

Can Chromebooks reduce classroom and school energy consumption and GHG emissions?

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Abstract

End user computing (EUC) generates over 1% of global greenhouse gas (GHG) annual emissions caused by the production of over 460 million new devices annually and the use-phase activity of 4.2 billion users. As much as one-third of the total carbon footprint of personal computers (PC), such as desktops and notebooks, is generated during the use-phase due to electricity consumption. Consequently, legislation, policies and third-party certifications exist to ensure devices are produced and consumed responsibly in line with the United Nations Sustainable Development Goals (SDG). The rationale being that organisations are able to select energy efficient devices using available typical energy consumption (TEC) data and therefore reduce concomitant scope 2 (electricity) GHG emissions in the workplace. However, empirical research identifies that current EUC use-phase energy consumption methodology does not accurately reflect device electricity use when subjected to human-interaction. This is because the TEC benchmark data used to determine efficiency focuses on measuring only the low power modes such as off, sleep and idle. As such, the results exclude the active state when power draw is at its highest causing inaccuracies between -48% to +107% and creating a disparity maxim of 155%. The reason for this is that varying operating systems and components require different levels of power draw during active use. The difference is so great, that despite comparable low power mode results, devices using alternative operating systems can exhibit energy consumption reductions of 46% on average. Consequently, organisations believing they are purchasing computers that will consume the least electricity and produce the fewest emissions can often be unintentionally misled. To overcome such issues, recent research has developed Device Use Phase Analysis (DUPA) testing to generate energy consumption data that includes the active state. The resulting commercial typical energy consumption (CTEC) value measured in kilowatt hours (kWh) per year enables organisations to achieve three key outcomes. Firstly, to accurately compare prospective devices by real-life energy-based sustainability criterion. Secondly, to predict ongoing lifespan utility costs. Thirdly, to quantify anticipated annual scope 2 end user computing GHG emissions.

In this research, an Acer Chromebook 311 is measured to determine energy consumption when used in a classroom. The results are then compared to other alternative operating system notebooks tested in the same way. The results substantiate that the Chromebook consumes 65% less electricity than average notebook computers. The results also highlight that the device is capable of reducing mixed EUC estate energy GHG emissions by 85% based upon transitioning to 100% mobile computing strategies. Additionally, the Chromebook energy consumption results validate that selecting devices using benchmarks that include active use power draw delivers both financial and environmental reductions that may be otherwise overlooked when comparing efficiency based upon existing low power mode only TEC results used by Energy Star.

Keywords: Information technology, environmental sustainability, low carbon IT, green IT

Introduction

Since the Industrial Revolution, human polluting activity known as anthropogenic interference has already caused 1.0°C of global warming ^[1]. A further increase to 1.5°C will be reached by 2033 if GHG emissions continue to rise at the current annual growth rate ^[1]. However, scientists calculate that reaching and sustaining net zero global anthropogenic CO₂ emissions by mid-century, will halt global warming on a multi-decadal scale and temperature gains will begin to peak ^[1]. To achieve this goal, it is suggested that the world cannot rely solely on emerging key GHG abatement strategies, such as vehicle electrification and renewable energy transition. This is because evidence indicates current adoption rates and subsequent GHG abatement will not be sufficient to bridge the anticipated annual emissions gap forecast for 2030 ^[2]. To compensate, the United Nations Environmental Programme (UNEP) suggests that existing technology should be examined as an enabler of societal emissions reduction ^[2].

