Device Use Phase Analysis

End User Computing GHG Emissions

Google ChromeOS for Digital Signage

Px³ Ltd
The Surrey Technology Centre
40 Occam Road
The Surrey Research Park
Guildford
Surrey GU2 7YG
United Kingdom
info@px3.org.uk

Abstract

End user computing generates over 1% of global greenhouse gas annual emissions caused by the production of over 460m new devices annually and the use-phase activity of 4.2bn users. Approximately one-third of the total carbon footprint of personal computers 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. The rationale being that organisations are able to select energy efficient devices using available typical energy consumption data and therefore reduce concomitant scope 2 (electricity) greenhouse gas emissions in the workplace. However, empirical research identifies that current end user computing energy consumption methodology does not accurately reflect device electricity use when subjected to human-interaction. This is because the typical energy consumption benchmark data used to determine efficiency focuses on measuring only the low power modes such as off, sleep and idle. The results exclude the active state when power draw is at its highest causing inaccuracies between -60% to +121% and creating a disparity maxim of 181%. 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, Px^3 conducts 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 accurately compare prospective devices by real-life energy based sustainability criterion, predict ongoing lifespan utility costs and quantify annual scope 2 emissions.

In this research, Google's ChromeOS operating system is examined to determine if the capacity to deliver electricity consumption, emissions and utility cost reduction is exhibited when compared to Microsoft operating system devices used for digital signage. This is achieved by comparing a Chromebox device with a similar Microsoft Windows micro desktop computer. Plus, by transforming the latter device using ChromeOS Flex. The results substantiate that the Chromebox is 42% more energy efficient than the Microsoft operating system based device and the newly transitioned ChromeOS Flex device reduces electricity consumption by 21%. Consequently, comparative scope 2 use-phase emissions and utility costs are reduced by similar percentages therefore substantiating that Google's ChromeOS for digital signage generates gains for both planet and profit.

Introduction

Since the Industrial Revolution, anthropogenic interference has caused 1.0°C of global warming [1]. A further increase to 1.5°C will be reached by 2033 if greenhouse gas (GHG) emissions continue to rise at the current annual growth rate [1]. However, scientists calculate that by reaching and sustaining net zero global anthropogenic CO_2 emissions by mid-century, global warming may halt 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 enabling strategies are applied without delay [3].

As an example, significant supply chain (scope 3) GHG emissions reductions can be achieved by selecting hardware with the lowest manufacturing carbon footprint [3, 4] and then retaining equipment for longer periods [3, 5, 6, 7, 8] to displace procurement refresh cycles. Electricity consumption (scope 2) emissions can also be reduced by adopting low energy products [3, 5, 8, 9,10] and low carbon computing services [3, 7, 11, 12]. Additionally, associated behavioural changes such as remote working enabled by IT solutions can reduce scope 3 commuting emissions [3, 6, 7, 9, 13].

Consequently, end user computing (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 4.2bn active users [3, 4].

Based upon current world emissions, this annual carbon footprint is 556,000,000 tCO_2e. This is equivalent to 1.4bn fossil fuel car miles and requires a 2.8m km^2 forest the size of Argentina to sequester the pollution [3].

IT Sustainability Drivers

The concept of sustainable EUC procurement and use contributing to GHG abatement is already internationally recognised [3, 4].

Linked with the United Nations Sustainable Development Goal (UN SDG) number 12, 'responsible consumption and production' [15], 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 detailing GHG emissions associated with production, transportation, the use-phase and end of life processes.

Considering that ICT now accounts for over 10% of all commercial electricity consumption [16] and 14% of all waste electrical and electronic equipment (WEEE) recycling [3], selecting computers using sustainability criteria is becoming more prevalent. This is encouraged by both a growing realisation and substantiation that sustainable IT can drive climate action plus national and regional legislation and strategies that require commercial and public sector organisations to include sustainability as a criterion when procuring ICT products and services [3, 4, 16].

Valid Sustainability Data

To determine which EUC devices have the lowest carbon footprint, organisations rely on two key data sources [3, 4, 10, 16-18]. The first is typical energy consumption (TEC) data published by organisations such as Energy Star and as part of the Eco Declaration process. Using this data organisations can select devices that they believe will consume the least amount of electricity during the computer's useful lifespan. The TEC data is also used to calculate concomitant scope 2 (electricity) use-phase GHG emissions within the second data source of product carbon footprint reports generated by EUC manufacturers such as Acer, Apple, ASUS, Dell, HP, Lenovo and Microsoft.

However, research determines that such data sources, whilst accurate within the parameters of their function, lack contextual validity [3, 4, 10].

As an example, the TEC data only measures low power modes including off, sleep and idle. Consequently, the active-state power draw measurement, when the device will experience human interaction, is not included within the projected electricity consumption value.

Arguably, if all computers are judged by energy efficiency when measured in low power modes, then it is logical that the resulting TEC data is created with parity and therefore devices can be compared and selected with confidence.

However, research also determines that unlike operations in low power modes, different operating systems require more or less power during the active-state [3, 10]. As such, computers that appear almost equivalent based upon the existing low power mode TEC data often produce very different electricity consumption outcomes when used in the workplace [10].

