WHITE PAPER

The Internet of Things for Urban Sustainability

OCTOBER 2020 // PREPARED BY CASEY CHATTERTON & ANDREW FINNEGAN

EXECUTIVE SUMMARY

The megatrend of urbanisation is placing untenable strains on urban and environmental systems. Though cities occupy a fraction of the earth's surface, the worlds finite resources are disproportionately being consumed by urban environments. Environmental degradation, climate change and a host local governance issues are highlighted as major concerns for cities as their populations bludgeon. The need for a more sustainable approach to urban environments is a major priority for the sustainable development agenda. The maturity and amalgamation of sustainability and information and communication technology has brought about the notion of a smart city as a tool to create sustainable urban environments in the face of mass urbanisation. The Internet of Things (IoT) is a wireless technology which shows great promise in enabling urban environments to find and create efficiencies in their systems, resulting in optimal use of resources. By incorporating sensing technology within urban systems and connecting them, people, the environment and millions of 'things' via the internet, insights can be created, and informed decisions can be made based on a rich source of data. Melbourne has embraced IoT technologies and has implemented various initiatives throughout the metropolis area. Using Melbourne as a reference point, a number of emerging IoT dependant technologies have been identified and explored for their capacity to improve a cities sustainable performance across three major sectors, energy, water and waste. It was found that the technologies identified are significantly mature enough and capable of contributing to sustainable urban pursuits. Some technologies have shown increased levels of adoption in Melbourne, for example, smart energy metering when compared to smart water metering. The industries where adoption of such technology has been observed is driven mainly by economic factors, the rate of which could be increased by government incentives. Though market forces will undoubtedly lead to the broad adoption and implementation of IoT technologies, if cities are to move towards the smart sustainable city model to achieve sustainability, government incentives to stimulate the adoption process are required.

ACKNOWLEDGEMENTS

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ecomon Energy Monitoring empowers businesses with appropriate energy monitoring tools and knowledge, maximising capital investment and minimising energy usage.

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An Urbanising World

The past 60 years has seen the number of people living in urban areas quadruple, overtaking the rural population in the past 20 years (Figure 1). Over half of the world's population currently lives in urban environments and the UN predicts that this figure will be close to 70% by 2050 (UN, 2018). Global cities are diverse in nature, varying in terms of size, population, wealth, environmental impacts, governance and physical structures. Populations of cities can span from only a few thousand living in small cities to tens of millions of people living in megacities (UN, 2018).

Historically, economic development has not been possible without urbanisation and in this regard, cities are a commodity that can improve quality of life (Henderson, 2010). The agglomeration of people and resources results in greater opportunity for innovation, interaction and development. This is demonstrated by the fact that cities are disproportionately responsible for the production global wealth, producing 80% of the worlds GDP, yet covering approximately only 2% of the worlds surface (UNEP, 2013). Urbanisation is an unprecedented issue, and as the world experiences the biggest waive of urban growth in history, the focus turns to engineers, scientists, governments and the private sector to ensure that this mega migration trend is managed in a sustainable way.

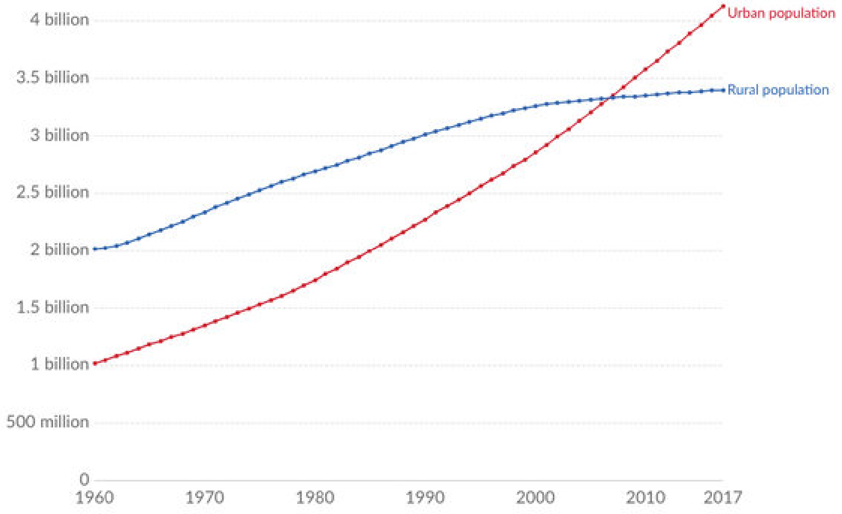


Figure 1: Urban Population Growth vs Rural Population Growth (Ritchie & Rosser, 2018)

Sustainability in Urban Environments

Cities occupy far less area per person than rural developments. This is advantageous for cities in pursuit of a sustainable future due to the potential for a low ecological footprint. However, cities are responsible for two thirds of the world's energy consumption, they produce over 70% of global carbon emissions and consume 75% of the world's natural resources (UNEP, 2013). This level of consumption is depleting finite resources, driving climate change and facilitating the destruction of ecosystems (Stephan et al., 2016). Furthermore, rampant urbanisation creates a host of local challenges in urban environments. The provision of basic services, the demand for affordable housing, access to well-connected public transport, traffic congestion, job creation, air pollution, land and waterway contamination are just some of the central concerns for the sustainable function of a city (World Bank, 2020).

Many definitions of sustainable development have been proposed, however the first, and still most commonly referenced definition, is perhaps the most succinct: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987). Urbanisation has driven the need for sustainable practices to be implemented in the design, planning and operation of cities. So, what does sustainability look like in urban environments? For a city to move towards a sustainable future, "four pillars of urban sustainability" (UN/DESA, 2013) should be considered – social development, economic development, environmental management and urban governance (Figure 2). While all the pillars are necessary for the sustainability of urban areas, this paper focuses on the pillar of environmental management as technology has the potential for drastic impact in this space.

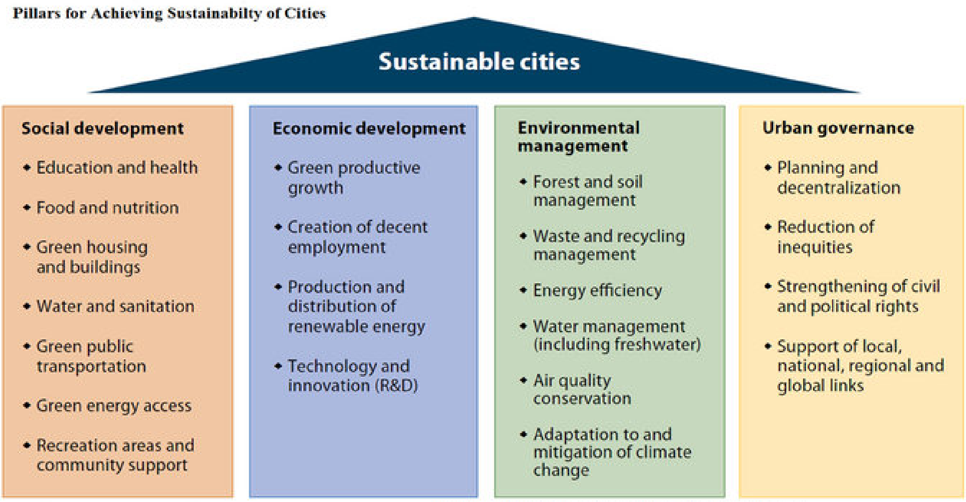


Figure 2: Pillars for Achieving Sustainability of Cities (UN/DESA, 2013)

The Role of Technology in Creating Sustainable Cities

Historically, technologies have evolved in response to population increases and economic pressures (Sweden, 1995). Thomas Malthus theorised in 1798 that civilisation would likely collapse in “An Essay On The Principle Of Population” (Malthus, 1798) due to the geometric growth of the population overtaking the linear growth of the food supply. It is clear now that with a global population of almost 8 billion, food production is less of an issue than it was once thought. The development of knowledge, scientific understanding and its application in technology – such as genetic modification of crops - has allowed for more abundant food production from the available land (Trewavas, 2002).

