Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 224 (2023) 336–342

Procedia Computer Science

www.elsevier.com/locate/procedia

The 13th International Conference on Sustainable Energy Information Technology (SEIT)
August 14-16, 2023, Halifax, Nova Scotia, Canada

Determining UK government scope 2 and 3 computer greenhouse gas emissions

J. Sutton-Parker [a,*] and R. Procter [a, b]

[a.] *University of Warwick, Computer Science Department, Coventry, CV4 7AL, United Kingdom*
[b.] *Alan Turing Institute for Data Science and AI, London, NW1 2DB, United Kingdom*

Abstract

The objective of this research is to determine the potential of scope 3 supply chain emissions generated by end user computers within the United Kingdom government and to test current scope 2 calculation methods to improve annual reporting procedures. The supply chain analysis is accomplished by using existing asset profile data to determine the number of devices owned by computer type combined with manufacturer scope 3 product emissions data averages by type. In this example, 2.2 million computing devices are examined and found to produce emissions in excess of 623.45m kgCO_2e. By suggesting devices are retained beyond the current 5-year periods, it is determined to be feasible that this value could be reduced by 37.5%. Additionally, by selecting devices with the lowest carbon footprint in the future when computers require replacement an estimated total reduction of 65% is achievable. The scope 2 emissions calculation compares the current methodology used to generate kWh/y values and concomitant greenhouse gas emissions to results generated by field measurement using the commercial typical energy consumption methodology. The results substantiate that the government is currently over reporting scope 2 emissions values by as much as 697% due to owned but not used devices being included in the calculation and fixed electricity consumption data used by the current methodology being too high when compared to actual use. As such, the findings are presented to the government and included as recommendations in the latest national sustainable information and communications technology strategy document.

Keywords: Computer carbon footprint; computer energy efficiency; human-computer interaction

* Corresponding author. Tel.: +44-(0)7976-818-530.
E-mail address: Justin.Sutton-Parker@warwick.ac.uk

1877-0509 © 2023 The Authors. Published by Elsevier B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the Conference Program Chair
10.1016/j.procs.2023.09.045

1. Introduction

End user computing (EUC) contributes 1% to global greenhouse gas (GHG) emissions; predominantly caused by product manufacturing and the use-phase when electricity is consumed [1-9]. Research has determined the positive environmental impacts of abatement strategies enabled by changes to computer purchasing and use behaviour [10-15]. This includes, device selection using sustainability as a criterion and extending computer useful lifespans to displace new product demand. Adopting both approaches has been shown to support United Nations sustainable development goals 12 (responsible consumption) and 13 (climate action) [16].

Due to their high number of employees, public sector organisations represent one of the largest computer procurement sectors in the world. Consequently, national and regional legislation and policies exist to guide public sector organisations to purchase computers that are energy efficient and responsibly manufactured [17-19]. However, attaining compliance with these policies does not necessarily lead to a reduction in scope 3 supply chain and scope 2 electricity GHG emissions. This is because the eco-labels governing the process, such as Energy Star, EPEAT and TCO, do not consider the product carbon footprint as a metric for certification. As an example, Microsoft's Surface Laptop 3 has a published total carbon footprint of 138 $kgCO_2e$ [20] compared to 809 $kgCO_2e$ attributed to a Lenovo ThinkPad P51 [21]. While the similarly functioning notebooks meet current sustainability buying criteria, the latter is theoretically six times more harmful to the environment due to its increased carbon footprint. As such it is reasonable to suggest that while eco-label compliance is a positive step towards adopting sustainable IT, including the identification of low carbon footprint devices at the point of purchase is necessary to drive meaningful abatement.

To achieve this, the United Kingdom (UK) government's Sustainable Technology Advice & Reporting (STAR) organisation has begun using an application capable of dynamically comparing end user computing devices by carbon footprint values [14]. By ensuring the eco-labels are combined with identification of computers exhibiting low carbon footprint values, emissions reduction will be achieved as existing devices are replaced. Considering the UK government is responsible for 2.2 million end user computing devices (Table 1), the impact of this change is potentially significant. However, if an organisation is not able to calculate the carbon footprint of current computing devices, then abatement delivered by procurement behavioural change cannot be calculated.

