

DRS2020
BRISBANE, 11–14 AUG
SYNERGY



Edge of Tomorrow: Designing Sustainable Edge Computing

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<https://doi.org/10.21606/drs.2020.293>

Abstract: Vaunted as the next frontier within the scope of the Internet of Things (IoT), Edge Computing (EC) is seen as a means to improve efficiency and privacy across IoT infrastructures. This is because it enables data to be processed where it originates, that is, at the so-called ‘edge’ of the network, this being within, or close to, individual Internet-connected devices. Consequently, EC is considered more secure than conventional processing methods as data need not travel over networks to and from the centralised ‘Cloud’. We argue that EC optimisation might also offer credible benefits for environmental sustainability, particularly regarding decarbonisation by minimising data-distribution. To make this case, we outline the creation of two integrated design fictions which highlight environmental harms resulting from widespread Cloud data management, as well as envisioning potential future sustainability advantages of Edge-based processing. Based upon our process, we put forward an initial model for *Sustainable Edge Computing*.

Keywords: Edge Computing; data; decarbonisation; Internet of Things

1. Introduction

The term *Internet of Things* (IoT) was first coined by Kevin Ashton (2009) in 1999 to describe the idea that any, and potentially every physical artefact, could be connected to the digital infrastructures of the Internet in order for it to be able to collect and share information. From voice activated smart speakers and fitness tracker wearables, to autonomous vehicles and vacuum cleaner robots, the IoT continues to expand at a staggering rate. Whilst global estimates vary regarding the current number of devices which make up the IoT, Statista (2018) contend that there are approximately 27 billion IoT products at present and predict that this number will increase almost threefold to around 76 billion by 2025.



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As we progress towards a denser and more complex ecosystem of IoT products, services and systems, it is extremely probable that *datafication* – the generation, processing and storage of both user and automated IoT data – will also increase dramatically in the near future.

Current estimates maintain that globally 2.5 quintillion bytes of new data are created every day (IBM, 2017). Goodbody (2018) states that this equates to 16 zettabytes of data globally every year with the potential to increase tenfold to 160 zettabytes by 2025. The ensuing growth in datafication will likely be accelerated by increasingly fast networks (for example, 5G) which will facilitate quicker data transfers across IoT infrastructures (Kenworthy, 2019).

Today, the ‘Cloud’ serves as the primary locus for IoT data management, processing and storage. Some believe however, that the Cloud, in its current form at least, will be unable to efficiently facilitate a more advanced, accelerated and demanding IoT infrastructure (Miller, 2018). It is posited that such issues can be alleviated by the development of improved *decentralised* and *localised* data management methods, specifically, those which occur at the ‘edge’ of the network, that is, where data is processed and stored closer to where it is first generated – that being either within the IoT’s physical devices themselves or, at the very least, in close proximity to such devices (Chakraborty & Datta, 2017). This alternate, nascent method for processing data has been termed *Edge Computing* (EC).

2. Cloud-Fog-Edge

Like *Cloud Computing*, EC is also intrinsically linked to *Fog Computing*. Figure 1 demonstrates the linkages and key differences between these three primary mechanisms through which IoT data is presently processed (PETRAS, 2019). In simple terms, the Cloud enables people to store data beyond the confines of their physical devices’ internal storage, often in very large quantities. For example, an *Apple iPhone* user might regularly ‘back up’ photos they have captured to *Apple’s iCloud* platform for safekeeping, while work colleagues situated in different locations might collaborate on shared documents through *Google’s Drive* service.

Importantly, although the Cloud is predominately referenced in terms of being a single *centralised* entity, Figure 1 illustrates that it actually manifests as thousands of interdependent *data centres*. The so-called *Big Five* tech firms (Simon, 2011; Sterling, 2014) – *Google, Microsoft, Amazon, Apple and Facebook* – have all developed sophisticated Cloud data centres, both to process and store data generated via their own IoT ecosystems, and to also manage data silos emanating from a host of competitor connected products and services. *Fog Computing’s* role in relation to the Cloud and the Edge could be described as acting almost like a ‘middleman’. The ‘Fog’ is essentially the network connections – millions of remote servers – which transfer troves of data between billions of IoT devices located at the edge of the network and thousands of Cloud data centres (CB Insights, 2018).

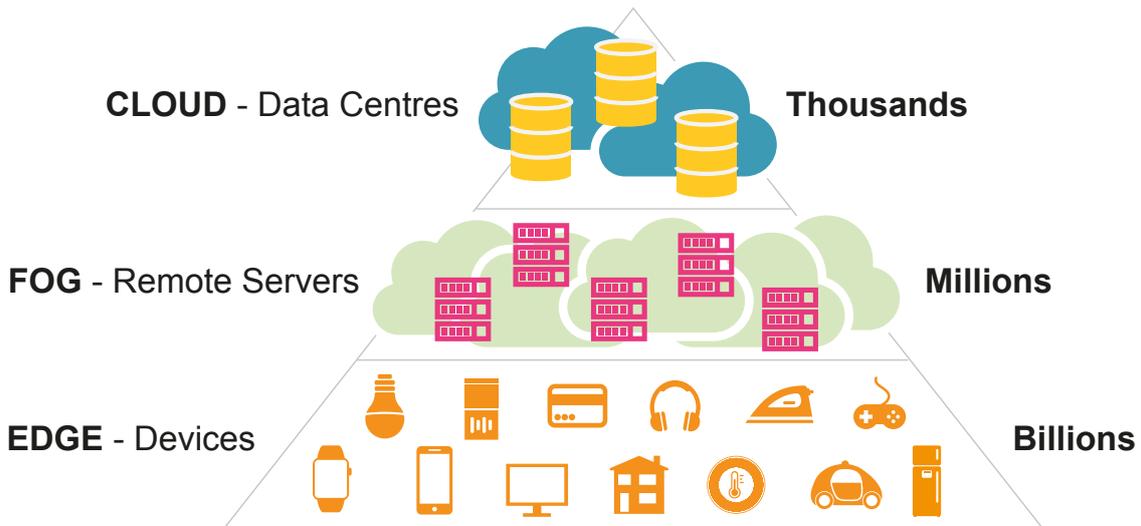


Figure 1 The relationships and contrasts between Cloud, Fog and Edge Computing (PETRAS, 2019).

3. Getting closer to the Edge

As it would still be required for some crucial operations, it is unlikely that EC would replace the Cloud in its entirety. However, the promise of EC is attracting considerable investment (MIT Technology Review, 2019). Two core debates seemingly sit at the heart of current EC research, namely the *efficiency* and *privacy* advantages of processing data at the edge. If devices were to begin to act as ‘micro data centres’, Kalal et al (2019) envision that the efficiency benefits for the IoT would be threefold – *accelerated processing*, *decongested networks* and *decreased latency*. EC’s *accelerated processing* for example, could be critical to safeguarding passengers and pedestrians lives in a future world where millions of autonomous vehicles are generating troves of data – the processing of which would likely overwhelm existing Cloud infrastructures (CB Insights, 2018; AECC, 2018).

