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Whole-Life Environmental Impacts of ICT Use

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***Abstract*—In this paper we apply a whole-life assessment approach to estimate the environmental impact of the use of ICT of an individual within the UK over a one-year period. By estimating the energy and data consumption of an average user's use of a typical device, and estimating the associated energy usage (and thus CO_2 produced) of each stage in the data chain, we are able to calculate the summed CO_2 value for embodied carbon of an average device.**

Overall, device energy is seen to dominate; within device, desktops dominate, both due to their high energy use for a given task, but also their high standby power, which is the most significant point of behaviour-driven waste. Geographical, behavioural and chronological factors are all evaluated to be highly significant to the impact of a user's ICT use, along with a number of secondary factors. Finally, we present policy recommendations to further the understanding of the factors affecting the environmental impact of ICT, particularly focusing on sustainability, resource efficiency and the social implications of ICT in a low-carbon transformation.

Keywords*—*Life Cycle Assessment, Environmental Impact, Low Carbon Society, Green ICT, Emissions, Policy

I. INTRODUCTION

The creation, development and broad application of Information and Communication Technology (ICT) is frequently cited as one of the most defining characteristics of humanity over the last 100 years. Arguably, no other development can claim to have had such a profound effect since the first exploitation of fossil fuels. Today, no other service or utility has as vast reach across the global population; over five billion people now own an ICT device of some kind [1], more than those who have access to clean water or sanitation. Despite this penetration, ICT use still continues to grow, with 90% of all digital data generated has been created in the last two years [2]. Further to the technical impact, there has been significant socio-cultural impact. Relevant developments such as social networking have redefined how individuals interact with one another; digitisation of finance networks now permits the trading of incredible (and increasingly abstract) wealth across the world over fibre and microwave networks; and the computational power of modern supercomputers has enabled us to better understand the makeup of ourselves and our universe. For all the benefits of ICT, it is also possible to identify negative, unintended consequences – political, social, economic and environmental – both now and potentially in the future. We also have seen emerging UK (as well as wider global) imperatives around technology education and digital skills [3], contextualised by strategic priorities around cyber-infrastructure and cyber security [4], as well as the explosion in technologies surrounding the development of smart cities [5] and future transport infrastructure [6], all at some level predicated on cost-effective and sustainable ICT infrastructure. Such costs beg the question: just how sustainable is ICT? A complex question, transcending short-term policymaking and infrastructural investments, underpinning both global competitiveness and national security; the consequences and our reaction to them will be one of the defining challenges of the 21st century.

Rising concerns over man-made climate change and resource use, set amongst a context of rapid user growth, has driven increased focus on sustainability and the wider environmental impact of ICT. They have been associated with 1.3% of the world's total carbon footprint and 3.9% of global energy use [7], [8]. While modest in terms of overall impact, the continued penetration of ICT brings potential concerns to how this will grow [9]. Like any product or service, ICT has environmental impacts across all parts of its life cycle, from design to its disposal. However, our globally interconnected but geographically dispersed ICT systems often make assessment of the impact of a given ICT action complex and highly open to interpretation [10]. A process life cycle carbon assessment (LCA) [11]–[13] is a common way of holistically exploring a product's life – from cradle to grave – and logically identifying and categorising the environmental impacts involved [14]; for example, mobile phones [15], [16] and the wider telecommunications industry [17]. Nevertheless, we should not overlook environmental impact in terms of toxicity and pollution; for example, e-waste dumping sites in Africa.

A. Definitions

1) ICT: In this paper we define the "use of ICT" as the use of information and communication technologies that satisfies two criteria: it uses stored-program architecture (excluding a myriad of other electronic devices in use, as well as older forms of information technology) and that the primary function is that of the creation, processing or display of data (excluding electronic devices that use stored-program architecture only as a supplement to a different core function, such as cars, white goods, electrical toothbrushes, watches and bike computers). We propose that the majority of ICT meeting these two criteria can be summarised as follows:

- Smartphones: A mobile phone based upon a stored-program architecture with a range of communication technologies (e.g. GSM, GPS, Bluetooth, etc.).
- Tablets: A device that is possible to be held in one's hand with WiFi connectivity but usually no mobile data capability.