Already subject to mandatory GHG emissions accounting and reporting [22], plus regulations within the Greening ICT policy [19], the STAR group is required to complete an end user computing annual electricity consumption and scope 2 emissions estimation for all devices. To achieve this STAR uses the Joint Information Systems Committee (Jisc) model [23]. The exercise involves government IT managers populating an .xls spread sheet with owned computer quantities. Each is classified by major device type categories such as notebook or desktop. For each quantity of device type the Jisc model applies a kWh/y value devised from original field measurement conducted by Cartledge [24] and Hopkinson and James [25]. The total electricity consumption value for all computers by government department is then submitted to the Department of Environment, Food and Rural Affairs (DEFRA), which leads the government's STAR team. Analysts then use the relevant UK electricity to GHG emissions conversion factor (BEIS, 2022) to calculate end user computing device scope 2 emissions. The results are published in the Greening government ICT annual report [26].

To date, no analysis of computer scope 3 supply chain emissions has been undertaken, so the UK government's end user computing supply chain environmental impact is unknown. In anticipation of emerging legislation requiring scope 3 emissions to be reported [27] the STAR group recognises a necessity to begin supply chain analysis planning. Additionally, STAR members also recognised that the Jisc process for scope 2 quantification is potentially highly flawed due to the assumed uniform legacy electricity consumption values [23-25]. STAR wishes to improve end user computing total carbon footprint analysis to drive responsible consumption and climate action.

The objective of this research is to begin the process and includes two key focal areas. Firstly, to quantify scope 3 emissions at a device type level in order to estimate existing supply chain values and highlight potential improvements delivered by alternative low carbon footprint devices and longer computer retention periods. Secondly, to determine if the suspected scope 2 reporting inaccuracy caused by the Jisc methodology is confirmed. Achieving both will assist in improving methods and results delivered by the annual reporting process.

2. Method

Scope 3 quantification has been achieved by using the asset profile data created during the most recent Jisc scope 2 GHG emissions reporting process. The data excludes make and model information, instead focusing upon device type and quantities for existing standard desktops computers, thin client computers, notebooks and tablets, plus displays. Supply chain kilogram carbon dioxide equivalent ($kgCO_2e$) values are derived from an average by device type generated by the application used by the government to select computing devices [28]. With a product carbon footprint database of over two thousand different computer models, this application also populates an online average end user carbon footprint calculator [29]. This average value is used for this research as it represents the most likely carbon footprint at a device type level.

The same application was used to enable a representation of the lowest product carbon footprint computer available in each category. This provides a feasible reduction of future carbon footprint achievable by selecting computers using sustainability criterion. Scope 3 emissions examples are also included to show an annualised value when keeping the device for 5 years and an extended 8 year period. Logically, the latter reduces by 37.5% as the supply chain impact is spread across three additional years. A tangible alternative emissions value is also shown in the form of equivalent car miles. This value is derived from the published UK emissions factor [30] and is calculated by dividing the total GHG emissions value by emissions generated by driving an average car for 1 mile.

Scope 2 emissions quantification used to examine the accuracy of the Jisc model is achieved by watt metre field measurement of popular computer devices used within the government's largest department. Following the device use phase analysis (DUPA) [31] test set up and conduct and commercial typical energy consumption (cTEC) methodology [31], annual kilo watt hour (kWh) electricity consumption values are produced for each device model. The data is then converted to GHG emissions ($kgCO_2e$) using the UK electricity to emissions factor. The process is then applied using the Jisc methodology to the department to enable comparison.

3. Results

Thirteen UK central government departments were included within the scope 3 supply chain estimation. Collectively, the departments employ 408,200 staff [32] representing 7% of the UK public sector workforce [33]. 2.2 million devices were identified, including 1.2 million computers and almost 1 million displays. Table 1 provides a detailed breakdown of these device types and numbers

The computers generate an average scope 3 GHG emissions total of 290.5 million $kgCO_2e$. This is equivalent to emissions generated by driving a combustion engine car over 1billion miles [30]. Notably, desktop computers account for 31% of the end user computing estate, being 383,466 units. This suggests that despite analyst data indicating that of the world's 460 million computers manufactured annually, only 14% are in the desktop format [34, 35], it is clear that such computers remain popular in business environments.

The average supply chain value for computers is 237 $kgCO_2e$ per device. Hence, it is feasible that a significant reduction could be achieved by future procurement selecting devices with the lowest available carbon footprint. Table 1 highlights that for desktops and notebooks reductions of 31% and 53% respectively are realistic. As an example, replacing current devices at the appropriate moment in the future with the lowest available scope 3 devices would reduce the overall supply chain impact by 44% to 161.5 million $kgCO_2e$.