Databox (Figure 2) is an Edge device that has been designed with built-in *privacy-preserving functionality*. Instead of automatically transmitting domestic IoT data to Cloud servers, the home router grants its users’ *control* of how their data is processed (Databox Project, 2019; BBC, 2019b). Consequently, *Databox* is a practicable example of a new strategy for IoT design which Mortier et al (2016) term *Human-Data Interaction* (HDI). Gradinar et al (2019) advocate that HDI can help address three key IoT privacy design challenges:

- *Legibility* ensures that IoT data processes are made clearly understandable to users;
- *Agency* ensures that users can easily use and store their data as well as manage third party access to it;
- *Negotiability* ensures that users are able to manage the social interactions that result from data processing and derive value for themselves.

We contend that in addition to *efficiency* and *privacy*, shifting data management away from the Cloud to IoT devices themselves could also provide tangible benefits for *environmental sustainability*, particularly with regards to reducing Cloud related carbon emissions.



Figure 2 The Databox home router is an Edge IoT data processing device (www.databoxproject.uk).

4. The Carbonised Cloud

The IoT is regularly couched in rhetoric which promises a future where our lives are made easier through increased datafication, affording us more time to do other things whilst our devices and services consume less energy and save us money. What is frequently absent from this narrative are discussions regards the tsunami of data which will be generated as billions of additional products and services become networked, and perhaps most importantly against the backdrop of a climate emergency, what the environmental impacts of this surge in datafication will be. As noted earlier, it is often easy to consider the ‘Cloud’ to be a single *benevolent* and *ephemeral* entity. Efoui-Hess (cited in Stone, 2019, para. 20) agrees, stressing how “the digital mythology is built on words like cloud... something that isn’t really real. That’s how we picture it.” Figures 3 and 4 help to further clarify that the Cloud is in fact an immense, permanent, physical infrastructure characterised by thousands of interdependent data centres – commonly referred to as ‘server farms’ – which host the Internet and manage its unrelenting dataflows. Similarly, because ‘data’ is not considered to be *visible* to the naked eye, it is often referred to as ‘immaterial’ and believed to be relatively harmless and of little impact, certainly in an environmental capacity. However, like the Cloud, we argue that data is in fact *in material* – it is stored within billions of physical IoT devices, within the labyrinth of cables that connect global computer networks, and within the plethora of aforementioned Cloud data centres. Further, alongside the embedded



Figure 3 The interior of a Cloud data centre or so-called ‘server farm’ (Laboratorio Linux, 2017, <https://creativecommons.org/licenses/by-nc-sa/2.0/>).



Figure 4 The exterior of Google’s data centre – ‘The Dalles’ – in Oregon, USA (Visitor 7, 2011, <https://creativecommons.org/licenses/by-sa/3.0/deed.en>).

energy and material resources that are used to manufacture connected devices (Stead et al, 2019a), the vast infrastructure upon which they operate consumes copious amounts of energy, generates large amounts of heat and releases prodigious amounts of carbon emissions – all of which actively contribute to climate change (Crawford & Joler, 2019).

Figure 5 seeks to visualise the relationship that IoT devices have with their data and the wider infrastructures to which they are connected. In short, data transactions are not just one simple transfer from user devices to the proverbial Cloud. Despite their apparent ‘immateriality’, IoT infrastructures are obscure and complex, and have a tangible and detrimental impact upon resources, energy and the natural environment. Thus, the unsustainable realities of what Strengers (2013) calls the *smart utopia* – the narrative which dominates mainstream technological discourse – are becoming clearer. Globally, Cloud data centres currently consume 200 terawatt hours annually – which is approximately the same amount as South Africa (Tarnoff, 2019). Andrae & Edler (2015) estimate that by 2030, Internet technologies will account for more than a fifth of the world’s electricity consumption. Meanwhile, French climate think tank *The Shift Project* (2019) state that widespread digitization is currently responsible for producing 4% of global carbon emissions; a figure which is likely to double by the 2025. Based upon these figures, use of digital technologies will soon eclipse the civil aviation industry in terms of both fossil-fuel derived energy consumption and harmful carbon emissions.

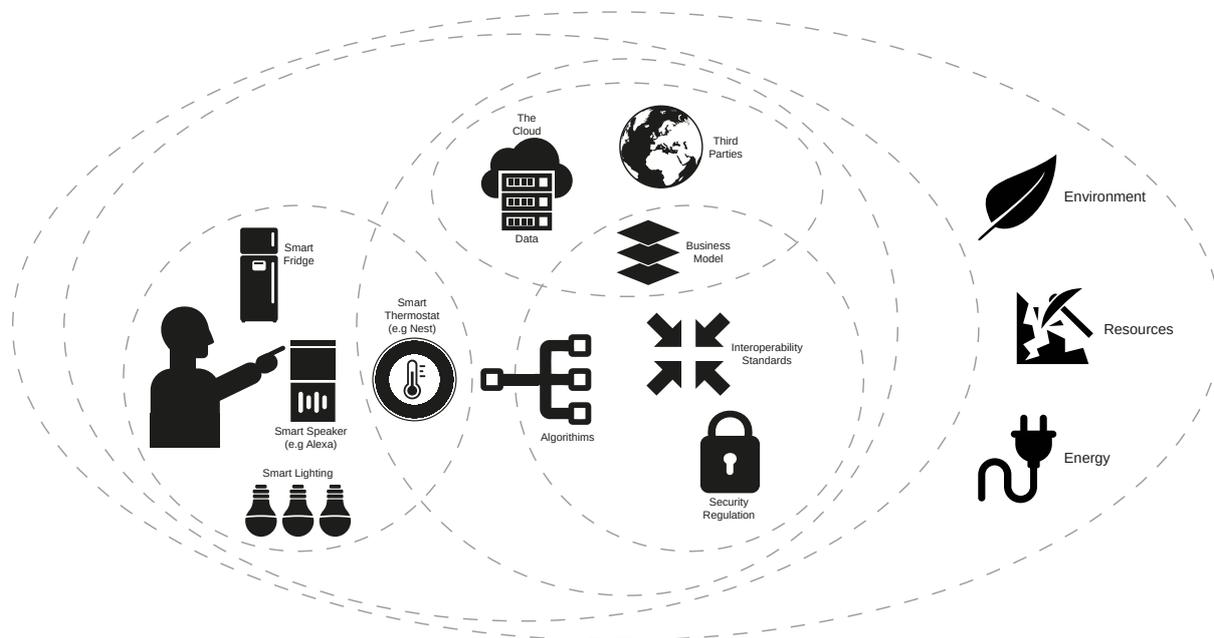


Figure 5 Visible and invisible things in an IoT enabled smart home system (Gradinar et al, 2019).

The United Nations (UN.org, n.d.) uses the term ‘data exhaust’ to describe how an enormous share of peoples’ data is “passively collected [and is derived] from everyday interactions with digital products or services, including mobile phones, credit cards, and social media.”

