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Determining end user computing device Scope 2 GHG emissions with accurate use phase energy consumption measurement

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Abstract

Energy creates 35% of global greenhouse gas (GHG) emissions [1]. Information technology (IT) is a significant end user of energy, consuming over 10% of commercial electricity [2]. 0.37GtCO2e of IT GHG emissions are attributed to end user computing (EUC) devices, such as desktop computers and notebooks [3]. The United Nations (UN) indicates combining existing technology innovative and behavioural changes has the potential to transform societies and reduce GHG emissions [4]. As the commercial and public sector transitions from desktops to notebooks [5], accurately identifying energy efficient mobile devices offers the ability to support this concept by reducing concomitant GHG emissions. However, accurately measuring device use phase energy (UPE) generated GHG emissions is elusive. Organisations currently avoid the direct measurement due to scale, complexity and logistical issues that cause the practice to become costly and therefore impractical [6]. As an alternative, EUC energy consumption is estimated based on typical electricity consumption (TEC) benchmark data, extrapolated by the number of users and then converted to GHG equivalent units. Conducting a field experiment measuring EUC energy consumption in a business environment, this research substantiates that accepted estimation methods introduce an error range between -48% to +107%. Consequently, the error causes EUC GHG scope 2 accounting to be underestimated by 30% and abatement opportunities of up to 55% to be overlooked.

Keywords: Energy & sustainability; Energy saving products; Carbon footprints; Using IT to reduce carbon emissions; Green business practices; Green Technology

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1. Introduction

To support the attainment of international [7], regional [8] and national [9] greenhouse gas (GHG) abatement targets designed to slow climate change, legislation has been introduced to ensure businesses report GHG emissions in an accurate and uniform manner. Accounted for using the international standard carbon dioxide equivalents (CO2e) unit of measurement, emissions are categorised as Scope 1 (direct emissions from owned or controlled sources), Scope 2 (indirect emissions from the consumption of purchased energy) and Scope 3 (indirect emissions that occur in the value chain of the reporting company) [10]. The practice of reporting and documenting GHG abatement strategies in company annual reports has become mandatory in many countries [7,8,9] and consequently environmental performance is now public knowledge. As a result, organisations are examining a variety new ways to reduce their carbon foot print including efficient IT estates.

Global warming drives climate change and is caused by an increase in atmospheric GHGs that create radiative forcing [11]. This process causes the Earth to become less efficient when dissipating heat back into space and instead GHG molecules trap heat and radiate warmth back towards the Earth's surface. The primary source of global GHG emissions is human activity including electricity, heat production and other energy (35%), agriculture, forestry and other land uses (24%), industry (21%), transportation (14%), and buildings (6%) [1]. IT is recognized as a major energy consumer using over 10% of all business electricity and is estimated to contribute to in excess of 2.3% (1.27bn tCO2e) of Global CO2, N2O and CH4 emissions [12]. This IT related carbon footprint requires a forest estimated as two thirds of the size of Canada to sequester the pollution [13].

The United Nations (UN) indicates combining existing technology innovative and behavioural changes has the potential to transform societies and reduce GHG emissions [4]. In line with this concept, a recent survey of over five hundred large companies confirmed that 75% have CSR strategies focused on lowering end user computing (EUC) device GHG emissions [14]. The practice includes sourcing devices, such as notebooks, that have a low embodied CO2e (scope 3) carbon footprint, are energy efficient during the use phase (scope 2) and can be efficiently recycled (scope 3). Eco-efficient manufacturing [15] and recycling standards [16] have been applied to the IT industry, making two of the three practices relatively simple to accomplish and measure. However, selecting an energy efficient device and measuring concomitant GHG emissions created by use phase energy (UPE) accurately is arguably fraught with error. Currently, energy efficiency buying decisions are undertaken using typical electricity consumed (TEC) benchmark data supplied by computer manufacturers in accordance with Energy Star guidelines [17]. The benchmark data is generated to determine a computer's annual TEC in several modes including idle, sleep and off. Accessible online, the data acts as a comparative energy efficiency guide for a myriad of EUC devices.