This could be further improved by moving from a current 5 year device retention period to an 8 year period, which has shown to be feasible by previous research [10-15, 36]. Coupled with sustainable device selection these actions would reduce the current annualised supply chain emissions value of 58 million $kgCO_2e$ by 65% to 20.2 million $kgCO_2e$ per year. This would be equivalent to eliminating emissions caused by 137,370,281 car miles annually [30].

Table 1. Information and communication technology supply chain scope 3 emissions ($kgCO_2e$) and feasible abatement (%)

Hardware Type	Units	Scope 3 Per Device ($kgCO_2e$)	Scope 3 Total ($kgCO_2e$)	Car Miles Equivalent	5-year Annualised Supply Chain ($kgCO_2e$)	8-year Annualised Supply Chain CFP ($kgCO_2e$)	Lowest Available Scope 3 ($kgCO_2e$)	Selection by CFP Reduction ($kgCO_2e$)
Computers								
Desktops	383,466	221	84,745,986	307,095,180	16,949,197	10,593,248	153	31%
Notebooks	724,750	266	192,783,500	698,592,187	38,556,700	24,097,938	124	53%
Tablets	68,795	110	7,567,450	27,422,271	1,513,490	945,931	65	41%
Thin clients	49,711	108	5,368,788	19,454,950	1,073,758	671,099	106	2%
Displays								
Monitors	983,009	324	318,494,916	1,154,134,353	63,698,983	39,811,865	169	48%
Screens	12,207	1,184	14,453,088	52,373,851	2,890,618	1,806,636	970	8%
Computers	1,226,722	237	290,465,724	1,052,564,589	58,093,145	36,308,216		
Displays	995,216	335	332,948,004	1,206,508,204	66,589,601	41,618,501		

Displays are categorised by two types. The first is a computer monitor with a primary function to display visual information to an individual user. The size range for such devices is set to 14-38” based upon the assumption that an interface larger than this will be inappropriate for desk-based user productivity. The second type is a screen used to display visual information to a group or within a communal area. The size range for such devices is set to 40”-70” to enable an average quantification of scope 3 emissions.

Monitors represent almost 99% of all displays, being 983,009 units. The average supply chain value for the monitor category is calculated as 324 $kgCO_2e$. This generates a supply chain total of 318.5 million $kgCO_2e$ or 63.7 million $kgCO_2e$ when annualised to 5 years. The total scope 3 emissions for monitors are equivalent to emissions generated by 1.15 billion car miles [30]. Selecting future products with the lowest available carbon footprint such as a popular sized 24” model with a scope 3 value of 169 $kgCO_2e$ per unit would deliver a 48% reduction in supply chain emissions.

At 12,207 units, screens represent 1% of all displays. The average supply chain value for the screen category is 1,184 $kgCO_2e$ and the total scope 3 emissions generated are 14.5 million $kgCO_2e$. As with monitors, the annualised representation is based upon the 8 year retention period as advised by STAR. This creates 1.8 million $kgCO_2e$ of scope 3 emissions for each year of the device useful lifespan. The total supply chain environmental impact is equivalent to emissions created by 52.4 million car miles [30]. In total, the 995,216 displays generate scope 3 greenhouse gas emissions of 332.95 million $kgCO_2e$. This is equivalent to 1.2 billion average miles driven in a standard passenger car.

The high number of computers identified suggested that based upon published employee figures [32] the thirteen government departments have 3 computers and 2.4 displays for every member of staff. The exact values include 383,466 desktops, 724,750 notebooks, 68,795 tablets and 49,711 thin clients. Assuming that desktop devices and thin clients will be used as kiosk devices for general public interaction, such as building security check-in and information points, the notebook values appear excessive with 1.8 units available per employee. Triangulating government statistics suggesting 67% of roles require access to computers to conduct their role [37] the total ratio increases to 4.5 computers to every staff member.

The finding supports the conclusions from previous research that contextual data, such as actual operational use, must be generated if meaningful scope 2 emissions are to be calculated. Currently, this is not addressed by the Jisc [23] process as all devices owned, whether in use or not, have an assumed kWh/y applied. While the apparent excess of devices does not affect the quantification of scope 3 emissions as the devices evidently exist, the lack of contextual data relating to the device use-profile will produce inaccurate assumptions for concomitant scope 2 reporting regulations [19]. As an example, should a proportion of the devices be stock items or held for new staff, part-time workers or device replacement purposes then applying energy consumption and concomitant scope 2 emissions values during the Jisc reporting process will be flawed.

