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# Is sufficient carbon footprint information available to make sustainability focused computer procurement strategies meaningful?

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**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 produced by production and use-phase electricity consumption. As such, new international legislation exists to ensure businesses include sustainability criteria when assessing and purchasing computers. Such criteria must include valid science based evidence that the selected devices, contribute to greenhouse gas abatement and net-zero emissions strategies based upon exhibiting a low life cycle carbon footprint. As such, it is reasonable to suggest that sufficient carbon footprint information must be publicly available to enable the selection process to be meaningful. The rationale being that if information is limited or misleading, then accurate identification and comparison between computers cannot be assured. Consequently, the research objective is to quantify availability of end user computing carbon footprint information, examine data uniformity and validity and propose a solution to overcome identified issues. To enable this, asset profiling of 71,990 end user computing devices located at six organisations is undertaken to generate an unbiased data pool representing popular devices used by organisations subject to the new procurement rules. Carbon footprint reports are sought for each unique model identified to examine both scope 2 use-phase emissions and scope 3 supply chain manufacturing emissions data. The findings substantiate that 22% of the 707 unique end user computer models identified have associated published information. The predominant limitation being that only six of the forty-two computer brands identified participate in product carbon footprint reporting. Additionally, methods used to form and present the carbon footprint data are incongruent for both emissions sources. Scope 3 is affected by a feasible range of emissions methodology being adopted by 50% of manufacturers compared to exact values published by the remainder. Scope 2 emissions are affected by a lack of uniformity applied to use location and device retention periods. To overcome the parity issue, a dynamic carbon footprint application is developed to harmonise available data. Consequently, it is concluded that sufficient carbon footprint information is not currently available to make sustainability focused computer procurement strategies meaningful. However, the diffusion of the proposed application and illustrated increased participation from manufacturers to publish data in the near future will enable such strategies to achieve legislative compliance and most importantly, reduce greenhouse gas emissions associated with end user computer procurement and use.



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

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## 1. Introduction

End user computing generates over 1% of global greenhouse gas annual emissions [1-8]. This is caused by four phases of the product life cycle. These include embodied emissions created by raw material acquisition, supply, manufacturing, assembly and packaging. Transport emissions generated by the product's journey from the site of the manufacturer to a distribution hub. Use-phase energy consumption emissions generated during human interaction. Finally, end of life emissions from recycling and/or disposal. Whereby transport and waste emissions contribute approximately 5% and 1% to the total carbon footprint respectively [9-13], life cycle assessment research indicates that the embodied and use-phase emissions are responsible for the majority of emissions [9-13]. Specifically, the research suggests that the contribution of the embodied phase ranges from 12% to 97% and conversely use phase emissions from 3% to 88% [14-27] depending upon materials used to construct the device and the resulting electrical efficiency of the product. Computers such as notebooks and desktop computers are subject to international environmental certification [28-30] and legislation [31-35] ensuring both sources of emissions are limited through environmentally conscious design and production. As an example, from a material content and manufacturing perspective, third party eco-labels, such as the Electronic Product Environmental Assessment Tool (EPEAT) [28] and TCO [29], award certification levels determined by a computer's estimated impact upon the environment. Included within the assessment are focus areas such as avoidance of conflict minerals and hazardous substances during manufacturing, energy efficiency during use and high recyclability upon disposal. In relation to energy consumption, this is governed by further certification criteria and standards. These are determined by the Energy Star programme [30] and enforced by legislation such as Europe's eco-design requirements [31] and the United States Tier 2 energy efficiency law [32] that requires end user computing devices to not exceed pre-defined power draw and energy consumption thresholds. To ensure that it is in the best commercial interests for computer manufacturers to comply with both design standards and legislation, additional procurement legislation has been created. Specifically, in the United States, the Federal Acquisition Regulation Part 23.7 [33] mandates that all computers purchased by federal agencies must bear the EPEAT and Energy Star labels. Similarly, in Europe the United Kingdom's greening information and communication technology policy [34] and the European green public procurement criteria for computers directive [35] require public sector organisations to procure end user computers that comply with the eco-label and energy efficiency standards. Considering, governments represent some of the largest computer purchasers in the world, manufacturers excluded from such procurement frameworks due to non-participation in sustainability certification will most likely suffer a significant loss of market share.

