Horizon Scanning Series

The Internet of Things

Some Environmental Sustainability Concerns about IoT-enabled Smart Cities

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Suggested Citation

Foth, M, Mitchell, P, Mann, M, Rittenbruch, M and Anastasiu, A, (2019). Some Environmental Sustainability Concerns about IoT-enabled Smart Cities. Input paper for the Horizon Scanning Project "The Internet of Things" on behalf of the Australian Council of Learned Academies, www.acola.org.

Introduction

Digital innovation has been playing an increasingly significant role socially, economically as well as across all three levels of government, policy and regulation. Since 2016, the Australian Government – first through the Department of the Prime Minister and Cabinet and now through the Department of Infrastructure, Transport, Cities and Regional Development – has been running the $50 million Smart Cities and Suburbs Program[1] (Australian Government, 2017), which has been invested in the rollout and deployment of IoT infrastructure and associated data analysis facilities.

In parallel, Australia announced its ratification of the Paris Agreement on 10 November 2016,[2] which is concerned with the reduction of greenhouse gases in order to tackle the climate emergency. After the 2005 Kyoto Protocol, the 2016 Paris Agreement as well as The New Urban Agenda endorsed at the 2016 UN Habitat III conference[3] were major milestones in linking smart cities to sustainable growth under global trends of increasing urbanisation and resource scarcity. While there is no commonly agreed-upon definition of the "smart city," there is largely agreement in the literature that a key element of the smart city agenda is about using information and communication technology (ICT) to monitor, manage, and optimise city services (Trindade et al., 2017; Yigitcanlar, Kamruzzaman, et al., 2019). Afforded by big data analytics and urban science, the premise of such optimisations is about maximising economic productivity, human well-being and liveability, and environmental sustainability through more efficient use of energy, transport, food, and other urban infrastructure and resources (Choi, Foth, & Hearn, 2014; Farr-Wharton, Choi, & Foth, 2014; Filonik, Medland, Foth, & Rittenbruch, 2013; Foth, Schroeter, & Ti, 2013).

The Internet of Things (IoT), a similarly broad and contested concept, is an umbrella term referring to digital devices, sensors, and related hardware that are connected to the internet – these days usually through LoRaWAN (Long Range Wide Area Network) networks (Andrejevic & Burdon, 2015; Manwaring, 2017). The deployment of IoT underpins optimised and efficient urban management through automation, as it creates an "open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in [the] face of situations and changes in the environment" (Madakam, Ramaswamy, & Tripathi, 2015, p. 165).

Smart Cities, Sustainability and Rebound Effects

Sustainability in cities is increasingly driven by aspirational goals regarding efficiency gains in resource consumption. Vehicles in public transport systems use less fuel than their predecessors. Green star rated buildings use less energy than buildings of comparable size that do not have efficiency strategies, such as automated heating and cooling systems and lighting, built into their design.

[1] https://www.infrastructure.gov.au/cities/smart-cities/

[2] https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1718/Quick_Guides/ParisAgreement

[3] http://habitat3.org

Within the smart cities and IoT domain, a similarly efficiency-focused approach prevails, one that assumes more efficient resource use will result in a net reduction in overall consumption of that resource. Yet, in both contexts, the potential “rebound” or unintended effects of efficiency measures are not widely considered. For example, smart parking or traffic control may reduce energy use and greenhouse gas emissions for particular car trips in specific areas, but improved travel and parking conditions might encourage more car trips overall, leading to a total increase in energy use and emissions (Wang & Moriarty, 2019). Improved convenience for travel by car may also lead to a decrease in the use of public on non-motorised transport options, in spite of their better environmental footprint (Foth, 2018b). Significant investments in IoT-enabled smart grids may increase energy delivery efficiency and reduce distribution losses (Gellings, 2009), but may – counterintuitively according to the efficiency-focused approach to sustainability – lead to an overall increased energy consumption at the macro level (Kovacic & Giampietro, 2015).