Generating in excess of 2.5% of all global greenhouse gases, it is reasonable to suggest that information technology (IT) represents a viable source of abatement if sustainability strategies are applied with urgency ^[3]. As an example, significant supply chain (scope 3) reductions can be achieved by selecting hardware with the lowest manufacturing carbon footprint ^[3, 4] and retaining equipment for longer periods ^[3, 5, 6, 7, 8]. Electricity consumption (scope 2) emissions can be avoided by adopting low energy products ^[3, 5, 8, 9, 10] and low carbon computing services ^[3, 7, 11, 12]. Plus, remote working enabled by IT solutions can reduce scope 3 commuting emissions ^[3, 6, 7, 9, 13]. Consequently, EUC as a subset of IT, is a prime candidate to contribute to this sustainability strategy. Setting aside data centre and networking emissions, personal computing generates over 1% of global GHG annual emissions ^[14]. This is caused by the yearly manufacturing of 460 million devices and the associated energy consumed by 4.2 billion active users ^[3, 4]. Based upon current world emissions, this annual carbon footprint is 556,000,000 tCO₂e. This is equivalent to 1.4bn fossil fuel car miles and requires a 2.8m km² forest the size of Argentina to sequester the pollution ^[3].

The concept of EUC procurement and use contributing to GHG abatement is internationally recognised ^[3, 4]. Linked with the United Nations SDG number 12, 'responsible consumption and production', legislation ^[4], standards ^[4], certifications ^[4], protocols and policies ^[4] exist to ensure environmental impact is reduced and monitored at each stage of the device lifespan. As an example, EUC manufacturers are subject to eco-product design directives ^[4] and certification ^[4] to ensure raw materials are sourced responsibly, products are manufactured in safe environments and to strict standards and include energy efficiency as a key criterion. Before products are ready for sale, standards and protocols act as a framework for life cycle assessment (LCA) activities ^[4] that result in customer facing carbon footprint reports. At the point of assessment and selection, organisations utilise this data and third-party certification labelling to ensure the prior expectations have been achieved.

This latter activity is becoming more prevalent in order to respond to national and regional requirements relating to IT procurement and use ^[3, 4, 16]. From a UK national perspective, the public sector is subject to a combination of government strategies, associated laws and policies that, beyond a desire to tackle climate change, drive the necessity to adopt sustainable IT from a compliance and cost perspective. At the highest level, the Climate Change Act ^[17] includes an amendment to the Companies Act ^[18], ensuring that organisations operating in the UK are subject to mandatory GHG emissions reporting. Specifically, from April 2019, all organisations listed on the London stock exchange, all large unquoted companies and large limited liability partnerships (LLPs), government departments, non-ministerial departments, agencies and non-departmental public bodies must adhere to the legislation. This includes reporting electricity purchased for consumption and concomitant scope 2 GHG emissions.

These organisations, known as the 'service sector', represent over 50% of the total national workforce with 10.74m working in large companies and 5.4m in public organisations ^[3, 19]. The sector

is so significant that it consumes 32% of all UK electricity [19]. To ensure organisations not only report emissions but also focus on efficiency, the Climate Change Levy (CCL) exists [20]. In simple terms, this is an environmental tax charged on energy consumed by organisations. As such, reducing utility consumption avoids emissions and improves profitability due to lower operational costs and associated taxation. 11% of commercial electricity consumption is attributed to the use of IT solutions [19]. Consequently, information technology (IT) is the UK service sector's third largest consumer of electricity behind lighting (14.5%) and cooling (13.4%) [3].

Beyond cost as a driver, to directly address this growing GHG emissions source, the UK government's 'Greening ICT' policy [21] also exists. As contributing research [22] and resulting strategy documents highlight [23], public sector organisations must quantify and report EUC scope 2 emissions plus adopt environmentally conscious procurement practices. To achieve the former, public-sector organisations calculate annual device electricity consumption (kWh) and multiply this by GHG conversion factors that reflect the carbon intensity of the national grid. To achieve the latter, IT and procurement teams adhere to what are described as 'hard targets' [21]. These include all future IT purchases to be accompanied by a scientific target capable of supporting the Government plan for net zero by 2050 [21]. In response, this could be as simple as selecting EUC devices proven to be energy efficient when operated in the workplace. The rationale being that the concomitant scope 2 GHG emissions would therefore be reduced during the useful lifespan of the product.

