# Determining United Kingdom government information and communications technology scope 3 greenhouse gas emissions

Justin Sutton-Parker*

*University of Warwick, Computer and Urban Science Department, Coventry, CV4 7AL, United Kingdom*

**Abstract**

End user computing generates 1% of global greenhouse gas emissions therefore contributing to environmental pollution, global warming and ultimately climate change. Research indicates the carbon footprint is predominantly generated by production and use-phase electricity consumption. As such, evolving legislation exists to ensure public sector organisations include sustainability criteria when assessing and purchasing computers. This is designed to encourage such organisations to procure computers with a low total carbon footprint. The rationale being that both scope 2 use-phase and scope 3 supply chain emissions can be reduced in the long term to contribute to wider reaching abatement targets and climate emergency strategies. As such, it is reasonable to suggest that sufficient carbon footprint information must be publicly available to enable meaningful quantification of both current and potential emissions reduction. Using an existing tool that leverages power draw averages by device type, the United Kingdom government has evaluated the scope 2 electricity consumption values for the end user information and communications technology estates of thirteen departments including 3,196,146 devices. Moving forward, DEFRA wishes to calculate scope 3 emissions for the same ICT estates in the hope that doings so will encourage the availability of data as manufacturers respond to such efforts and to ultimately reduce long term supply chain emissions impact as existing devices are retired and new product purchased. Consequently, the research objective is to identify or generate scope 3 data related to the same devices previously subject to scope 2 quantification. Doing so determines current gaps in available data plus a credible and meaningful estimation of current ICT supply chain greenhouse gas emissions. Derived from existing research, manufacturer carbon footprint reports and lifecycle assessment comparison, the results determine that the departments' current collective ICT estate has generated 718.7m kg$CO_2$e scope 3 greenhouse gas emissions. In analogous terms this is equivalent to the pollution generated by driving an average fossil fuel propelled car 2.6bn miles. In context, this is a distance exceeding nine return journeys to Mars when experiencing an average orbit cycle. As such it is concluded that whilst manufacturers need to increase efforts to conduct life cycle assessment reports for all new ICT products, the emphasis to reduce existing and future supply chain impact is shared by large public organisations. This is achieved by responding to the prevailing legislation by leveraging two key yet obvious strategies. The first being new product procurement displacement driven by extended device retention periods that will reduce annualised scope 3 impacts by 37.5% when transitioning from 5-year to 8-year useful device life spans. The second being the identification and procurement of devices that offer the same user experience yet exhibit a greatly reduced total carbon footprint. Specifically, executing the latter will act as a catalyst for manufacturers to produce product carbon footprint reports should they wish to remain as strategic suppliers to a market that employs over 16% of the UK's entire workforce.



*Keywords:* Computer product carbon footprint; computer life cycle assessment; computer science; computer human computer interaction; sustainable information technology

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

## 1. Introduction

Since the Industrial Revolution, human polluting activity known as anthropogenic interference has caused 1.0°C of global warming [1]. A further increase to 1.5°C will be reached between 2030 and 2052 if greenhouse gas (GHG) emissions increases continue at the current rate [1]. However, scientists calculate that by reaching and sustaining net zero global anthropogenic $CO_2$ emissions by mid-century, global warming will halt on a multi-decadal scale and temperature gains will begin to peak [1]. To achieve this goal, it is calculated that the world cannot rely solely on key greenhouse gas (GHG) abatement strategies, such as vehicle electrification and renewable energy transition [2]. This is because evidence indicates that the rapidity of adoption and associated abatement will not be sufficient to bridge the projected 32Gt$CO_2$e annual emissions gap forecast for 2030 [2]. As an alternative, scientists and governments agree that all aspects of human pollutant activity must be examined and low carbon alternatives researched and diffused during the next decade to compensate for this limitation [1]. Specifically, the United Nations Environmental Programme (UNEP) suggests that to bridge the gap, the world must combine existing technology with innovation to drive behavioural changes capable of reducing societal emissions [2].

Considering this criterion, it is reasonable to suggest that being both mature and highly diffused, information and communications technology (ICT) represents a key candidate to participate in this strategy. The rationale is twofold. Firstly, research indicates that ICT is responsible for generating approximately 2.5% of global GHG annual emissions and is therefore a significant source of global warming potential [3-10]. Secondly, a further body of empirical research substantiates that focusing upon adoption of sustainable ICT strategies can abate and avoid substantial quantities of scope 2 and scope 3 emissions [11-16] caused by changes to purchasing and use behaviour. For example, selecting notebooks utilising energy efficient operating systems and components will reduce concomitant electricity emissions by as much as 57% during the device's useful lifespan [11]. Extending a device's retention period from 5-years to eight will create procurement displacement and reduce supply chain emissions by 37.5% [13, 16]. Plus, assessing and selecting devices based upon the lowest available carbon footprint can also reduce scope 3 emissions by over 600% even within the same device categories [15].

As such, applied to a business setting with a high number of computer users causes the potential positive environmental impact to be enhanced. Associated research identifies that the United Kingdom public sector represents such an opportunity. Specifically, employing 5.37m people and representing almost 17% of the country's workforce, [17, 18] statistics indicate that 67% of workers use an end user computing device as part of their job role [19]. This suggests that applying sustainability criteria to the ICT behaviour of 3,597,900 people using a top-down approach may drive the societal emissions abatement sought by UNEP [2].

Already subject to mandatory scope 2 emissions reporting [20] and the greening ICT policies [21], it is clear that the public sector is already striving to achieve such strategies from an energy perspective. The rationale being that consuming almost 11% of electricity within the sector [19], ICT is the sector's third largest consumer of electricity behind lighting (14.5%) and cooling and ventilation (13.4%). As an example, over 70% of service sector organisations [12, 22] now use publicly available benchmarks [23] to select energy efficient devices and quantification tools [24-26] to estimate scope 2 ICT use-phase emissions. Comparatively, the same organisations currently avoid scope 3 quantification citing cost and time as barriers to overcoming complexity [12]. The complexity ultimately lies with ICT total product carbon footprint being limited in availability predominantly due to a lack of participation by major manufacturers [15]. In fact, research identifies that only 22% of end user computing products have accessible scope 3 data [15]. The inertia to adopt scope 3 criteria within equipment selection practices and supply chain impact reporting is also exacerbated by, unlike scope 2 reporting being mandatory, scope 3 accounting remains discretionary [20].