As for energy consumed after purchase, the UPE and concomitant GHG emissions are currently reported using estimation techniques discussed below. In precis, the practice involves multiplying the published TEC ratings by the number of computer users and converting the results to GHG CO2e units of measurement. In both examples, relying on TEC benchmarking and estimation introduces significant error. The published device TEC will inevitably differ vastly from the real life UPE value due to a multitude of differing employee use profiles. Consequently, if the UPE does not equal the benchmark TEC, not only will the resulting GHG emissions calculation be incorrect, the device efficiency will never truly be assessed in the field. As such, this research hypothesises, substantiates and quantifies that this reliance on TEC benchmarking is not only creating highly inaccurate GHG emissions accounting data, it may also be causing companies to overlook devices that have a raised TEC but actually create up to 55% less GHG Emissions during the end use phase. Considering that computing device UPE consumption equates to 83% of IT GHG emissions [18] and globally in excess of 254 million desktop computers and notebooks are sold each year [19], the impact of proving the theory is arguably significant when employing existing technology innovation, such as computers, to abate GHG emissions.

In order to validate this impact, the paper contains three sections. Firstly, a discussion of how the current estimation process evolved and why it is accepted as an adequate practice. Secondly, a field experiment designed and conducted to measure UPE in a business environment and create a validated range of inaccuracy compared to the published TEC.

Thirdly, a GHG impact projection highlighting the extent such inaccuracies may have in the commercial and public sector when delivering against IT focused emissions abatement strategies.

2. Current end user computing (EUC) device use phase energy (UPE) consumption measurement

The following section examines the evolution of EUC device UPE calculation and explains why the practice of estimation is used today in place of physical and accurate measurement.

In 1985 [20] US office energy monitoring data signalled an early indication that personal computers (PC) were contributing to high electricity consumption. Squitieri et al, [21] noted the new demand equated to 20% more energy per square foot than comparative commercial real estate from the previous decade. To enable the necessary evolution of building design and planning, a method of measuring computer UPE was required. Methods emerged [22] focusing on survey and estimation using computer chassis power ‘nameplate ratings’. Norford et al, [23] hypothesised the method could be inaccurate as the manufacturer data was not validated and ever improving PC efficiency was not factored into demand projections. To substantiate the claim, a watt meter was used to measure actual electricity consumption of office PCs. Results indicated the nameplate data was incorrect by a factor of 2-4, caused by varying employee use profiles. Further research [24, 25, 26, 27, 28, 29] delivered similar results, concluding that if future energy demand was to be managed, manufacturers should be encouraged to publish uniform energy efficiency data available to both planners and companies wishing to buy electricity efficient PCs.

In 1992, the US Environmental Protection Agency (USEPA) responded by founding Energy Star [30]. The voluntary programme created an agreement between computer manufacturers and the US EPA to enable businesses and users to easily identify electronic products that offered superior energy efficiencies. Johnson, B.J., and Zoi, C.R. [31] noted that consumers adopting Energy Star labelled computers would both lower electricity consumption by 25bn kWh per year collectively, and consequently reduce concomitant carbon dioxide emissions by 20m tonnes annually. The paper represents one of the earliest examples of IT UPE being linked with GHG pollution. Szydlowski and Clivala [32] noted that although Energy Star was supported by over seventy manufacturers, limited UPE data had emerged. In response, the researchers published PC UPE values by measuring 189 computers with a watt metre. Whilst highly accurate, the research highlighted that physical field measurement was best restricted to very small numbers of PCs due to practicality and complexity. As described by Greenblatt et al [6] two decades later, the authors note, ‘*device metering is the most accurate method for gathering electricity consumption data, but it can be very costly, logistically challenging, and time consuming to deploy’*. In context, the prevailing 189 computers represented 0.0008% of the twenty-four million commercial PCs in operation in US offices [33]. As such, a simplification of delivering scale repository of PC energy consumption data that avoided endless field measurement remained a priority not only in the US but globally.

In Europe, Rotourier et al [34] noted that despite acknowledging the Swedish Nutek equivalent, Energy Star was recommended as the programme most likely to achieve this nirvana, although stricter UPE test criteria was recommended. Smith et al, [35] suggested that if benchmarking uniformity could be introduced and the data be made freely accessible on the emerging internet, the original Energy Star goal could be met. Energy Star responded again with strict benchmarking test set up and conduct guidance designed to enable manufacturers to uniformly determine a computer’s annual TEC in several modes including idle, sleep and off. Published online, Energy Star’s website has evolved to offer a publicly accessible database of thousands of popular EUC device models highlighting kilo watt hours (kWh) TEC values that are used globally by planners and procurement departments today.

Whilst the tests do involve various modes, they do not emulate energy consumptions fluctuations generated by the expansive variety of business use profiles. As such, the TEC data offers an indication of device energy efficiency worthy of enabling informed procurement but does not overcome the loss of accuracy in results when compared to field measurement. To overcome the void between ‘good enough’ necessitated to avoid costs and complexity and a need for ‘accuracy’ driven by GHG accounting protocol, further methodologies were attempted and developed.