The counterintuitive effects of efficiency measures have long been noted as an efficiency paradox. In the 1980s, economists Daniel Khazzoom and Leonard Brookes independently postulated that – in the context of energy consumption – increased energy efficiency would paradoxically lead to increased overall consumption. Since the 1990s, this *Rebound Effect* has been known as the *Khazzoom-Brookes Postulate* (Saunders, 1992). This postulate is in turn an updated version of the *Jevons Paradox* (Alcott, Giampietro, Mayumi, & Polimeni, 2012), proposed in the late 19th century by economist William Stanley Jevons, who observed that improved efficiencies in the steam engine, requiring the use of less coal, paradoxically increased the demand for and use of coal.

The fact that energy efficiency and sustainability measures produce counterintuitive rebound effects that offset expected gains has long been known, and yet this is regularly downplayed or ignored in smart city and IoT discourse surrounding sustainability objectives. Researchers have suggested ways that these rebound effects might be adequately addressed.

“According to the Jevons paradox explained above, increases in efficiency in the short term may lead to an increase in electricity consumption in the long term (Polimeni, Mayumi, Giampietro, & Alcott, 2008). [...] The Jevons paradox can be interpreted as a heuristic tool that makes it possible to highlight the high levels of uncertainty (indeterminacy) linked to changes in complex adaptive system. Complex adaptive systems respond to changes in conditions and in context (such as increased energy availability from energy savings) leading to a change in the organisation of the system itself. In other words, complex adaptive systems can be defined as far from equilibrium (Snowden, 2011). On the contrary, the efficiency argument is based on a static representation of the system, where energy savings do not affect the performance of the system.” (Kovacic & Giampietro, 2015, p. 72)

Gossart (2014) conducted a review of the ICT literature and found several suggestions of ways for addressing the rebound effect: (a) efficiency strategies should not solely rely on technological change but should be complemented by sufficiency strategies; (b) deployments should be accompanied with education, awareness and behavioural change strategies on the consumer side; (c) both energy efficiency evaluations and life cycle assessments should account for rebound effects, and; (d) efficiency evaluations need to stop focusing on individual products and look at the broader picture, even if the difficulty of finding data makes this challenging.

Adopting a Holistic Ecology Perspective: More-than-Human Smart Cities

The sustainability trajectory of Australian cities and their collective response to the climate emergency will not be directed towards a sustainable urban form that meets the expectations of the UN Intergovernmental Panel on Climate Change if strategies are limited to efficiency gains only. Australian cities driven by a technocentric approach may invest in smart technology such as Internet of Things (IoT) devices and sensors, as well as the required ICT backend infrastructure, data centres and cloud computing capabilities. Such investments may produce the aforementioned efficiency gains, and to date many ICT and design approaches were also predominantly focussed on user and consumer-centric approaches to sustainability (Paul Dourish, 2010; Foth, Paulos, Satchell, & Dourish, 2009; Paulos et al., 2008). However, genuine sustainability requires a holistic ecology perspective (Foth, 2018a; Yigitcanlar, Foth, & Kamruzzaman, 2019).

"Information and communications technology, data and networks have an important place in our shared urban future. But this future will be determined by our attitudes toward these technologies. We need to make sure that instead of being short-term gimmicks to be thrown away when their novelty wears off, they are thoughtfully designed, and that they put the needs of citizens and environments first." (Sawyer, 2018)

The call to put citizens first has been echoed by various commentators not just in response to the release of Australia's Smart Cities Plan (Foth, 2016) but also in response to the technocentric deployment of smart cities (Foth, 2018a; Foth, Hudson-Smith, & Gifford, 2016; Mattern, 2017). However, Sawyer's call to put *both* citizens *and* the environment first rightly questions human exceptionalism and requires a new, post-anthropocentric paradigm in the design of cities and smart cities to be considered that re-conceptualises humanity's entanglement with nature and planetary health. Forlano (2016) describes this process as 'decentering the human in the design of collaborative cities.' Questioning humans as the exclusive inhabitants of the built environment allows designers to consider a more inclusive and encompassing worldview. This post-anthropocentric perspective requires a re-think of how human-centred design and architectural methods to build smart cities can become more-than-human (Abrams, 1996; Clarke et al., 2019; Foth & Caldwell, 2018) using world-centric design methods (Foth, 2017a; Luusua, Ylipulli, & Rönkkö, 2017; Smith, Bardzell, & Bardzell, 2017).