Technological advancement is responsible for the development of systems that make urban environments viable. Increased food production, advanced water and waste networks, traffic infrastructure, public transport, new energy sources, new building materials, improved healthcare, global communications are all examples of innovations that have allowed for prosperity in urban environments. For existing and emerging cities to move towards a sustainable future, energy and resource efficiency must be improved whilst negative impacts on the environment due to human activities must be reduced (Sweden, 1995, Goi, 2017). Six priority investment streams which can be improved by technological advancements are identified by the UN/DESA (2013): renewable energy sources efficiency in the use of water and electricity, design and implementation of compact cities, retrofitting of buildings and increase of green areas, fast, reliable and affordable public transportation and improved waste and recycling systems.

Smart Sustainable Cities

The ‘smart sustainable city’ paradigm – a technology driven movement - is increasingly dominating the debate around the future of sustainable urban development (Hollands, 2008). This is demonstrated by the extent of smart city studies and projects that are forming the basis for new urban developments as well as leading the way in regenerating existing cities (Reiche, 2010; De Jong et al., 2015; Yin et al., 2015; Caprotti & Cowley, 2016; Aina, 2017; Cowley et al., 2017; Trencher & Karvonen, 2017; Wu et al., 2017; Cugurullo, 2018). The notion of a smart city has been borne from the maturity and amalgamation of three global trends; sustainability, urbanisation and information and communication technology (ICT) (Birbri, 2018). The definition of a smart city can vary, however, there is a widely accepted understanding that a smart city is a city which is supported by complex ICT connected to urban systems. This interlinkage allows a city to monitor and control resource consumption and find improvements and efficiencies through urban systems to improve social and economic outcomes (Hollands, 2008; Yigitcanlar & Lee, 2014; March & Ribera-Fumaz, 2016; Birbri, 2018). In this context, as ICT permeates through the built environment, ecosystem services, human services and objects, cities are becoming 'smarter'. As such, cities improve their capacity to approach environmental, social and economic issues effectively whilst the provision of services to residents is improved to increase quality of life. (Caragliu et al., 2011; Batty et al., 2012; Zanella et al., 2014; Bibri & Krogstie, 2016; Bibri & Krogstie, 2017). The incorporation of ICT throughout urban environments will provide a foundational rich source of data on which to better observe, analyse, plan and design smart sustainable cities of the future to better align with the principles of sustainable development.

Internet of Things and The Smart Sustainable City

Smart cities are made possible by the Internet of Things (IoT). The IoT allows for the augmentation of the everyday physical objects and environments with smart sensing devices with "sensing, actuation and computing capabilities" (Mehmood et al., 2017), such as, GIS, infrared sensors and accelerometers (Bibri & Krogstie, 2016). This enables the physical and informational spheres to connect, merge and communicate using the internet. Millions of "things", including roads, appliances, people, machines and environmental systems (land air and water) can communicate real-time data to centralised control systems (ITU, 2019). The purpose of the IoT is to develop intelligent operations through data collection and exchange, enabling us to learn about, monitor and manage 'things' (Bribri, 2018).

The IoT in urban environments, generates enormous masses of data, known as 'big data'. Big data sets gathered from urban systems are often automatic and streamed from different types of sensors whilst holding varying spatial and temporal tags (Uddin & Gupta, 2014; Bribri, 2018). This provides challenges for smart sustainable cities in the management and analysis of this data, which requires exceptional computational capacity to create useful insights. Currently, uses of big data in urban sustainability have focussed on the condition of the urban environment, economic activities and the patterns of urban human behaviour (Kong et al., 2020). The tracking and management of resources, particularly across the water, energy and waste sectors can benefit greatly from the collection and analysis of big data (Wang & Moriarty, 2018).

Melbourne as a Smart Sustainable City

The Institute of Management Development's recently released Smart City Index has ranked Melbourne 20th of 107 cities in the world – behind both Sydney (18th) and Brisbane (14th) (IMD, 2020). This places Melbourne 4 places higher in this index than the year before. This improvement is reflected in an increase of smart city initiatives throughout Melbourne's metropolitan area. Of the 32 councils in Melbourne's metropolitan region, 4 have developed a smart city strategy, 3 are currently developing smart city strategies, 18 are implementing fragmented but diverse smart city initiatives, independent of a core strategy with the remaining 9 councils deemed to have minimal smart city initiatives (Dowling et al., 2019). Figure 3 presents a breakdown of Melbourne's smart city initiatives, identified by Dowling et al. (2019), by sector.

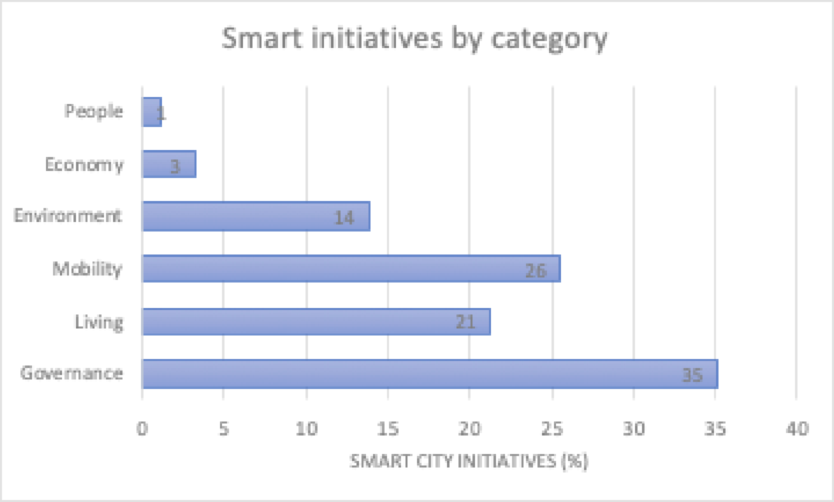


Figure 3: Melbourne's Smart City Initiatives (Adapted from Dowling et al., 2019)

The majority of Melbourne's smart city initiatives are taking place in the categories of governance, smart living and mobility. These categories primarily relate to improving the physical and communicative structures of the city. Only 14% of Melbourne's smart city initiatives are directed towards environmental pursuits – this includes issues pertaining to resource management. Though the groundwork is being laid in Melbourne for future IoT initiatives. Long range wireless area networks (LoRaWAN) are being implemented across numerous councils which will enable IoT connectivity. The "Northern Melbourne Smart Cities Network" project has installed LoRaWAN networks in five major inner-city council districts, integrating five types of sensor. This initiative is intended to assist the councils in monitoring services and identifying efficiencies to improve existing practice and deliver new services (DIDRTC, 2020). This is a pioneering project, representative of the positive steps Melbourne, as a whole, is taking towards the adoption of IoT technology across the spectrum of city services.