It is recognised that in order to achieve procurement compliance, organisations can simply ensure that new computer equipment meets the defined sustainability criteria by selecting from lists of qualifying equipment. These are accessible via government databases such as the Federal Energy Management Program [36] and via the National Desktop and Notebook Agreement [37]. However, as a label is indicative of compliance but does not define a product's carbon footprint, it is feasible that organisations are simply buying computers deemed to be within an acceptable environmental impact range rather than seeking out products that will deliver incremental and meaningful emissions abatement. As an example, the Microsoft Surface Laptop 3 has a published carbon footprint of 138 $kgCO_2e$ [38] compared to 809 $kgCO_2e$ attributed to a Lenovo ThinkPad P51 [39]. Whilst the similar notebooks meet the buying criteria, the latter is theoretically six times more harmful to the environment. To highlight such considerable differences, manufacturers produce specific product carbon footprint reports detailing lifecycle greenhouse gas emissions [38-43]. In doing so comparison between brands can be undertaken to ensure that not only is the relevant organisation complying with the high level requirement of federal and public sector mandates, it is also seeking out computers proven to have the least impact upon the environment. Considering that computing generates as much as 10% of all business scope 2 electricity emissions [44-46] and organisations are also now required to annually report both greenhouse gas emissions and associated abatement strategies [47], the importance of doing so is growing in popularity. As an example, associated research determines that 76% of organisations subject to emissions reporting already have a sustainable end user computing strategy that supports net-zero goals included in corporate and social responsibility (CSR) and environmental social and governance (ESG) strategies [48]. Further research also notes that to quantify these computing emissions, 74% utilise the manufacturer product carbon footprint reports as their data source [49].

As such, in the face of increasing environmental diligence, it is reasonable to suggest that the availability and accuracy of such information is key to success. The rationale being that if data sources are restricted then prospective buyers may be forced to narrow selection criteria to specific brands. Additionally, if information is complex or misleading then comparison may not be conducted with parity and incorrect conclusions made. Consequently, the objective of this research is to answer the research question, 'Is sufficient carbon footprint information available to make sustainability focused computer procurement strategies meaningful?'.

## 2. Method

To achieve the objective, the methodology is fourfold and includes qualitative data gathering and exploratory research designed to identify gaps in current carbon footprint data availability and uniformity plus development of an online application to overcome identified issues. Firstly, as over 450 million end user devices are manufactured annually [50-52], it is reasonable to suggest that this scope be narrowed to the inspection of computer models exhibiting contextual relevance. As such, it is determined that models of end user devices used within organisations subject to sustainable procurement and greenhouse gas emissions reporting represent the most relevant computers to be included in the research. To achieve this, an asset profiling exercise of end user computing estates is conducted using asset management software and survey techniques developed in associated research [53] within six large willing participant organisations. Doing so generates a sizable, varied and unbiased pool of equipment descriptive data structured by type, make and model. Secondly, further to sorting and filtering the profile data by unique model, it is attempted to locate the associated product carbon footprint reports from manufacturer websites [38-43]. To ensure the task is thorough, where reports do not exist, the manufacturer is contacted directly to request the missing data. Using data tables, the existence of a carbon footprint report is noted either positively or negatively against each unique model. Where reports do exist, information and data points such as the methodology used to produce emissions data, scope 2 and 3 emissions values, number of years included within the use-phase calculations, annual typical energy consumption values and electricity to greenhouse gas emissions factors are documented. Thirdly, having identified incongruous inputs such as differing use-phase years and conversion factors an application capable of extracting mean scope 3 data and harmonising scope 2 data is developed [54] to provide data parity for all devices. Finally, the results are discussed to document the limitations and the perceived impact upon realising meaningful sustainability focused computer procurement strategies.

## 3. Results

Of the 71,990 end user computing devices profiled, 56% (40,456 units) are computers and 44% (31,534 units) are displays, meaning that the ratio is 1.3 computers for every monitor (table 1). In total, 42 different brands are represented by 707 unique device models. The variety of manufacturer brands is lower within the computer category, being 11, whilst the display category includes 36. As explained below this incongruity influences both the number of unique models in each category and the availability of product carbon footprint data. Specifically, 70% (495) of the models are generated by the displays, indicating that on average each brand is responsible for fourteen variations of monitor. As such, 30% (212) appear within the computer profile data creating an average of nineteen models per brand.