Such inertia represents a potential barrier to meaningful delivery of significant ICT emissions abatement. The rationale being that research determines the supply chain or scope 3 emissions contribution to the average product total carbon footprint is 77% [15]. As such, if left unaddressed, the most significant global warming potential generated by ICT cannot be knowingly reduced and avoided. Consequently, and in response the evolving public sector sustainable ICT policies [21] and to support existing national net zero aspirations, thirteen UK government departments and offices have begun to examine ICT scope 3 emissions in more detail in order to reduce their collective long term digital footprint. Specifically, the organisations are leveraging summary ICT asset profile data generated during the annual scope 2 ICT emissions calculation to enable the same exercise to be undertaken for the ICT supply chain. The organisations include the Department for Environment, Food and Rural Affairs, the Department for Business, Energy and Industrial Strategy, the Crown Prosecution Service, the Department for Education, the Department for Transport, the Department for Health and Social Car, the Department for Work and

Pensions, Her Majesty's Revenue and Customs, the Home Office, the Met Office, the Ministry of Defence and the Ministry of Justice plus the Chief Digital Information Officer.

The asset profile data, summarised by DEFRA, includes device type and quantities from six distinct ICT end user equipment categories. These include computers, displays, communications hardware, networking equipment, image and print devices plus audio visual equipment. Being the first instance that an attempt to quantify the associated supply chain impact has been attempted, the UK government recognises both the existing complications and prevailing research conducted to advance this process within the field of computer and urban science [11-16]. As such, DEFRA has instructed this exploratory research study to be undertaken. The rationale being that the results generated will leverage findings and methods developed to surmount the barriers of limited data. Plus, create a credible science based response that will act as a foundation to enable academics, suppliers and interested parties to improve future accuracy. Consequently, the summary objective of this research paper is to identify available scope 3 data for each device type, whether extracted from existing manufacturer carbon footprint reports or derived from prevailing life cycle assessment (LCA) research, and apply the values to the existing ICT asset profile data. Doing so allows for device, category and total scope 3 supply chain values to be determined in carbon dioxide equivalent ($kgCO_2e$) GHG units, in accordance with international accounting protocol [27]. To improve contextual appreciation of the to the significance of scope 3 emissions and available abatement opportunities, analogous pollution values such as equivalent car miles, lowest carbon footprint device examples and annualised displacement reductions are included within the results.

## 2. Method

To achieve the objective, scope 3 data is captured where available from existing sources. For the computers and displays asset list, an application developed by prevailing research that is capable of automating the identification of scope 3 supply chain emissions is utilised as source data [28]. The supply chain value is derived directly from available manufacturer carbon footprint reports conducted in line with LCA international standards [29] and is therefore delivered with high confidence. Where feasible, similar manufacturer or third party certification reports are identified for products within the remaining categories and average scope 3 $kgCO_2e$ values generated for each device. Similarly, due to the same rationale, the results are delivered with high confidence. Where gaps in the data exist, prevailing research is examined in order to create a credible supply chain value. As such, this is judged to be delivered with moderate confidence. This is not because of credibility but due to reduced number of available data points. Where neither research nor manufacturer reports are available, life cycle assessment (LCA) estimation is undertaken using $kgCO_2e$ values for common attributes such as device chassis, power supplies, printed circuit boards and proportional contribution calculations [30]. Due to the nature of this approach, the data is delivered with low confidence. The rationale being that the bill of materials is common yet not specific and based upon a methodology that utilises feasible ranges as opposed to exact calculation [30]. The data is then applied to a table (table 1) to enable clear identification of key values required to accomplish the task. Specifically, summary results pertaining to the headline categories of all devices, computers, displays, communications, networking, image and print plus audio visual equipment are initially presented. Doing so allows for each category to highlight its contribution to proportional representation by units, a category level average device scope 3 $kgCO_2e$ value, total supply chain carbon footprint, plus contextual data such as the equivalent car miles and annualised accounting values based upon a standard 5-year useful device life span and an extended 8-year period. The format is repeated at a device level with the additional inclusion of devices with the lowest available carbon footprint by type scope 3 emissions. This is included to highlight the impact of informed sustainable device selection. In relation to the equivalent car values, the concept is to add immediate comprehension of the emissions value irrespective of technical understanding. Proven to be highly effective in similar models [31], the mileage calculations are achieved by using UK government conversion values for an average passenger car [32].

## 3. Results

As highlighted by table 1, the asset profile exercise captures a total of 3,196,146 devices. The total supply chain carbon footprint is determined to be 718,701,267 kg$CO_2$e and therefore equivalent to the emissions generated by 2,604,367,542 car miles. At a category level, the computer category consists of 1,226,722 units (38%) producing 40% of supply chain emissions. Displays represent 995,216 (31%) of the asset estate, although the GHG contribution is raised to 46% highlighting the high embodied carbon footprint of visual interfaces. Communications consists of 710,510 devices (22%), producing just 7% of the overall emissions due to the low carbon footprint of phones in general. Networking products include 123,101 (3.9%) devices and produce an almost equivalent 3% in supply chain impact. Image and print is similar with 117,624 (3.7%) units and 3% of the total scope 3 emissions, although it is noted that consumables such as paper are not included within the scope of this research. Whereas finally, audio visual includes 22,973 devices and generates less than one percent of both assets unit values and resulting supply chain emissions. To explore the specific impact of each device type and category, a detailed discussion for each is undertaken before the supply chain quantification impact is summarised.

### *3.1 Computers*

Four types of end user computers are identified by the asset profile exercise, including desktops, notebooks, tablets and thin clients. As determined in associated research [15], sufficient product carbon footprint data is available to deliver scope 3 analysis for all types with high confidence.

Desktops account for 31% of the end user computing estate, being 383,466 units (table 1). The finding substantiates associated research that challenges analyst data indicating the proportionate representation and therefore implied decline in popularity of the desktop is universal [15]. As an example, currently, manufacturing and annual shipping data combining both commercial and consumer quantities, indicates that 53% of end user computers are notebooks, 33% tablets and 14% desktops [33-35]. However, as the prior research focused upon the commercial sector determined the desktop install base to be 34.7% [15], this current finding is congruent. As such it is reasonable to suggest that with such a large comparative data sample, the decline of the desktop is isolated currently to consumer markets. Accessing over one hundred desktop computer scope 3 values via the online dynamic carbon footprint tool [28] designed to enable IT and procurement teams to assess computers using sustainability criteria, an average supply chain GHG emissions value of 221 kg$CO_2$e is determined. As such, the total scope 3 emissions for desktop computers is 84,745,986 kg$CO_2$e or 16,949,197 kg$CO_2$e per year when accounted for across a 5-year retention period. The analogous pollution is equivalent to driving 307,095,180 miles in a standard car on UK roads. It is noted as feasible for the impact to be reduced by 37.5% through displacement delivered by transitioning to an 8-year retention period. Additionally, by selecting new desktop devices based upon the lowest available scope 3 value of 153 kg$CO_2$e, a further reduction to each unit of 31% is available.