Peoples' limited understanding about unsustainable data production and distribution is in many ways analogous to the lack of societal awareness regards the damaging impacts that characterise the production and distribution of material goods. Berners-Lee (2010) drew attention to this issue by measuring the amount of carbon dioxide equivalent (CO₂e) for a variety of everyday objects and actions. For example, an individual orange will create 90g of CO₂e if transported by boat which increases to 1kg CO₂e if transported by air. Larger commodities such as a new 4x4 car creates 35 tonnes of CO₂e during its manufacture, while a single 5-mile drive in it creates as much as 22kg CO₂e (1 tonne per 45 miles driven). Berners-Lee also calculated average carbon metrics for several digital interactions including sending an email (4g CO₂e, increasing to 50g if an attachment is included), making an Internet search (between 0.7 and 4.5g CO₂e depending on computer's energy efficiency rating) and using a computer for 1 hour (around 63g CO₂e). While these figures appear innocuous in isolation, they quickly come into sharp relief when considered in relation to the growing proliferation of the IoT and its associated datafication. 2018 bore witness to 5 billion Internet searches, 500 million tweets, 294 billion emails, 65 billion *WhatsApp* messages and 4 petabytes of *Facebook* data (Desjardins, 2019).

To temper the growing carbonisation of the Cloud, Stone calls for radical transformation:

“We'll need to... find cleaner ways to power the web, and reimagine how we interact with the digital world. Ultimately, we need to recognise that our tremendous consumption of online content isn't free of consequences—if we're not paying, the planet is.” (Stone, 2019, para. 3).

Unable to ignore climate science any longer, many governments have begun to set ambitious mandates for decarbonisation (European Climate Foundation, 2018). Yet, such mandates do not call for reductions in data-driven emissions. Tarnoff concurs with Stone, arguing that in order for societies and governments to meet mandated decarbonisation targets, they must begin to 'decomputerise'. In his view, combating climate change will “require something more radical than just making data greener... we should reject the assumption that our built environment *must* become one big computer” (Tarnoff, 2019, para. 9). Such perspectives are routinely being undermined by other dominant voices which promote the almost Elysian benefits of adopting widespread 'smartness'. For example, Carmichael on behalf of the UK Government's *Committee on Climate Change*, cites increasing IoT datafication as:

“An important asset... for enabling consumers to make informed decisions about technology adoption (electric cars and heating)... product information and feedback on purchasing habits (diet)... for redesigning financial incentives for shifts in demand (diet and aviation) and change at the system level (diet)” Carmichael (2019, para. 7).

Despite these analytic advantages, such a narrative is ignorant of the deeply carbonised nature of IoT technologies. Moreover, it allows tech firms like the *Big Five* to press on regardless with their IoT implementation plans. For whilst *Google* has announced that it is committed to only using carbon-free renewable sources of energy to power its Cloud data centres (Google, 2018), the company has also been accused of funding climate change denial campaigns (Hamilton, 2019) – perhaps in order to slow the growing backlash regards its data

management's poor environmental credentials. In Figure 6, we have sought to illustrate the carbonised nature of present-day Cloud and IoT related infrastructures. Our visualisation also emphasises the inconsequential role that EC currently plays across these networks in regard to decarbonising IoT data.

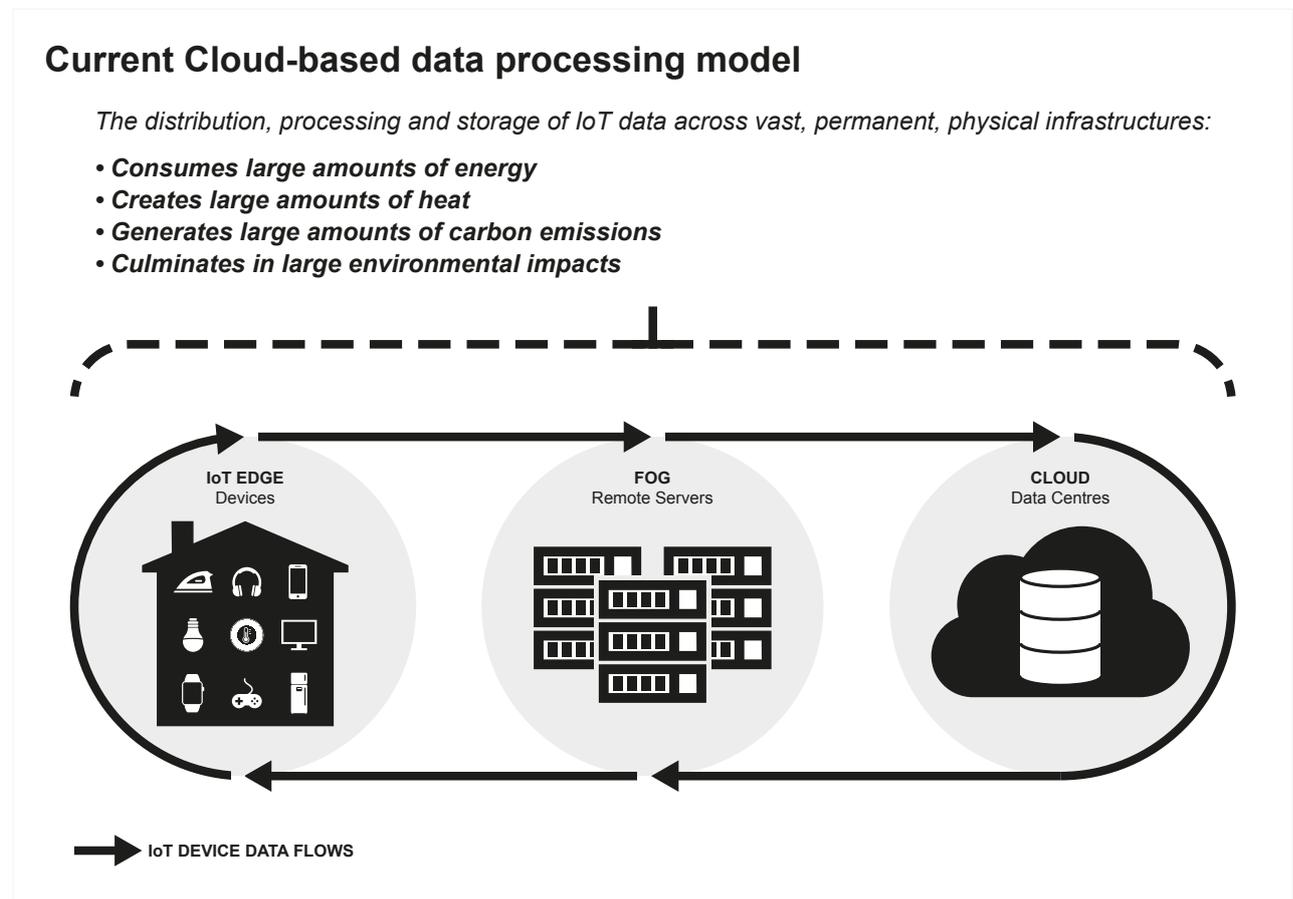


Figure 6 The unsustainable Cloud-based model presently used for processing IoT data (Authors).

5. Designing Sustainability at the Edge

Given the highly carbonised nature of the Cloud, we argue that it is judicious to begin to speculate about the sustainable possibilities of EC. To this end, we will next outline how we applied *Design Fiction as World Building* (DFasWB) methods to explore how EC may support the *decarbonisation* of IoT datafication, as well as highlight the growing unsustainable implications of present-day Cloud data management.