### *3.1 Carbon footprint data availability*

The computer category is unsurprisingly dominated by Apple, Dell, HP, Lenovo and Microsoft, considering that the companies collectively supply over 73% of the world's end user computers [50-52]. As all five brands produce product carbon footprint reports, the availability of data proved to be 51%. The limiting factors preventing a higher success rate were twofold. Firstly, participating companies focus on publishing data for only the most popular models. As an example of best practice, Apple and Microsoft publish reports for 100% of computer product models whilst the remainder achieve between 53-74%. Specifically, of the 104 Lenovo models, 55 associated reports were located resulting in quantification of 53% of the device variations. In context, Lenovo produces 27% of global personal computers [50-52] and as such has a far wider portfolio than, for example Apple, that supplies 9% of end user computing devices [50-52]. As such, the proportionate availability could be judged as reasonable considering the myriad of models produced by Lenovo. To justify this opinion, it is worth comparing the outcome with the second and third placed global suppliers. Attaining 20% of global sales [50-52], a similar outcome is experienced in relation to HP with 12 (57%) of the 21 models quantified. However, Dell with 17% market share [50-52], excels by enabling 74% quantification, publishing 29 reports for 39 models. As such, it is reasonable to suggest that whilst the perfect solution would be to publish 100% of reports as Apple and Microsoft do, an availability benchmark of almost three quarters is achievable even at scale. The second limitation was simply due to non-participation in the production of product carbon footprint reports. Specifically, companies such as Acer and Asus that collectively supply over 11% of the world market [50-52], do not produce relevant data. This behaviour causes 12% of the profiled computers to be excluded from scope 2 and 3 quantification. Combined, it is therefore reasonable to determine that even before examining data validity and parity, organisations wishing to introduce sustainability as a criterion for computers during the assessment and procurement phase will fail to do so for almost half of all available computer models.

Comparatively, within the display category, the increased number of brands that do not produce product carbon footprint information reduced the available data further to just 10%. Of the thirty-six manufacturers it is determined that only four consistently produce carbon footprint reports including computer companies Dell, HP, Lenovo and electronics manufacturer Philips. However, these manufacturers also limit the number of models included in the process further narrowing available information. As an example, HP produced only 8 (10%) carbon footprint reports of the seventy-eight identified display models. Philips raise the success rate marginally to 13%, producing three reports for twenty-four models. Of the eighty-four Dell models identified, 24 reports were available resulting in 29% quantification, whilst Lenovo's thirteen reports produced for the thirty-four models generated the highest outcome of 38%. As such, it is reasonable to suggest that participation is higher within companies involved in predominantly computer or joint computer and display manufacturing compared to brands focusing in isolation on producing displays. Specifically, removing Dell, HP and Lenovo from the results based on the fact that these are computer manufacturers that also produce displays, it is reasonable to state that, only 1 display manufacturer, Phillips, produces product carbon footprint reports. Considering that displays represent 44% of the end user computing estates profiled, this indicates that displays not produced by leading computer manufacturers cannot be quantified nor assessed for sustainability criteria.

Consequently, combining the findings it proved feasible to source and quantify the potential carbon footprint for just 22% of all end user computing devices (table 1). Setting aside popular model limitation, the availability issue is predominantly driven by the fact that 86% of the identified manufacturers do not currently produce product carbon footprint reports. These include Acer, AGN, AIC, AOC, Asus, Aures, AVD, Benq, B&R Industrial Automation, Eizo, ELO, Gigabyte, GVT, Hyundai, IGEL, Iiyama, ITE, Kenowah, Kogan, KVM, LG, Medion, MSI Optix, NEC, Peaq, Planar, Ricoh, Samsung, TCL, Toshiba, Viewsonic, Viglen, Viotek, Vizio, WAC and WDT. As such it is reasonable to state that 78% of end user computing device models captured during the asset profiling exercise do not have available data that would enable identification of computers and displays with a low carbon footprint.