The high levels of devices in stock being counted in Jisc reports but not used in the work place led to the largest government department, the Department for Work and Pensions (DWP), agreeing to field-based computer electricity consumption measurement. With 88,380 staff (ONS, 2022) this department owns 227,987 (Table 2) or 19% of the total computer stock within the thirteen departments (Table 1). The assets consist of 97,565 desktops (43% of total), 13 integrated desktops (<0.01%), 130,409 (57%) notebooks plus 128,757 monitors (0.6 displays to every computer) (details in Table 2). Excluding 5,557 desktop computers and 24" display combinations used for customer kiosks, this means that the department holds sufficient hardware to supply 2.5 end user computer devices to each employee.

Table 2. Jisc electricity consumption (kWh) and scope 2 emissions ($kgCO_2e$) versus measured values

Hardware Type	Units	Status	Jisc kWh/y value per unit	Jisc Total kWh/y value	Scope 2 emissions total $kgCO_2e$	Measured kWh/y value per unit	Measured Total kWh/y value	Scope 2 emissions total $kgCO_2e$	Jisc vs. Measured
Desktops	97,565	Owned	200	19,513,000	4,143,195	31.92	3,114,275	661,254	+850%
Desktops	64,351	In use	200	12,870,200	2,732,730	31.92	2,054,083	436,143	+526%
Notebooks	130,409	Owned	30	3,912,270	830,692	21.02	2,741,197	582,038	+114%
Notebooks	87,088	In use	30	2,612,640	554,742	21.02	1,830,590	388,689	+42%
Displays	128,757	In use	179	23,047,503	4,893,676	21.65	2,787,589	591,889	+726%
Total	356,731	Owned		46,472,773	9,867,563		8,643,061	1,835,181	+697%
Total	280,196	In use		38,530,343	8,181,148		6,672,262	1,416,721	+478%

On further examination and discussion with the department, it was found that only 156,452 computers were in use, meaning that 71,535 remained in storage awaiting use. Examining historical employment records indicates that from 2019 the department's staffing numbers rose by 5,110 from 83,270 [32], so overstocking cannot be assumed as legacy equipment no longer required. Two errors in scope 2 quantification are generated by not including use-profile data within the Jisc methodology. Firstly, the total number of devices will have kWh/y and concomitant emissions values applied regardless of whether they are in-use or dormant as previously noted. Secondly, the average kWh/y values used by Jisc will be applied to all models of computer type regardless of specification.

Table 2 shows the Jisc tool calculates the total for all desktop computers to be 19,513,000 kWh/y, producing 4,143,195 $kgCO_2e$. Using the same Jisc [23] process but this time recognising only the in-use devices reduces the values by 34% to 12,870,200 kWh/y and 2,732,730 $kgCO_2e$. This substantiates the first point that contextual data noting whether the device is operational or simply stored must be accounted for in the process.

Applying the field measurements to the devices further compounds the issue related to using the Jisc model. In this example it is determined that the Jisc tool [23] over estimates desktop energy consumption by +526%. Specifically, the tool suggests desktop devices consume 200 kWh/y, whereas when measure with a watt meter, the actual model used by the department actually consumes 31.92 kWh/y. The new calculation produced using the measured values calculate the total in-use electricity consumption to be 2,054,083 kWh/y and 436,143 $kgCO_2e$. It is therefore feasible that by using the non-contextual asset profile data in conjunction with the Jisc tool, the UK government departments are over reporting desktop energy consumption and scope 2 emissions by as much as +850%.

Similarly, the department has a significant number of Dell Latitude notebooks and Microsoft Surface Books within the mobile computing estate. Following the same approach and using the measured average for the two models, the over quantification for notebooks is +114% due to the more realistic 30 kWh/y used by the Jisc tool for a standard laptop compared to the 21.02 kWh/y measured value. Comparatively, the 128,757 displays were all confirmed as in use. Therefore, the over quantification of energy and emissions is +726%.

In total, the error created by using the Jisc model without considering whether a device is in use or in storage is +697%. The total Jisc value of electricity consumed by end user computing devices in the department is calculated to be 46,472,773 kWh/y, with concomitant scope 2 emissions of 9,867,563 $kgCO_2e$. Comparatively, the measured value is 6,672,262 kWh/y and producing scope 2 emissions of 1,416,721 $kgCO_2e$.

By using the non-contextual Jisc model, the largest department within the STAR group is therefore potentially over reporting end user electricity consumption by 39,800,511 kWh/y and related emissions by 8,450,842 $kgCO_2e$.