Study Rationale

The past decade has seen revolutionary developments in smart technologies such as remote sensing technology, the internet of things (IoT), computational processing capacities and mobile devices (Eiza et al., 2020). These are the developments that create the foundation for smart sustainable cities to become effective means of improving efficiencies in urban environments. This paper looks at emerging technologies in the context of Melbourne's urban sustainability. Through this research, the following questions will be answered:

- What are the main mechanisms for the adoption of sustainable practices and technology?
- What contribution can the Internet of Things have in urban sustainability?
- What are the main challenges for the development of smart sustainable cities over the next 5-10 years?

This paper develops an understanding of the extent of contribution technology, and specifically IoT can have to sustainability in urban areas. A literature review has been undertaken focusing on urban sustainability and IoT technology, with a focus on the local Melbourne context.

Technology and Innovation Adoption

Continually evolving knowledge and learning has enabled individuals to create new technologies. In fact, since the dark ages technology creation has been increasing at an exponential rate (Huebner, 2005). The rate, diversity and diffusion of new technological advancements is phenomenal. The first computer, developed in 1945, weighed 25 tons and could process 5000 instructions per second, 70 years later, 3.5 billion smart phone users are integrating their lives with a device that can process billions of instructions per second. (Hines, 2016). Technology has served to increase the capacity of scientific communities to develop knowledge, in turn increasing the capacity for innovation (Kurzweil, 2014).

Technology has increased the quality of life across the spectrum of society by enhancing growth and socio-economic development of Nations (Ahmed & Stein, 2004). However there have been, and will continue to be, unintended consequences of new technologies. The creation of the combustion engine, for example, triggered the industrial revolution, releasing greenhouse gases into the atmosphere causing global warming (Healy, 2012). Though unintended consequences of technology have facilitated the degradation of environmental systems, it is through technological development and innovation by which society hopes to mitigate environmental impacts of human activities. Which technologies, how they work and if they are adopted are key to the sustainability movement.

The success of a technology in any context is dependent on the adoption of the technology by the target market. Two frameworks commonly referenced are the “Diffusion of Innovation (DOI)” (Rogers, 1976) and the “Technology Acceptance model (TAM)” (Davis, 1989). DOI offers a framework for how new ideas are spread through groups of people. Diffusion describes the mechanisms, channels and time taken for a new innovative idea or technology to be communicated through social networks (Rogers, 2003). Innovation describes a novel concept, a new practice or idea. Figure 4 provides a graphical interpretation of Rogers DOI theory. TAM suggests a framework in which the “perceived ease of use” and the “perceived usefulness” impact a user’s behaviour and subsequent adoption of a novel technology (Patel & Connolly, 2007).

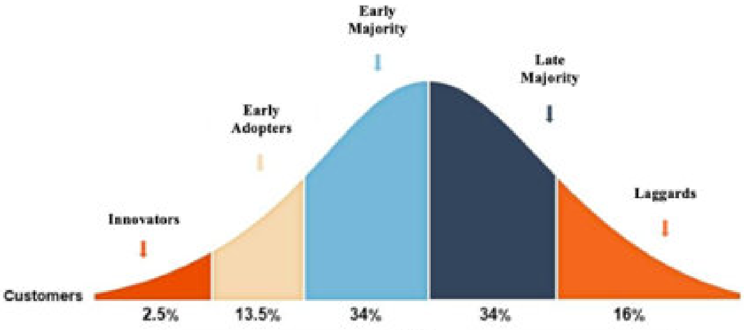


Figure 4: Diffusion of Innovation – Adopter Categories (Adapted from Rogers, 2003)

Based on the TAM theory, technology which is useful and easy to use should diffuse across society in the progression outlined by the DOI theory. Of course, several individual determinants can impact whether or not a user considers a technology ‘useful or not’. Factors such as cost, ease of use, product performance and network effects can all impact the uptake of a new technology (Hall & Khan, 2002). Cost can be prohibitively expensive when technologies first emerge (generally in the innovator and early adopter phases), while the performance of early products may not be optimal. Solar PV’s are a great example of this. Solar PV technology has seen a rapid decline in total installed costs in the past 10 years (Figure 5).

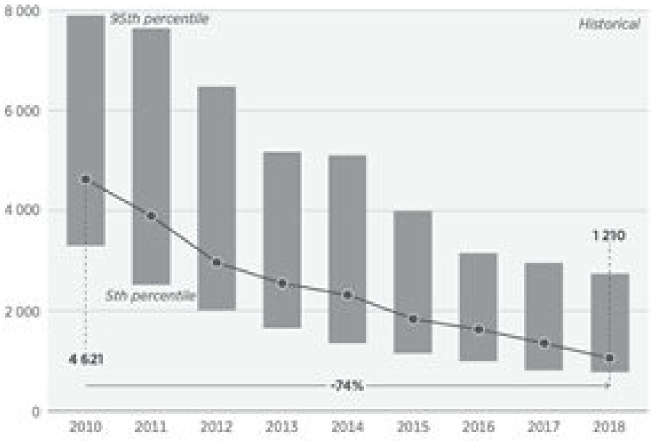


Figure 5: Decline in total installed costs of solar PV (IRENA, 2019)

As panel efficiency has increased from approximately 5% ten years ago to over 20% for the average user with modern systems (IRENA, 2019). This has facilitated a shift in perceived usefulness to the user, resulting in the kind of exponential growth in global solar capacity shown in figure 6.

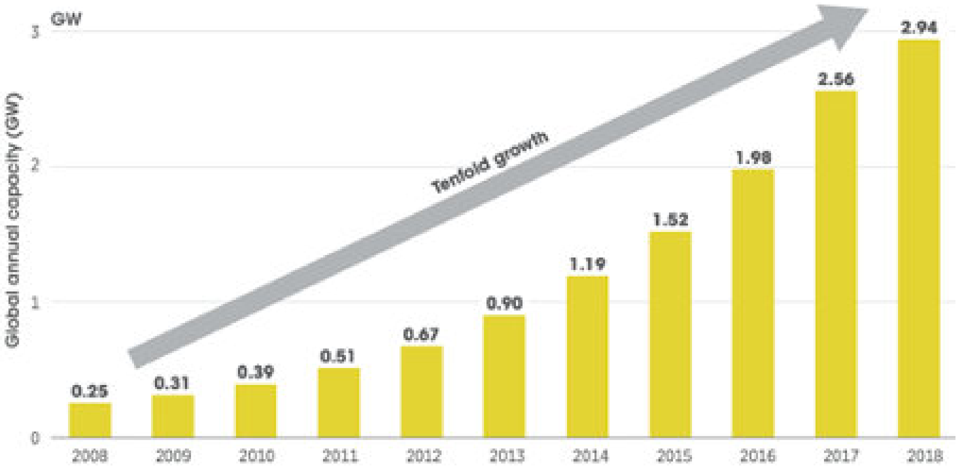


Figure 6: Global power capacity, off-grid solar PV, 2008–18 (IRENA, 2019)

Disruptive Technology The term disruptive technology was first used by Prof. Clayton M. Christensen to describe a new technology which unexpectedly displaces an established technology (Ebersold & Glass, 2015). Disruption can often occur as an unintended consequence, i.e. the development of the laser, harnessed to read DVD's, heralding the end of the video cassette’s viability. However, disruption can also be very much intended. Renewable energy is a prime example of a modern technological pursuit, the development of which is designed to disrupt and displace fossil fuels as the primary source of energy. There are a number of overlapping factors that drive the disruptive capacity of a technology, summarised by Miller et al. (2019):

- Cost - new technologies make old ones unprofitable as new ones are so cheap
- Quality - new technologies raise the quality which make old ones uncompetitive
- Customers - changes in customer preferences make old technologies unattractive
- Regulation - new laws or regulations change the permitted ways of working
- Resources - scarcity of important resources are no longer avaliable for the technology

There are two predominant categories of technology model: sustaining and disruptive. The sustaining model builds on existing technology to improve and develop it, whereas disruptive technology is new, often unproven and unrefined with a limited market (Ebersold & Glass, 2015). Corporations, in general, are designed to operate using the sustaining technology model as they have a developed market and processes in place in which to develop existing technology and services related to their product. Large corporations have historically been slow to move with and dismissive of disruptive technologies, which can result in large organisations being caught off guard when a technology matures and claims a large part of a market share (Bui & Zorzi, 2011). A pertinent paradigm shifting example of this is the recent observation that the market value of Tesla – a renewable energy company – has surpassed that of Exxon Mobile Corps – an oil and gas giant (Wethe, 2020).