Specifically, research determines that by excluding the active state data, the typical energy consumption benchmark data is proven to become inaccurate in the context of real world electricity consumption by between -60% to +121% causing a disparity maxim of 181% [10].

As the TEC data is used to generate scope 2 use-phase GHG emissions data for product carbon footprint reports, the lack of contextual validity is passed on to this second source of data.

Within carbon footprint reports, parity between manufacturers is further eroded as each utilises varying approaches to use-phase emissions calculation [4]. Some manufacturers will include just one year of electricity consumption within a carbon footprint report, whilst others will include as much as 6-years. Additionally, where one brand may use high carbon intensity factors, such as those published in the USA, to convert TEC values to scope 2 GHG emissions, other brands may use low carbon intensity factors, such as those published in Europe to reduce the apparent impact.

Consequently, the substantiated success experienced by including sustainability as a criterion when procuring ICT products and services is effectively compromised [4]. This is because organisations inadvertently procure products that appear to have a lower carbon footprint but in reality are increasing GHG emissions due to a lack of contextual sustainability data.

Device Use-Phase Analysis (DUPA)

The Px^3 device use-phase analysis (DUPA™) energy measurement practice and associated commercial typical electricity consumption (cTEC™) methodology overcomes such issues.

Created during PhD research with the University of Warwick Computer Science faculty [3], the results include both low power mode and operational active state power draw data.

Specifically, the measurement process accurately captures power draw (watts) and energy consumption values (kilo-watt hours) for EUC devices during use. Two sets of data are produced during the comprehensive analysis, proven to be accurate within +/- 0.1% [3].

The first data set being power draw when conducting common activities. The second data set includes real world use scenarios such as energy consumption during a working day that reflect accurately how a device performs when used in a specific environment.

The findings enable organisations to identify end user computing devices that are scientifically proven to reduce electricity consumption during the device's useful lifespan and therefore abate scope 2 electricity based GHG emissions.

Digital Signage

Digital signage represents a specific form of end user computing solution. Displays of differing sizes are powered most often by micro form factor desktop computers that remain active for predominant periods of the device's useful lifespan. Whether informative visual displays or interactive kiosks, digital signage is common in business, public sector, education and retail sectors.

Logically, selecting a desktop computer with the lowest power draw whilst in the active state will reduce overall electricity consumption. By doing so, utility costs will decline during the device's useful lifespan as will concomitant scope 2 GHG emissions.

To determine the planet and profit impact of selecting devices based on real world energy consumption data, two similarly specified EUC device models popularly used to power digital signage are measured for annual electricity consumption.

The results are converted into both scope 2 electricity GHG emissions and utility costs and then compared to highlight feasible climate action and operational cost reductions achieved by adopting sustainable IT strategies.

Methodology

To achieve the objective, the research is conducted in four key stages.

Firstly, power draw and electricity consumption measurement testing is conducted using the Px^3 DUPA™ practice [3, 19]. This is undertaken three times, accurately capturing power draw (watts) and energy consumption values (kilo-watt hours).

The first test measures an Acer Chromebox CX14 (Intel Core i5 CPU, 8GB DDR4 memory, 256GB SSD, installed with the Google ChromeOS operating system). The second an Intel NUC 8i5BEH (Intel Core i5 CPU, 16GB DDR4 memory, 512GB SSD, installed with the Microsoft Windows 11 operating system) and the third measures the same Intel NUC device converted to a Chromebox using Google's ChromeOS Flex operating system. The rationale for the process is to compare results of two similar micro form factor desktop computers in their original equipment manufacturer (OEM) state. As existing research finds that Google ChromeOS devices are capable of reducing energy consumption in the workplace by an average of 46% [3, 10] when compared to alternative operating systems. Therefore testing the ChromeOS and Windows OEM devices will determine such results within a signage environment. As further research indicates that the ChromeOS operating system directly contributes to 19% of the energy consumption reduction [8] then converting the NUC device from Windows to ChromeOS Flex will further examine this aspect of efficiency. This is because the Intel NUC device component specification remains identical in both instances and therefore any energy consumption reduction experienced will be caused by the change of operating system.

The second stage uses the Px^3 cTEC™ methodology [3, 19] to generate two commercial typical energy consumption values for 1-year (kWh/y) for each device. The first value represents annual energy use when facilitating signage in a business or education environment and the second value represents a retail environment (based upon average retail opening times). As such, six sets of annual electricity consumption results are produced.

The third stage of the research is to calculate concomitant scope 2 emissions created by electricity consumption. This is achieved by converting the kWh/y cTEC results to kgCO_2e units using current published and forecasted UK electricity to GHG emissions factors in line with GHG reporting protocol [20]. The individual device results are then compared to highlight abatement achieved by whichever device / device version proves to be the most energy efficient during a computer's useful lifespan.