Table 1. Asset profile data captured and available carbon footprint data by computer type

| **Computer Type** | **Units** | **Unique Brands** | **Unique Models** | **% of Total** | **Available CFP data (%)** | **Scope 2 Contribution (%)** | **Scope 3 Contribution (%)** | **Total CFP Range ($kgCO_2e$)** | **Feasible Abatement Per Device (kgCO2e)** |
|---|---|---|---|---|---|---|---|---|---|
| All devices | 71,990 | 42 | 707 | 100% | 22% | 23% | 77% | 63-2,867 | 585 |
| Computers | 40,456 | 11 | 212 | 56% | 51% | 27% | 73% | 63-2,867 | 581 |
| Displays | 31,534 | 36 | 495 | 44% | 10% | 18% | 82% | 290-881 | 591 |
| Static computers | 22,931 | 8 | 61 | 32% | 44% | 38% | 42% | 63-2,867 | 594 |
| *Desktops* | 17,321 | 6 | 42 | 24% | 36% | 35% | 65% | 278-782 | 504 |
| *Integrated desktops* | 3,354 | 4 | 8 | 4.8% | 88% | 35% | 65% | 489-878 | 389 |
| *Thin clients* | 855 | 2 | 3 | 1.2% | 33% | 53% | 47% | 63-197 | 134 |
| *Workstations* | 1,401 | 3 | 8 | 2% | 50% | 53% | 47% | 389-2,867 | 2,478 |
| Mobile computers | 17,525 | 8 | 151 | 24.3% | 54% | 14.2% | 85.8% | 75-731 | 565 |
| *Laptops* | 16,923 | 8 | 139 | 23.5% | 53% | 14% | 86% | 149-731 | 582 |
| *Tablets* | 302 | 2 | 3 | 0.4% | 100% | 23% | 77% | 75-135 | 60 |
| *Mobile thin clients* | 150 | 1 | 1 | 0.2% | 100% | 9% | 91% | 295-355 | 60 |
| *Mobile workstations* | 150 | 3 | 8 | 0.2% | 50% | 23% | 77% | 390-539 | 149 |

*3.2 Carbon footprint data parity*

Of the six companies publishing product carbon footprint reports, the variety of methodology and representation of data further exacerbates the prospect of valid comparison between brands and even models of the same brand. This is caused by three different approaches used to calculate scope 3 emissions and whilst scope 2 emissions are all derived from the same electricity consumption source, a lack of uniformity applied to influencing factors and subsequent calculations, causes the data to become incomparable.

Whereby all six companies follow the standardised life cycle assessment (LCA) input and output framework [55], Dell, HP and Lenovo harmonise their approach using the Product Attribute to Impact Algorithm (PAIA) methodology when producing scope 3 emissions data for production and delivery [56]. Comparatively, Apple, Microsoft and Philips create values independently using LCA software that accesses a variety of life cycle inventory databases to calculate scope 3 global warming potentials [38, 40]. The lack of uniformity in relation to these methods is subject to review by Andre et al. [10] concluding that incongruity in results is caused by the lifecycle inventory data sources. The rationale being that whilst the process is governed by international standards [55], not all databases follow the same methodology to generate greenhouse gas impact values for actions such as raw material extraction and production. Consequently, if the life cycle inventory input values differ then so too will the output results, even though each one is substantiated as theoretically accurate [57-60]. The difference in output is highlighted by the fact that where the Apple, Microsoft and Philips product carbon footprint reports offer a precise value for the scope 3 supply chain emissions, Dell, HP and Lenovo offer a mean together with a feasible +/- range. The estimated range is generated by the PAIA tool that seeks to simplify carbon footprint calculation by applying most likely emissions values to common attributes such as a notebook's screen size. As an example, the carbon footprint report for an HP EliteBook 850 G8 laptop states the estimated greenhouse gas emissions to range from 210-790 kg$CO_2$e with a mean of 370 kg$CO_2$e [42]. This creates a range of doubt equal to 276% and consequently prospective buyers may misinterpret data points. This is most likely to happen in relation to Lenovo computers as the manufacturer leads with the highest impact value and accounts for the range within subsequent small print [39]. Comparatively, both Dell and HP take the opposite approach leading with the mean and positioning the range in additional commentary [41, 42]. Whilst certainly a complexity that may create a barrier, for the purposes of this research the mean, together with exact values from the other brands, is used in all discussions involving representation of scope 3 emissions.

