB-IoT. Will only be supported for as long as there are LTE networks.	Relatively high band-width applications where prices lower than 5G is required, or 5G is not available. For instance road traffic management, public transport or drones.

Source: Transforma Insights, 2023

TECHNOLOGY	WHAT IS IT?	STRENGTHS	WEAKNESSES	OPTIMUM FOR
LTE-M (LTE Cat M or Cat M1/2)	A public network cellular standard aimed at low power IoT applications.	Cheap devices, relatively good battery life. Will be supported for lifetime of 5G.	Only moderate data speeds and latency. LTE-M support is not universal by all operators globally.	All use cases except where low latency is required (e.g. drones).
NB-IoT (aka Narrowband IoT, Cat NB1/2)	A public network cellular standard aimed at low power IoT applications.	Very cheap devices, good in-building coverage, long battery life. Will be supported for lifetime of 5G.	Low data speeds and high latency. Network deployments are country specific.	Power constrained low data use cases, where networks are available, for instance air quality monitoring or crop management.
5G RedCap (Reduced Capability)	A public network cellular standard aimed at low power IoT applications. Variant of 5G offering a cheaper and more power efficient (but more limited) version of 5G.	Good data rates, decent battery life.	Limited deployments of 5G and support for RedCap. Power consumption signifi-cantly higher than NB-IoT. Still high costs.	None currently due to limited network availability and minimal benefit versus existing LTE technologies. Future iterations will make this a key technology for all use cases.
5G New Radio (NR)	A public network cellular standard. Full capability cellular 5G, providing very high bandwidth and low latency connectivity.	Very high data speeds and very low latency.	Not universal coverage of 5G (and/or upgrades to 5G Stand Alone), very high costs.	Drones, farm automation, public transport.
NR+	Mesh network technology using licence-exempt spectrum. Part of the 5G standard. Deployed as field area networks e.g. for smart metering.	Decent battery life. Good (3Mbit/s) data speeds and low latency. Good in-building coverage.	Requirement to build dedicated network.	Smart Metering.
Wi-Fi HaLow	IEEE standard 802.11ah. Network technology close-ly related to Wi-Fi using licence-exempt spectrum. Can be deployed as mesh. typically deployed in campus environments. Range of 1-3km.	Good battery life. Can provide high bandwidth (up to 15Mbit/s). Moderate latency. Good in-building coverage due to use of sub-GHz frequency bands.	Requirement to build dedicated network. No ecosystem of device makers today.	None, currently.
LoRaWAN	Network technology using license exempt spectrum, typically deployed as a private network, but there are public networks available in some geographies.	Cheap devices. Useful for managing campus/building deployments of multiple devices without need to manage via the owner's network.	Requirement to implement dedicated network in most countries.	Most low data applications, depending on availability of networks. Particularly relevant for applications deployed in a particular limited geographical area, such as irrigation or crop management.

4.1

Public vs private networks

The first thing to note is that there are two main categories of network technologies: public and private. Public networks, such as 2G, LTE, 5G and numerous variants of those technologies as outlined in table above, are deployed and operated by mobile network operators (MNOs). Private networks, such as Wi-Fi, LoRaWAN and various mesh networks used in smart metering, are rolled out by the user themselves, or by a third party on their behalf. Several technologies overlap the two, with some public and some private deployments, such as LoRaWAN and LTE/5G.

Public networks have the obvious advantage that they do not require the user, for instance a water utility or farmer, to be involved in the deployment, operation and management of the network. In the case of the cellular networks operated by MNOs there are typically multiple options within any give territory, with good availability, high performance, and high levels of security.

Private networks provide benefits in terms of greater control over the network, and in the case of private 4G/5G higher levels of security. Furthermore, in some of the use cases profiled here, where there is a large number of connected devices within a quite limited area, such as with irrigation, often with poor cellular coverage, a private network might be more appropriate.

4.2

Licensed vs unlicensed spectrum

One major challenge with many of the private network technologies is that they rely on license-exempt spectrum bands, i.e. spectrum that can be accessed by almost anyone (as long as deployments fulfil certain criteria related to transmit power and frequency of messages). As such it offers fewer guarantees over the availability of network resources, compared with those using licensed bands. For applications that require guarantees over network availability, technologies using licensed bands (e.g. 4G/LTE, LTE-M, NB-IoT, and 5G) will generally be more reliable options.

4.3

Range and in-building penetration

The most critical consideration for anyone choosing a connectivity technology is whether they meet the performance characteristics required. To be viable, any selected technology choice has to be able to firstly provide coverage for the relevant device. In many cases, devices might be located in basements or remote locations.

Public cellular networks typically have the best country-wide coverage, albeit with some limitations. The first consideration is the availability of a network at all. While almost all countries have 4G networks deployed, the IoT variants available, e.g. LTE Cat 1, may not be the most appropriate for IoT applications, given their higher power consumption. LTE-M and NB-IoT networks have been deployed in most mature IoT market countries with over 270 networks now available according to the GSMA IoT Community.