Notebooks represent 59% of the computing estate, being 724,750 units (table 1). Following the same methodology as applied to the desktops, an average scope 3 GHG emissions value of 266 kg$CO_2$e is determined. It is noted that whilst this is 20% higher than the desktop value, notebooks include an integrated screen. Comparatively, a desktop requires a peripheral monitor in order to operate. As such, adding the average monitor value to the desktop value raises the per unit total to 545 kg$CO_2$e causing a 105% higher supply chain footprint. In context, as the audit identifies a ratio of 1.25 computers per available monitor it is most likely that even where dual screens are experienced with desktops, many of the notebooks will connect and use the surplus monitors. The total scope 3 emissions for notebooks is 192,783,500 kg$CO_2$e for the useful lifespan of the device or 38,556,700 kg$CO_2$e when annualised. This is equivalent to the pollution created by 698,592,187 car miles. A reduction of 53% in supply chain emissions for new devices is available by transitioning to the lowest scope 3 emissions value device being 124 kg$CO_2$e. As before, displacement also has the potential to reduce long term supply impact by 37.5%.

Tablets represent 5.6% of the computer estate, being 68,795 units (table 1). The considerable available scope 3 data [28], enables an average value of 110 kg$CO_2$e to be determined. This lower supply chain impact is simply due to the reduced material content when compared to both a notebook that exhibits an additional keyboard chassis and a desktop that will include further components such as solid state hard drives and mechanical cooling plus increased central processing unit sizes. As such, the total scope 3 emissions generate 7,567,450 kg$CO_2$e or 1,513,490 kg$CO_2$e when annualised. This is equivalent to the pollution created by 27,422,271 car miles. Examining beyond displacement, a 41% reduction is available by selecting a device with the lowest supply chain value of 65 $kgCO_2e$ per unit.

Thin clients represent 4% of the computer estate, being 49,711 units (table 1). Using the same methodology, an average of 108 $kgCO_2e$ scope emissions per device is determined. Comparatively, this is 52% less in embodied impact than a desktop computer. This is because a thin client differs from all other desktops as it does not conduct tasks such as program execution and storage locally. Instead, the device type relies upon data centre based remote computing resources such as a virtual desktop infrastructure. The significantly reduced carbon footprint of thin clients is caused by the product's chassis being very small due to fewer component parts required, therefore reducing material requirements and power draw. However, from a sustainability perspective, it is recognised that the carbon footprint of the data centre infrastructure required to enable the device diminishes the environmental gain [16]. In total, the scope 3 emissions of thin clients within the ICT estate is 5,368,788 $kgCO_2e$ or 1,073,757 $kgCO_2e$ when annualised. This is equivalent to the pollution created by 19,454,949 car miles. Due to the low carbon footprint of thin clients, the greatest available abatement of supply chain emissions is via a displacement strategy extending the device useful lifespan before replacement.

In summary, the 1,226,722 end user computers represent 38% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 290,465,724 $kgCO_2e$ represents 40% of the environmental supply chain impact overall as noted. As such, the computer device scope 3 element of the ICT estate is currently responsible for pollution equivalent to 1,052,564,589 miles being driven in a standard passenger car. The congruity achieved by proportional and contributory representation suggests that with an average supply chain value of 237 $kgCO_2e$ per device, significant reduction could be achieved by leveraging the scope 3 31% and 53% reductions available for desktops and notebooks by introducing sustainability criteria during procurement. As an example, replacing the 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 161,475,536 $kgCO_2e$. This could be further improved by moving from a 5-year device retention period to an 8-year period, proven feasible by existing research [13,15]. If coupled with sustainable device selection, the results could reduce the current annualised supply chain impact value of 58,093,145 $kgCO_2e$ by 65% in total to just 20,184,442 $kgCO_2e$. Doing so would be equivalent to avoiding the pollution caused by 137,370,281 car miles each and every year.

### *3.2 Displays*

Displays, in this instance are categorised by two types. The first is a computer monitor used as an interface with a primary function to display visual information supplied by a computer to an individual user. The size range for such devices is set to 14-38" based upon the rationale that an interface larger than this will arguably 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. Both use case assumptions are validated by prior research [15].

Monitors represent almost 99% of all displays, being 983,009 units (table 1). The average supply chain value for the monitor category is 324 $kgCO_2e$. Similar to the computers, this value is generated by accessing manufacturer scope 3 values via the dynamic carbon footprint tool [28]. The nuance in this example is however that proportional representation is applied to account for preferential monitor sizes determined in prior associated research [15]. As an example, of 31,534 displays, sizes between 22" and 27" were found to be popular representing 98% of the estate. Specifically, 23" displays accounted for 16,640 units and 53% of the total, followed by 24" (8,557 units and 27%) and 27" (4,404 units and 14%).

Table 1. Information and communication technology supply chain scope 3 emissions (kgCO2e) and feasible abatement (%)