In relation to scope 2 emissions generated by electricity consumption during the use-phase, all six manufacturers use the annual typical energy consumption value (kWh) generated by Energy Star [61] during energy efficiency benchmark testing to calculate concomitant use-phase emissions. However, a lack of uniformity is evident when presenting the final values that causes the total carbon footprint values to again become incomparable. The problem is caused by the manufacturers including different numbers of years of electricity consumption within the report totals and by using different electricity to greenhouse gas emissions factors to calculate the scope 2 emissions results. Both influences are important to the viability of equivalent comparison and are intrinsically linked. The first is simply explained by the fact that if more or less years of electricity consumption are included within emissions quantifications then results will alter accordingly. The second is related to the way in which greenhouse gas accounting protocol [62] requires scope 2 emissions to be determined. The method used is to multiply the annual electricity consumption value (kWh/yr) by a numeric conversion factor produced by governments each year to represent the intensity of carbon within a nation's electricity grid. Obviously, all countries will have differing factor values due to the percentage of fossil fuel used to generate electricity locally [63-65]. As an example, the United States factor is currently 0.45322 [66] whereas Iceland, a country where the majority of electricity comes from clean energy sources such as geothermal activity [61-63], is 0.00011 [66]. Consequently, 10 kWh/yr of energy consumed in the United States will produce 4.5 kg$CO_2$e annually whereas the same energy in Iceland will produce almost no emissions at 0.0011 kg$CO_2$e.

In order to reflect such differences, computer manufacturers use national or blended regional factors to represent where the products will predominantly be marketed and therefore used. Inspecting the available carbon footprint reports it is clear that Dell uses a low carbon intensity factor based upon a European Union blended value. Whilst HP and Apple predominantly apply a higher intensity global value, Lenovo utilises European, USA and global values and Philips alternates between a country specific Netherlands factor and the worldwide variant. As such, scope 2 emissions can be under represented by just over 30% if the buyer is not aware of this influencing factor.

From an inclusion of years of use perspective, manufacturers range from between 1-year to 6-years. As such, it is apparent that in the extreme, the impact of 5-years (83%) of electricity consumption and concomitant greenhouse gases are excluded from what appear to be equivalent carbon footprint reports. Consequently, the lack of harmonisation within the published data causes potentially misleading values against which to judge and procure devices as previously explained.

To overcome the issue and enable data parity, an application called the dynamic carbon footprint [54] was developed as part of this research. Extracting scope 3 mean and exact data from carbon footprint reports and cross matching the profiled models with the Energy Star benchmark data base, the online tool enables users to set carbon factors based upon the anticipated region of use plus the number of years the device is to be retained. This allows users to compare results within or across device types such as laptops, desktops and displays having harmonised the methodology used to present the data. Additional data is included such as the EPEAT rating [28] to ensure that each product has been certified for responsible material sourcing. The rationale being that in such a format each device's sustainability criteria is presented with parity thus forming a level playing field for assessment prior to purchase. Consequently, if adopted, sustainability focused computer procurement strategies can become meaningful although remaining limited by the available number of reports published by manufacturers.

The effectiveness of such harmonisation upon selection decision making and environmental impact is arguably best highlighted by examining data examples before and prior to creating parity. In the case of the profiled desktop computers, using the published data, the Lenovo ThinkCentre M910q device appears marginally less impactful, generating a 338 kg$CO_2$e total carbon footprint [39] compared to the 350 kg$CO_2$e of the HP device [42]. However, the Lenovo device only includes 3-years of use phase emissions compared to the HP device data that includes 5-years. Additionally, the HP device applies a worldwide greenhouse gas electricity conversion factor that is 18.4% lower than the United States value applied to the Lenovo device. Consequently, when both are harmonised by the application to the European Union factor value with 5-years of use, the Lenovo device is quantified as 360 kg$CO_2$e and the HP device 328 kg$CO_2$e. In this example, where originally the Lenovo device is portrayed by the published data as being 3.5% lower in carbon footprint than the HP device, the reality is that the HP desktop computer is 9.75% less impactful. The issue is however not unique to competing brands. As an example, because Lenovo does not standardise on either input, the Lenovo ThinkCentre M73 model discovered during the profile exercise appears to be a 5% more sustainable choice than the Lenovo M90 model when comparing existing carbon footprint reports. However, after the same harmonisation, the M90 actually has a 12% lower total carbon footprint.