The second consideration for public networks is how well the technology provides coverage within the country in which it is deployed. NB-IoT in particular is optimised for superior range and in-building coverage, making it a technology that is particularly appropriate for agriculture applications, or smart water metering. This consideration is even more pronounced for use cases at sea, such as fish farming or fishing vessels, where satellite connectivity might be the most appropriate.

Turning to non-cellular technologies, range is usually very limited, to just a maximum of a few kilometres. In one or two cases, technologies such as LoRaWAN offer much wider coverage, and are sometimes deployed nationally by network operators, although with inferior in-building coverage and very limited data speeds. Some hybrid deployments involve deployment of a gateway that is cellular connected but which uses an alternative such as LoRaWAN for connected to the devices within a building.

In some cases, relevant technologies can be architected as mesh networks, i.e. connecting from one deployed device to another rather than each connecting to a network transmitter. These types of topologies can work well if there are large numbers of quite densely packed devices, such as in agriculture. They will be inappropriate for many of the more geographically remote devices.

4.4

Uplink/downlink/latency

Assuming that it is possible to connect the device using the selected technology, considerations then turn to whether the capabilities match the requirements of the application in terms of uplink/downlink speeds and latency. Very few environmental use cases require particularly high data speeds, meaning that almost any technology is appropriate from that standpoint. Smart water metering or remote irrigation management, for instance, requires only very limited amounts of data to be sent and received, although requirements may increase as more load balancing requirements are added. Anyone making technology selections needs to have one eye on future requirements.

Requirements for latency vary tremendously. Drones, for instance, may require real-time interaction, which would necessitate the use of a technology with very low latency, such as 5G.

4.5

Power consumption

Minimising power consumption is one of the key requirements of many IoT applications, and one for which many new technologies have been optimised. In the case of environmental use cases, few have access to mains power. As such, the use of low power consumption technologies such as LTE-M and particularly NB-IoT, as well as LoRaWAN, provide a significant benefit. NB-IoT has been very widely deployed for smart water metering and in agriculture.

4.6

Lifespan and support

Some use cases covered in the report will have deployment lifespans stretching into decades. Smart water metering certainly fits into this category, and many of the agriculture applications will be expected to have a long lifespan. Those organisations will need to give careful consideration to the likely long-term availability of the network technologies and ongoing support for them.

The most obvious manifestation of this lifespan issue is in the availability of public cellular networks. In many countries around the world 2G and 3G networks have already been switched off, with spectrum refarmed to use to support 4G and 5G. The result is that typically 2G and 3G networks are not appropriate for energy deployments. The most future-proof option, where available, is to opt for either 5G or one of the massive Machine Type Communications (mMTC) technologies that have been developed specifically to support IoT devices. While NB-IoT and LTE-M were initially developed as part of 4G, devices can be supported on 5G networks, giving them the optimum longevity compared to purely LTE technologies such as LTE Cat 1 or LTE Cat 1 bis. Recent developments in 5G have also provided a more IoT-oriented pure 5G technology in the form of 5G RedCap, but as discussed in the Transforma Insights report 'What is 5G RedCap and how does it fit into the portfolio of cellular IoT connectivity technologies?' it is still not yet optimised for requirements of low cost and long battery life relative to NB-IoT and LTE-M; but future iterations promise improvements.

For private networks, the questions are two-fold: firstly, will the technology continue to be widely used, supporting an ecosystem of device developers and service providers, and secondly, will the organisation deploying the technology want to continue to support it itself for the duration of operations. The IoT connectivity landscape is littered with technologies that were too limited in functionality or not sufficiently widely supported, for long-term success.4.7

4.7 Cost

Decisions over each of the requirements listed above will inevitably require a trade-off with each of the other factors, e.g. good in-building coverage will often require sacrifices over latency or bandwidth. In all cases, there are also considerations of cost. Some technologies, such as 5G and to a lesser extent 4G LTE Cat 1, have expensive connectivity modules, ranging from USD20 up to north of USD100. In comparison, LTE Cat 1 bis, LTE-M are priced at around USD10 and NB-IoT closer to USD5 per unit. Unit costs for the unlicensed technologies are typically even cheaper, at USD1-2 per unit.

We should also consider connectivity costs too. The public cellular networks will involve a recurring cost for the connectivity, albeit one which not be explicitly stated and may be bundled into the full price of a solution. Prices here have been dropping substantially over the last decade. For low data IoT use cases such as smart metering, it is not unusual for prices to be below USD1 per annum, a trend highlighted by Transforma Insights as '$1 IoT'. Private network deployments do not have this specifically attributable connectivity cost.

The thing to consider with cost is not the unit cost of the individual items, but the total cost of ownership (TCO) for the whole project over the duration of the deployment, including potential unexpected costs. This includes the price of devices and connectivity, of course, but also includes the cost of rolling out a network (if relevant), the risk of having to rip-and-replace redundant technologies, the impact of any security breaches that might occur, and any future upgrades that need to be supported.

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