| **Hardware Type** | **Units** | **Scope 3 Per Device ($kgCO_2e$)** | **Scope 3 Total ($kgCO_2e$)** | **Car Miles Equivalent** | **Supply Chain Emissions Contribution** | **5-year Annualised Supply Chain (kgCO2e)** | **8-year Annualised Supply Chain CFP (kgCO2e)** | **Lowest Available Scope 3 (kgCO2e)** | **Selection CFP Reduction (kgCO2e)** |
|---|---|---|---|---|---|---|---|---|---|
| All devices | 3,196,146 | 225 | 718,701,267 | 2,604,367,542 | 100% | 143,740,253 | 89,837,658 | | |
| Computers | 1,226,722 | 237 | 290,465,724 | 1,052,564,589 | 40% | 58,093,145 | 36,308,216 | | |
| Displays | 995,216 | 335 | 332,948,004 | 1,206,508,204 | 46% | 66,589,601 | 41,618,501 | | |
| Communications | 710,510 | 71 | 50,795,309 | 184,067,651 | 7% | 10,159,062 | 6,349,414 | | |
| Networking | 123,101 | 176 | 21,639,807 | 78,416,463 | 3% | 4,327,961 | 2,704,976 | | |
| Image & Print | 117,624 | 177 | 20,811,352 | 75,414,379 | 3% | 4,162,270 | 2,601,419 | | |
| Audio Visual | 22,973 | 89 | 2,041,071 | 7,396,257 | 0% | 408,214 | 255,134 | | |
| | | | | | | | | | |
| 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% |
| | | | | | | | | | |
| Communications | | | | | | | | | |
| *Smart phones* | 253,381 | 64.5 | 16,343,075 | 59,222,621 | | 3,268,615 | 2,042,884 | 53.7 | 17% |
| *Mobile phones* | 53,767 | 22.5 | 1,209,758 | 4,383,815 | | 241,952 | 151,220 | NA | NA |
| *PABX* | 122,462 | 219 | 26,819,178 | 97,185,020 | | 5,363,836 | 3,352,397 | NA | NA |
| *Video conf.* | 3,129 | 231 | 722,799 | 2,619,217 | | 144,560 | 90,350 | 211 | 9% |
| *VOIP phones* | 276,655 | 20 | 5,533,100 | 20,050,370 | | 1,106,620 | 691,638 | NA | NA |
| *Fax* | 1,116 | 150 | 167,400 | 606,610 | | 33,480 | 20,925 | NA | NA |
| | | | | | | | | | |
| Networking | | | | | | | | | |
| *10/100 switch* | 15,540 | 219 | 3,403,260 | 12,332,439 | | 680,652 | 425,408 | NA | NA |
| *10-1000 switch* | 21,004 | 219 | 4,599,876 | 16,668,633 | | 919,975 | 574,985 | NA | NA |
| *Core switch* | 8,214 | 869 | 7,137,966 | 25,865,944 | | 1,427,593 | 892,246 | NA | NA |
| *POE class 1* | 761 | 30 | 22,830 | 82,729 | | 4,566 | 2,854 | NA | NA |
| *POE class 2* | 1,191 | 30 | 35,730 | 129,475 | | 7,146 | 4,466 | NA | NA |
| *POE class 3* | 1,307 | 30 | 39,210 | 142,086 | | 7,842 | 4,901 | NA | NA |
| *POE class 4* | 3,593 | 30 | 107,790 | 390,600 | | 21,558 | 13,474 | NA | NA |
| *POE other* | 13,651 | 30 | 409,530 | 1,484,019 | | 81,906 | 51,191 | NA | NA |
| *Room hubs* | 1,601 | 158 | 252,958 | 916,647 | | 50,592 | 31,620 | NA | NA |
| *Edge switches* | 18,824 | 158 | 2,974,192 | 10,777,620 | | 594,838 | 371,774 | NA | NA |
| *W. access points* | 37,415 | 71 | 2,656,465 | 9,626,268 | | 531,293 | 332,058 | NA | NA |
| | | | | | | | | | |
| Image & Print | | | | | | | | | |
| *Copier* | 638 | 928 | 592,064 | 2,145,470 | | 118,413 | 74,008 | NA | NA |
| *Ink jet printer* | 4,391 | 75 | 329,325 | 1,193,379 | | 65,865 | 41,166 | NA | NA |
| *Laser printer* | 87,662 | 65 | 5,698,030 | 20,648,029 | | 1,139,606 | 712,254 | NA | NA |
| *MFD (b/w)* | 7,329 | 670 | 4,910,430 | 17,793,992 | | 982,086 | 613,804 | NA | NA |
| *MFD (colour)* | 5,441 | 670 | 3,645,470 | 13,210,139 | | 729,094 | 455,684 | NA | NA |
| *Prod. MFD (col)* | 2,297 | 1,178 | 2,705,866 | 9,805,283 | | 541,173 | 338,233 | NA | NA |
| *Prod. MFD (mo)* | 1,789 | 1,178 | 2,107,442 | 7,636,766 | | 421,488 | 263,430 | NA | NA |
| *Scanner* | 5,672 | 70 | 397,040 | 1,438,759 | | 79,408 | 49,630 | NA | NA |
| *Other imaging* | 2,405 | 177 | 425,685 | 1,542,561 | | 85,137 | 53,211 | NA | NA |
| | | | | | | | | | |
| Audio Visual | | | | | | | | | |
| *Projectors* | 4,107 | 118 | 484,626 | 1,756,146 | | 96,925 | 60,578 | NA | NA |
| *Other AV* | 18,866 | 82.5 | 1,556,445 | 5,640,111 | | 311,289 | 194,556 | NA | NA |

This generates a supply chain total of 318,494,916 $kgCO_2e$ or 63,698,983 $kgCO_2e$ when annualised. It is noted however, that research determines [15, 16] public sector organisations retain monitors for extended periods of up to 8-years. As such the most likely annualised value will be 39,811,864 $kgCO_2e$ as highlighted in the displacement strategy section of table 1. The total scope 3 emissions for monitors is equivalent to pollution generated by 1,154,134,352 car miles. An abatement is available based upon assessing and selecting monitors for sustainability criteria such as a low embodied carbon footprint. In this instance, a popular sized 24" model with a scope 3 value of 169 $kgCO_2e$ per unit would deliver a 48% reduction in supply chain impact if selected as a replacement when necessary.

Screens represent just 1% of all displays, being 12,207 units (table 1). The average supply chain value for the screen category is 1,184 $kgCO_2e$. The 265% increase is caused by additional raw materials and processes required to produce the larger devices plus high associated transportation flow increases caused again by size [28]. The total scope 3 emissions generated is 14,453,088 $kgCO_2e$. In context, this is 4% of the total display supply chain value, despite representing just over 1% of the physical estate as noted. As with monitors, the most likely annualised representation is based upon the 8-year retention period resulting in 1,806,636 $kgCO_2e$ for each year of the device useful lifespan. The total supply chain environmental impact is equivalent to pollution created by 52,373,851 car miles.

In summary, the 995,216 displays represent 31% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 332,948,004 $kgCO_2e$ represents 46% of the environmental supply chain impact overall. The imbalance is directly attributed to the size of the products that affects both life cycle processes such as manufacturing and flows including transportation emissions when compared to, for example, computers. Holistically, the display element of the ICT estate is responsible for pollution equivalent to 1,206,508,204 average miles being driven in a standard passenger car.

### *3.3 Communications*

Six types of communications devices are indicated by the asset profile exercise, including smart phones, mobile phones, distributed private automatic branch exchange (PABX), video conference, voice over internet protocol (VOIP) phones and fax machines. The distinction between smart and mobile handsets is defined by DEFRA as the latter being for telephone use only and not internet connected.