5.1 Design Fiction as World Building

Dunne & Raby (2013) use the term *affirmative design* to describe normative design practice which actively seeks to solve real-world problems through improvements to, and/or commercial production of, products, services and infrastructures. *Design Fiction* (DF) is different to *affirmative design* because rather than solving existing problems, we can use this research method to conduct design practice which aims to create fictional prototypes

which seek to highlight and critique present day cultural, technological, environmental, political and economic concerns. Furthermore, the prototypes help us to facilitate a greater understanding of the future implications inherent to new devices, developing technologies and nascent socio-economic trends (Bleecker, 2009; Hales, 2013; Coulton et al, 2018).

Coulton et al (2017) argue that DFasWB is an emergent form of DF which enables more compelling and constructive prototypes to be produced. This is because instead of creating a singular prototype, DFasWB is characterised by *collections of prototypes*, that when viewed together, *build a fictional world*. Moreover, each of the generated artefacts defines an 'entry point' into the said world. However, in order for the world to appear *plausible*, it is important that the individual artefacts "are mutually consistent and congruent with one another" (Coulton et al, 2017, p.177). We applied the DFasWB method to generate two integrated sustainable EC fictions – a user interface or 'dashboard' titled *InterNET ZERO* and an Internet connected fruit bowl called the *Fruit Sentry*.

5.2 InterNET ZERO dashboard

The *InterNET ZERO* dashboard visualises *decarbonisation metrics* based on the dataflows created by the different IoT devices and related services found inside a near future 'smart home'. Figure 7 depicts a householder interacting with the *InterNET ZERO* platform. The decarbonisation or 'D-CARB' metrics that can be accessed through *InterNET ZERO* are calculated as a result of EC data processing technologies. The domestic connected devices within the fiction are able to operate as individual and/or collective micro data centres. This means that they *locally* manage and store the data that they have generated through autonomously sensing their environment, by sharing information with fellow devices on the local network and via direct interactions with their user(s). Thus, in our fictional world, IoT data would not be passing back and forth from devices, through the Fog and to the Cloud.

We chose to name the fictional interface '*InterNET ZERO*' as an inference to the fact that many recent UK government body and environmental agency reports which call for rapid decarbonisation across modern societies – for example, Carmichael (2019) and Committee on Climate Change (2019) – have set *net zero* carbon emission targets by the year 2050. The *InterNET ZERO* dashboard can therefore be viewed as an attempt by progressive IoT platforms to work toward these decarbonisation directives, as well as a way that helps to make the datafication processes that underpin the Internet and IoT more *legible* to smart home users.

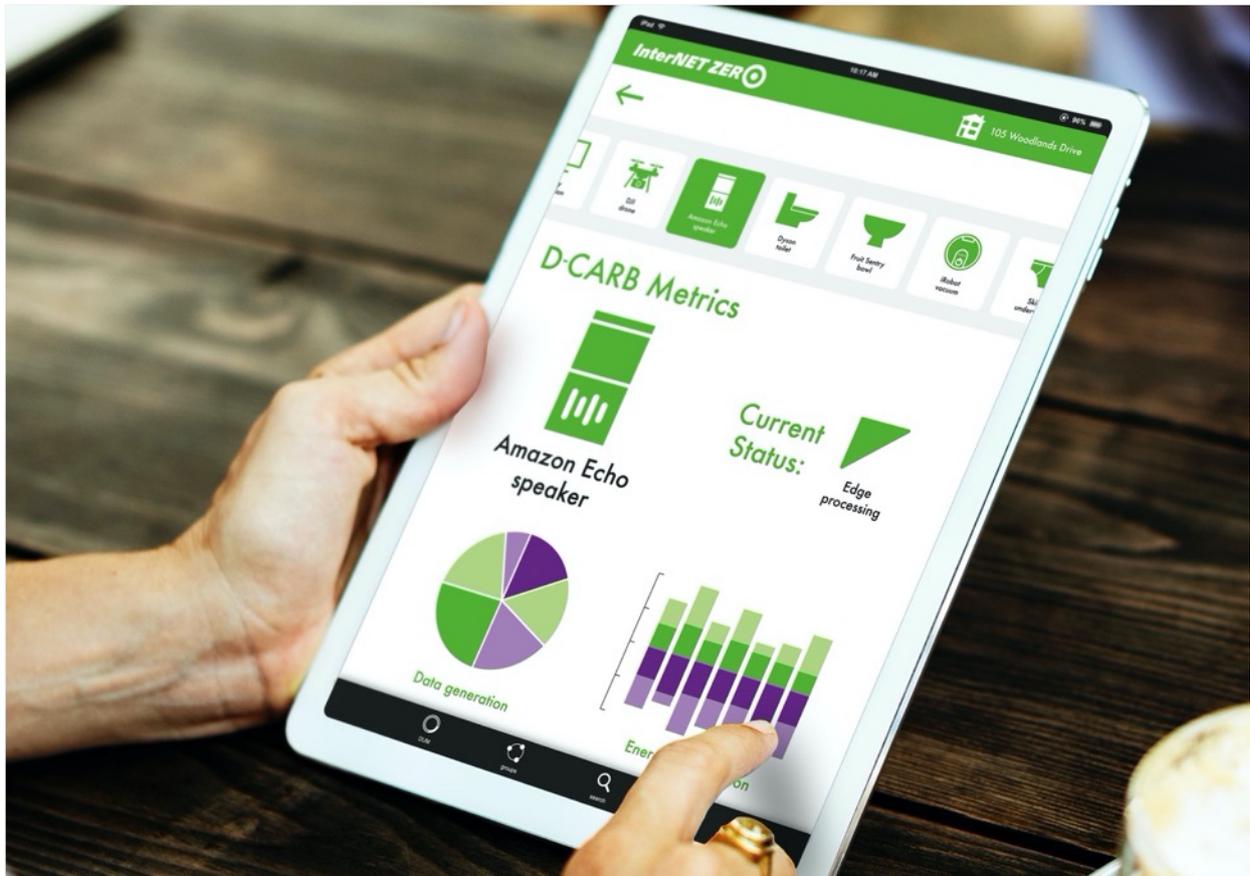


Figure 7 Users can view their device 'D-CARB' statistics on InterNET ZERO (Authors).

In Figure 8 we can see that it is possible to view the metrics which have been calculated for typical IoT products like a smart speaker, smart thermostat, wearables, lighting and an autonomous vehicle. In the fiction, we have also chosen to include a selection of what we deem to be *superfluous* IoT devices. Connected underwear (Skiin.com, 2019); IoT dental floss (SmilePronto.com, 2019); a smart fruit bowl – present day IoT design cultures provide a breeding ground for these kinds of gratuitous connected products. Some commentators such as Rose (2014) use terms like 'enchanted objects' to describe material things, which ostensibly, have no genuine need to be connected to the Internet other than for the novelty factor. We contend that such devices offer little meaningful value for users, other than providing short-term functionality. In addition, their lifespan is complex, obscure and unsustainable. They embody a design culture built on what Morozov (2013) terms *technological solutionism*. Though promoted as solving real-world issues, with perverse effect, these devices 'solve problems that do not really exist.' Developing upon Sterling (2005), we classify such superfluous IoT devices as *gizmos* – *unsustainable computerised things designed to have short lifespans* (Stead et al, 2019b). Material resources are wasted to manufacture *gizmos*, while their operation creates unnecessary data-driven carbon emissions. As such, the *gizmo* classification is the antithesis to the *spimes* concept which proposes strategies for designing IoT devices with sustainable attributes *baked-in* throughout their entire lifecycle (Stead et al, 2019b).