These debates around new posthumanist approaches to design (Forlano, 2017) are embedded in a larger debate around the ethics and responsibilities of the design sector and the digital technology industries (Monteiro, 2019).

Assessing the Environmental Impact of IoT-enabled Smart Cities

In addition to the considerations of smart cities and sustainability as outlined above, we turn to discussing more specific environmental issues related to IoT devices and systems. At the core of common understandings of smart cities lie both hard and soft infrastructure that are used to collect, distribute, analyse and act upon information in the distributed network of IoT.

Its environmental implications, therefore, need to be considered not only in relation to hardware, e.g. smart devices, sensors or data storage, transmission and computation infrastructure, but also software that autonomously evaluates, learns from and responds to available data, or those that make predictions, or more broadly recent developments in Artificial Intelligence (AI) and machine learning.

Additionally, there is a mutually shaping and interdependent relationship between culture and technology (Herdin, Hofkirchner, & Maier-Rabler, 2008). The widespread adoption of smart city hardware and software shapes individual and collective behaviour, as well as institutions, industries, and their policies and practices, which in turn shape hardware and software. The sustainability impacts of IoT devices and systems need to be considered in relation to any potential unintentional negative environmental effects due to socio-cultural changes in response to IoT technologies, such as rebound effects – as outlined above.

Environmental impacts of IoT devices and systems in smart cities should be considered with regards to their entire lifecycle, including production, distribution, operation and disposal, as well as the socio-cultural effects of their deployment. In the following, we unpack some of these aspects.

Demand for Minerals

In addition to the socio-political conditions of manufacture that often involve child labour, low pay, unsafe environments, systematic oppression,[4] the environmental and sustainability related impact of manufacturing IoT devices is great. The production of IoT devices requires a significant amount of raw natural resources, including metals such as copper for wiring and cabling of electrical components and cobalt for lithium-ion batteries. Significant mining of minerals occurs in regions with little or no legislation and enforcement of social and environmental protection regulation, such as Sub-Saharan Africa.[5]

The mining sector in such regions has a track record of contaminating water and soil with heavy metals and hazardous substances, or causing air pollution, e.g. with sulfur dioxide affecting the suitability of habitat for flora and fauna as well as human health, and which also acts as a precursor to acid rain. While significant investment in the mining sector has reduced environmental contamination through the modernisation of extraction and processing facilities (OECD, 2002), the demand for these raw materials continues to rise, increasing the risk of contamination and thus environmental degradation (Bleischwitz, 2014; Finch, Borst, & Hutchison, 2019).

While the miniaturisation and technological innovation of IoT hardware can reduce the amount of raw resources per device, it is unlikely that miniaturisation will result in the reduction of total material demand at the macro level (Köhler & Erdmann, 2004). The increasing number of devices produced will counteract any positive consequences of miniaturisation of technology (Hilty, Som, & Köhler, 2004), as integrated smart city systems

[4] Forced labour is central to the Chinese economic miracle
https://www.theguardian.com/commentisfree/2013/oct/14/forced-student-labour-china-apple
https://www.abc.net.au/4corners/xinjiang-tell-the-world/11350450

[5] Unregulated and harmful cobalt mining in the congo to produce lithium ion batteries for IoT and personal devices: https://www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/

continue to require the parallel operation of an increasingly large number of networked components.