Government Subsidy

The rate of diffusion of a given technology can be influenced, however. If there is a perceived benefit to the adoption of a technology, governments can ‘sponsor’ such products to accelerate the market diffusion (Kalish & Lilien, 1983). This is a technique which can assist users in overcoming the initial hurdle of investment. In 2011, the Australian Federal Government implemented a solar incentive which reduced the initial installation costs for early adopters of solar. This was implemented as a means of assisting the government in meeting renewable energy targets. The scheme has been reviewed and evaluated, concluding that subsidising solar has increased uptake and lowered greenhouse gasses (Best et al., 2019). Another example of government subsiding a new environmentally friendly technology is occurring in Dehli where the government is offering a subsidy to buyers of electric cars as the city grapples with its congestion and pollution problems (Economic Times, 2020). Subsidies are an effective means of influencing the adoption of technologies and have been shown to effectively support the ongoing development of products (Best et al., 2019).

Regarding IoT technology, potential users are thought to base their decision on whether products are deemed ‘useful enough’ on a risk-reward ratio (Jalali et al., 2019). IoT possesses several advantageous qualities such as, applying monitored data to predict future scenarios, identifying and reducing energy requirements, creating deeper understanding of human movements and behaviours (Balaji et al., 2019). And though sensor technology is affordable, services to analyse data can be costly. However, the main risk factor is based on real and perceived risk of cyber security threats. Dutton et al. (2014) state that “As with any data connection, the connections that allow remote machines to take action without a human operator are subject to hacking by criminals or terrorists”. Privacy implications are a major hurdle for the adoption of IoT, a comprehensive review of such implications has been undertaken by Hwang (2015).

IoT

IoT is a collection of different standards and technologies which enable sensing, connection, analysis and operation capabilities. The fragmentation of these standards and the variety of the technologies pose challenges for deployment. Exponentially accelerating infrastructure and smart device adoption is driving the trend towards an increasingly sophisticated network capable of intelligent functions in many facets of the urban world. Widely available sensors can detect and transmit data about all manner of physical objects, including roads, buildings, water systems, soil, air and transport systems. The addition of communication gateways and powerful computing capabilities, which can extract useful data to make accurate and rapid decisions, enables a level of intelligent automation not possible through traditional human interventions (Čolaković, 2018).

IoT comprises of several layers of technology, allowing the collection, communication and analysis of environmental data. Due to the wide-ranging applications of IoT there is no single definition of the underlying architecture, or functional blocks necessary to achieve the task, however, several architectural structures for IoT have been proposed, in this paper we look at the typical 5-layer IoT architecture proposed by Wu et al (2010). This architecture expands on the well-known 3-layer architecture consisting of the application layer, networking layer and perception layer to include a processing layer and a business layer (Figure 7). These two additions reflect the importance of big data, and business models to successful IoT implementation (Wu et al., 2010).

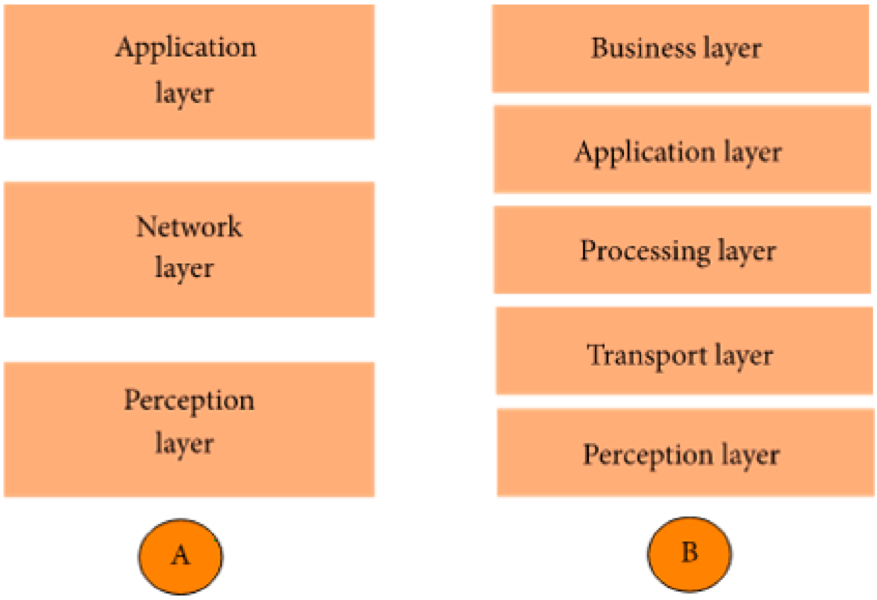


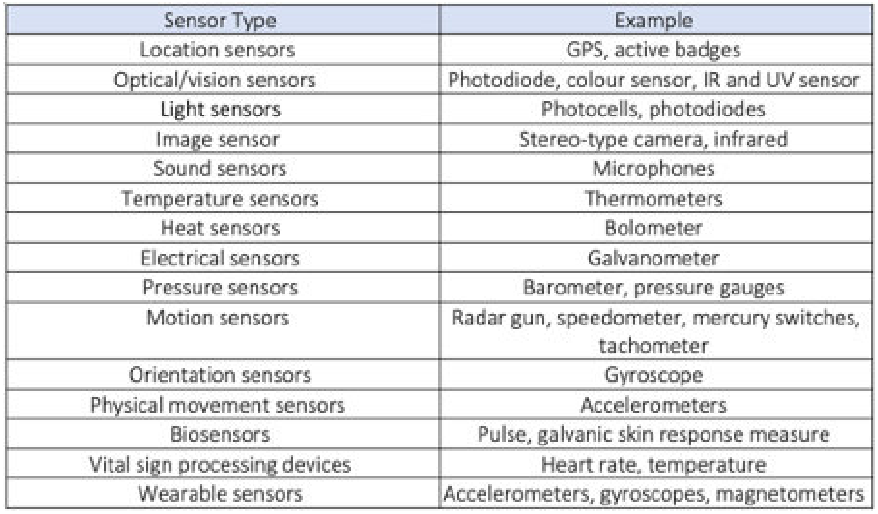
Figure 7: Three and Five-layer IoT architecture (Wu et al., 2010)

Sensing layer

The sensing layer or perception layer includes the sensors of the IoT implementation which are collecting and processing information. A sensor is a technological device which detects and measures a physical property and records, indicates, or responds to it in an appropriate way. Sensors can record data or transmit data across a network to be processed by computing software (Bribri, 2018). Sensors can be classified based on the method of collection, specifically what type of energy they detect. Table 1 outlines sensor types and examples used in big data collection.