However, despite public sector stakeholders expressing a want to realise climate action via responsible IT consumption, organisations face barriers to adopting meaningful sustainable IT strategies [16]. As an example, the Department for Education has a vision to become 'the world-leading education sector in sustainability and climate change by 2030'. However, almost one half of surveyed universities and multi-academy trusts do not yet have strategies that include emissions reduction targets [24]. The problem is caused by data used to form potential strategies being complex to compile and limited in relevance. Of those that do attempt to create science-based targets, currently, 39% convert the publicly available energy efficiency benchmark data to GHG emissions [16, 25] and a further 35% rely upon the manufacturer published GHG use phase emissions values [16, 25]. In both cases, research identifies that the resulting GHG emissions values are underestimated by 30% and cause substantiated abatement opportunities in excess of 55% to be overlooked [10].

The existing benchmark data error is caused by the exclusion of the active-state power draw measurement. As this same value is used to populate manufacturer carbon footprint reports, it is proven that the error is passed forward [4, 10]. Additionally, the reports vary in the number of years of use included in calculations and utilise electricity to GHG conversion factors applicable to single sales regions. Consequently, a UK public sector organisation that retains devices for 5-years, will be relying on comparing product carbon footprint reports that exclude the impact of actual human-computer interaction (use) [10], include anywhere between 1 and 6-years of electricity use (depending on brand) [4] and will reflect scope 2 carbon intensity based upon values for Europe, the USA or a worldwide average [4].

This lack of specific validity causes organisations to incorrectly perceive sustainable IT strategies in two ways. Firstly, as costly to implement due to time spent on complexity [16]. Secondly, as limited in impact due to a lack of substantiated and relevant data proving otherwise [16]. Such barriers cause inertia within an organisation as stakeholders struggle to form science-based targets that realise and justify that sustainable IT reduces both utility and procurement costs whilst driving climate action [16]. When overcome, the rewards from both a planet and profit perspective are substantial and the perception of complexity and impotence proven to be unfounded [3, 5, 6, 9]. Recent scientific case studies identify that implementing practices, such as selecting devices based upon sustainability criteria, displacing procurement cycles with extended device lifespan and remote working enabled by IT, support all aspects of corporate and social responsibility (CSR) and environmental, social and governance (ESG) strategies [3, 5, 6, 9]. As an example, by adopting such practices, a greater London

council has reduced IT related GHG emissions by 4.5 million kgCO₂e and now saves over £200,000 per year in operational and capital expenditure ^[9].

To achieve this, organisations are increasingly ensuring the data they use to form science-based IT abatement targets are relevant to their specific IT retention and use policies. To overcome the lack of parity between computer carbon footprint reports, organisations are using unique online tools ^[4]. The application is used by IT and procurement teams for selecting EUC devices based upon comparable carbon footprint data. This is achieved by the application recalculating the scope 2 contribution of each device based upon inputs from the user. These include the number of years the device will be used for and the location of use, whether that be at a national, regional or international level. Additionally, organisations are ensuring that products assessed for purchase have energy data available that represents an accurate quantification of anticipated electricity consumption in the workplace or institute ^[3, 5, 6, 9, 26-28]. Doing so enables public sector and commercial businesses to select devices that will reduce utility costs and lower scope 2 emissions. While the necessity to safeguard profit through electricity efficiency is increasing due to supply cost escalation, the environmentally focused assessment supports both climate action and compliance.

In relation to the latter, GHG accounting protocol for scope 2 (electricity purchased for consumption) emissions require quantities of carbon dioxide equivalents (CO₂e) to be calculated as 'neither over nor under actual emissions' ^[29]. As such, without contextual data that defines actual use-phase emissions, accuracy and therefore compliance cannot be assured when forming annual reports ^[3]. At scale, the impact of including relevant sustainability data as a foundation for IT sustainability strategies is significant. As an example, in relation to scope 2 emissions, research indicates that energy consumption can be reduced by an average of 46% if suitable low energy computers are selected ^[10]. Consequently, almost half of all scope 2 (electricity consumed) GHG emissions could be avoided if such practices were diffused within large markets and sectors.