The fourth stage applies the results to highlight the planet and profit impact of energy efficient devices when deployed at scale within both a business/education and a retail environment. The theoretical case study is based upon one-hundred devices operating for a standard 5-year retention period [3,4]. In this instance, electricity consumption calculation is based upon the current and projected costs of electricity in the UK and future scope 2 emissions based upon projected conversion factors as the UK energy grid adopts increasing percentages of renewable energy.

Beyond the standard unit of measurement for GHG emissions (kgCO_2e) a tangible equivalent is included to enhance comprehension of impact and feasible abatement via analogous representation. In this instance car miles are used to represent the equivalent volume of pollution avoided [3].

All tests are conducted under scientific conditions and results are delivered pragmatically and without bias.

Results

To generate a substantiated and valid baseline, the results section examines the findings of the electricity consumption measurement experiment ahead of determining associated GHG emissions values, utility costs and feasible climate action (planet) and financial (profit) savings highlighted by the example of use at scale.

Computer Electricity Consumption

As noted, three device variations are measured to generate comparable electricity consumption results for possible signage computer solutions using either ChromeOS or Windows operating systems.

Acer CX14 Chromebox ChromeOS

The Acer CX14 Chromebox active state average power draw is 6.55W. For digital signage activity in a business/education environment, a single device consumes 24.98 kWh of electricity per year. In a retail setting, consumption rises to 33.02 kWh (figure 1). In both examples, the active state represents a 52% increase in power draw when compared to the short idle mode measurement of 4.3W. The increase from the short idle to active state is anticipated and congruent with associated research [3, 8, 10] determining that all devices will experience raised power draw during this mode due to additional processing not experienced during the low power modes such as off, sleep and idle.

Intel NUC 8i5BEH Windows 11

The Intel NUC Windows 11 active state average power draw was 9.6W. For digital signage activity in a business/education environment the device will consume 34.67 kWh per year and 46.95 kWh in a retail environment (figure 1). The active state represents a 71% increase in power draw when compared to the short idle mode measurement of 5.6W.

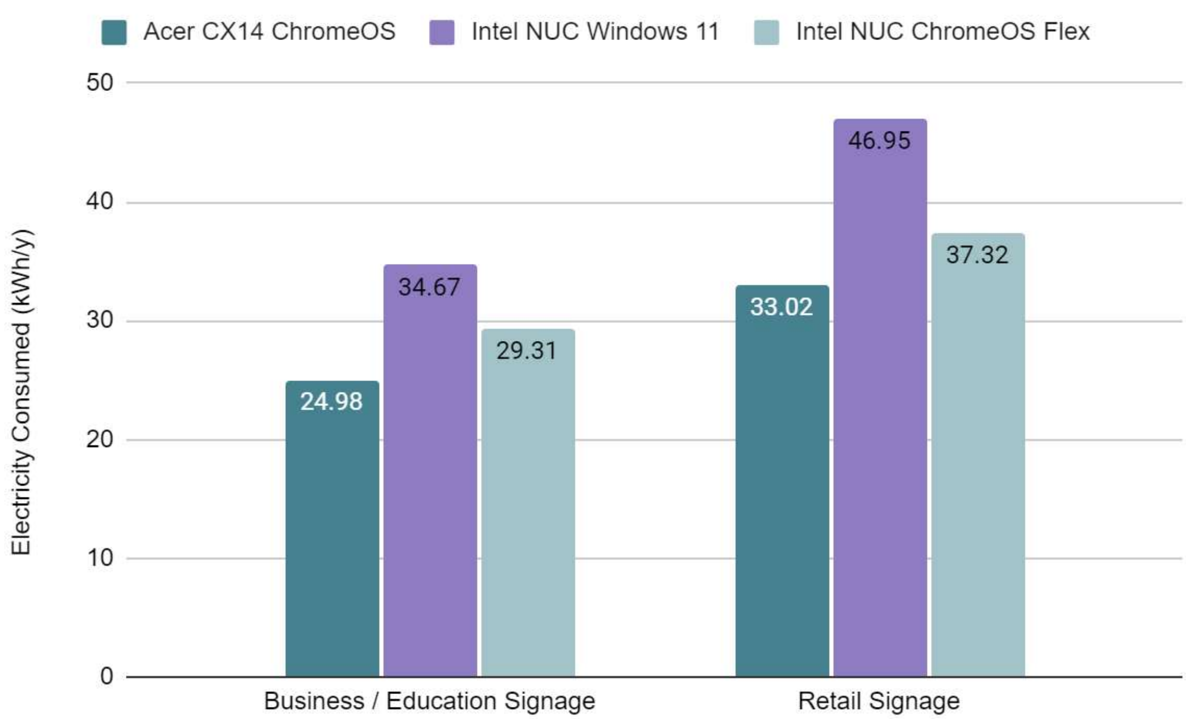
Comparatively, the Windows device exhibits an active state power draw 46.6% or 3.05W higher than the [OEM] ChromeOS device. Consequently, the increase in total annual electricity consumption is 39% in a business/education signage setting and 42% when used in retail environments. The results are congruent with existing research determining that Windows desktop operating systems require an increased power draw during the active state when compared to ChromeOS [3, 8, 10].