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- Laptops: A device that weighs less than 4kg but greater than 1kg, and has the ability to run off batteries for a tangible duration.
- Desktops: A device that has no ability to run off batteries for a tangible duration, with a primary function to service user requests, rather than those of another computer.
- LAN: The primary channel between devices and Internet-supporting infrastructure (Ethernet, WiFi).
- WAN: The supporting infrastructure of the Internet linking servers and nodes (3/4G, LTE).
- Servers: The destination for data transferred from the device (also referred to as data centers).

Items 1 to 4 are classified as 'Devices'. These are items that are created for their own purpose to serve the user, not to service the existence of other ICT items. Items 5 to 7 are classified as 'Supporting Infrastructure'. These are items whose primary function is to service the existence of the devices.

2) Individuals: The user is defined as an individual in the domestic, private, or public sectors; this excludes any industrial setting. Industry is deemed to have extreme variation in the characteristics of ICT use, and the integration of ICT and mechanical/chemical systems make valid identification and categorisation problematic. For example, a worker in an aluminium refinery may operate a computer embedded in an electrolysis machine with a total power consumption of over 1MW; how much of this can be accredited to ICT could involve extensive analysis of pre- and post-ICT states of all dependent/related industries. As such, workers in industry will simply be modelled as standard private sector workers with an average amount of ICT in their occupation. We will consider specific types of user/non-users individually, as well as an aggregated 'average' UK citizen. We will also include the impact of non-users and nearly-non-users. The specific user types and how they make up the UK market will be discussed a later section.

3) Environment Impact: We consider environmental impact exclusively as greenhouse gas (GHG) emissions using the CO_2e metric [13], [18]. This encompasses global warming potential of CO_2 as well as the relative global warming severity of other greenhouse gases, relative to the severity of CO_2.

4) Life Cycle Stages: The life cycle stages of the devices are outlined below:

- *Creation* – Conception to Gate: the design, extraction of raw materials, manufacture and all actions necessary to retail and deliver the device to the user.
- *Use* – Gate to End Use: from the users first ownership of the device to when it ceases to be their property. Broken down into two subcategories:
  - Use – Device: the actions of the device itself.
  - Use – Supporting Infrastructure: made up of supporting ICT and other supporting infrastructure.
- *End of Life* – End Use to Grave: from when the device ceases to be property of the owner, to when all components have been reused/recycled/disposed.

II. SCOPE

We have identified four principle areas: user behaviour, chronological variation, geographical variation and device interchangeability, that form the principle focus of our LCA design, model and primary data collection. Geographical and chronological variations are easily applied to the existing system. This allows modelling of the carbon cost of electricity generation. Behavioural and device substitution themes can be addressed through a strong focus on the use-device and use-supporting infrastructure life cycle stages. Creation will be included in the LCA though end of life will not. This is because the latter is perceived to have negligible impact on energy and GHG emissions, whereas the contribution by the former is deemed significant and will provide a comparison with the use phase impacts. The GHG and energy of each prototypical day for each user type (exclusive of embodied) will be displayed chronologically across the day.

A. User-Centric Input

To accurately capture user behaviour, it is necessary to obtain it from primary data at the source. While this is time-consuming, we have created a tool to collect user data from 200 individuals in an online survey, targetted towards a range of ICT users. This tool works on the concept of prototypical days. These are defined as days that usually have very similar patterns. For example, all days where the user is at work and in the office on a typical work schedule. The tool permits the user to enter what each of their devices is doing, to a half hour resolution over the 24 hour duration of a prototypical day. This includes inputting when the device is on but not actually in use. Finally, the individual is asked how many of each prototypical day makes up a year, with the request that all sum to 365 days. The values given for each device for each prototypical day can then be multiplied by the number of such prototypical days in a year, and then summed, to evaluate the individuals' overall impact in a year.