The sensing layer is responsible for the perception of the physical world and includes sensors and actuators with specific functions depending on the task. There is a necessity of standardisation at the sensing layer to allow the wide variety of technologies to be accessible. The main functions of devices in this layer are to be able to perceive and record data about the physical world, some ability to do some basic computing, self-identification and connection to the transport layer for communication (Silva, 2018).

Table 1: IoT Sensor Types and Examples (adapted from Bibri & Krogstie, 2017)



Sensor Type	Example
Location sensors	GPS, active badges
Optical/vision sensors	Photodiode, colour sensor, IR and UV sensor
Light sensors	Photocells, photodiodes
Image sensor	Stereo-type camera, infrared
Sound sensors	Microphones
Temperature sensors	Thermometers
Heat sensors	Bolometer
Electrical sensors	Galvanometer
Pressure sensors	Barometer, pressure gauges
Motion sensors	Radar gun, speedometer, mercury switches, tachometer
Orientation sensors	Gyroscope
Physical movement sensors	Accelerometers
Biosensors	Pulse, galvanic skin response measure
Vital sign processing devices	Heart rate, temperature
Wearable sensors	Accelerometers, gyroscopes, magnetometers

Transport later

The transport layer enables the communication between the physical and information worlds. Data collected by sensors is transmitted through a diverse range of communication technologies (Čolaković, 2018). Wi-fi, Bluetooth and cellular networks are some of the most common, however newer communication protocols such as LoRa are enabling low cost, low power and long-range networking seen as game-changing technology of IoT adoption (Pham, 2016). These gateway devices act primarily as networking devices, similar in function to WiFi routers which allow our devices to connect to the internet. A gateway device can connect to and aggregate data from numerous sensing layer devices and relay this to the processing layer, typically located in cloud hosted servers.

Processing layer

This layer receives the data from the sensing layer for storage and processing. Due to the large amounts of data that can be expected in IoT implementations, this layer has an important function of extracting useful information from the enormous volumes of data collected and provides and additional layer of security. This is the layer of databases and data processing modules which enable decisions to be made from the collected sense data (Wu et al., 2010).

Application layer

The application layer is responsible for providing services for the needs of the user, for example environmental monitoring or smart city applications. This layer makes use of the data being collected and implements the decisions from the data processing layer. This user centric layer is responsible for displaying the results of analysis or further engaging the physical world, essentially the front end of the IoT architecture and the actuating component of the system (Wu et al., 2010).

Business layer

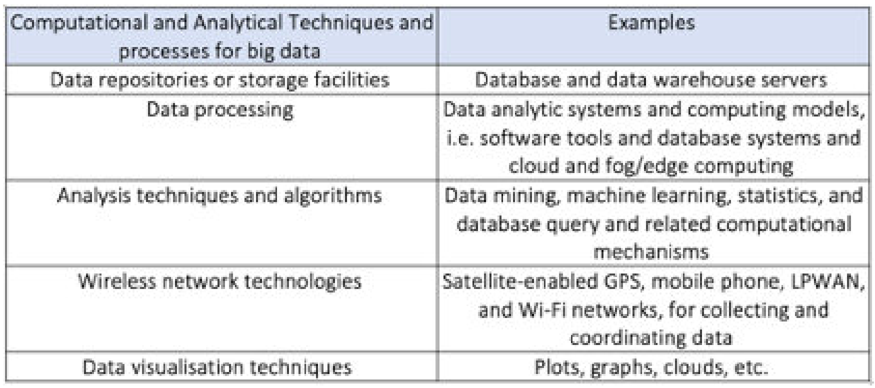
The business layer provides an overarching control of the IoT implementation as a component of the organisational strategy. Monitoring the functions of the IoT implementation, this layer focuses on aligning the actions of system to the objectives of an organisations business model. The business model must consider the who, what, how and why of the IoT implementation. ‘Who’ describes the target group the service is being designed for, ‘what’ refers to the value or solutions being provided to the target group, ‘how’ describes the ability for the IoT implementation to achieve the designed goals, and the ‘why’ describes the economic model underpinning the implementation. This layer demonstrates that the IoT application is a part of a wider functionality and purpose of an organisation (Wu et al., 2010; Burhan, 2018).

Big Data Collection and Analysis

Sensors distributed throughout urban systems in smart sustainable cities enable an immense amount of data to be collected. Big data is a term given to the collection, extraction, analysis and application of data from multiple domains. Big data is characterised by the massive nature and complexity of the data sets collected. The volume, velocity, variety, and flexibility of big data is such that standard analytical data software is unable to process it as it exceeds the computational capacity of ordinary systems (Katal, et al., 2013; Bribri, 2018; Bibri, 2020).

For knowledge to be extracted from big data sets and applied to decision making processes in a timely manner, advanced tools, techniques and technologies – algorithms, data mining, machine learning etc. - must be adopted and applied (Bribri, 2018). Table 2 outlines the key enabling technologies, analytical techniques and processes used in big data analytics in the context of sustainable cities.

Table 2: Big Data Enabling Technologies, Analytical Techniques and Processes (Adapted from Bibri & Krogstie, 2017)



Computational and Analytical Techniques and processes for big data	Examples
Data repositories or storage facilities	Database and data warehouse servers
Data processing	Data analytic systems and computing models, i.e. software tools and database systems and cloud and fog/edge computing
Analysis techniques and algorithms	Data mining, machine learning, statistics, and database query and related computational mechanisms
Wireless network technologies	Satellite-enabled GPS, mobile phone, LPWAN, and Wi-Fi networks, for collecting and coordinating data
Data visualisation techniques	Plots, graphs, clouds, etc.

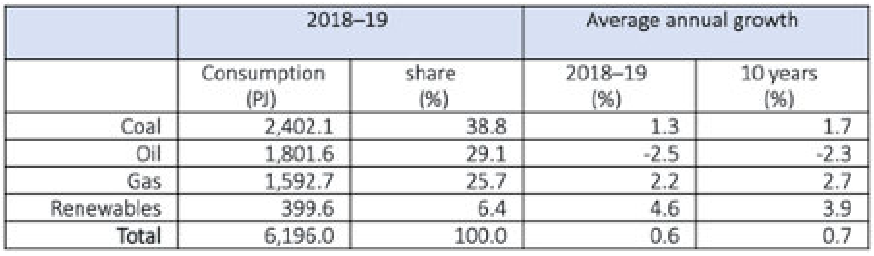
Technology Solutions

The pervasiveness of technology in the urban environment, enabling integration between physical objects and people, create an extremely diverse range of applications. Technology has been identified as an integral tool for cities aiming to progress towards a sustainable future (Wang & Moriarty, 2018). With a focus on Australia, a review of such technologies, some of which are starting to reach maturity, and some which are only beginning to demonstrate thier potential has been undertaken.

Energy

Energy is vital to almost all functions of a modern society, utilised for lighting, heating, cooling, transport, cooking and to power ICT devices. In Australia, almost 93% of the nation's energy came from burning of fossil fuels in 2018/19 (table 3). The trends in average annual growth of energy consumption (table 3) clearly indicate that the energy portfolio of Australia is shifting as the uptake of renewable energy increases and the use of oil, gas and coal reduce. With over 70% of the Australian population residing in urban areas and this number predicted to increases, this data poses two major challenges for the modern sustainable city, 1) How can energy consumption be managed in order to reduce emissions? 2) How can the transition from fossil fuels to renewable energy be managed effectively? Recent developments in technology offer solutions to these problems, which are introduced and discussed in this section.