Intel NUC 8i5BEH ChromeOS Flex

Further to conversion using ChromeOS Flex, the Intel NUC active state average power draw declined by 27% to 7.03W. For digital signage activity in a business/education environment the device will consume 29.31 kWh per year and 37.32 kWh in a retail environment (figure 1).

The electricity reduction experienced by transitioning from Windows 11 to ChromeOS Flex is 16% for the business/education environment and 21% for a retail setting.

Figure 1. Annual electricity consumption (kWh/y) results for 3 devices in 2 environments



The power draw and electricity consumption test results for all three devices (figure 1) support existing research that determines the ChromeOS operating system requires less energy when experiencing the active state than alternative operating systems such as Microsoft's Windows [3, 8, 10] . Signage devices are not subject to individual user device patterns that will include dormant periods caused by events such as holidays or leisure time. As such the use-profile is influenced by extended periods of operation in the active state delivering either informative or interactive visualisations to staff, students, visitors and consumers. Consequently, the finding is highly relevant to both planet and profit impacts caused by reduced energy consumption opportunities magnified by long periods of active use. This is examined in the following sections.

Planet: GHG Emissions

Logically, greater energy efficiency enables avoidance of scope 2 GHG emissions as less electricity is consumed by each computer during the useful lifespan. Energy based GHG emissions generated will differ depending upon the location of use [4]. This is because national electricity grids exhibit different levels of carbon intensity defined by the percentage adoption of low carbon energy sources such as hydro, solar or wind in favour of fossil fuel sources. The following results are based upon the national grid in the UK.

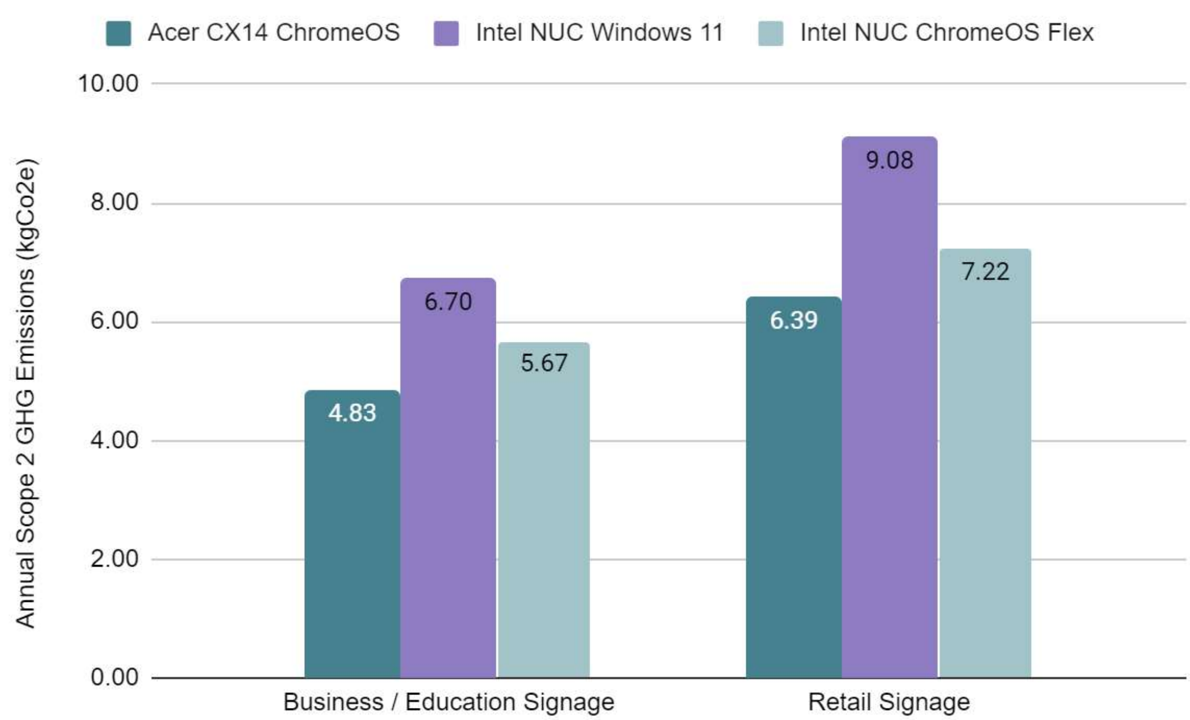
Scope 2 GHG Emissions: Single Device Values

The Acer CX14 scope 2 GHG use-phase emissions for the initial year are 4.83 kgCO_2e in a business/education environment and 6.39 kgCO_2e in a retail setting (figure 2).

Comparatively, the Intel NUC Windows 11 device generates 39% more emissions per year at 6.7 kgCO_2e in a business/education environment and 42% more in a retail setting at 9.08 kgCO_2e (figure 2).

When transitioned with ChromeOS Flex, the Intel NUC scope 2 emissions declined by 16% to 5.67 kgCO_2e and by 21% to 7.22 kgCO_2e in the respective environments (figure 2) when compared to the Windows version. Consequently, this means that the ChromeOS version of the Intel device generates 17% and 13% more emissions than the Acer CX14.