In terms of utility costs calculated using government published values [38] this indicates that, the department is actually spending £14,328,830 less on end user computing electricity than the current scope 2 reporting process suggests. To emphasise the significance of the error created by the tool it was suggested to the department that, based upon their current Jisc reporting, they are spending £16,730,198 per year on end user computing utility costs. The response was that this is entirely incorrect. It was suggested that it could be closer to £2.4 million or £200,000 a month and equating to £2.26 per user. As such, setting aside the proven environmental errors generated by the current methodology, the utility costs using the cTEC methodology proved to be closest to real-world values.

4. Summary

As identified by the examination, there is potential to significantly reduce UK government end user computing supply chain GHG emissions by 65% by selecting devices with low carbon footprints and retaining devices for longer periods. In addition the scope 2 emissions test highlights an opportunity to improve current quantification practices for annual reporting that has been shown to be inaccurate by 697%. Considering that the internationally recognised GHG accounting protocol [39] requires emissions to be reported as neither over or under the actual value, this latter point requires attention if the UK government is to comply with its own sustainable ICT policy [19].

Further to presenting the findings to the STAR group during their quarterly autumn 2022 meeting, Adam Turner, head of STAR noted (October 2022), '*STAR pioneers, and is responsible for the reduction of the government's ICT carbon footprint. This is especially important within the supply chain when the majority of environmental impact occurs. Having access to never previously available scope 3 data is essential to evolving our policies, procurement practices, accurate government reporting and ensuring our technology partners focus on low carbon footprint production and supply.*'

Tony Sudworth, Sustainability Lead at DWP added (May 2023), *'Correct measurement of the emissions from end user devices is essential. It needs to be based on actual usage figures (scope 2) and include scope 3 emissions. If reported incorrectly we're not going to tackle this in the right way. This report shows clearly that extending the lifecycle of the devices can make a demonstrable reduction in embodied emissions. By knowing the emissions caused by the actual operation of these devices (rather than an estimate) we can make operational decisions on how we use these devices to reduce emissions; as well as measuring them correctly. Although we in government are not required to report scope 3 (yet), if we are prepared for what is inevitably needed to meet the 2050 Net Zero target, we can start to make informed choices to reduce the emissions from one of the largest components of IT based emissions.'*

The findings of this research have subsequently been included in the 2022 government ICT strategy and policy report [26] to the UK parliament with a recommendation that scope 3 emissions reporting become part of the greening ICT policy in the coming years.

References

[1] Andrae, A. S. G., and Edler, A.T., (2015). ‘On global electricity usage of communication technology: trends to 2030.’ Challenges 6, 117e157.

[2] Bekaroo, G., Bokhoree, C., Pattison, C. (2014), ‘Power Measurement of Computers: Analysis of the Effectiveness of the Software Based Approach’. New Delhi, India: Int. J. Emerging Technol. Adv. Eng.

[3] Belkhir, L., and Elmeligi, A. (2017) ‘Assessing ICT global emissions footprint: Trends to 2040 & Recommendations’. Oxford: Science Direct

[4] Global e-Sustainability Initiative. (2008), SMART 2020: Enabling the low carbon economy in the information age. Figure 3.1 The global footprint of PCs – desktops and laptops: 19. Brussels: GESI

[5] Global e-Sustainability Initiative. (2012), ‘SMARTer 2020: The Role of ICT in Driving a Sustainable Future.’ The ICT Industry’s GHG Emissions: 22. Brussels: GESI

[6] Global e-Sustainability Initiative. (2015), ‘#SMARTer2030 ICT Solutions for 21st Century Challenges.’ Executive Summary: ICT Solutions for 21st Century Challenges: 8. Brussels: GESI

[8] Global e-Sustainability Initiative. (2019), ‘Digital with Purpose: Delivering a SMARTer2030’. Brussels: GESI

[9] Malmodin, J., Bergmark, P., Lunden, D., (2013). The future carbon footprint of the ICT and E&M sectors. In: On Information and Communication Technologies

[10] Sutton-Parker, J. (2020), ‘Quantifying resistance to the diffusion of information technology sustainability practices in United Kingdom service sector’. 1877-0509. Amsterdam, the Netherlands: Science Direct, Elsevier B.V.

[11] Sutton-Parker, J. (2020), ‘Determining end user computing device Scope 2 GHG emissions with accurate use-phase energy consumption measurement’. 1877-0509. Procedia Computer Science. Amsterdam, the Netherlands: Science Direct, Elsevier B.V.