Similar examples appear throughout the computer categories and types. Offering a further example, the product carbon footprint report for the Dell P2717H 27" display indicates a total carbon footprint of 508 kg$CO_2$e compared [41] to the Lenovo L27q-10 at 444 kg$CO_2$e [39]. The difference is caused because 3-years less use phase emissions are included in the Lenovo report. Consequently, when harmonised the Dell display has a total carbon footprint of 484 kg$CO_2$e which is 12% lower than the Lenovo device at 540 kg$CO_2$e. The impact of this lack of parity is arguably emphasised by the range of carbon footprint values determined during the research (table 1). Specifically, popular devices such as desktop computers and laptops that combined account for almost half of all devices, exhibit a range of carbon footprint between 278-782 kg$CO_2$e and 149-731 kg$CO_2$e respectively (table 1). As such, it is reasonable to suggest that by enabling comparative data during the assessment and procurement phase, scope 2 and scope 3 emissions could be reduced per device by 504 kg$CO_2$e for desktops and 582 kg$CO_2$e for laptops based upon a 5-year retention period (table 1). The issue of unintentionally overlooking low carbon footprint computers is particularly relevant within the workplace. Examining the computer category asset profile results reveals that 57% exhibit a static chassis, such as a desktop or thin client, whereas 43% are mobile devices, such as laptops or tablets. Compared to annual manufacturing statistics [50-52], the finding indicates that static chassis computers are significantly more prevalent in business than compared to consumer instances. The rationale being that combined business and commercial preferences indicate that only 14% of computers sold annually are in a static format. In the context of end user carbon footprint impact, this increases potential emissions values and abatement opportunities for business operations. This is because, the findings reveal an average desktop computer and monitor combination generates 1,034 kg$CO_2$e during a useful lifecycle compared to 349 kg$CO_2$e for an average laptop (table 1). Consequently, in a business environment it is reasonable to determine that comparing the two computer types, 75% of emissions are derived from desktop computers. As such, an opportunity to reduce desktop emissions by 45% (table 1) through the valid identification and procurement of products with the lowest carbon footprint would support wider net zero aspirations and therefore achieve legislative compliance.

## 4. Summary

The objective of this research phase is to determine if current availability of end user computing carbon footprint data is adequate to support sustainable procurement strategies and to offer a viable solution if found to be currently inadequate. To enable sustainable procurement strategies, it is proposed that the available data must be comprehensive and presented in a uniform manner. Doing so will allow meaningful assessment of differing brands and models using sustainability criteria such as the total carbon footprint and the contribution of both scope 3 supply chain and scope 2 electricity emissions. Arguably, based upon the findings, if a company restricts purchasing to a single brand such as either Apple or Microsoft, then meaningful assessment based upon sustainability criteria is possible. The rationale being that both companies produce product carbon footprint reports for all available products. Additionally, the information is predominantly presented using uniform numbers of years applied to the use phase, plus a common electricity to greenhouse conversion factor in all instances. However, doing so would restrict the ability to select a device, such as a laptop, with the lowest carbon footprint if it is manufactured by an alternative brand. As table 1 highlights, abatements available by investigating beyond third party certification labels range from 60-2508 $kgCO_2e$ depending upon the device type. In reality, the asset profiling of six large organisations indicates that companies do not procure equipment in such a brand restricted manner. The findings instead reveal that 42 unique manufacturers were identified among the 71,990 end user devices creating an average of seven brand choices per organisation. Of these manufacturers, only six publish product carbon footprint reports meaning that 86% of brands producing end user computing devices do not participate in generating publicly available scope 2 and 3 greenhouse gas emissions data. Of the participating brands, excluding Apple and Microsoft, the remainder restrict the process to popular models. In relation to computers, availability ranges between 53-74% and for displays 10-38% between manufacturer portfolios. Consequently, of the 707 unique device models identified within the organisations, only 22% have an associated carbon footprint report available to be inspected for the purposes of sustainable device assessment and subsequent procurement.