Smart phones represent 36% of all communications devices, being 253,381 units (table 1). Scope 3 carbon footprint data is sufficiently available to enable emissions quantification of smart phones. Specifically, the production, transport and end of life emissions for one hundred models aged new to 5-years old, is used to generate an average value of 64.5$kgCO_2e$ value per device. The total quantification of scope 3 emissions for the 253,381 devices is therefore 16,343,074 $kgCO_2e$ or 3,268,615 $kgCO_2e$ when annualised to 5-years retention. Consequently, the pollution created by supply chain emissions for smart phone stock held by the UK government is equal to 59,222,619 car miles. There is potential to reduce the impact by 17%, via selection of devices exhibiting the lowest carbon footprint of 53.7 $kgCO_2e$ per device. Transitioning to reduced scope 3 devices when replacement becomes the only option would reduce the equivalent ongoing impact by 10,067,845 miles. Due to the high availability of carbon footprint data, the quantification for smart phones is considered to be made with high confidence.

Mobile phones represent 7.5% of all communications devices, being 53,767 units (table 1). Mobile phone embodied emissions data is not available from manufacturers despite companies such as Nokia publishing thorough environmental profiles and conducting offsetting schemes based upon purchase [36]. The data does however indicate weights and percentages of materials used such as printed circuit board, liquid crystal displays, plastic and metal proportionate content plus evidence of high recyclability to over 90% [36]. However, existing research defines embodied impact value to be between 20-25 $kgCO_2e$ [5, 37]. Consequently, a mid-point of 22.5 $kgCO_2e$ is assumed and quantification considered to be made with moderate confidence. As such, the 53,767 mobile phones identified generate a scope 3 carbon footprint of 1,209,758 $kgCO_2e$ or 241,952 $kgCO_2e$ when annualised to a 5-year retention period. This is equivalent to pollution generated by 4,383,816 car miles. Due to the scope 3 device value being derived from research data no alternative reduction is indicated.

PABX modules represent 17% of all communications devices, being 122,462 units (table 1). No environmental supply chain data exists with regards to private automatic branch exchange devices. As such an assumption is made based upon a cumulative emissions value derived from common components used within other ICT products. These include printed circuit boards, connectivity, power supply units and chassis used within this device. As such 219 $kgCO_2e$ of estimated scope 3 is used to represent each PABX unit. The values are therefore determined to be delivered with low confidence. The 122,426 identified devices generated a scope 3 value of 26,819,178 $kgCO_2e$ or 5,363,836 $kgCO_2e$ when annualised using the standard retention period. This is equivalent in pollution to 97,185,019 car miles. Due to the value being assumed no alternative is indicated although displacement delivered by an 8-year retention period will reduce associated supply chain emissions by 37.5%.

Video conferencing systems represent less than one half of a percent of all communications devices, being 3,129 units (table 1). The video conferencing system is based upon available but limited scope 3 data. An average value for the unit is 231 $kgCO_2e$. Due to the low number of product carbon footprint reports available, whilst the data is generated using valid LCA methodologies, the information is considered as delivered with moderate confidence. As such the 3,129 studio units generate 722,799 $kgCO_2e$ of scope 3 emissions or 144,556 $kgCO_2e$ when annualised. This is equivalent to pollution derived from driving 2,619,217 car miles. As the data is extracted from existing reports then a lowest impact value device would reduce emissions by 9%.

VOIP devices represent 39% of all communications devices, being 276,655 units (table 1). VOIP manufacturers do not publish product carbon footprint data although prevailing research calculates the average scope 3 value to be 20$kgCO_2e$ [37]. As such, quantification is determined to be delivered with moderate confidence. The 276,655 devices are responsible for 5,553,100 $kgCO_2e$ scope 3 emissions or 1,106,620 $kgCO_2e$ per year for a 5-year period. The total environmental impact is equivalent to 20,050,370 car miles. Due to the data points being derived from empirical research, no alternative low carbon value is offered although as before, displacement strategies based upon 8-year retention periods will reduce overall impact by 37.5%

Fax machines represent 0.2% of all communications devices, being 1,116 units (table 1). No environmental data exists with regards to fax machines beyond numerous studies examining standby energy consumption and paper versus paperless operations. As such an assumption is made based upon the similarity of PCB, connectivity and chassis used within this device and a small laser printer. Consequently, 150 $kgCO_2e$ is used to represent the fax devices and therefore the data is determined as low confidence. The 1,116 devices generate 167,400 $kgCO_2e$ during the useful lifespan or 33,480 $kgCO_2e$ for each year of retention. This is equivalent to the pollution created by 606,609 car miles. As the scope 3 value is assumed, then no alternative abatement beyond displacement of 37.5% delivered by a further 3-years of use.

In summary, the 710,510 communications devices represent 22% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 50,795,309 $kgCO_2e$ represents 7% of the environmental supply chain impact overall. This imbalance is most likely due to the significant number of VOIP handsets that exhibit a relatively low scope 3 value. Additionally, the PABX systems may be higher in impact in reality as discussed. Holistically, the communications element of the ICT estate is responsible for pollution equivalent to 184,067,651 miles being driven in a standard passenger car.

### *3.4 Networking*

Compared to computers whereby scope 3 dominates the product total carbon footprint [15], networking manufacturers indicate that the use-phase contributes to over 90% [36,] due to high power draw and long periods of active use. Specifically, Cisco determines that, using the PAIA methodology [38], electricity accounts for 92.4% of lifecycle emissions of a desktop based hub switch, 88% for a standard switch and 92.7% for a large switch. However, no published data exists to define the actual scope 3 product carbon footprint of networking equipment. As an example, Cisco indicates the company may move forward with reports for specific models in the future but does not commit to a date. Comparatively, Arista, HPE and Juniper offer no such commitment and confine environmental narrative to the continued goal of improving product energy efficiency. As such the networking scope 3 data is produced by focusing upon Cisco hardware and generating two feasible $kgCO_2e$ values. The first being based upon a simple calculation using the typical power draw for each model of switch selected to reflect the equipment indicated by the UK government. This value is then multiplied by the USA electricity to greenhouse gas conversion factor based upon Cisco's PAIA evaluation being conducted in this region. The published percentage use-phase contribution for each switch type is then used to calculate a supply chain value based upon proportional contribution defined by the PAIA. The second scope 3 value is generated following the same approach used for the PABX systems. The two results are then compared for similarity to generate validity and, where feasible, assessed as to similarity with limited existing research calculations with an average created. As such, the networking scope 3 quantification results are delivered with moderate confidence based upon this approach (see table 1). However, as the data is speculative, there is no comparative lowest carbon footprint option and therefore no feasible abatement percentage indicated other than the displacement strategy.