Figure 2. Annual scope 2 GHG emissions (kgCO_2e) results for 3 devices in 2 environments



Positive Impact at Scale

Research determines that key barriers to the adoption of sustainable IT include a limited perception of the environmental gains delivered through transformation and anticipated costs associated with making the change [16]. Further research determines that in reality, climate action is substantial in relation to IT and usually generates a reduction in capital and operational costs [5, 6, 9]. Both outcomes are delivered by strategies such as procurement displacement caused by devices lifespan extension and lowered utility consumption.

As previously noted, digital signage is prevalent in both the public and commercial sectors. Where small businesses may operate low numbers of signage instances, scale can often be extreme. As an example, recent sustainable IT research conducted in the UK central government revealed that in thirteen government departments, over 12,000 signage displays were present [21]. This means that over nine-hundred devices per unique organisation are in use annually.

To contextualise the environmental and cost improvements delivered by energy efficient devices at scale, the following section applies the single device electricity consumption and concomitant scope 2 GHG emissions results to 100 units for both a business/education and a retail environment.

The value of doing so allows organisations operating in these sectors to simply increase or reduce the findings based upon their digital signage install base numbers. Values used for the cost of electricity and scope 2 emissions are based upon current and projected utility prices and emissions factors to account for expected change to both influencing factors.

The time horizon for the example is 5-years as research indicates this to be a standard retention period [3, 4].

In the absence of published product carbon footprint reports for both the Acer and Intel devices and for the purpose indicating the percentage contribution to the total product carbon footprint of each device, the following assumption is made.

To generate a total carbon footprint value for the devices, the use-phase emission results are used in conjunction with an average scope 3 supply chain (production, distribution and end of life processes) for micro form factor desktop computers determined by existing research [4, 22].

Consequently, supply chain emissions applied to both the Acer and Intel devices is determined with confidence to be 190 $kgCO_2e$.

Business or Education Environment Example

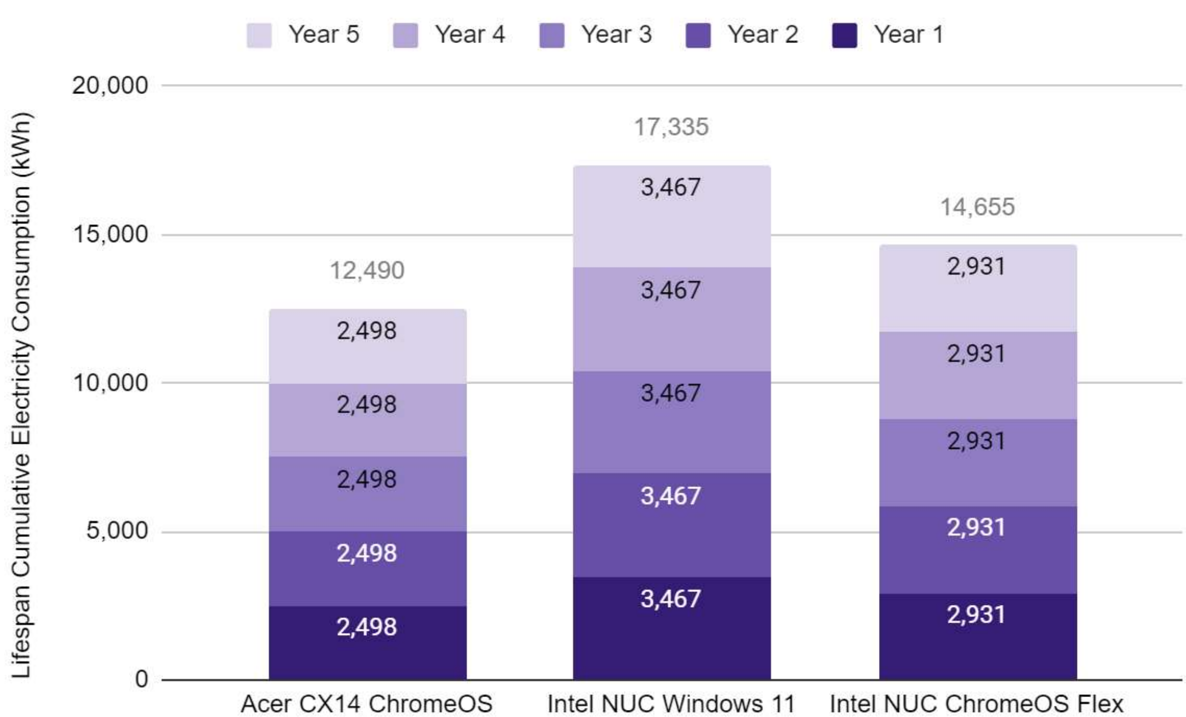
In a business or education environment, the total lifespan electricity consumption for one-hundred Chromebox signage computers is 12,490 kWh.

Comparatively, the Windows 11 signage install base consumes 39% more energy at 17,335 kWh.

Whereas the Intel NUC ChromeOS Flex variant estate consumes 16% less energy than the OEM Windows version and 17% more than the Chromebox at 14,655 kWh (figure 3).