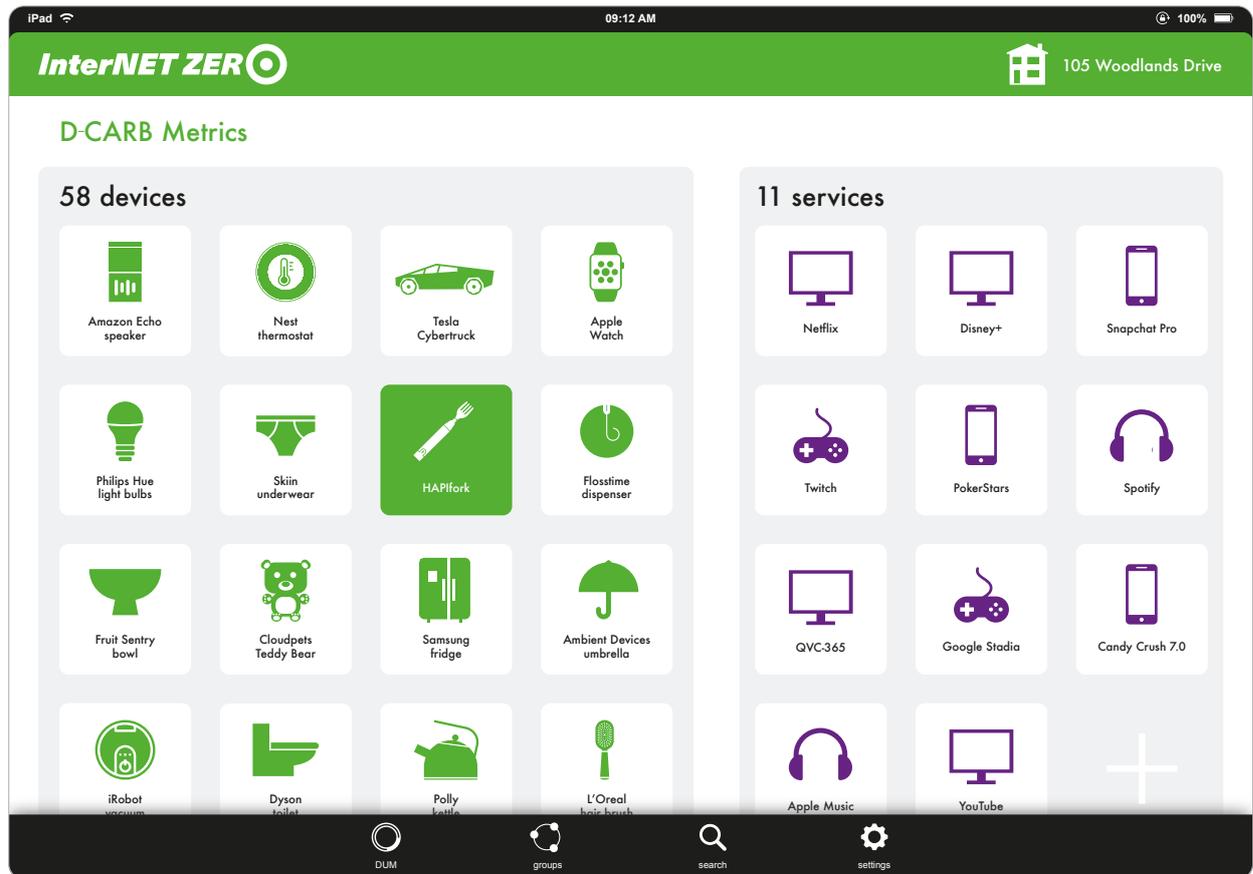


Figure 8 The dashboard provides 'D-CARB' metrics for most domestic devices and services (Authors).

In a similar fashion, alongside major, established online platforms like *Netflix*, *Disney+* and *Google Stadia*, we have also included more frivolous streaming services, for example, the fictional *QVC-365* and *CandyCrush 7.0*. Like physical devices, connected services which stream content have also been shown to be the source of large amounts of datafication, and are thus incredibly energy inefficient, resource intensive and heavily *carbonised* (Widdicks et al, 2019). Figure 9 begins to visualise how users have the opportunity to interact with more detailed 'D-CARB' feedback based upon 'grouping' metrics rather than solely data spawned by individual devices, namely by *Consumption* (of more or less data), *Distance* (from the source(s) of data), *Nodes* (the number of devices used to gather data) and *Value* (the perceived value of collected data to external third parties). We contend that, like the *Databox* project, these comparative metrics help us to begin to explore the key attributes of the HDI concept, principally notions of user-data *legibility*, *agency* and *negotiation* and how these might potentially impact the sustainability of growing IoT-centric datafication.

By choosing to include novelty *gizmo* style devices and services as key actors in the fiction, we intend to draw attention to the usefulness, or to put it in a better way, the *lack of usefulness* of integrating 'smartness' and automation throughout the home environment. To emphasise this point, in addition to the 'D-CARB' metrics, the *InterNET ZERO* dashboard is also able to assign each individual device a 'DUM' classification based upon individual



Figure 9 InterNET ZERO also visualises more detailed comparative 'D-CARB' metrics by grouping devices and services (Authors).

device's perceived usefulness when connected to the home network. 'DUM' is an acronym formed from the words *Decarbonisation Utility Metric*. In essence, the 'DUM' classification seeks to emphasise the proliferation of *gizmo* type products within IoT culture and how such devices are markedly contributing to data-driven carbon emissions within the smart home context. 'DUM' is a reference to the notion that with the advent of the IoT, 'non-connected' material objects have often been labelled as 'dumb' and redundant when compared to newer 'smarter', data-driven connected devices. By reclassifying many superfluous networked objects as in fact, not 'smart' but 'DUM', we seek to call into question the perceived utility of 'smartness' which continues to dominate mainstream IoT discourse. This revisionist stance is exemplified in Figure 10 where we have depicted the 'DUM' rating for both a connected thermostat and fork. Whilst, arguably, the thermostat offers some useful functionality when connected to the Cloud by allowing the user to remotely set the temperature in their home, we contend that the HAPIfork is a perfect example of a *gizmo*. Thus, this device has been awarded a considerably lower 'DUM' rating on InterNET ZERO as it will generate data-driven carbon emissions when it really does not need to be connected.