B. Energy Calculation

Energy is calculated in half hour sections through the prototypical day. Energy per section is calculated by summing the Device, LAN, WAN and Server energy values. Device energy is found as described above, while the remaining elements are calculated based upon the data throughput (D) and a number of constants (all energy values are in Joules, and the energy-data constants are given in J/MB):

$$
\begin{aligned}
E_{LAN} &= E_{standby} + k_{energy} - data_{LAN} * D \\
E_{WAN} &= k_{energy} - data_{WAN} * D \\
E_{server} &= k_{energy} - data_{server} * D
\end{aligned}
$$

C. Carbon Calculation

Carbon produced is calculated as a function of energy consumed in each section, geographical location and time. The latter two data sets are discussed later in this document, and take the form of look- up tables. The carbon produced is calculated as below (CO_2 produced is measured in g, and time-location constants are given in g/J, translated from the g/kWh that is input):

$$
\begin{aligned}
C_{device} &= k_{C\_time\_location} * E_{device} \\
C_{LAN} &= k_{C\_time\_location} * E_{LAN} \\
C_{WAN} &= k_{C\_time\_location} * E_{WAN} \\
C_{server} &= k_{C\_time\_location} * E_{server}
\end{aligned}
$$

III. DATA COLLECTION STRATEGY

The purpose of this section is to determine the average device within each device type: Phone, Tablet, Laptop and Desktop.

A. *Manufacture*

This paper does not have a strong focus on the embodied energy and carbon of ICT devices resulting from the production phase in the life cycle; instead the key focus is the use phase. However, not taking the energy and carbon involved in producing the devices that individuals use would not give a satisfactory answer for the environmental impact of an individual's ICT use in one year. As such, this paper does not focus on the embodied carbon and energy of devices, but does take it into account in the analysis of an individual's ICT use. Using relevant research which has had a strong focus on embodied energy and carbon, an analysis was undertaken to give reasonable estimates for typical embodied GHG in each device type. These are then used to identify a value for the footprint of an owner of each device type by estimating the device lifetime. Finally, due to the disparity in the estimated values for Apple products and those of other manufacturers, an average value was achieved by drawing on the market share of Apple products for each device type (Apple environmental data for products shows this as a relatively insignificant stage: typically accounting for 2-4% of the GHG emissions associated with a device, with production and use phase typically the greatest contributors); the resulting figures for each device type are: Desktop: 127.275 kgCO_2e; Laptop: 85.456 kgCO_2e; Tablet: 45.9 kgCO_2e; Phone: 18 kgCO_2e.

B. *User Input Strategy*

The purpose of this section is to determine the average user of ICT devices; using our primary market research we have produced a high-level market segmentation of all ICT users. For each segment we have defined key behavioural points and the device types owned by each; the resulting market segmentation can be seen in Figure 1, with our estimations of the relative proportions of each segment can be seen in Figure 2. Using primary market research into user behaviour, we decided upon the types of days of use; typically 'average weekend' and 'average weekday' for most users. For each day a timetable of use, to a resolution of 0.5 hour slots, was specified.

C. *Device Use*

We wish to define an average user's ICT use and to explore how a device behaves in general under different use cases. A device can be used for many different purposes, any one of which we will define as a use case. To identify a suitable selection of use cases, we initially identified a large number of possible use cases, which were then filtered to satisfy the following criteria:

Excluding those that show unusual behaviour in the device components: this excluded gaming, where Graphics Card power can be up to 250% of a standard desktops power, discussed in the other components section later.

Including those that are most prevalent: this excluded listening to music and scanning.