Consequently, when compared to the Windows device consumption, the OEM Chromebox signage estate will consume 4,845 kWh less electricity during the 5-year period. Additionally, by transitioning existing Intel NUC Windows devices to ChromeOS flex, consumption is reduced by 2,680 kWh.

Figure 3. Lifespan electricity consumption (kWh) results for 3 devices in a business / education environment



PLANET: Responsible Consumption and Climate Action

The reduction of electricity consumption translates into scope 2 GHG abatement. Unlike the kWh value, the GHG emissions value is not equal for all 5-years. The reason for this is that the UK national grid will slowly transition away from reliance on fossil fuel energy sources, therefore reducing carbon intensity during the time horizon.

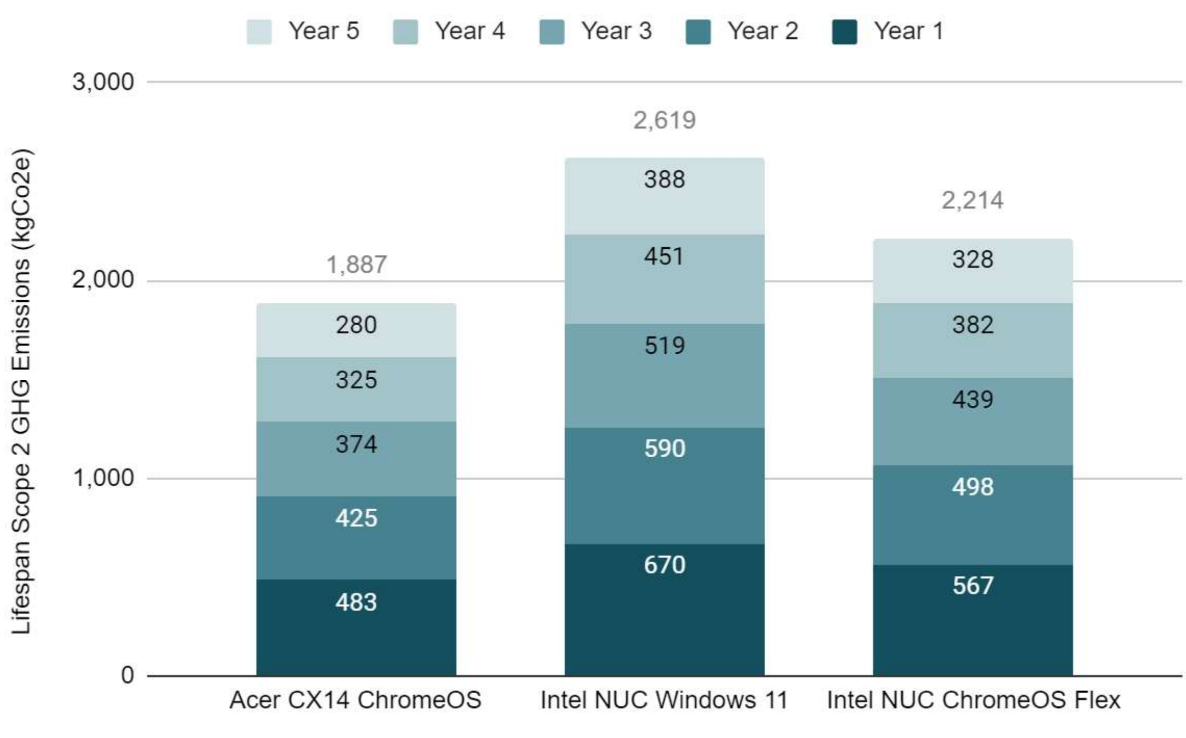
As the OEM Chromebox is the most energy efficient device, it therefore produces the lowest total lifespan scope 2 GHG emissions at 1,887 kgCO_2e (figure 4). If the scope 3 emissions for each device are 190 kgCO_2e, then electricity GHG emissions contribute to just 9% of the total product carbon footprint.

The Windows micro form factor desktop computer estate generates 2,619 kgCO_2e. This is 39% more scope 2 emissions than the similarly specified Chromebox. In this example, the use-phase emissions to the total product carbon footprint therefore rises to 12%.

In this example, it is feasible to reduce GHG emissions by 732 kgCO_2e by selecting the Chromebox to power signage displays. This is equivalent to avoiding pollution caused by 2,652 car miles.

In relation to the newly transformed ChromeOS Flex device, scope 2 emissions are reduced by 16%, generating 2,214 kgCO_2e and causing the proportional contribution to the total product carbon footprint to decline to 10%.