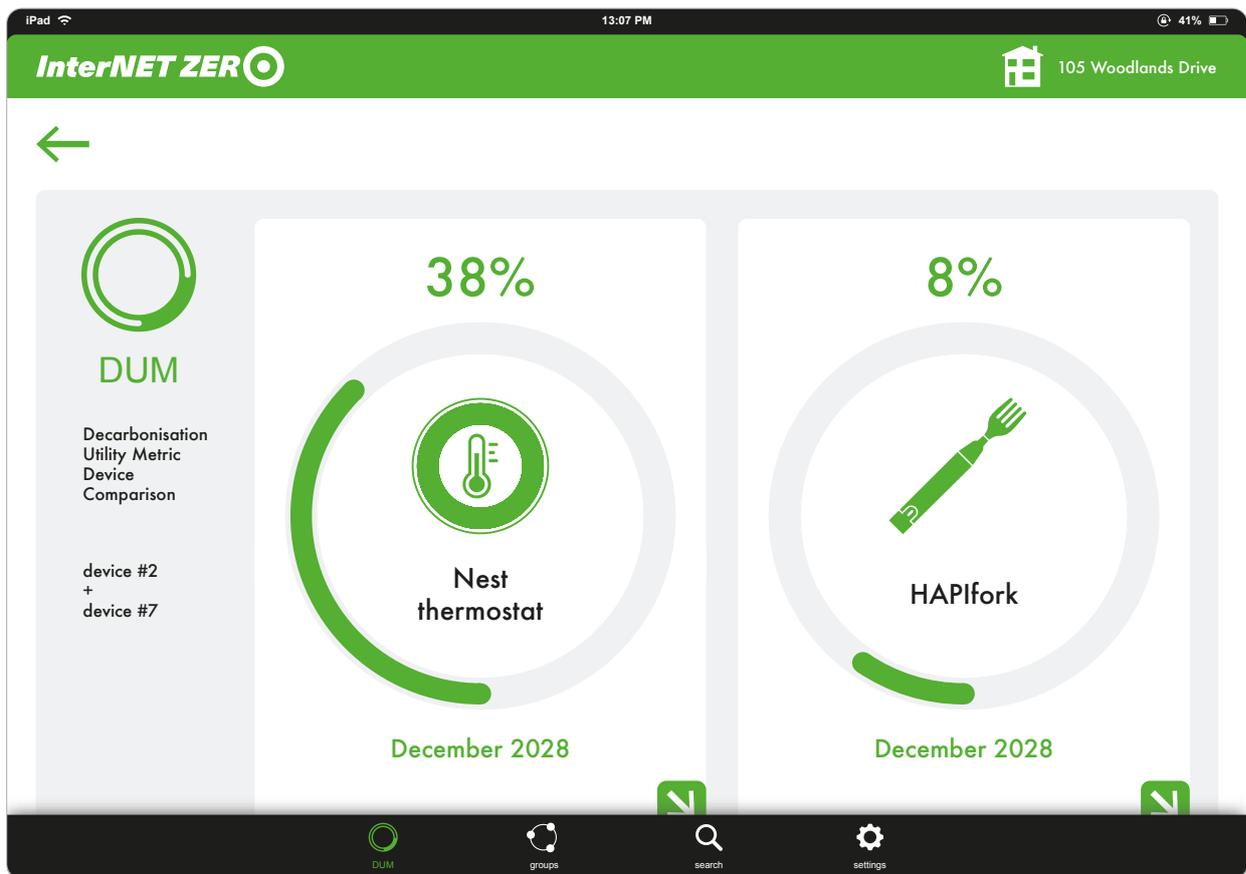


Figure 10 The contrasting ‘DUM’ – Decarbonisation Utility Metric – classifications for a connected thermostat and fork. (Authors).

Our ‘DUM’ classification is inspired by an episode of the science fiction television series *Black Mirror* called ‘Nosedive’ (Brooker & Jones, 2016) which closely resembles, and was likely influenced by, early forms of China’s impending *Social Credit System*. Nascent forms of the system have been operating in China for some years, for example *Ant Financial’s Zhima Credit*. *Ant Financial* is a payment firm spun out of *Alibaba*, China’s largest online retail platform and a leader in AI technologies (Kobie, 2019). The *Social Credit System* is believed to be coming into operation in 2020 (BBC, 2019a). Mozur (2018) stresses that it is probable that the system will be a means for China’s totalitarian state government to exercise a form of ‘algorithmic governance’ over its citizens. The system will apparently be governed via the use of approximately 626 million state-owned surveillance cameras installed throughout the country which will use facial recognition and AI technologies to monitor citizen behaviour and assign *credit scores*. ‘Nosedive’ presents a similar scenario where citizens use technology to share their daily activities and score their social interactions with others via a ratings system. These ratings can have a positive or negative effect on people’s socioeconomic status depending on whether they receive high or low scores (Brooker & Jones, 2016). While neither draconian nor ‘Orwellian’ as these examples, we will explore the wider social implications of assigning peoples’ IoT devices ‘DUM’ classifications in our next fiction.

5.3 Fruit Sentry bowl

As previously outlined, in order for it to be processed, today's IoT devices perpetually transmit data to and from the Cloud. Our second EC fiction begins to examine how the individual physical devices that constitute domestic IoT networks might also become effective mediators for improving the sustainable management of the data that they themselves generate. Figure 11 depicts the fictional device that we designed – an Internet connected fruit bowl called the *Fruit Sentry*. Inspired by real-world IoT products like the *Ambient Umbrella* which alerts its user if it is raining (Rose, 2014), the *Fruit Sentry* bowl sends its users' metrics such as daily *tweets* detailing the expiration data (temperature, humidity, light and air quality) of each of the individual fruits placed inside it, *WhatsApp* messages reminding users' to eat a portion of fruit or vegetables at least 5 times a-day, and monthly emails outlining new recipes for fruit-based meals. Although some users might find this data useful, from a performative point of view, a fruit bowl is normatively an artefact that has no apparent need to be connected to the Internet. With this in mind, we felt that redesigning this banal object as a connected device would be an effective way to emphasise the growing trend for *gizmo* style 'smart' products. Moreover, and perhaps most importantly, the fiction enables us to stress the need to start combatting the increases in data-driven carbon emissions which will result from networking billions of these types of 'solutionist' devices.

Crucially however, the *Fruit Sentry* is distinct to present day real-world *gizmos* because, within the fiction, it possesses EC capabilities and is therefore able to operate as a micro-data centre. This functionality minimises the distribution of the data it generates as well as the privacy threats that accompany such transactions. Moreover, users can also set the device to send data to the Cloud to be processed *if they so wish*, as well as *not* to collect or process *any data at all*. The latter capability means that the device's connectivity or 'smartness' can be negated entirely. This threefold *negotiation* of the device's level of decarbonisation is enabled via a simple user control switch – the 'DD' switch – which is located on the side of the device (Figures 12 and 13). 'DD' stands for *Data Detox*. Here we are making reference to the growing cultural practice of *digital detoxing*. The term is used to denote when a person makes a conscious decision not to interact with any digital devices and services for a period of time. Digital detoxing is said to improve peoples' mental health, particularly when they limit their engagements with smart phones and social media as these have been shown to be addictive (Friday, 2017). We also wanted to connote the notion of food or beverage related detoxification – the idea that a person will restructure their diet in order to minimise their intake of toxic substances, for example restricting alcohol intake, as a means to cleanse their metabolism. In a similar vein, the *Fruit Sentry's* 'DD' switch grants users a level of agency with regards to detoxing their device of carbonised dataflows.