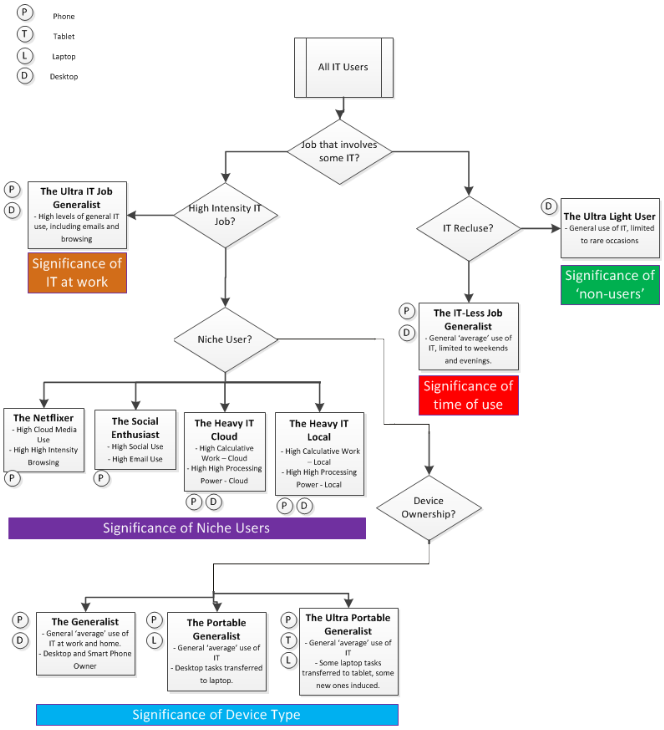


Figure 1. ICT Users in UK, device ownership and significance to this analysis

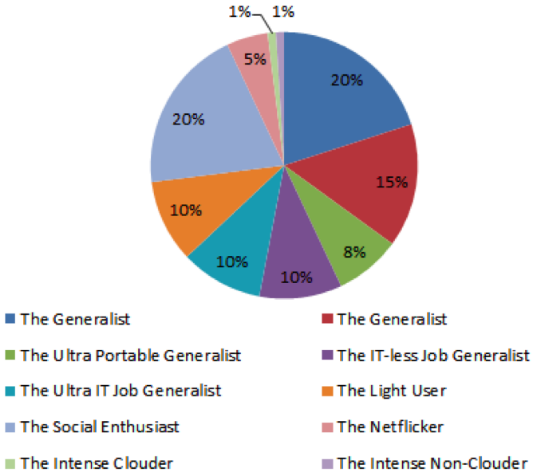


Figure 2. Assumed market share of ICT user types in UK

Excluding those that are insufficiently different to an idle state: this excluded background system tasks such as watchdogs and network updates.

Including those that are necessarily distinct in order to comment on the key issues within our scope: including cloud and non-cloud variations of similar tasks.

For this analysis we categorise the power consuming components of a device into four categories:

- CPU: Including all integral elements.
- Display: Inclusive of the power used by the display only.
- Network Components: Any power-consuming component that is used to transfer data in or out of the device.

- Other: Inclusive of all power-consuming components of the device not covered in the previous categories as well as peripherals. Includes RAM, hard drive, motherboard, graphics card, sound cards in the first element; printers, scanners and input devices in the second.

A use case has four principle characteristics:

- CPU Power Factor: CPUs power in a given use case;
- Display Power Factor: display's power in a given use case;
- Other Power Factor: other factors in a given use case;
- Data Flow: the magnitude of data (summation of in and out) flow during a use case.

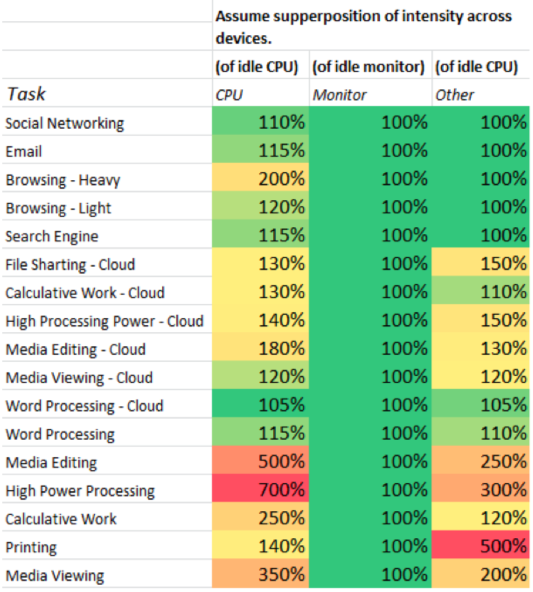
The aforementioned power factors affect the given power use of each device component, on average, in a given use state. These are calculated thus:

$$CPU = CPU_{idle\_power} * CPU_{power\_factor}$$
$$Display = Display_{idle\_power} * Display_{power\_factor}$$
$$Other = CPU_{idle\_power} * Other_{power\_factor}$$

CPU power use and CPU utilisation does not follow a linear relation. In practice, the CPU consumes tangible power when idle, and then increases from this to anything from 2-10 times the idle power at 100% utilisation. During primary research, we observe that certain types of use case manifest themselves as different tasks on different devices. For example, high intensity browsing, such as viewing of a video on YouTube [19] will typically be done at a resolution of the device or lower. As such, the task will require less processing power on smaller devices. Others will not scale in this way, for example a word document will be the same size and complexity of word document regardless of device size. We theorise that for scalable tasks, the downscaling of task intensity can be approximated as balancing out with the decrease in processing power for smaller devices. For non-scalable tasks, we theorise that applying the same approximation will be of little inaccuracy, as such unscalable tasks are typically of such low processing intensity that the practical utilisation will be only slightly higher on less powerful CPUs. These assumptions culminate in having a 'power factor' for a given use case that is common to all four device types.