Figure 4. Lifespan scope 2 GHG emissions (kgCO_2e) results for 3 devices in a business / education environment



PROFIT: Utility Cost Reduction

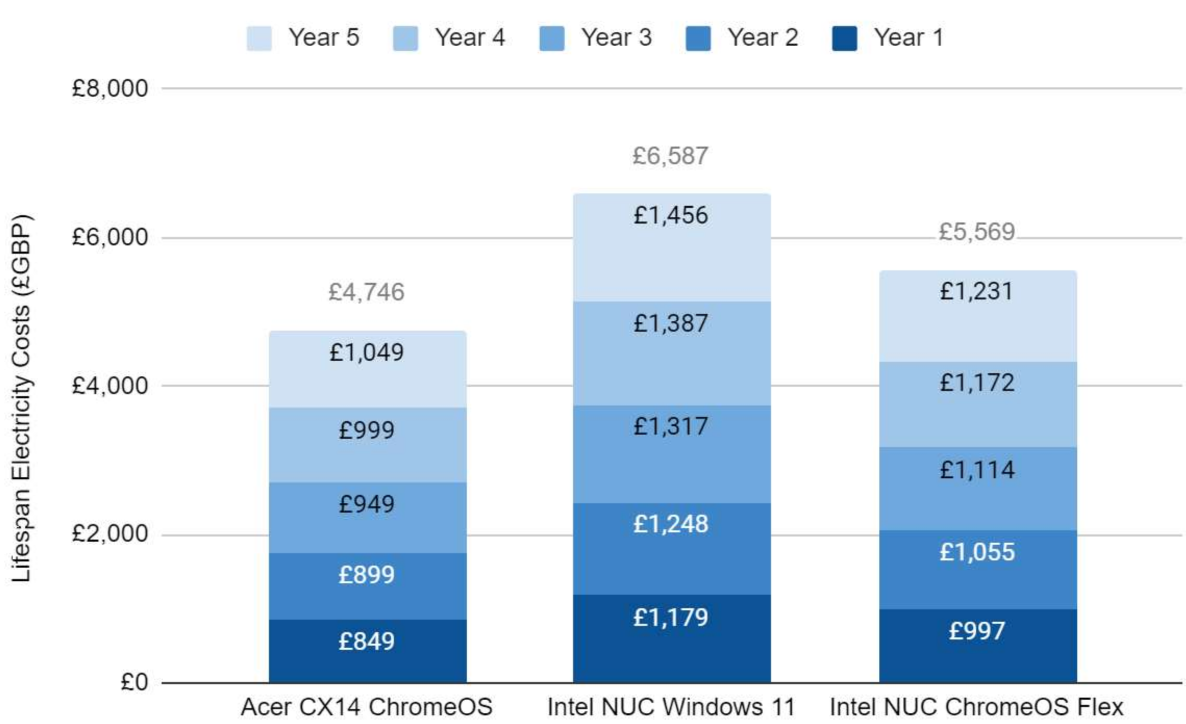
Having determined that climate action is achievable by selecting low energy ChromeOS devices for signage solutions, it is worthwhile examining associated utility savings. Doing so improves awareness that adopting sustainable IT strategies also reduces cost.

As highlighted in figure 5, the annual electricity costs for the 100 device signage environment varies as time progresses for each computer model due to rising electricity costs.

Selecting an OEM Chromebox, utility expenditure for the 5-year period is £4,746. Due to the increase in electricity consumption associated with the Windows device the cost is 39% higher at £6,587. In this example, £1,841 is saved in total by selecting the more energy efficient device.

For existing Windows devices converted to Chromeboxes using Google ChromeOS Flex, the cost of electricity consumed is reduced 18% to £5,569, saving £1,018.

Figure 5. Lifespan electricity cost (£GBP) results for 3 Devices in a business / education environment



Retail Environment Example

Due to the extended hours retail environments experience compared to average work environments, energy consumption will be higher as indicated by the test results (figure 1).

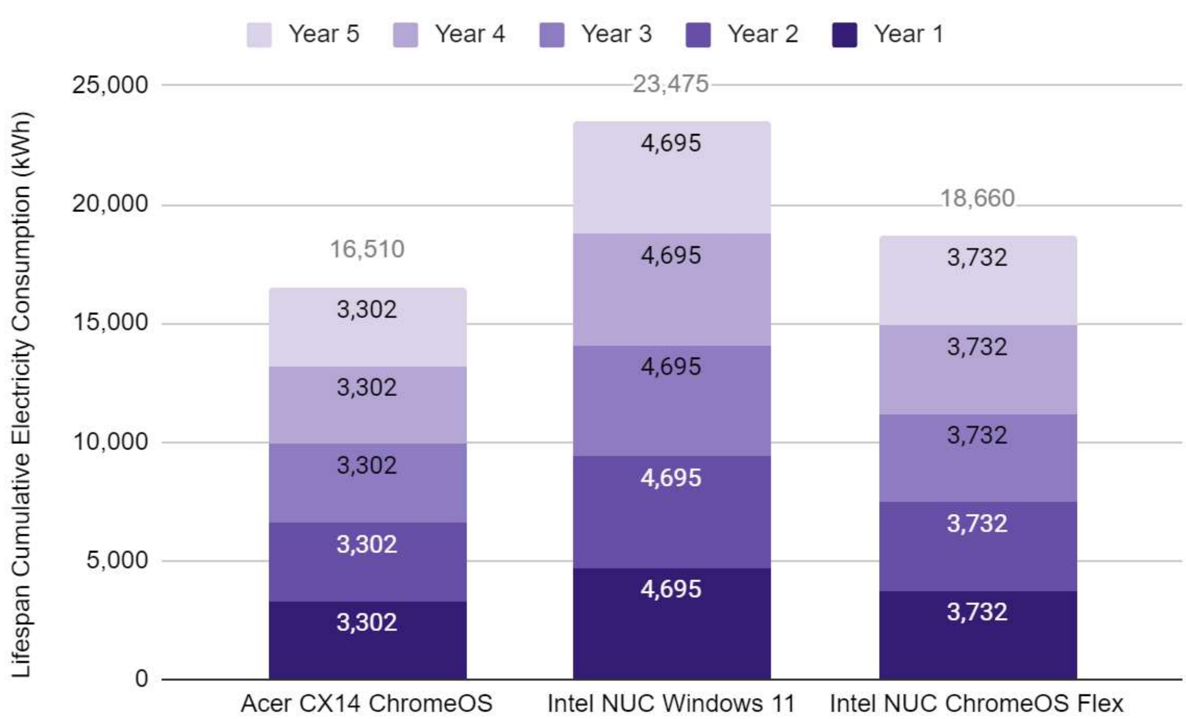
Consequently, in a retail environment, the total lifespan electricity consumption for one-hundred Chromebox signage computers is 16,510 kWh.