Figure 11 The Fruit Sentry bowl in situ (Authors).



Figure 12 The Fruit Sentry's 'DD' switch (Authors).

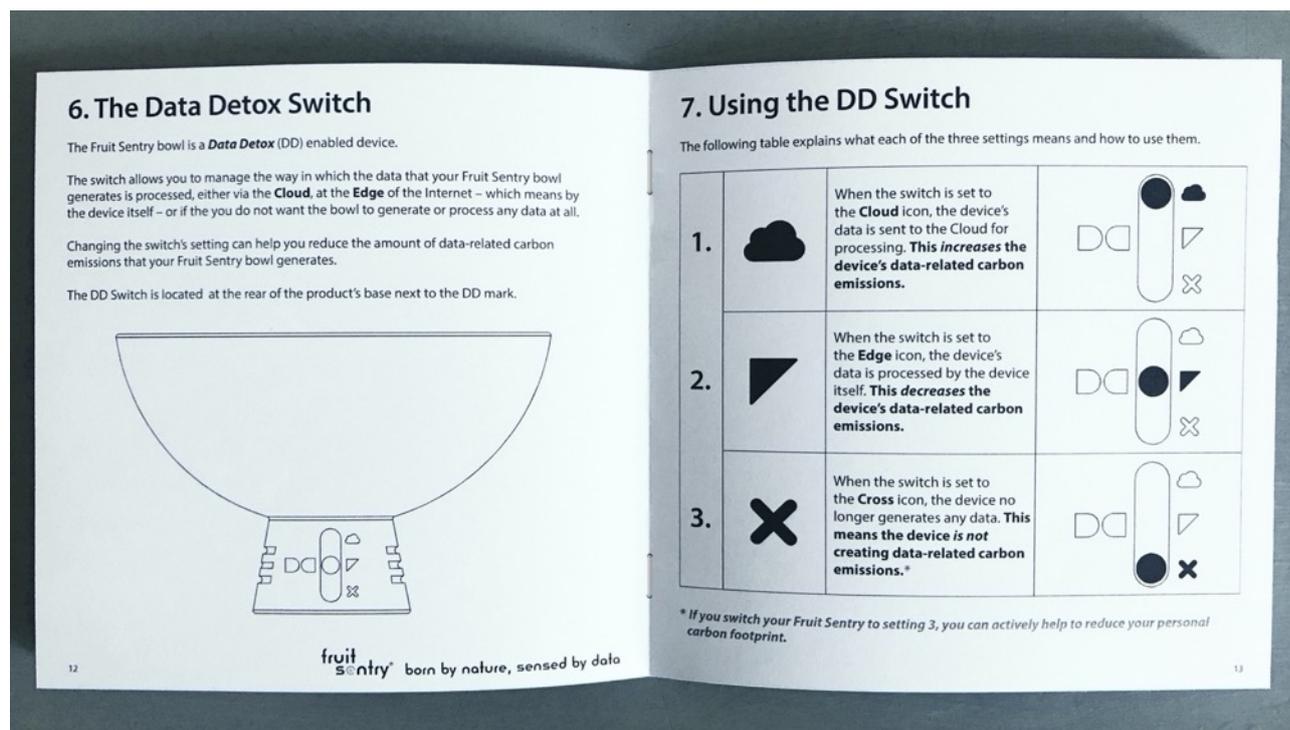


Figure 13 User instructions for the device's 'DD' switch (Authors).

The physical nature of the switch is also important, in that it transforms the *digital interactions* – user-data *negotiation* and *agency* – into *physical interactions*. This is significant because, as we noted earlier, the environmental harms caused by increasing datafication are not clearly visible or easily understood. As such, the 'DD' switch can be seen as a metaphor for the material characteristics of data. This feature is also comparative to a light switch. We are accustomed to switching off a light source if it is no longer required, as well as in order to save energy and related resources. *Could 'DD' switches on IoT devices become as everyday an interaction as switching off a light? Will people want to switch off the 'smartness' of their devices if they know this will increase data decarbonisation metrics?* The fiction aims to initiate this type of discourse.

The switch functionality also helps us to build the *Fruit Sentry* into the same near future world in which the *InterNET ZERO* platform exists. Like other devices featured on the dashboard, we have given *Fruit Sentry* a 'DUM' classification. Yet, Figure 14 illustrates how the device's 'DUM' rating is acquiescent based upon how its user negotiates its 'D-CARB' levels using the 'DD' switch. If switched to the Cloud setting for data processing, *Fruit Sentry's* 'DUM' rating will be very low. When switched to process its data itself at the Edge, its 'DUM' improves. Finally, when the 'DD' switch is 'off', that is, the device is no longer connected to the smart home network *at all*, *Fruit Sentry's* 'DUM' is rated highly.



Figure 14 The 'DUM' classification for the Fruit Sentry device as viewed on InterNET ZERO (Authors).

Ultimately, we created *Fruit Sentry* to counter the mainstream consensus that increased physical-digital connectivity, data generation and 'smartness' are an unreservedly positive socio-technological development. The fiction serves to emphasise the notion that products that have previously been labelled as 'dumb' because they are non-connected, might actually be smarter *environmentally* because they do not build up data-driven carbon emissions in addition to the established harmful impacts which result from manufacturing said physical products in the first instance. As a means to embody this *environmental smartness* within our fictional world, we again draw upon the *Black Mirror* episode 'Nosedive' and China's *Social Credit System*. Figure 15 and 16 begin to explore the wider socio-economic implications of assigning 'DUM' classifications to peoples' IoT devices. We can see that within the fictional world, citizens who have actively chosen to decarbonise their IoT datafication receive sustainability-related rewards, while others who are not as proactive are penalised, in this case they must pay higher council tax rates.



Figure 15 Data decarbonisation reward coupons which will further offset emissions (Authors).