Table 3: Australian Energy Consumption – By Fuel Type (Adapted from Department of Industry, 2020)



	2018–19		Average annual growth	
	Consumption (PJ)	share (%)	2018–19 (%)	10 years (%)
Coal	2,402.1	38.8	1.3	1.7
Oil	1,801.6	29.1	-2.5	-2.3
Gas	1,592.7	25.7	2.2	2.7
Renewables	399.6	6.4	4.6	3.9
Total	6,196.0	100.0	0.6	0.7

Smart Grids

The transition away from carbon intensive fuel sources is becoming a necessity from both economic and environmental perspectives. The renewable technologies driving this transition have characteristics in stark contrast to conventional power generation. Distributed rather than centralised and intermittent rather than constant, the intense implementation of these technologies requires an efficient and advanced management of the energy grid (Nižetić, 2020). Smart grids enable the two-way flow of data and electricity, enabled by IoT technologies which can detect analyse and react to events in order to increase the efficiency and reliability of the electricity grid (Lund et al., 2012). Smart grids are also a necessary transition for the wide scale adoption of renewable energy, enabling decentralised energy generation (Nižetić, 2020).

Like all IoT implementations, smart grids consist of several layers of interconnected technologies. Sensors responding to electrical, physical or magnetic signals which transmit data through a network layer to the grid operator (Lund et al., 2012). These sensors monitor equipment such as power lines and transformers, and record data related to the performance and characteristics of components. This data is transmitted to data assemblers and assessors, collecting and displaying information. Smart grid technologies identify and prevent power outages and optimise energy distribution (Cooper, 2016). They also enable associated urban sustainability technologies, including virtual power plants (VPP) and microgrids.

Virtual Power Plants & Microgrids

VPPs and Microgrids are both approaches to managing decentralised grid resources. Both aim to improve grid resilience and increase efficiency of energy distribution. Microgrids operate as a distinct section of the electricity grid, geographically defined, that can operate autonomously from the main grid (Lasseter, 2011).

Microgrids contain all the components of a conventional grid, generally multiple sources of power generation, storage and consumption. As microgrids are designed based on the local production and delivery of electricity, the objectives of the grid can be optimised for efficiency in that context. Similarly, VPPs manage the distribution of decentralised power. Though instead of focusing on a defined geographical region, VPPs aggregate power for different resources using monitoring and software technology to respond to fluctuating demands (Zia, 2018). In VPPs and microgrids, IoT technologies are incorporated to autonomously schedule loads, detect faults and improve the efficiency of the energy consumption (Phung, 2017)

VPPs provide sustainability benefits and encourage adoption through economic incentives to both the consumer and the owner. Encouraging the use of energy efficient appliances and incentivising the use of renewable energy, VPPs were shown to reduce the costs of energy by 24% in a Western Australian case-study (Behi, 2020) and the aggregation and efficiency benefits of VPPs in German examples show that revenue for VPP owners increases by 11% to 30% (Loßner, 2017).

Increasing adoption of distributed solar energy generation, residential and commercial and advancements in storage technologies have driven investments into pilot projects across Victoria. The Victorian Government's Microgrid Demonstration Initiative, announced in 2017, has funded more than $27 million worth of projects to test and demonstrate the abilities of VPPs and Microgrids. However, Victoria still lags other states leading the progression towards smarter grids. South Australia, with the big-name initiatives including the Tesla VPP delivering 10MW of distributed energy (Parkinson, 2020), and AGL in the final stages of completing a 5MW VPP project (ARENA, 2020), eclipse event the planned Victorian commitment (DEWLP, 2020)..

Meters

One of the critical competent of a smart grid is the smart meter, which enables two-way communication about energy demand and usage. Aside from energy, smart meters also collect data on water and gas consumption, providing information enabling optimisation of resource consumption. Smart meters encourage energy efficiency from users, changing user behaviour, by delivering real time resource consumption data, as opposed to the monthly accumulation in conventional metering (Nižetić, 2020). Studies on energy consumption patterns dating back to the 1970s have shown that feedback to consumers have demonstrable effects on consumer behaviours (Davies, 2020).

Building efficiency

Dense urban environments are characterised by buildings. The environmental impact of urban areas is in large part determined by contribution of these buildings. In the City of Melbourne, over 50% of all carbon emissions are attributed to existing buildings (City of Melbourne, 2020), improving the efficiency of buildings will play a significant role in urban sustainability.

The economic motivation for improving the efficiency of buildings can be significant. One example, a building in Sydney achieved a 48% reduction in energy usage, saving over $500,000 pa), primarily through upgrading the building management and control systems along with improved strategies for controlling the heating, ventilation, and the air conditioning system (Burroughs, 2010). With up to 80% of a building's energy use attributed to HVAC and lighting (Cellucci, 2015), managing and monitoring these services through sub-metering has substantial benefits to the resource sustainability of a building.

IoT technologies supporting building sustainability becomes more important as the complexity of buildings increases due to the proliferation of services such as electric car charging, renewable energy generation and storage capacity technologies (Moreno, 2014). IoT allows for the analysis of the main components of energy consumption on a granular scale. Energy systems can be optimised to the usage patterns and profiles identifies with this data (Davies, 2020). Energy metering assists with detecting inefficiencies in energy systems, provides benchmarking of energy usage, improves load planning and manages energy demands to increase system reliability. Additionally, comprehensive environmental monitoring and energy metering encourages energy efficiently across all building stakeholders including the tenants, owners and operational managers (Ahmad, 2016).

In Australia, rating systems for building sustainability (eg. Green Star & NABERS) have set the standards for efficiency. These systems encourage the optimisation of resource consumption and provide benchmarking across the industry (Doan, 2017). IoT technologies are increasingly implemented to support these rating systems, turning the countries buildings into smart and sustainable buildings. Currently less than 1% of the buildings in Australia are considered smart buildings, though this is an area of rapid development for IoT sustainability driven by the advancement of connected sensors and the increasing adoption of sustainability ratings for buildings (IoT, 2017).

Water

The water cycle is a crucial component of the urban environment and is intrinsically linked with to a city's operations through housing, health, recreating, water management energy and economic development. Increasing density of urban areas flows on to an increasing demand on water sources. Water sustainability needs to be managed in four key areas of risk: water shortages, quality risks, water excesses and maintaining the resilience of water ecosystems (Johannessen, 2017). Technology presents opportunities to increase the productivity and efficiency of water resources, contributing to the sustainability of the urban environment.

Layers of water technologies in urban environments working together can significantly decrease system losses and improve the management of wastewater and storm water (Leigh & Lee 2019). Similar to other IoT implementations, water technologies rely on a physical sensing layer to acquire the data about services and usage, which is then transmitted for analysis and modelling which informs decision making and controls. The overlapping functionalities provide reliable data enhancing the ability for the system to respond to events and deliver service.