[12] Sutton-Parker, J. (2022), ‘Can analytics software measure end user computing electricity consumption?’ Clean Technologies and Environmental Policy. 1618-9558. New York, USA: Springer.

[13] Sutton-Parker, J. (2022), ‘Quantifying greenhouse gas abatement delivered by alternative computer operating system displacement strategies’. 1877-0509. Procedia Computer Science. Amsterdam, the Netherlands: Science Direct, Elsevier B.V.

[14] Sutton-Parker, J. (2022), ‘Is sufficient carbon footprint information available to make sustainability focused computer procurement strategies meaningful?’. 1877-0509. Procedia Computer Science. Amsterdam, the Netherlands: Science Direct, Elsevier B.V.

[15] Sutton-Parker, J. (2022), 'Determining the impact of information technology greenhouse gas abatement at the Royal Borough of Kingston and Sutton Council’. 1877-0509. Procedia Computer Science. Amsterdam, the Netherlands: Science Direct, Elsevier B.V.

[16] United Nations (2015), ‘Sustainable Development Goals’. New York: United Nations.

[17] United States Government. (2021), ‘The Federal Acquisition Regulation Part 23.7’. Washington DC, USA: US Government

[18] European Commission. (2021), ‘EU green public procurement criteria for computers, monitors, tablets and smartphones’. Brussels: EU

[19] Department for Food Environment and Rural Affairs. (2020). ‘Greening government: ICT and digital services strategy 2020-2025’. London: Crown copyright.

[20] Microsoft. (2022), ‘Eco Profiles.’ Redmond: USA

[21] Lenovo. (2022), ‘ECO Declarations and Product Carbon Footprint Information Sheets’. Quarry Bang: Hong Kong.

[22] HM Government. (2013) ‘The Companies Act 2006 (Strategic Report and Directors’ Report) Regulations).’ Section 416 (c)

[23] Jisc. (2019), ‘SusteIT ICT Energy and Carbon Footprinting Tool

[24] Cartledge, C. (2008), ‘Energy Impacts of ICT at the University of Sheffield, Bradford: SusteIT, July, 2008.’ Bristol: SusteIT

[25] Hopkinson, L and James, P. (2009), ‘Energy and Carbon Impacts of ICT User Guide for the SusteIT Footprinting Tool’. Bristol: SUSTEIT

[26] HM Government. (2022), ‘Greening government ICT: annual report 2021 to 2022’. London, England: Crown Copyright

[27] European Union (2002), ‘Corporate sustainability reporting directive (CSRD)’. Brussels: European Union. Brussels: EU

[28] Sutton-Parker, J. (2022), ‘The Dynamic Carbon Footprint’. Available at <https://dcf.px3.org.uk/>

[29] Sutton-Parker, J. (2023), ‘The EUC Carbon Footprint Calculator’. Available at <https://itcf.px3.org.uk/>

[30] Department for Business Energy and Industrial Strategy (BEIS) and Department for Environment Food and Rural Affairs. (2022), ‘UK Government GHG Conversion Factors for Company Reporting’. London: Crown Copyright

[31] Sutton-Parker, J. (2022), ‘The impact of end user computing carbon footprint information on human behavioural change and greenhouse gas emission abatement’. University of Warwick. Warwick: United Kingdom

[32] Office for National Statistics (ONS). (2022), ‘Public sector employment’. London, England: Crown copyright

[33] House of Commons. (2022), ‘Business Statistics. London: House of Commons Library’.

[34] Gartner, (2021). ‘Gartner Says Worldwide PC Shipments Grew 10.7% in Fourth Quarter of 2020 and 4.8% for the Year.’ Arlington, VA: Gartner Inc.

[35] Statistica Research Department. (2021). ‘PC unit shipments worldwide from 2019 to 2025, by type.’ Amsterdam: SRD

[36] Google. (2022), ‘Modernising and extending device lifecycles to support climate action’. Mountain View, California: Google

[37] Department for Business Energy and Industrial Strategy (BEIS). (2021), ‘Energy consumption in the UK 2021.’ Table 5.05

[38] Department for Business Energy and Industrial Strategy. (2021) ‘BEIS and National Statistics 2021 Energy Statistics.’ London, England

[39] World Business Council for Sustainable Development and World Resources Institute (WBCSD and WRI). (2004), ‘The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard’. Geneva, Switzerland and New York, USA.