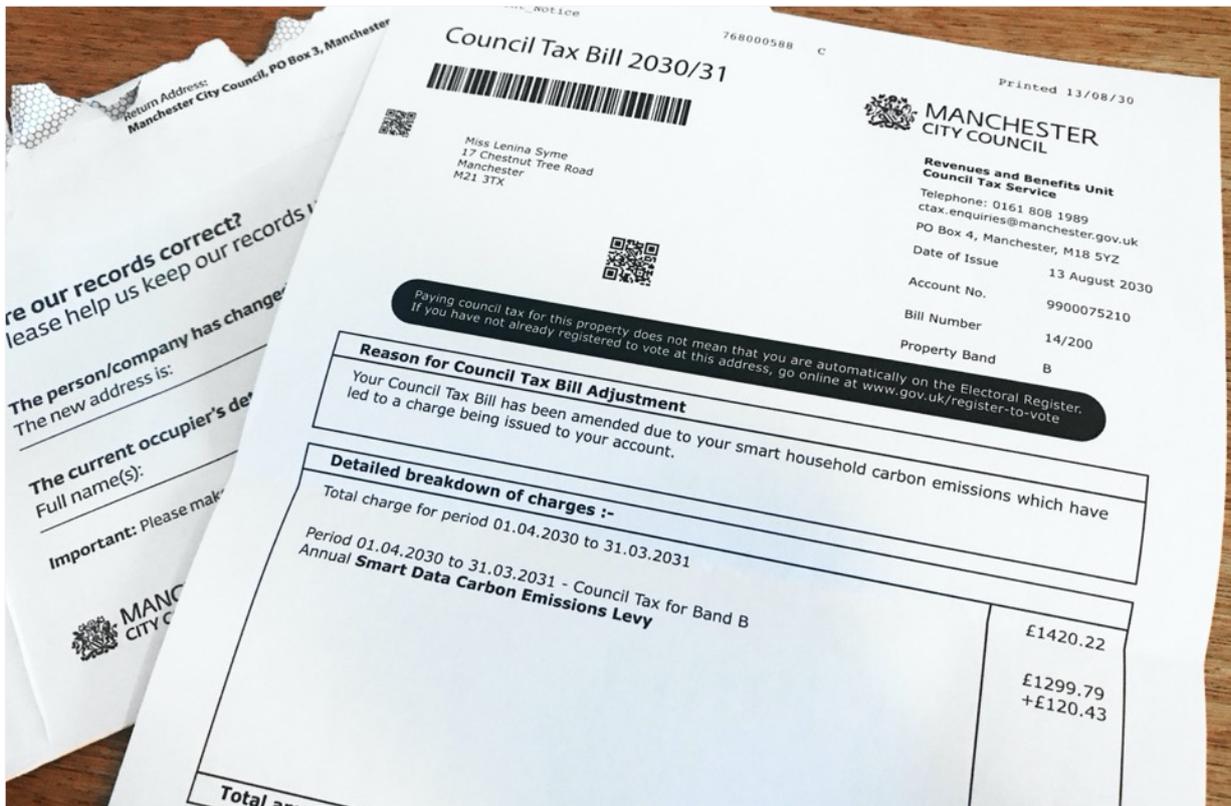


Figure 16 This householder receives a Smart Data Carbon Emissions levy (Authors).

6. Initial Conclusions

As Schulte (2019) makes clear, the development of “technologies takes time, deploying them is complicated and it might take years until their impacts can be observed.” We noted in section 5 that Design Fiction is an effective method for gaining a better understanding of the possible future implications of technological adoption and the socio-economic trends and values said technologies may facilitate. Reflecting back upon our own design process, we applied DFasWB techniques as a means to explore a potential world in which the *edge of tomorrow* plausibly exists. We wanted to generate insights regarding the possible sustainable advantages and disadvantages that might arise if EC technologies were to be adopted. We also created the two fictions to emphasise the current unsustainability of IoT datafication, particularly the impacts of rising data related carbon emissions.

We believe that our fictional world also effectively embodies the main design concerns of HDI – *InterNET ZERO* highlights the importance of making the environmental impacts of IoT data emissions more *legible* to users, whilst the *Fruit Sentry* fiction symbolises the need to empower users with the *agency* to personally *negotiate* the extent to which their data can affect the environment. Without disregarding the users of these potential sustainable Edge devices, our principal audience for this research is the design and computing communities, who, through their development and implementation of IoT technologies, presently wield the most power with regards to cultivating future environmentally responsible IoT data practices. As opposed to simply continuing to add more processing and automation capabilities to billions of physical things, these communities need to reconsider what makes devices ‘smart’ or ‘dumb’ in relation to the wider environmental issues to which they contribute. Essentially, practitioners must ask themselves – “*just because I can, does this mean that I should?*” As a means to instigate such reflective discourse and provide a counterpoint to Figure 6 (page 8), we have visualised how Edge-based data management might possibly facilitate the decarbonisation of IoT datafication (Figure 17). We have termed this potential approach *Sustainable Edge Computing* (SEC). The diagram is intended to contribute to the outlined debate and our understanding of what EC is *and* can be, namely its prospective relationship to environmental sustainability. As such, it is by no means exhaustive, but rather additive.

Sustainable Edge Computing (SEC) model

SEC could aid **decarbonisation** of IoT data as it potentially will:

- **Distribute less data across physical Cloud infrastructures**
- **Consume less energy**
- **Create less heat**
- **Generate less carbon emissions**

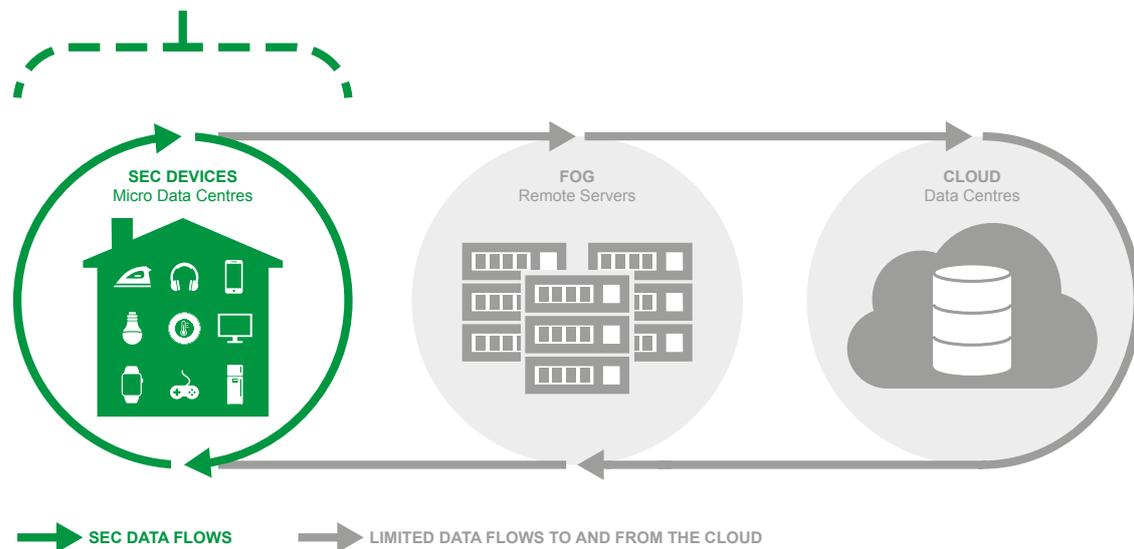


Figure 17 Our initial model for SEC – Sustainable Edge Computing (Authors).

7. Future Work

As Edge technologies are still in their infancy, there is ample opportunity for the authors and others to continue to explore the implications and values that might underpin the adoption of SEC. We foresee immediate follow on research utilising *InterNET ZERO*, *Fruit Sentry* and further SEC fictions, alongside the initial SEC model, as the basis for engagement activities with key stakeholders. These stakeholders will likely be drawn from across industry and academic IoT development communities. This engagement will aim to raise awareness of the growing unsustainability of IoT datafication as well as enable the co-design of new development strategies for SEC. The key question such future work will ask is – *can SEC research help governments reach mandated net-zero decarbonisation targets by 2050?*

Acknowledgements: This research was conducted as part of the *Beyond Imagination* project and supported by *Education England*.

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