Pipes and sensors

Modern pipes are designed with sensing technologies which can detect changes in temperature, pressure and other anomalies, and analyse the volume and quality of water flows (Sadeghioon et al., 2014). When connected through networking technology, this information can be analysed in real-time to enable the efficient detection of leaks. Networks of sensors provide an additional layer of analysis, detecting changes in soil moisture, the acoustic signature of pipes and fluctuations in flow rates. When these sensors are combined with geographic information systems (GIS), system leaks can be identified, alerted and repaired more rapidly (Geetha, & Gouthami, 2016)

Sensors also provide the ability to manage water quality and health of freshwater assets. Conventional methods of manual testing are resource intensive and leave a lag between monitoring and actions. In-situ sensor networks detecting parameters of water quality, including pH, turbidity, conductivity, chemical oxygen demand and nutrient levels enhance the efficiency water quality management (Geetha, & Gouthami, 2016). Sensors are also used in the optimisation of irrigation by measuring humidity, air temperature, wind speed, rainfall and pressures, enableing the efficient allocation of water resources in areas such as parks or commercial irrigation systems (Goap et al., 2018).

Smart water meters

The lack of detailed information on when and where water is being consumed, or lost, creates inefficiencies in the water system, and a problem for both customer and water utilities. Mechanical meters provide a limited understanding of water use, and limit consumer empowerment to make sustainable water decisions. Undetected leaks, inaccurate metering and unaccounted water contributes to around 28ML of water leakage from urban systems in Melbourne alone (BOM, 2012).

As in energy sustainability, smart water meters allow the two-way communication between a meter and the central system of the utility. The meters consist of a sensor with a controller and a wireless communication device, connected to data loggers which take regular recordings of consumption. Urban applications of smart metering enable the remote monitoring of water consumption, illegal connections and leak detections (Boyle, 2013).

Water smart metering projects are primarily implemented through new development or pilot utility programs in Australia and have demonstrated several water conservations benefits. A 2016 project in NSW focused on providing water use information to households created changed consumer behaviours leading to water savings of around 8%. In another study in QLD, smart water meters were deployed to facilitate communication with households about potential post-meter leakage, resulting in baseline flow reductions of 89% (Randall & Keoch, 2019).

In Victoria, the Digital Metering Joint program brings together the three-metropolitan water utilities; City West Water, South East Water and Yarra Valley Water, to research and trial smart water metering technologies. The trials focus on the implementation of smart meters utilising the separate low powered wide access network technologies; LoRaWAN, NB-IoT and Wize, selected for their open standards, two-way communication, regular transmission abilities an ability for long operating lives (<10 years). An update on the project from January 2020 reviewing the effectiveness of around 3000 smart meter installations have identified savings of more than 40,000 L/day from leakage detection and repair, through the evidence on changed consumer behaviour is not yet conclusive (IoT Alliance Australia, 2020).

Waste Management

The efficient management of waste is a major challenge for modern sustainable cities. Urban populations are predicted to rise by approximately 15% by 2050 (UN, 2018), and it is predicted that over the same period, solid waste generation will increase by 30% (Kaza et al., 2018). Waste management is a catch all term that includes all phases; waste generation, collection and transport, separation, treatment, disposal and recycling (Aazam et al., 2016). The lack of an effective and efficient solid waste management plan can result in detrimental impacts on human health, contamination of the local environment, increased production of greenhouse gas emissions, increased odour and noise (Kaza, 2108; City of Melbourne, 2019). Application of smart technologies in solid waste management aim to increase efficiencies in the system improving timing of waste collection and disposal.

Intelligent Waste Containers (IWC) - Cloud Based Waste Management System

IWCs are an IoT based solution for municipal solid waste collection. By equipping bins with radio frequency identification (RFID) tags, sensors for waste level detection, actuators to close and lock the unit once full and wireless transmitter hardware, data can be relayed to waste collection authorities. This technology creates efficiencies and optimisation in the waste collection routes (Chowdhury & Chowdhury, 2007). IWCs can also be installed with internal waste compactors which can reduce the frequency of emptying (SBA, 2019). The IoT connects IWCs to the control centre where an optimisation software can process the data and develop efficient management routes for waste collection fleets based only on IWCs that are full (Zanella et al., 2014). An efficient waste collection route based on data collection can reduce emissions of greenhouse gases in two ways, 1) reducing the frequency of emptying and hence reduction in distance travelled by waste collection fleets, 2) reducing traffic due to efficient route planning and reduction of collection vehicles on the road.

Intelligent sorting machines (ISM)

ISMs can create massive efficiency gains in the recycling centres of urban environments. Through the application of optical or robotic sorters, ISMs are capable of sorting 65 recyclable items every minute. The ISMs use machine learning to evolve and adapt to new waste streams and materials while operating 24 hours a day (Infrastructure Victoria 2019). This technology can be improved with upstream implementation of smart recycling containers, which are able to identify and pre-sort recyclables by harnessing AI, machine learning and cameras to identify types of waste.

The collection containers, using IoT can communicate estimates of waste types and masses to central recycling centres (Matchar, 2017). These systems can increase the efficiency and effectiveness of the recycling process, lowering costs and increasing yield.

Melbourne is Australia's fastest growing city which has seen its waste generation double in the past 20 years. Melbourne directed the majority of it's recyclables to landfill last year as previous arrangements to export the states recyclable materials to China were unable to continue due to policy change in China (City of Melbourne, 2019). A new recycling plant has been developed by Advanced Circular Polymers, though there is no technical specifications available which detail the technology utilised. The opportunity exists for Melbourne and Victoria to implement advanced recycling, cloud-based systems as it rebuilds its recycling capacity from the ground up. The is already the basis for the uptake of cloud-based waste management in Melbourne. As of 2018, the city of Melbourne adopted Ecube smart bins throughout the CBD. 397 Ecube IWCs were installed in 2018. These units compact trash, reducing collection frequency by up to 80% (Ecube Labs, 2018). The IWCs utilise IoT technology to signal waste disposal units when they are nearing capacity, resulting in lower emissions and less traffic. Current practice in Melbourne still remains for contracted workers to drive down every street in Melbourne's residential areas, collecting every bin, weekly, regardless of how full it may be (Rybnytska etal., 2018). The opportunity exists for IWC systems to be expanded to residential waste collection, which would allow Melbourne to move toward a truly smart sustainable solid waste collection strategy.

Discussion

This research demonstrates there are a number of factors influencing the adoption of technology. The economic driver is a significant force in the rapid adoption of building sustainability and water infrastructure management technologies. In both examples, the commercial driver to reduce costs and improve efficiencies is creating incentives to transition to newer, more competitive technologies. The economic incentive is an important component for sustainability adoption, especially in commercially active urban areas. The economics are driven sometimes by cost-savings, as in the case of smart water pipes reducing water losses, and in response to changes in consumer behaviour. The case of smart and sustainable buildings is partially driven by the desire to reduce costs by implementing energy efficient strategies, and to satisfy the changing market demands for healthier spaces (Petrillo et al., 2018).

In Australia, these changes to consumer expectations can be partly attributed to government initiatives such as the Commercial Building Disclosure (CBD) program which promotes the disclosure of energy efficiency information on buildings. The CBD receives some credit for reducing the average energy use in buildings by more that 20% from 2010-11 to 2018-19 (Centre for International Economics, 2019).

Governments have a further role to play in the adoption of sustainable technology in urban areas, as seen in the regulatory response which required the installation of smart meters across Victoria. This approach to force adoption of technology has mixed results. Smart meters were installed in all homes at a cost of more than $2.2billion, which was to be offset from the benefits from both the efficiency gains in the distribution system and the behaviour changes driven by access to improved data. A report from the Victorian-Auditor General from 2015 found that this benefit was far from fully realised (Doyle, 2015), though the widespread installation of these devices is likely to benefit the continuing development of grid management solutions such as microgrids and VPPs.