The asset profiling exercise identifies eleven types of networking devices including 10/100, 10/100/100, core and edge switches, power over Ethernet (POE) class 1-4 and POE 'other' units, room based hubs and wireless access points. As the research focuses upon supply chain emissions and excludes scope 2 electricity concomitant emissions the POE categories are combined. The rationale being that whilst each utilises differing power draw, the construct of the casing and components are similar in each example. As such, in context of environmental impact, seven categories are analysed.

10/100 switches represent 12.6% of all networking devices, being 15,540 units (table 1). Using a 24-port switch as the basis for power draw calculations and LCA comparisons, the scope 3 estimated value is determined to be 219 $kgCO_2e$. As such, the total supply chain impact is 3,403,260 $kgCO_2e$ or 680,652 $kgCO_2e$ when annualised using a 5-year useful lifespan. Consequently, the emissions are equivalent to 12,332,439 car miles.

10/100/1000 switches represent 17% of all networking devices, being 21,004 units (table 1). The same scope 3 value as the 10/100 switch is used to support the estimate of supply chain impact. The rationale being that the forming and assembly processes plus component parts will be similar, as will the weight in relation to delivery emissions. As such, the total supply chain impact is 4,599,876 $kgCO_2e$ or 919,975 $kgCO_2e$ when annualised. As such, the pollution is equivalent to 16,668,633 car miles.

Core switches represent almost 7% of all networking devices, being 8,214 units (table 1). Due to the density of electronic components within core switches the estimated scope 3 value is higher by 297% at 869 $kgCO_2e$. Consequently, the total supply chain impact is 7,137,966 kgCO2e or 1,427,593 kgCO2e when annualised using a 5-year useful lifespan. As such, the emissions are equivalent to 25,865,944 car miles.

POE devices as a category represents almost 17% of all networking devices, being 20,503 units collectively (table 1). The determined scope 3 value per device is estimated to be 30 $kgCO_2e$. The quantification is low due to the compact size of POE devices therefore reducing material content and influence from transportation flows. In total, the supply chain impact is 615,090 $kgCO_2e$ or 123,018 $kgCO_2e$ when annualised. This is equivalent to emissions produced by 2,228,910 car miles.

Room based hubs represent 1.3% of all networking devices, being 1,601 units (table 1). The scope 3 value is based upon a 16-port variant and is estimated to be 158 $kgCO_2e$ per device. As such the total supply chain emissions are 252,958 $kgCO_2e$ or 50,592 $kgCO_2e$ when annualised. This is equivalent to the pollution created by 916,647 car miles.

Edge switches represent 15% of all networking devices, being 18,824 units (table 1). The quantification for the device type is based upon the same calculation used for the room based hub. The rationale being that material content and size will be similar. Consequently, the total supply chain emissions are estimated to be 2,974,192 $kgCO_2e$ or 594,838 $kgCO_2e$ when annualised. This is equivalent to greenhouse gas emissions generated by 10,777,619 car miles.

Wireless access points represent 30% of all networking devices, being 37,415 units (table 1). The smaller size and component simplicity compared to switches means that the determine scope 3 value is 71 $kgCO_2e$ using the same energy based proportional contribution and LCA comparison. As such, the total supply chain emissions are 2,656,465 $kgCO_2e$ or 531,293 $kgCO_2e$ when annualised. This is equivalent to 9,626,268 car miles being driven.

In summary, the 123,101 network devices represent 3.8% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 21,639,807 kgCO2e represents 3% of the environmental supply chain impact overall. Holistically, the networking element of the ICT estate is responsible for pollution equivalent to 78,416,462 average miles being driven in a standard passenger car.

### *3.5 Image and Print*

The asset profiling exercise determines that eight types of image and print devices exist within the ICT estate. These include ink jet and laser printers, production and standard multifunction devices (MFD) in both colour and black and white, plus scanners and an unspecified category noted as other. Similar to communications equipment, image and print manufacturer product carbon footprint reports are limited in context with the wide range of available models. This is arguably due to the majority of sustainability rhetoric published by companies focusing instead upon energy efficiency and standby power management plus paper consumption reduction via digitisation. This is reflected by the majority of vendors participating in a number of recognised eco label standards that govern energy efficiency and apply scoring systems based upon material content and manufacturing process [39-47]. The exception to this is the Ecoleaf certification that generates data rich LCA reports as used by Brother, Konica Minolta, Fujitsu, Sharp and Xerox [47]. Combined with prevailing research [5, 37], this latter scope 3 data source enables a supply chain value for the multi-functional devices, scanners and printers to be produced with high confidence as an average range of impact is determinable. It is noted that scope 3 quantification focuses upon the hardware identified by the asset profile exercise and does not include paper consumption nor consumables such as ink and paper.

Copiers represent 0.5% of the total image and print devices, being 638 units (table 1). This device type is the exception to the determination of confidence within the category in relation to supply chain emissions. This is because the copy function is included within all MFD and as such no specific copier carbon footprint data proved available. To overcome this, an average value is created using all of the MFD data based upon the rationale that the devices are similar in chassis and component construction. The resulting value is 928 kg$CO_2$e and considered to be delivered with low confidence. As such the estimated supply chain impact for copiers is 592,064 kg$CO_2$e or 118,412 kg$CO_2$e when annualised using a 5-year retention period. This is equivalent to emissions generated by 2,145,470 car miles.

Ink jet printers represent 3.7% of the image and print estate, being 4,391 units (table 1). As categories exist within the asset profile exercise for MFD devices at both standard and production level, the ink jet printer category is based upon a commercial desktop local device style common within office environments. Combining both LCA reports and research findings [5,37], the determined scope 3 emissions value for ink jet printers is 75 kg$CO_2$e per unit. This equates to 329,325 kg$CO_2$e or 65,865 kg$CO_2$e when annualised. This is equivalent to pollution from 1,193,380 car miles being driven.

Laser printers represent 75% of the image and print estate, being 87,662 units (table 1). Using the same approach as applied to the ink jet printers, the scope 3 single unit quantification of 65 kg $CO_2$e, again based upon a commercial desktop local device style common within office environments. This equates to 5,698,030 kg$CO_2$e or 1,139,606 kg$CO_2$e when annualised. Analogously, this is equivalent to pollution from 20,648,028 car miles.