As such CPU power use varies with undertaken task intensity. Through primary research we have identified that instantaneous CPU power use, on modern CPUs, is typically low – $<30\%$ for most tasks – and that average CPU intensity lower still. Through primary research we have obtained estimations of average CPU powers for all of the use cases defined; these can be seen in Figure 3. We can see that the majority of applications use little power above idle, with a few select tasks actually using the full power of the device. This aligns with other research in the field of CPU design and use. For a standby mode of any device, the CPU rests at its idle power.

Network connection power is typically perfectly inelastic to data, and as such is evaluated as constant for each type, discussed by device in later sections. As such, no power factors exist for network devices. The power from the remaining components is difficult to estimate without considering the power uses of individual devices. As such, these can be inferred from the remaining observed power use of a given device when network and CPU powers have been taken out, as determined in later sections. With regards to power factors, there are two elements that exist: (*i*) The use of peripherals to service a task: the inclusion of extra devices to facilitate an end, such as printers, scanners and such. The power impact of such devices is given by their independent power ratings; (*ii*) The power of internal components in relation to task intensity: research suggests most other components scale very little with task intensity, and change their power more based on specific nuances, for example the HD with file sharing, the graphics card with media viewing. As such, this is considered to be a smaller influence than the peripherals.



	Assume supperposition of intensity across devices.		
	(of idle CPU)	**(of idle monitor)**	**(of idle CPU)**
Task	*CPU*	*Monitor*	*Other*
Social Networking	110%	100%	100%
Email	115%	100%	100%
Browsing - Heavy	200%	100%	100%
Browsing - Light	120%	100%	100%
Search Engine	115%	100%	100%
File Sharting - Cloud	130%	100%	150%
Calculative Work - Cloud	130%	100%	110%
High Processing Power - Cloud	140%	100%	150%
Media Editing - Cloud	180%	100%	130%
Media Viewing - Cloud	120%	100%	120%
Word Processing - Cloud	105%	100%	105%
Word Processing	115%	100%	110%
Media Editing	500%	100%	250%
High Power Processing	700%	100%	300%
Calculative Work	250%	100%	120%
Printing	140%	100%	500%
Media Viewing	350%	100%	200%

Figure 3. CPU intensity by use case

Research suggests display power is not dependent upon the level of activity on a screen: changing content does use energy in the display. In modern displays, the exact colour of the content is not related to power consumption. The only distinct characteristic proven to influence the power consumption is the brightness setting of the display [14]. This is typically unrelated to a task; indeed, it could be said that individuals may lower the brightness during long working hours, such as extensive typing, or raise it when the quality and clarity of the image is crucial, such as when watching a film. This however, is most probably a matter of personal taste, and the inter-use-case-brightness-level variation is likely to be less significant than the individuals average preferences on brightness. However, it should be noted that for LED screens, used on many high-end smartphones today (OLED/AMOLED), the content does indeed make a difference: black pixels consume zero power.

The final data requirement for this analysis is the carbon intensity of the energy used by the individual and their ICT-related activities. As previously mentioned, this project assesses the chronological impact of the ICT use, and this has been achieved using primary data collected from the Realtimecarbon project, rather than a static average value for the GHG impact of grid electricity. The figure commonly quoted for UK National Grid carbon intensity is 445.48g CO_2 (via Carbon Trust) per unit of energy (1kWh), however in reality this figure changes over the course of the day, and over a longer time period, depending on what energy sources are being used and their relative contributions to the current grid mix.

IV. RESULTS

Figure 4 demonstrates the energy use, by the device that causes it, and then by component, for The Generalist's 'Average Weekday'. Point A shows the minuscule standby power (erroneously including the screen being on) of the phone overnight. Point B highlights the increase in device power of printing. Point C demonstrates the only perceptible time the phone's energy consumption is tangible, during heavy browsing. Point D demonstrates the deactivation of the work computer as the user travels home; Point E shows the activation of the home desktop upon arrival, entering standby mode. Point F shows the increase in device power due to a small period of media viewing; shortly before this we see the only tangible power consumption of WAN and Servers, during the high data task of Heavy Browsing. Immediately, we can observe that in almost all situations, the phone's power is imperceptibly small compared to the desktop power. Secondly, we can observe that idle computer power is a significant point of wastage.