The underlying technologies for many of the applications discussed in this paper are sufficiently mature from a technology perspective to be contributing to sustainability efforts in urban areas. However, as described in a 2020 report from KPMG, “Smart sustainable cities is a journey. Not a final destination” (KPMG, 2020). Urban areas are a complex web of infrastructure, competing priorities and existing governance arrangements. Retrofitting urban areas with technologies to enhance sustainability is a continuously evolving process. The maturity of technology isn't necessarily the primary issue for many sustainability applications, rather strong policy and governance should focus on identifying and supporting the unique needs of a particular urban area to ensure successful implementation.

The use cases presented in this paper demonstrate the ability for IoT contribution to sustainable outcomes in urban areas. IoT is a potential game-changer for sustainability enabling the remote monitoring and measuring of things in the environment that were previously unconnected. The World Economic Forum estimates that 84% of IoT deployments are currently addressing or have the potential to address sustainable development issues (World Economic Forum, 2018). As the cost of these technologies decrease, the frameworks for adoption mature, and customers' expectations trend towards sustainable outcomes, the incentives for widespread adoption will become stronger.

Technology is becoming increasingly advanced, and this is enabling us to build more complex, multidimensional systems. However, the ability to respond to and manage this complexity is increasingly beyond our scope (Barile, 2018). IoT has the ability to manage complexity and optimise for efficiencies. Deep connections with people and objects are not possible to the same extent with other approaches to sustainable technology. IoT unlocks information about the physical environment of our urban areas, and valuable insights can be inferred about how things work. This deep understanding facilitates the development of real-world applications which seek to optimise our use of resources, enabling smarter decisions to improve the sustainability of urban environments (Gil et al., 2019).

In Australia, there is still a great deal of work to be done in improving the efficiency of the built environment and efficiently managing resources. Melbourne is ranked 81st among cities for environmental sustainability (Arcadis, 2018), a drop of 32 places from 2016 and the lowest ranking of any Australian city. While Melbourne places well on the index of smart cities, this is largely attributed to the economic and human indicators of smart cities (Tariq et al., 2020). Melbourne's performance in environmental indicators of smart cities, eg energy initiatives and environmental management, demonstrates an average performance (Figure 8)

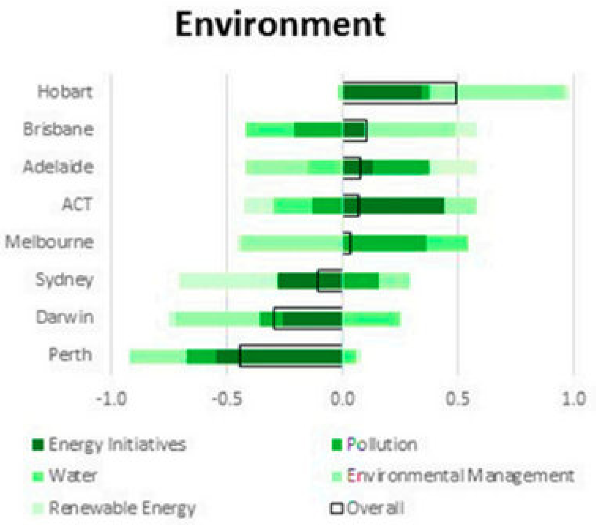


Figure 8: Environmental smart city performance (Tariq et al., 2020)

The primary focus in Australia and Melbourne should be to encourage the adoption of sustainable IoT technologies. Structural incentives to prioritise sustainability in the development of IoT projects has the ability to maximise the sustainable impact of the project. Market forces will eventually require the adoption of these technologies as the economic incentives are tilted in their favour, however, to promote rapid transformation some Government interventions are necessary. In fact, Government incentives are the preferred option to encourage the quick adoption of IoT sustainability (Figure 9).

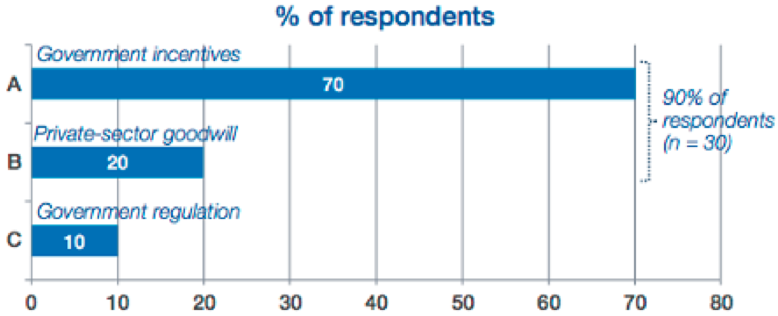


Figure 9: Preferred mechanism to encourage sustainability at the design phase of IoT projects (World Economic Forum, 2018)

In addition to government incentives to encourage adoption from industries, Governments have a necessary role in addressing infrastructure issues which facilitate the scale of adoption required. The smart energy meters rolled out across Victoria may have provided a less than expected initial benefit from reduced maintenance and behaviour changes (Doyle, 2015), however this has created a basis for future energy initiatives such as VPPs and microgrids. The adoption of smart water meters is significantly less advanced, though could the widespread access to this data and control provide the basis for future large-scale water sustainability initiatives? Services are not possible without having infrastructure in place first. Government should take the lead in this 'chicken-and-egg' dilemma to identify and provide necessary infrastructure to enable business models to adopt IoT approaches.

Conclusion

Urbanisation is one of the most significant trends in the world today. Increasing population is set to create a range of challenges in urban areas from housing and job availability to water contamination and air pollution. The increasing pressure on resources and ecosystems has the potential to deliver substantial negative environmental impact. It is now the responsibility of engineers, scientists, governments and the private sector to ensure that this is managed in a sustainable way. Technological advancement is increasingly at the forefront of urban sustainability initiatives, and 'smart city' concepts are a dominant focus in this discussion. Smart cities are enables by the Internet of Things (IoT), a connected network of monitoring and measuring devices capturing vast quantities of data about the physical world. This paper set out to investigate the potential for technology, and specifically the IoT to enhance the sustainability of urban environments. Through a review of the available literature on urban sustainability and IoT technology we sought to answer the following questions:

- What contribution can the Internet of Things have in urban sustainability?
- What are the main mechanisms for the adoption of sustainable practices and technology?
- What are the main challenges for the development of smart sustainable cities over the next 5-10 years?

Undoubtably, the use cases presented in this paper demonstrate the ability for IoT technology to have a significant and wide-ranging impact on urban sustainability. Water conservation, energy efficiency and waste management are three core areas of environmental sustainability that are being enhanced through IoT technology. Some approaches, for example smart energy metering and building efficiency, have progressed further in the Melbourne context that others, for example smart water metering. The reasons for variation in technology can be attributed to differences in the disruptive capacity of technology factors summarised by summarised by Miller et al. (2019). Economic forces have thus far incentivised the adoption of technology in these areas, supported by some government incentives and regulation. Market forces will eventually lead to the adoption of many of the lagging and yet to be developed sustainability technologies as the economic imperatives increase. However, to respond to the challenges posed by growing urbanisation, and to enhance Melbourne's status as a smart sustainable city, rapid adoption of further sustainability technologies should be kick-started by initial government incentives.

To explore these issues in a structured way, please reach out to the skilled team at *ecomon*
www.ecomon.com.au

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