In 2010, hoping to achieve wide scale field measurement without complexity, Kansel [36] produced Joulemeter software that was distributed via the computer network. However, the application suffered a setback when measuring any device without a battery, such as a desktop or thin client. In such an instance, a wattmeter was required during a calibration phase thus re-introducing the original issue of field complexity and cost. Subsequently, the software failed to progress and is noted only by Microsoft as no longer publicly available and deprecated.

Similarly, a series of reports [3, 12, 18] utilised Kawamoto et al [37] estimated unit energy consumption (UEC) model triangulated with analyst PC trend/install base data and Energy Star EUC device TEC trends to calculate an EUC global GHG emissions value. Whilst delivering a credible assessment of emissions, the more elaborate and considered estimation enables scale but remains inaccurate due to no field measurement and reliance on fixed use profiles for all devices of 14 hours. Belkhir and Elmeligi [38] conduct a similar approach and again suffer from limited contemporary field EUC UPE measurement data being available. To calculate a global IT GHG emissions value the researchers utilise lifecycle analysis studies such as Teehan and Kandliker [39] as source data. The 2012 paper is at first sight relatively contemporary, although tracing the source data and methodology used, leads back to Kawamoto et al [37]. Additionally, of a selection of thirty papers cited only three involved physical device measurement with the most recent [40] being a decade old and including data from less than 100 devices.

Consequently, it is clear that whilst field watt meter measurement is the most accurate method to determine UPE, the practice is not widely undertaken due to cost, logistical challenges and time. As an alternative organisations required to report and abate IT GHG emissions rely on benchmarking TEC data to identify the most efficient EUC devices and to estimate the resulting GHG emissions during the UPE. Whilst the practice is currently accepted as good enough, the range of error introduced by this practice is unknown. Consequently, companies could arguably be purchasing devices that display excellent TEC ratings but under perform in the field. As such they could be unwittingly not only missing out on true abatement opportunities tied to IT but also submitting information in annual reports that does not reflect accurate EUC GHG emissions. As such, the following experiment was conducted to determine a range of inaccuracy and to highlight the disparity of benchmark TEC results compared to field energy performance.

3. Measuring and comparing field UPE consumption with benchmark TEC

As discussed, this research paper questions whether using benchmark TEC results [41] to select energy efficient devices and to estimate concomitant EUC GHG emissions introduces sizable error to both practices.

The specific doubt is caused by two key factors. Firstly, 'Mode Weightings' that represent the anticipated percentages of time the computer will operate in each mode (short idle, long idle, sleep and off) used for the Energy Star TEC values represent both consumer and business habits and are arguably not representative of a business use profile. Secondly, the benchmark data excludes a true 'Active State' described as when the user or network is undertaking active processing, seeking data from storage, memory or cache. Instead, the 'Idle State' represents this phase and is described as, *'The power state in which the operating system and other software have completed loading, a user profile has been created, activity is limited to those basic applications that the system starts by default, and the computer is not in Sleep Mode'* [17].

To substantiate the hypothesis, thirteen notebook computers of differing form factors and operating systems were measured for kWh energy consumption in a business environment. The results are compared to the equivalent Energy Star benchmark TEC values to uncover and discuss any major disparity that would cause doubt in relation to the device's energy efficiency capacity in the field and concomitant GHG emissions. Conducted in a manner [42] equivalent to Energy Star TEC benchmarking test set-up and conduct [17], the experiment tracked energy consumption across an average eight hour working day with one half an hour break defined in line with average lunchtime statistics [43]. Each of the thirteen notebooks were measured across a five day working week using a watt meter. The results were extrapolated to an annual basis using a working average year of two hundred and thirty-two days as per government guidance to account for national holidays, weekends and paid leave [44]. To reflect modern working, software applications used to complete the worker's daily tasks were accessed via a web browser as software as a service. Applications included Salesforce, Office 365, Workday, and Concur.

As the graph below indicates (Figure 1), the manufacturer TEC and experiment's field measured UPE consumption values differed considerably for eleven devices with the exception of the Surface Book 2 and Surface Go devices. The two Microsoft devices consumed +5% and -8% energy compared to their respective TEC of 21.2 and 12.8 kWh proving to be relatively accurate in comparison. The remainder presented no uniform percentage of difference between the TEC and measured UPE, instead generating a range of -48% to +107% energy consumption.