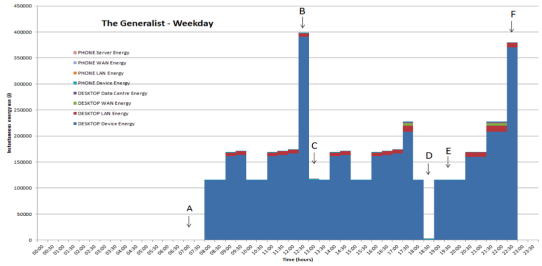


Figure 4. Energy use by device and component

Figure 5 demonstrates the energy, in use CO_2e and embodied CO_2e by user type. Observe the substantial variation in the environmental impact across user types; we will discuss the significance of this in the conclusion. Figure 6 demonstrates the energy use by infrastructure type. Immediately we can observe that the device dominates the power use across all user types covered. LAN appears an order of magnitude smaller, WAN and Server an order of magnitude smaller again, and roughly equal to each other. We also observe that the exact proportions of all four energy types vary considerably depending on the user type. Final calculations show that, when prototypical days and user type distribution is taken into account, the impact of one average UK individual in one year is: *Total energy use:* 259kWh; *Total in use carbon:* 123.7kg; *Total embodied carbon:* 127.1kg.

V. CONCLUSIONS

The benefit of exploring varying user behaviour is the ability to differentiate domestic and professional ICT use. The Generalist, the ICT-less Generalist and Ultra ICT Generalist all own the same devices. The ICT-less Generalist only uses a desktop at home; Generalists use it approximately 40% of their working hours, the Ultra ICT Generalist about 80%. This non-linear relationship can be explained by the significance of standby power. Having a computer on at work is the key factor – this immediately adds a large base power use (Generalist vs. ICT-Less Generalist), but further use of the computer makes a much smaller difference (Generalist vs. Ultra ICT Generalist). ICT-Less Job Generalist does a little more desktop use at home as a result and delegates some of the would-be-desktop day time activity down to a phone, but both are insignificant in comparison. This highlights the significance of workplace policies to minimise idle computer time. The energy use of workplace computers left on overnight is not covered in our LCA and could be hugely significant.

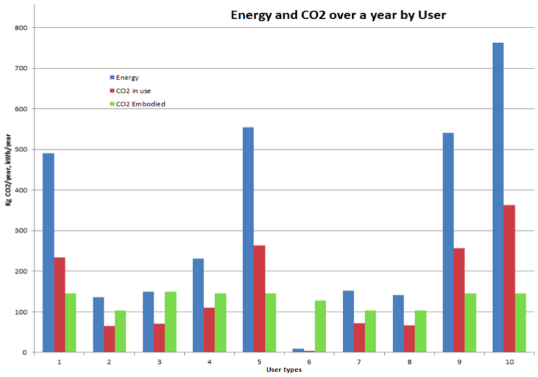


Figure 5. Comparison of energy use and CO_2e for users

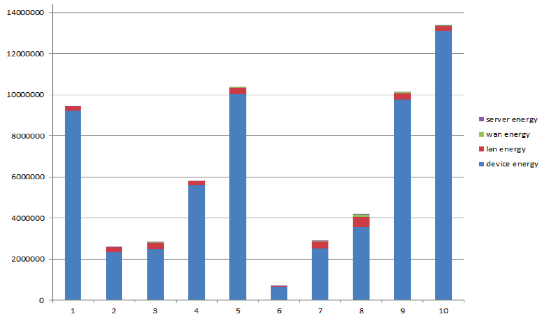


Figure 6. Comparison of energy use of device and infrastructure

Figure 6 shows that the in use CO_2 of near-non users is an order of magnitude smaller than other users. This is not only driven by low use, but exemplified by the efficiency of which they use their desktop: by turning it off immediately after use, they accrue no standby power wastage. However, even though they are modelled to only own a desktop, the embodied carbon of it is highly significant and as such they cannot be neglected as a user group – their total carbon footprint is only 20% lower than a Portable Generalist. Furthermore, despite their efficiency of use, this translates overall to a heavy impact per hours of use – 1.36kg/hour compared to 0.068kg/hour for The Portable Generalist.