While the public sector is sizable as noted, specific areas with high numbers of computers in active and constant use are key to success if the UN technology bridging strategy is to be realised. The education sector represents such an opportunity being twice the size of the entire UK public sector. Specifically, statistics indicate that in the UK there are over 10.9 million pupils, teachers and associated staff ^[30]. Data also suggests that there are in the region of over 4 million computers in operation within educational institutes ^[30]. As such, it is reasonable to suggest that unlike business environments where devices are supplied on a ratio closer to one unit per employee ^[3], the education system has almost three people for every available computer. Consequently, it is logical that computers in educational institutes will be subject to intensive active-state periods due to significant device sharing causing increased use. As such, to select devices based on energy performance criteria that excludes actual human-computer interaction can be considered counterintuitive.

To explore this oversight, the Acer Chromebook 311 notebook is measured for electricity consumption during the active-state with the results applied to several academic based scenarios. The objective being to generate data that highlights the GHG abatement and utility cost savings available by identifying EUC devices that are proven to deliver extreme energy efficiency during the use-phase. The Acer Chromebook 311 is specifically selected for two reasons. Firstly, it is speculated that the device will require a low power draw during the active-state due to the inclusion of an operating system and components previously identified to cause electricity consumption reduction ^[8, 10]. Secondly, because the Acer Chromebook 311's certified-durable design ^[31] makes it a suitable choice for learners of all ages and therefore appropriate for the education sector.

As such, the following sections discuss the methodology used to conduct the research plus the results, discussion and summary findings.

Method

The research is conducted in four key stages. Firstly, the device is subjected to electricity consumption measurement using the DUPA test practice [3, 32]. Secondly, using the CTEC methodology [3, 32] a commercial typical energy consumption value for 1-year (kWh/y) is calculated. Thirdly, scope 2 emissions are calculated and compared to a standard education EUC environment [3, 7, 24] to highlight abatement achieved by adopting the device. Finally, utility cost savings compared to average device consumption costs to highlight operational expenditure reductions delivered by the notebook. The device measured for energy metrics is an Acer Chromebook 311, exhibiting an 11.6" screen, MediaTek MT8183 CPU, 4GB LPDDR4 memory, 32GB eMMC storage and installed with the Google Chrome OS operating system. Test set-up and conduct procedures adhere to the DUPA methodology with active power draw measurements defined in watts (W). Specifically, the measurement process accurately captures power draw (watts) for EUC devices during active use. Two sets of data are produced during the comprehensive analysis, proven to be accurate within +/- 0.1%. The first data set being power demand when conducting common user interactions such as productivity tasks (e.g. email and application access), content streaming and video conferencing. The second data set includes real world user scenarios such as energy consumption during a working day that reflect accurately how a device performs when used in a business environment. The power draw results are applied to the CTEC equation that accounts for off, sleep, short and long idle and active state power and mode weightings as defined by the methodology. The calculation produces the electricity consumption value that is to be expected during commercial use and expressed in kWh/y.

The electricity to GHG emissions factor used in calculations is defined as the factor published by the UK government for 2022 [33]. All values are represented in kgCO₂e units as per international GHG accounting protocol. The average electricity consumption values for comparison devices are defined by prior primary research using the DUPA and CTEC approach to enable parity. The average install base EUC profile is derived from associated computer asset profile research within the education sector [3, 24]. The cost of electricity is based upon published current costs per kWh and extrapolated where relevant to 5-years of use. Tangible equivalents are included to ensure comprehension of the GHG unit values is achieved through analogous values. These include step counts [34], forest acres required to sequester resulting carbon emissions and car miles representative of volume of pollution [3]. All tests are conducted under scientific conditions and results delivered pragmatically and without bias.