MFD colour and black and white hardware represent 4.6% and 6.2% of all image and print devices being 5,441 and 7,329 units respectively (table 1). Due to the separate categorisation of production class MFD devices, the scope 3 value for both standard MFD types is based up a commercial desktop chassis common within office environments. As such the supply chain impact per device is determined using the detailed LCA reports to be 670 kg$CO_2$e. This equates to a total scope 3 emissions value for colour MFD hardware of 3,645,470 kg$CO_2$e or 729,094 kgCO2e when annualised. This is equivalent to the pollution caused by 13,210,139 car miles. Comparatively, the black and white MFD impact is 4,910,430 kg$CO_2$e and 982,086 kg$CO_2$e for each year of the device useful lifespan. This is equivalent to 17,793,992 car miles.

The production MFD colour and monochrome hardware represent 2% and 1.5% of all image and print devices being 2,297 and 1,789 units respectively (table 1). Due to the separate categorisation of production class MFD devices, the scope 3 value for both production MFD types is based up a commercial freestanding chassis common within office environments. As such the supply chain impact per device is determined using the detailed LCA reports to be 1,178 kg$CO_2$e. This equates to a total scope 3 emissions value for colour MFD production hardware of 2,705,866 kg$CO_2$e or 541,173 kg$CO_2$e when annualised. This is equivalent to the pollution caused by 9,805,283 car miles. Whereas, the monochrome production devices equate to 2,107,442 kg$CO_2$e and 421,488 kg$CO_2$e for each year of the device useful lifespan. This is equivalent to 7,636,766 car miles.

Scanners represent 4.8% of all image and print devices being 5,672 units respectively (table 1). Multiple variations of scanners exist and it is noted that the functionality is also included within MFD hardware. As such LCA reports associated with commercial desktop models common to office environments are used to determine an average scope 3 value of 70 kg$CO_2$e. Consequently, the total supply chain emissions value generated by scanners is 397,040 kg$CO_2$e or 79,408 kg$CO_2$e annualised. This is equivalent to 1,438,759 car miles.

Other imaging equipment represents a category of unspecified hardware contributing to 2% of all image and print devices, being 2,405 units (table 1). As the types of devices are not clarified an assumption is made to enable calculation of the supply chain impact. To achieve this proportional representation and associated scope 3 values for all other image and print devices creates a mean value of 177 kg$CO_2$e per other device. The resulting supply chain impact is therefore estimated to be 425,685 kg$CO_2$e or 85,137 kg$CO_2$e when annualised. This is equivalent to emissions caused by driving 1,542,560 car miles.

In summary, the 117,624 image and print devices represent 3.7% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 20,811,352 kg$CO_2$e represents 3% of the environmental supply chain impact overall. Holistically, the image and print element of the ICT estate is responsible for pollution equivalent to 75,414,379 miles being driven in an average passenger car.

### *3.6 Audio Visual*

The audio visual devices are determined as two categories including projectors and other AV. Determining a supply chain value for projectors is based upon an average of available LCA data for differing sizes of devices from super slim formats to larger commercial devices and results in 118 kg$CO_2$e. The other AV value is derived from an average created by scope 3 values associated with standard AV asset portfolios [48]. This includes video cameras, microphones, sound systems, televisions, DVD players and headphones. Consequently, the miscellaneous supply chain value is 82.5 kg$CO_2$e per device.

Projectors represent 18% of all audio visual devices, being 4,107 units (table 1). As such, based upon the determined supply chain impact the total scope 3 emissions are 484,626 kg$CO_2$e or 96,925 kg$CO_2$e when annualised. This is equivalent to 1,756,146 car miles.

Other AV represents 82% of all audio visual devices, being 18,866 units (table 1). As such, the total scope 3 emissions are 1,557,388 kgCO2e or 311,478 kg$CO_2$e when annualised. This is equivalent to 5,643,528 car miles.

In summary, the 22,973 audio visual devices represent 0.7% of the end user ICT physical estate. Comparatively, the scope 3 greenhouse gas emissions total of 2,041,071 kgCO2e represents 0.2% of the environmental supply chain impact overall. Holistically, the audio visual element of the ICT estate is responsible for pollution equivalent to 7,396,256 miles being driven in an average passenger car.

## 4. Summary

The objective of this research phase is to determine if a credible scope 3 supply chain GHG emissions value can be applied to 3,196,146 ICT devices discovered during a scope 2 audit. The results find that this is feasible and the resulting environmental impact of the existing ICT estate is 718,701,267 kg$CO_2$e. In analogous terms, this is equivalent to the pollution created by 2,604,367,542 miles being driven by a standard car. Extending the real world comparison, such a distance would enable in excess of nine return journeys to Mars when experiencing an average orbit cycle. From an ecological perspective, the impact of the thirteen organisations' ICT supply chain requires the sequestration capacity of 862,441 acres of mature forest. Perhaps alarmingly, such a forest is one third larger than the entire land mass of Luxemburg and emphasises the need to reduce the digital footprint of government end user computing operations moving forward.

To achieve this, existing research identifies that devices identified and procured based upon product carbon footprint data will deliver significant supply chain reductions. The example determined within this research is that replacing the current computers with the lowest available scope 3 devices would reduce the overall supply chain impact by 44%. If applied to the entire ICT asset base, then the strategy would lower the supply chain total by 316,228,557 kg$CO_2$e in the long term as transition is achieved. Doing so would avoid emissions equivalent to pollution generated by 87,266,432 car miles. However, to achieve this, access to scope 3 carbon footprint data must be improved in order enable informed decisions based upon sustainability criteria to be made before products enter government supply chains. Whilst computers and displays arguably offer sufficient data to enable high level summary quantification, it remains that only 22% of available device models have available product carbon footprint reports [15]. Exploring other types of ICT equipment during this process, such as communications, networking, image and print and audio visual devices, substantiates that information in these categories is further restricted. In all instances, the cause is a lack of participation from ICT manufacturers. As an example, whereby brands such as Apple, Dell, HP, Lenovo, Microsoft and more recently Acer excel in producing product carbon footprint reports for computers and displays, global networking manufacturers such as Cisco fail to deliver entirely. Comparatively, very limited data is also available from image and print companies being predominantly isolated within companies participating in the Japanese led Ecoleaf certification project [47].