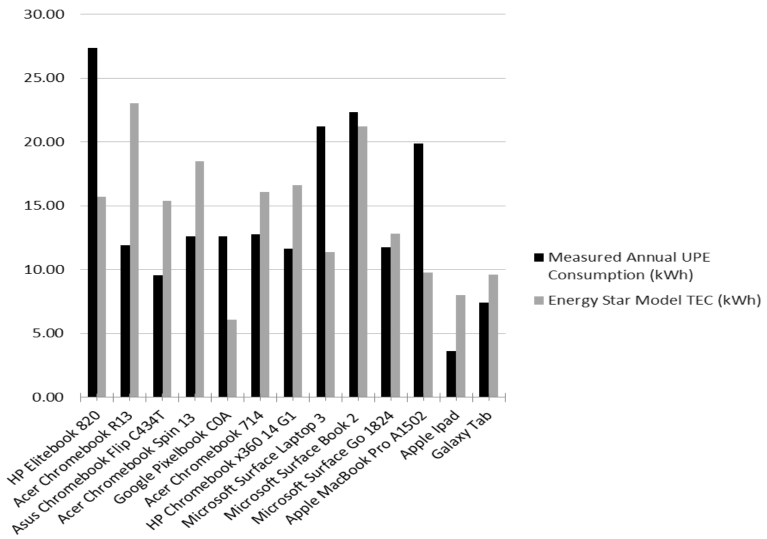

Fig. 1. Notebook Energy Star TEC versus total field energy consumption

Five (39%) of the devices consumed more energy than the published TEC with eight consequently consuming less energy. Excluding the Surface Book 2, over consumption, averaging +93%, was more extreme than compared to under consumption, averaging -31%. The lowest measurement recorded was the Apple IPad Mini consuming 3.62 kWh for the working year. In contrast to the highest consuming laptop, the HP Elite book 820 at 27.4 kWh, the smaller device was 87% more energy efficient. However, productivity must be questioned when making energy efficient choices. The type of work conducted during the 8 hour workdays realistically required a larger viewing screen. As such, connecting a Hewlett Packard 27fw monitor increased consumption to 40.3 kWh annually. Considering the average of the contemporary notebooks measured consumed approximately 21 kWh and incorporated screens large enough to remain productive, selecting a small tablet and needing to double the energy consumption to compensate is arguably counter intuitive.

Having highlighted an incongruity between the TEC and measured UPE in 85% of the devices, the results also substantiate the concept of companies potentially overlooking devices based on a TEC that is higher than the UPE. During the experiment it was noted that in all instances where a Google Chrome OS operating system was installed, the UPE consumption was as much as 57% lower than in comparable alternative operating system devices such as Windows and Mac OS. On examination and with exception to the Google Pixelbook, the Google Chrome devices delivered a field UPE consumption average of 34% below the published TEC at an average of 11.86 kWh.

Consequently, companies practicing energy efficient device procurement may select, as an example, a Microsoft Surface Laptop 3 with a published TEC of 11.4 kWh yet a measured UPE of 21.2 kWh. Doing so would cause the organisation to rule out a similarly specified Google Chrome OS Spin 13 due to the published TEC being 62% higher at 18.5 kWh, despite the measured UPE being 40% more efficient at 12.62 kWh. In this instance, the example company may have missed out on the opportunity to lower measured GHG emissions by 6 tCO2e annually per thousand users, equivalent to almost eight acres of sequestering forest.

In summary, the research substantiates that using TEC benchmark data for the selection of energy efficient devices is an appropriate indicator but not an accurate measurement that could be compliantly accounted for and included within GHG reports. Additionally, the TEC figures will inadvertently cause organisations to select less efficient devices over feasibly more efficient devices due to a lack of real life field data. To highlight the impact of such a range in error between TEC and measured UPE at scale, the UK service sector is used as a case study.

4. Projecting the GHG emissions impact of calculating EUC CO2e based on TEC consumption

To encourage increased GHG emissions reporting and abatement, as of April 2019, all quoted companies operating in the UK, all large unquoted companies and large Limited Liability Partnerships (LLPs), Government departments, non-ministerial departments, agencies and Non-Departmental Public Bodies are now subject to annual mandatory GHG emissions reporting [9, 45, 46, 47, 48]. These organisations are categorised as the 'Service Sector', employing 16.1m people with 10.7m people working in large companies and 5.37m in the public sector. This represents 50% of the UK total workforce (32.4m) [49, 50]. Statistics indicate that 67% of workers use a total of 15.1m notebooks as part of their job role [5]. Under the new legislation the GHG emissions created by the UPE consumption of these notebooks will be reported as scope 2 emissions in company annual reports [9] and quarterly estates reports within the Public Sector as part of the Greening ICT commitments [47, 48]. As previously described, notebook UPE consumption generating the GHG emissions will be estimated rather than measured. Whilst accepted as a method, this practice does not strictly meet accounting protocol that requires that emissions must be proven with sufficient confidence to be measured and attributed to the specific organisation to be accurate and valid [10].