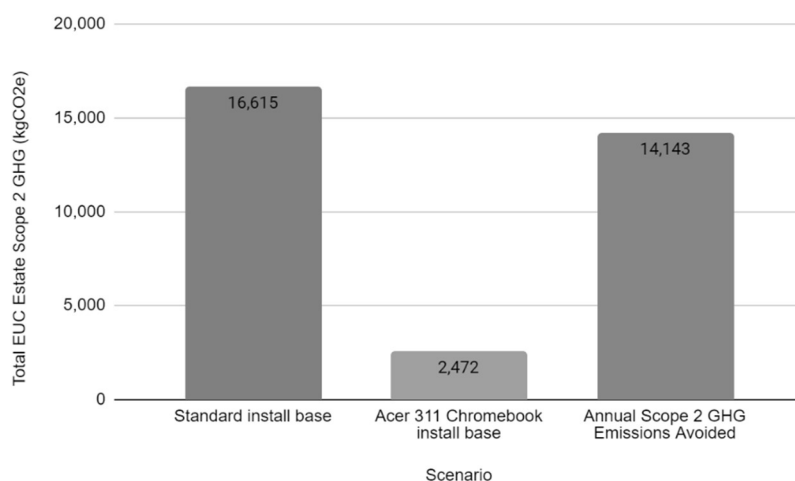
Results

The results section examines the findings of the electricity consumption measurement experiment before determining possible influences upon the environment (planet) and financial (profit) benefits delivered by adoption of the device. Measured for energy metrics using the DUPA methodology, the Chromebook's active state average power draw is 4.1W and 0.0041 kW when subjected to human-computer interaction. This represents a 58% increase in power draw when compared to the short idle mode measurement of 2.6W. The increase from the short idle mode to active state is anticipated and congruent with associated research [8, 10] determining that all computers will experience raised power draw during human-computer interaction due to additional processing not experienced during the low power modes such as off, sleep and idle. Extrapolated to one year using the CTEC methodology, it is determined that the device consumes 7.61 kWh/y in a working environment. For contextual purposes the device consumes the equivalent energy required to take 564 steps during each working day. As such, when compared to the average notebook computer energy consumption values of 22.35 kWh/y, the device is determined to be highly energy efficient. Specifically, electricity use is 65% lower than the average for measured devices in the notebook category.

As defined by prior associated research [8, 10], the extreme energy efficiency exhibited by the device is attributed to the ChromeOS operating system being combined with low energy components. The following section examines scope 2 (electricity consumed) GHG emissions generated by an average academic environment consisting of 1,680 devices in two scenarios. The first being based upon an average existing install base formed of 60% mobile computers and 40% desktop-based computers. The second being the same environment having transitioned to the Acer Chromebook 311 for the

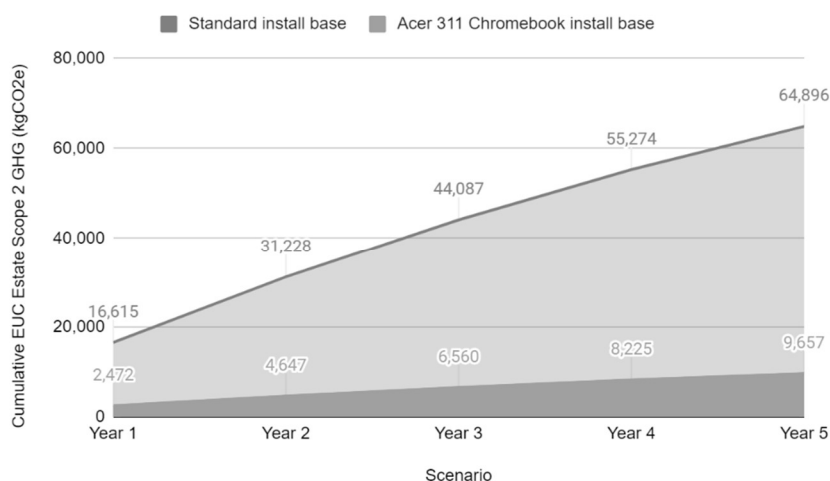
entire EUC estate. As indicated in figure 1, the standard install base generates 16,615 kgCO_{2e} scope 2 GHG emissions per year. The total is dominated by the desktop use-phase emissions created by the necessity of both the computer and a peripheral monitor. Specifically, although desktop computers represent 40% of the EUC estate, the contribution to the annual carbon footprint is 74%. In this example, the average per device annual emissions value is 9.9 kgCO_{2e}. Transitioning to the highly energy efficient Acer Chromebook 311 generates 2,472 kgCO_{2e} per year causing the per device value to be 1.5 kgCO_{2e}. As such, it is reasonable to indicate that transitioning from the average sized mixed desktop computer and mobile computing environment to the Acer 311 Chromebook reduces annual scope 2 emissions by 85%. The total abated GHG emissions are 14,143 kgCO_{2e}. This is equivalent to avoiding pollution generated by 51,500 car miles. Such emissions would otherwise require the sequestration capacity of 17 forest acres to remove the resulting carbon from the atmosphere via photosynthesis.