As such, whilst ICT is already subject to international environmental certification [39-47] and legislation [20,49,50] created to ensure emissions are limited through environmentally conscious design and production it remains the case that procurement policies [21, 51, 52] simply require public sector organisations to select ICT equipment that complies with eco-label and energy efficiency standards due to a lack of supply chain data. As a label is indicative of compliance but does not define a product's carbon footprint, it is feasible that organisations are simply buying ICT equipment deemed to be within an acceptable environmental impact range rather than controlling the supply chain impact by identifying devices that cause the least carbon footprint. As an example, the Microsoft Surface Laptop 3 has a published carbon footprint of 138 kgCO2e compared to 809 kg$CO_2$e attributed to a Lenovo ThinkPad P51 [15]. Whilst the similar notebooks meet the certified buying criteria, the latter is theoretically six times more harmful to the environment and could quite easily enter the supply chain based upon current assessment criteria.

Consequently, as progress at a manufacturer level appears slow, it is also reasonable to suggest that the availability of product carbon footprint data is not the sole responsibility of manufacturers. The rationale being that increased activities and research such as this may influence future procurement policy change capable of promoting the adoption of brands delivering scope 3 data. As, in this instance, governments represent some of the largest computer purchasers in the world, manufacturers not producing product carbon footprint reports will most likely suffer a significant loss of market share if this were the case. Therefore, through the tightening of policies it is feasible that manufacturer willingness and participation to produce scope 3 data would become accelerated if simply based upon profit criteria as opposed to being led by a concern for the planet. In doing so, beyond isolated advances such as this activity, ICT will be enabled to participate meaningfully in the UNEP strategy [2] to leverage existing technology to reduce societal emissions. The key being that behavioural changes such as the procurement of ICT equipment based upon sustainability criteria are made viable at a product level.

## References

[1] Intergovernmental Panel on Climate Change. (2018), 'Global Warming of 1.5oC'. Geneva, Switzerland: IPCC

[2] United Nations Environment Programme. (2021), 'Emissions Gap Report 2021'. Copenhagen, Denmark: UNEP Copenhagen Climate Centre (UNEP-CCC)

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

[4] 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.

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

[6] 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

[7] 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

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

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

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

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

[12] 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.

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

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

[15] 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.

[16] 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.

[17] Department for Business Energy and Industrial Strategy. (2021). HM Government, 'Business Population Estimates for the UK and Regions.'

[18] House of Commons. (2021), 'Business Statistics.' London: House of Commons Library. [19] Department for Business Energy and Industrial Strategy. (2021), 'Energy consumption in the UK 2021 Update.'

[20] HM Government. (2013) 'The Companies Act 2006 (Strategic Report and Directors' Report) Regulations).' Section 416 (c). London, England: Crown copyright.

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

[22] Sutton-Parker, J. (2022), "2021 JSP UK Service Sector Sustainable Device Selection Survey Data", Mendeley Data, V2, doi: 10.17632/6d7r874jtz.2

[23] Energy Star (2020) 'Product finder, product, certified computers, results.' Washington DC: United States Government

[24] Sutton-Parker, J. (2020). 'Commercial Typical Energy (cTEC): A new methodology to determine typical energy consumption values for end user computers'. Warwick, United Kingdom: University of Warwick, Computer and Urban Science faculty

[25] Sutton-Parker, J. (2020). 'Px3: An application to meaningfully quantify and present end user computing greenhouse gas emissions.' Warwick, United Kingdom: University of Warwick, Computer and Urban Science faculty

[26] HM Government. (2022), 'SusteIT ICT energy and carbon footprinting tool. ICT energy and carbon footprinting tool to support the 'Greening Government ICT Strategy'.

[27] World Business Council for Sustainable Development and World Resources Institute. (2004), 'The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard'. Geneva, Switzerland and New York, USA. [28] Sutton-Parker, J. (2022), 'The Dynamic Carbon Footprint: A new tool to enable sustainability as a criterion for end user computer procurement.' Warwick, United Kingdom: University of Warwick, Computer and Urban Science faculty. Available at https://dcf.px3.org.uk

[29] International Standards Organisation. (2016), 'ISO 14040:2006 Environmental management, Life cycle assessment Principles and framework'. Geneva: International Organization for Standardization

[30] Massachusetts Institute of Technology. (2016), 'Intended Uses and Limitations of the Product Attribute to Impact Algorithm (PAIA) Model. Massachusetts: MSL

[31] United States Environmental Protection Agency (2020). 'Greenhouse Gas Equivalencies Calculator.' Washington: United States Congress

[32] HM Government. (2022), '2022 HM Government GHG Conversion Factors, Condensed Set for Most Users.' London: National Archives

[33] 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.

[34] Statistica Research Department. (2020). 'Global shipment of tablets, laptops and desktop PCs 2010-2023'. Amsterdam: SRD

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

[36] Nokia (2022). 'Phones, environmental profiles'. Espoo, Finland: Nokia Corporation.

[37] Jens Malmodin, J. and Lunden, D. (2018). 'The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015'. Journal of Sustainability. Basel, Switzerland: MDPI.

[38] Cisco. (2020), 'Cisco 2020 Environment Technical Review'

[39] EPEAT. (2022), ‘Electronic Product Environmental Assessment Tool (EPEAT)’. Oregon, USA: Green Electronics Council.

[40] TCO Certified. (2022), ‘TCO Certified, generation 9’. Stockholm, Sweden: TCO

[41] Energy Star. (2020), ‘Energy Star Program Requirements for Computers version 8.0’. Washington, USA: USEPA

[42] Blue Angel. (2022), ‘The German Eco Label’. Germany

[43] China Environmental Labelling Program. (2022) ‘CELP’. China

[44] Green Mark (2022). UK

[45] European Union. (2022), ‘The EU Ecolabel Product Catalogue’.

[46] ECMA International. (2022), ‘ECMA-370 The Eco Declaration’.

[47] EcoLeaf. (2022), ‘EcoLeaf Environmental Label’. Japan: SuMPO.

[48] University of Bath. (2022), ‘Audio visual equipment list’. Bath, UK: University of Bath

[49] European Commission. (2009), ‘Directive 2009/125/EC and Regulation (EU) 2017/1369’. Brussels, Belgium: European Commission

[50] California Appliance Efficiency Regulations. (2021), ‘Title 20 Appliance Efficiency Regulations / Section 1605. Energy Performance, Energy Design, Water Performance, and Water Design Standards: Section 1605.3. State Standards for Non-Federally-Regulated Appliances.’

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

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