Even though the overall impact is dominated by device energy, situations exist that span many different proportional makeups. It is important that these are considered should any of these situations become particularly popular in the future. Furthermore, the analysis of individual behaviour allows us to evaluate common perceptions of the environmental impact of given device uses. Logic might suggest that streaming a video (using large amounts of data and increasing CPU load) would be poor behaviour environmentally. However, the Social Enthusiast, who typically keeps his device on longer

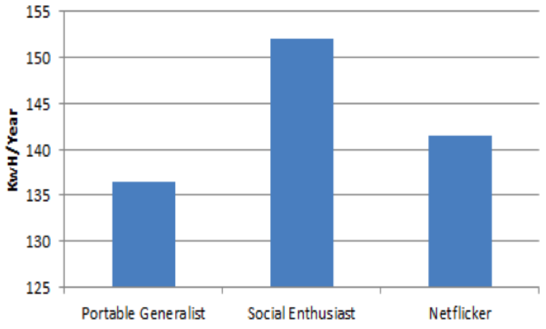


Figure 7. Comparison of notebook/phone use

(particularly on the weekends) to perform a relatively low intensity task is far worse. Furthermore, the Netflicker could be considered to be using the concept of cloud efficiency – streamed videos are typically of a lower codec complexity than downloaded or DVD/BluRay based video [19].

Modelling similar behaviour across different devices provides the ability to comment on how devices can be interchanged and the effects of this. In our model we assume the Generalist and the Portable Generalist have identical behaviours – the increase in portability of the device does not, for the prototypical days covered, induce additional ICT demand. For the Ultra Portable Generalist, we model there being a slight increase in ICT use induced by the inclusion of a tablet. The tablet is on the individual almost as much as a phone is, and this increase in portability is somewhat more significant than the desktop-laptop transition. Some tasks are deemed to be down-scalable to the tablet, but a lower percentage than those down-scaled the previous situation. Furthermore, some tasks on the phone are scaled up to the device, due to the overlap of possession.

Although the energy step up from phone to tablet is much smaller than the step down from laptop to tablet, the saving here roughly equates to the sum of the actions scaled up from the phone and the induced actions. When the greater embodied carbon is then included, we can see the inclusion of new smaller device has actually resulted in a greater environmental impact of the Ultra Portable Generalist than the Portable Generalist. Crucially, this difference is small compared to the differences between both of these users and the original, desktop-based Generalist. It could be logically concluded the extra carbon for The Ultra Portable Generalist is a small price to pay for the extra benefits of a tablet, and certainly preferable to The Generalist. Indeed, one could theorise that a policy to give away tablets in return for old desktop computers would, at least in theory, be highly effective.

What is perhaps the strongest trend in all of our findings is that device energy dominates. The logical progression of this is the CPU intensity of a task is a far better indicator of its environmental impact, at least in most situations, than the data flow. If accurate, this suggests that efforts to reduce server and LAN power would be better spent on reducing device energy. Ultimately this is an incredibly complex topic involving wider socio-psychological and market forces and is only briefly considered here. From the theory here, an ideal solution appears to make 98% of individuals use only a phone; this is clearly an unacceptable suggestion. Crucially though, the relationship between devices, behaviour and carbon is highly significant and demands further research, providing huge potential for national policy formulation [20], [21].