Figure 1. Annual Scope 2 (electricity consumed) GHG emissions comparison



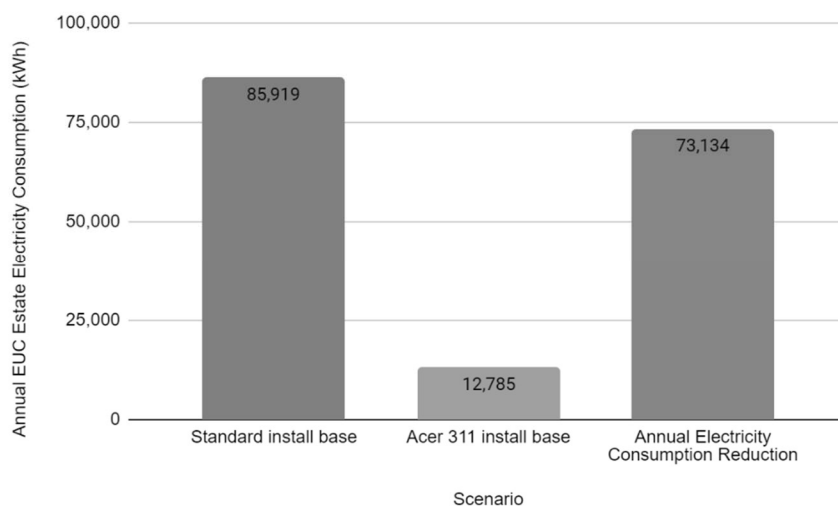
Applying an average useful device lifespan of 5 years^[4], the impact of cumulative GHG abatement becomes increasingly significant. Figure 2 includes an annually reducing electricity to GHG emissions factor incorporated to consider government predictions for growing renewable energy diffusion and therefore reducing carbon intensity in the national grid. During the device total use period, scope 2 emissions for the standard install base amount to 64,896 kgCO_{2e}. Comparatively, the Acer Chromebook 311 EUC estate cumulatively generates just 15% of this value at 9,657 kgCO_{2e}. This is equivalent to abating 55,239 kgCO_{2e} of scope 2 emissions during a 5-year period. This is equivalent to avoiding pollution generated by 201,125 car miles.

Figure 2. 5-year Scope 2 (electricity consumed) GHG emissions comparison



Consequently, it is reasonable to conclude that for every EUC device, 33 kgCO_{2e} or the equivalent pollution created by 120 fossil fuel car miles can be avoided by transitioning to highly energy efficient notebooks such as the Acer Chromebook 311. Logically, improved device energy efficiency reduces electricity consumption and therefore utility costs. As indicated in figure 3, the standard install base consumes 85,919 kWh per year. As before, the desktop and monitor combination is responsible for 74% of the total consumption. This is due to both desktop computers and monitors being less energy efficient than notebook and other types of mobile computing devices. As such, the per device consumption value is 51 kWh/y. Comparatively, the electricity consumption for the Acer 311 Chromebook estate reflects the 85% reduction experienced previously. Specifically, the total reduces by 73,134 kWh per year to 12,785 kWh/y. Consequently, the per device consumption value declines to 7.6 kWh/y.