Vendor Lock-In, Planned Obsolescence and Virtual Wear-Out

The demand for raw materials is at risk of multiplying if the service life of IoT devices is not maximised. Halving the lifespan of an IoT-enabled object can double the consumption of raw resources. While street assets and urban infrastructure objects are traditionally built from robust materials, their augmentation with IoT capabilities through retrofitting is costly, and can pose technical compatibility issues. This requires the complete replacement and disposal of the otherwise functional infrastructure. This new IoT-enabled infrastructure also risks replacement before the technically possible lifetime of its components, e.g. hardware no longer providing latest data sensing capabilities or compatible data transmission protocols may require the complete replacement of the smart lamp post which hosts it. The smart city operates in a perpetual beta stage (Fredericks, Caldwell, Foth, & Tomitsch, 2019).

A number of factors can lead to this, such as: (a) attempting to break out of vendor lock-in, that is, the associated lack of interoperability with other hardware, software, and data platforms (Anastasiu, Foth, Schroeter, & Rittenbruch, 2020; Robinson, Rittenbruch, Foth, Filonik, & Viller, 2012); (b) short innovation cycles can lead to incompatibility issues between hardware and software, leading to a virtual wear-out before a physical wear-out (Hilty et al., 2004), and; (c) short innovation cycles can also lessen a long lifespan in technological products while planned obsolescence means that newer products are released sooner and are more desirable to their predecessors, which is exacerbated by IoT manufacturers not willing to cover the higher costs for making products durable and long-lasting as well as repairable (Wilson, 2019).

Product Disposal, Recycling and E-Waste

The improper disposal of IoT devices or accidental damage of IoT devices installed in smart cites can cause environmental contamination with toxic substances. Furthermore, the entanglement of small electrical components with other recyclable and non-recyclable materials in one device makes waste separation difficult for consumers as well as institutional IoT owners. After their end-of-life, these devices are difficult to recycle and adequate recycling facilities are often missing, so they further contribute to the growth of e-waste dump sites in places such as China and Ghana.[6] While new recycling and resource extraction methods are being trialled for IoT and other digital devices (Voutsinos, 2018), the cross-contamination of e-waste and other types of waste continues to be environmentally harmful (Köhler & Erdmann, 2004).

Electricity Consumption

Smart city technology relies on cloud computing, which does not actually occur in the “cloud” but in data centres. These data centres currently consume more than 400 terawatt hours of electricity per annum (Whitehead, Andrews, Shah, & Maidment, 2014), which – together with other internet use represents about 10% of the global electricity usage (Jensen, 2019).

[6] China: https://www.theguardian.com/global-development-professionals-network/gallery/2016/oct/18/the-e-waste-reduce-waste-old-technology-mountains-in-pictures
Accra, Ghana: https://www.aljazeera.com/ewasterepublic/

The data captured by IoT devices in smart cities is increasingly fed into algorithmic analysis and machine learning processes, which are not only subject to critical assessments due to their lack of transparency and accountability (P. Dourish, 2016; Foth, Mitchell, & Estrada-Grajales, 2018; Kitchin, Coletta, Evans, Heaphy, & Donncha, 2019) but also due to the difficulty in rigorously assessing their energy consumption (García-Martín, Rodrigues, Riley, & Grahn, 2019).

Moreover, an increasing amount of data is required to ensure privacy, security and authenticity of data (Carron, Bosua, Maynard, & Ahmad, 2016; Peppet, 2014), which leads to deployment of new technology platforms such as blockchain and distributed ledgers (Damianou, Angelopoulos, & Katos, 2019; Foth, 2017b; Potts, Rennie, & Goldenfein, 2017). However, the demand for energy continues to increase as a result.

Conclusion

In summary, the deployment of IoT devices in smart cities for the purpose of driving sustainability outcomes is ironic. While the data captured from IoT devices in smart cities is said to drive sustainability strategies through efficiency gains – which on their own are insufficient to tackle the climate emergency (as discussed above) – the deployment of IoT per se in turn aggravates the planetary ecocide by worsening sustainability outcomes outside the smart city in other parts of the world.

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