To highlight the level of inaccuracy introduced by the practice of estimation, the following calculations compare the emissions results for the entire notebook estate derived from firstly the TEC values and secondly the UPE values measured in the field experiment using a watt meter. To arrive at a proportionate representation of the notebook estate, the popularity of operating systems (OS) is used within the calculation. Currently, Microsoft's Windows OS has 77% of notebook market share compared to Apple's 17% and Google's Chrome OS at 2% [51].

Applying these percentages to the 15.1m notebooks, multiplied by an average benchmark TEC value by OS (15.3kWh Microsoft, 9.8kWh Apple, 15.9kWh Google) for the notebook models included in the field experiment produces a value of 207.9m kWh (177.9m kWh Microsoft + 25. 2m kWh Apple, 4.8m kWh Google). This is equivalent to 53,139 tCO2e [52] requiring an estimated 69,000 acres of forest to sequester the pollution [13].

Using the same percentages, multiplied by an average UPE consumption value by OS from the experiment (20.7kWh Microsoft, 19.9kWh Apple, 11.9kWh Google) produces a value of 295.4m kWh (240.7m kWh Microsoft + 51.1m kWh Apple, 3.6m kWh Google). This is equivalent to 75,504 tCO2e [52] requiring 98,000 acres of forest to sequester the pollution [13]. Consequently, whilst simplified, the results indicate that the TEC based calculation is 30% lower than the measured UPE value. Therefore, the error introduced is substantiated as significant and creating a feasible under estimation of consumption and concomitant GHG emissions of 87.5m kWh and 22,365 tCO2e respectively. This is the equivalent of requiring an additional 29,000 acres of forest to sequester the pollution [13].

Exploring the effect TEC values may have on efficient device choice at the extreme range can be examined using two similarly specified notebooks and comparing the TEC and UPE emissions results in a similar manner. In this example the Microsoft Surface Laptop 3 and the Asus Chromebook Flip are selected. The rationale being that the specifications are similar from a hardware perspective although the TEC value of the Microsoft device is published at 11.9 kWh and the Asus device at 15.4kWh. This suggests that the former device may be procured in favour of the latter device as the published TEC indicates the Microsoft device is the more efficient of the two. However, as recorded in the experiment, the Asus device produced a UPE of 9.6 kWh and the Microsoft device 21.2 kWh suggesting the Chrome OS device is 55% more energy efficient when used in a business environment.

Focusing on the 15.1m notebook estate, the GHG abatement overlooked by this error could be as large as 175.2m kWh per year equivalent to 44,781 tCO2e [52] requiring 58,000 less acres of forest to sequester the pollution [13].

5. Summary

Driven by international GHG targets, legislation, accounting protocol and sustainable development goals designed to slow climate change, it is clear from the findings of this paper that sources of abatement can be found by combining existing technology innovative and behavioural changes. Used in vast numbers [5] and defined as high end use source of energy consumption [18], EUC devices represent such an opportunity. Through the examination and testing of current UPE estimation practices and TEC measurement in this research, it is substantiated that there is a range of error range of -48% to +107% causing a feasible misreporting of GHG emissions by -42%. Additionally, it is suggested that abatement opportunities as high as 55% per device are being overlooked due to current procurement practices rooted in concepts realised almost thirty years ago.

6. Conclusion

This paper identifies that the UK's largest employment sector could realise 55% lower EUC UPE device related GHG emissions if current practices of energy consumption measurement are improved. As such, ongoing research by the author is nearing completion to create a cloud computing application capable of measuring and reporting EUC energy consumption, concomitant GHG emissions and feasible abatement. The approach delivers a CO2e value for IT related GHG emissions, highlights money saved by reducing energy consumption and shows environmental gains in easily consumable formats, such as the car and forest equivalents adjusted for localised electricity carbon intensity. The design concept is based on Elkington's [53] 'Triple Bottom Line' approach suggesting Planet, People, and Profit need to be acknowledged in order to gain support for sustainability. The aspiration is to overcome the issues discussed that cause accurate measurement to become costly and therefore impractical from both a resource and economic perspective. Achieving the goal will arguably enable diffusion of accurate EUC energy consumption and consequently abate future EUC device Scope 2 GHG emissions. As such, it is suggested that the research supports the UN's advice that innovation in existing technology and behaviour can help to slow climate change [4].

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