Figure 3. Annual electricity consumption (kWh/y) comparison



Extrapolated to represent a standard 5-year retention period the standard install base cumulatively consumes 429,595 kWh/y and the Acer 311 Chromebook estate consumes 63,925 kWh/y. This causes the total electricity consumption value to decline to 15% of the original total having avoided 365,670 kWh/y of utility consumption. From a cost perspective, figure 4 highlights that annual electricity costs associated with the standard install base EUC estate are £29,212. This equates to £17.40 per year budgeted for single device utility expenses. In comparison, the 85% reduction in consumption experienced by the Acer 31 Chromebook estate causes the annual utility cost to decline to £4,347 or £2.60 per device.

Figure 4. Annual electricity cost (£GBP) comparison

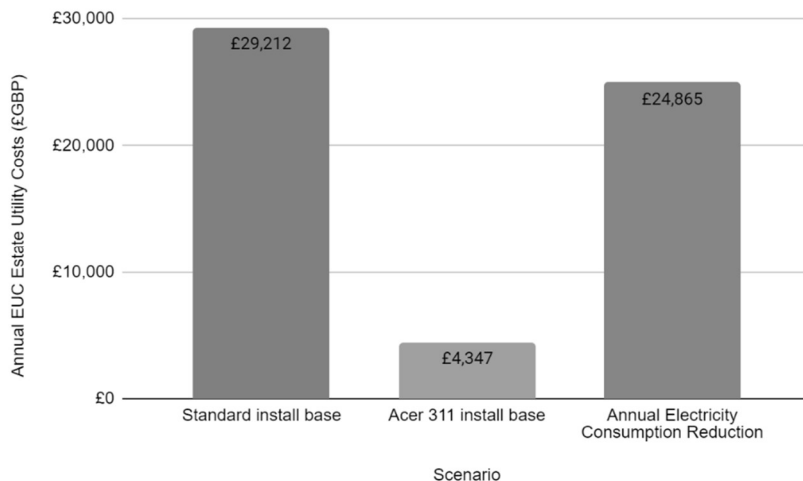
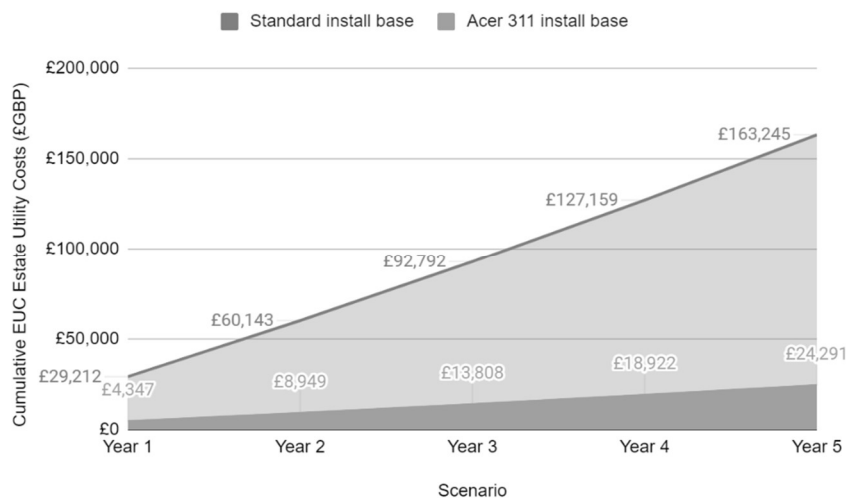


Figure 5. 5-year electricity cost (£GBP) comparison



As before, extrapolated to account for the entire 5-year device retention period, the cumulative impact upon profitability becomes emphasised. Figure 5 includes a median annual price increase anticipated for electricity costs in the UK. As such, the standard install base total utility expenditure will be £163,245 and £97 per device during device use-phase while comparatively the Chromebook electricity costs reduce to £24,291 in total and £14.45 per device. Consequently, it is reasonable to state that by transitioning to the highly energy efficient Acer 311 Chromebook, utility costs can be reduced by 85%. For an average sized EUC install base in the education sector this represents a saving of £138,954 during the device's useful lifespan and reduces device operational expenditure by £82.55 per computer.