To further complicate issues three of the six brands use a different lifecycle assessment quantification process when forming scope 3 supply chain values. As such, it is reasonable to state that the embodied emissions data produced by Dell, HP, and Lenovo can be compared with confidence due to the same product attributes impact algorithm method being applied if the mean data is identified in each instance. However, comparing these vendors' products to Apple and Microsoft will not ensure like for like comparison as both companies use an alternative methodology that relies upon LCA software that accesses lifecycle inventory databases. Whilst both approaches meet international standards, the lack of uniformity introduces doubt. This is important as the research determines that when harmonisation is introduced to the scope 2 emissions via the dynamic carbon footprint application, embodied emissions are identified as the dominant source of emissions (table 1). Specifically, scope 3 supply chain emissions account for between 47-91% of total emissions depending on the device type, generating a total emissions contribution of 77%.

As discussed, the lack of uniformity extends to two further influences including the amount of years applied to the use phase duration and the electricity to greenhouse gas conversion factor required for scope 2 emissions impact calculations. As identified, the number of years included range from 1 to 6-years. As such, it is apparent that in the extreme cases, as much as five times the scope 2 emissions are excluded from what appear to be equivalent carbon footprint reports. Additionally, manufacturers include regional variations of factors based upon the carbon intensity of electricity grids in the European Union, the United States and globally. As such, scope 2 emissions can be under represented by a further 30% if the buyer is not aware of this influencing factor. Consequently, the lack of harmonisation within the published data causes potentially misleading values against which to judge and procure devices meaningfully.

Overcoming the majority of the parity issues is achieved by the dynamic carbon footprint application that derives the mean scope 3 values and harmonises the scope 2 metrics. With a comparison functionality, organisations are able to rank all end user device types from the six participating brands by total carbon footprint, supply chain or use-phase emissions. Currently being trialled by United Kingdom central and local government departments and councils, the online tool creates an approach that delivers parity and enables meaningful assessment ahead of purchase where data is available from manufacturers. Whilst positive, the limitation of participation in product carbon footprint publication exhibited by manufacturers remains a limiting factor. Positively, having been made aware of the findings of this research, the world's fifth largest computer manufacturer, Acer has since committed to producing data for new laptops in 2022. As such it is reasonable to state that whilst almost half of the computers identified did not have an associated carbon footprint report, manufacturers responsible for over 79% of the world's computer supply now participate in producing such data. Negatively, setting aside computer companies that also market displays, Philips remains the only computer monitor manufacturer actively producing product carbon footprint data.

## 5. Conclusion

In conclusion, it is reasonable to state that as demonstrated, the product carbon footprint information currently available to information technology leaders and end user computing procurement teams is certainly not suitable to successfully support meaningful sustainable procurement strategies. The rationale being that 78% of device models do not yet have an associated carbon footprint report. Of the 22% that do, without widespread diffusion of applications such as the dynamic carbon footprint application, the data is predominantly incomparable by device type and even within a manufacturer's own portfolio. This is probably best represented by Lenovo as the company uses five different use-phase durations and three alternative conversion factors within available product carbon footprint reports. Adding such complications that render the already limited data incomparable adds to the lack of validity when selecting one device over another. As sustainable device procurement policies require device selection to be based upon substantiated data points that support abatement and net-zero strategies, then continuing with the current mix of presentational methods seems counterintuitive.

As such the recommendation produced by this research is twofold. Firstly, further presentation of these findings to non-participating major brands should be undertaken to ensure they plan for product carbon footprint reporting. Arguably, the most impactful approach would be to encourage display manufacturers such as Benq, Iiyama, LG and Samsung as only 10% (table 1) of the monitor unique device models currently exhibit associated emissions data. Secondly, to encourage the diffusion of the developed application to enable uncomplicated access to comparable end user computing carbon footprint data. Achieving both recommendations will enable sufficient carbon footprint information to make sustainability focused computer procurement strategies meaningful.

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