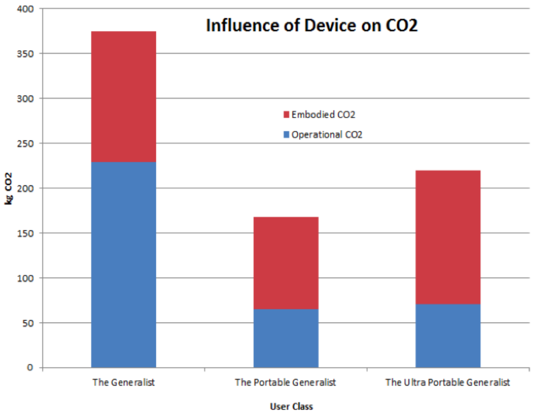


Figure 8. Variation in GHG impact for different device types

VI. RECOMMENDATIONS

A. Personal

As the above results show, different use characteristics produce wide variation in the consumed energy and CO_2 production. The most apparent variation is in the contrast between desktop use and smartphone use. This gives credence to recommendations to use a smartphone over a desktop where possible, especially for low power tasks such as internet browsing. This raises practical issues, so a significant benefit can also be made by the transition from desktop to laptop with much more ease. With the exception of the 2% of Intense Clouders and Intense Non-Clouders, the vast majority of users' tasks should be able to transition flawlessly (at least in the technical sense). However, we note that Intense Clouders and Intense Non-Clouders makes up c.2% of respondents, which, given the sample size, could allow potentially serious deviations on the conclusions derived from such a small sample. In a commercial context, the operating costs of an office run off laptops as opposed to desktops would be significant, and also provide more flexibility.

The results also shows a significant variation in the CO_2 produced and the time of day it is produced. It could be suggested that users carry out certain activities at particular times to make the most of the CO_2 per energy constant at that time but in practice this may not be suitable for the majority of users, and the benefits may not out-weigh the inconvenience. However, if the highest device energy users – the Intense Clouders and Intense Non-Clouders – have any flexibility as to when they are able to undertake their high power processing, careful monitoring of the live carbon value could result in as much as a 45% reduction in its carbon if done at a low point rather than a high point. These user types also have the highest proportion of device energy. That is to say, those with high energy use over a year typically pay a larger share of that (on the assumption WAN and Servers are not paid for by the user directly). As such, if carbon-based taxing or demand-based pricing, as has been suggested, becomes a reality, this time consideration will make economic as well as environmental sense.

B. Commercial

As highlighted throughout, on a work day, considerable power is wasted through idle desktops. Screen savers could be an easy quick win for the effort setting them would, but are unlikely to reduce the overall wastage by more than 30%. Suggesting individuals turn off their computers whenever they are not directly using them is likely to be completely impractical in the workplace. However, turning them off outside working hours could result in a substantial saving, albeit not modelled here. Some pioneering companies operate network protocols that attempt to shut down the computer, unless aborted by the user, at the end of working hours. However, from user experience, if there is any hint of unreliabilty or slowness to recover, power management usually gets turned off. However, coupled with the availability of computer hardware which is now capable of extreme power management (and will soon be even better with DRAM-style non-volatile memory structures), there is some synergy between this and the downsizing recommendation. Laptops would not only use less power in general, but waste far less sitting in idle.

C. Policy

From a wider policy perspective, encouraging large users of electricity (as well as to a lesser degree the average user) out of high-peak times is beneficial for reducing the environmental impact of ICT, but also to the national grid, to whom grid variation causes immense financial cost. Linking back to the discussion on re-scheduling in the previous section, if energy providers are unwilling to switch to 'smart pricing' – demand-based electricity pricing – then perhaps a carbon tax, charged based on what CO_2 intensity the grid is at any one point, will give an economic incentive for people to change behaviour. Furthermore, this will both improve the environment, but also reduce the cost of variability to the UK National Grid. This will also make de-carbonisation easier (as low carbon generation is typically baseload (geothermal, nuclear) or unpredictable (wind, solar). Another consequential benefit would be the motivation of the public for the government to reduce the carbon of the grid and so reduce their carbon tax. As we have seen in the run up to the 2015 UK elections, energy policy is an extremely politically-sensitive topic; however, a proactive national strategy with ICT-specific focus on 'greening' and energy management[1] (even for the UK Government's own IT function[2]), would – if successful – provide a potential model for other sectors where reduced electricity use and lower carbon footprint could be achieved [20], [21]. More generally, we note the work in the Green Grid Association[3] for their work on carbon footprint of ICT and data center lifecycle best practices.

In the same way that car buyers are put off inefficient cars by vehicle excise duty, a tax on high power consuming computer components could be the answer, such as 200W+ graphics cards. While this may be effective, it would also be hard to enforce, and ethically questionable if other more common commercial entertainment products (for example, televisions) were not taxed similarly. Implying individuals should adjust their leisure time to be more sustainable has become a increasingly unpopular viewpoint. Labelling however, such as common practice on other products sold in the EU, could be a reasonable compromise, encouraging consumers to make the choice themselves (these have been highly effective on fridges and other white goods).

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