Summary

The results substantiate that transitioning from standard EUC environments that include desktops and monitor combinations, to a 100% mobile estate based on highly energy efficient devices, such as the Acer Chromebook 311, supports the UN sustainable development goal of responsible consumption. This is achieved by an 85% reduction in electricity consumption that causes equivalent abatement of concomitant scope 2 GHG emissions. Consequently, the average use-phase emissions exhibited by a single device in a standard install base will decline from 38.6 kgCO_{2e} to 5.7kg CO_{2e} during the product lifespan. As such, it is possible to avoid 33kgCO_{2e} per device and realise tangible climate action.

While the abatement examples based upon average EUC install base sizes prove significant, the feasibility of meaningfully contributing to the UNEP aspiration of reducing societal emission via existing technology is emphasised when examined at scale. As an example, statistical data indicates there are over 4m computers operating in UK education establishments today [30]. Based upon the average values, the scope 2 emissions for the next 5-years created by such devices will be in the region of 154.5 million kgCO_{2e}. In context, this is equivalent to pollution created by 562.6 million car miles; a distance equal to four journeys to Mars. When buying incremental computers or replacing obsolete devices, selecting highly energy efficient devices at scale will reduce this footprint to just 15% of the current environmental impact.

Positively, if 100% diffusion of devices such as the Acer Chromebook 311 was experienced in the UK education system, 131.5m kgCO_{2e} of scope 2 GHG emissions would be avoided every 5-years. This is equivalent to preventing pollution from 478.9 million car miles. This quantity of emissions would otherwise require almost 115,000 forest acres to sequester the carbon from our atmosphere every year. To visualise this, it is worth considering that such a forest would cover the entire land mass of inner London and Manchester combined.

While there are obvious environmental benefits from responsible consumption, the results validate that profitability is improved too as utility costs decline. Specifically, the calculations determine that an average standard device utility expenditure is calculated to be £97 per unit during the use-phase. Selecting low energy consumption devices such as the Acer Chromebook 311 reduces this to £14.45 per device. As such, it is feasible that an estimated £82.55 of electricity costs can be saved per device during a 5-year period. Once again, at scale and considering rising utility costs, this value becomes increasingly significant in terms of financial efficiencies. Applying the savings generated by the Acer Chromebook 311 to the 4 million computers used within UK education determines an available utility cost reduction of £330.2 million achieved by simply selecting notebooks based upon scientifically validated energy data.

Consequently, the findings support prior research that sustainable IT is not complex to adopt if accurate environmental information is made freely available. Additionally, adopting sustainability as part of assessment and procurement criteria significantly supports both planet and profit. As such, it is reasonable to suggest that examining beyond standard benchmark energy data that does not consider the active-state power draw is beneficial. By determining electricity consumption during the use-phase when students, teachers, administrative and support staff are productive, enables science-based decisions and targets to be formed. From this foundation, abatement goals can be assessed and climate action documented to ensure that a more sustainable future is realised as organisations strive to attain net zero operations.

Conclusion

As IT procurement and use legislation and policy^[4] reaches beyond manufacturers and intensifies focus within consumer environments, institutes such as schools, academies, colleges and universities must focus upon reducing the impact of high emissions sources such as end user computing.

Energy consumption reduction via the adoption of low energy devices such as the Acer Chromebook 311 enables feasibility to become reality. Reducing scope 2 emissions by 85%, the carbon footprint of EUC estates is proactively reduced in both the short and long-term contributing directly to the UN aspiration to lower societal emissions via existing technology.

Arguably, taking such action at scale will make the difference between imminent incremental global warming or enabling a cessation of temperature gain in the short term. Such concerted climate action driven by responsible consumption will bridge the gap, facilitating long term strategies such as renewable energy diffusion to mature ahead of attaining national net zero aspirations in 2050.

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