Comparatively, the Windows 11 signage install base consumes 42% more energy at 23,475 kWh during the same period.

Whereas the Intel NUC ChromeOS Flex variant estate consumes 21% less energy than the Windows version and 13% more than the Chromebox at 18,660 kWh (figure 6).

As such, when compared to the Windows device consumption, the OEM Chromebox signage estate will consume 6,965 kWh less electricity during the 5-year period. Additionally, by transitioning existing Intel NUC Windows devices to ChromeOS flex, consumption is reduced by 4,815 kWh.

Figure 6. Lifespan electricity consumption (kWh) results for 3 devices in a retail environment



PLANET: Responsible Consumption and Climate Action

As before, the reduction of electricity consumption translates into scope 2 GHG abatement. Due to the elevated energy consumption caused by the extended active state profile the environmental impact increases as does the opportunity to avoid emissions.

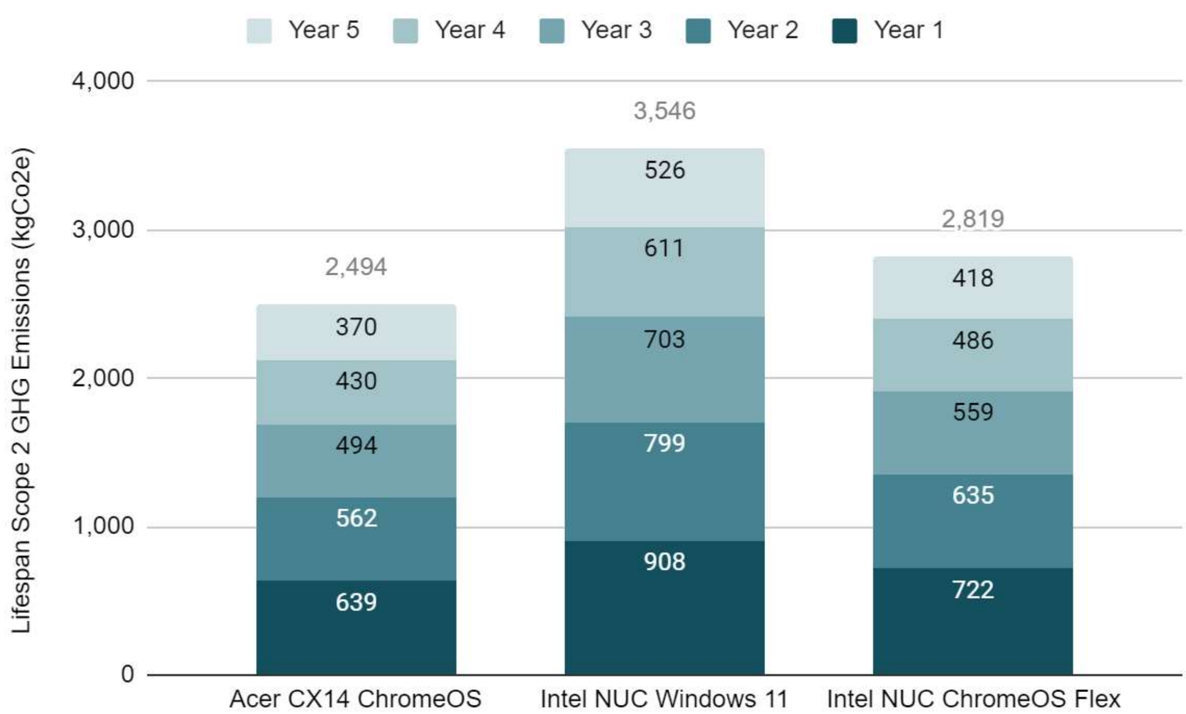
As noted, the OEM Chromebox is the most energy efficient device and therefore produces the lowest total lifespan scope 2 GHG emissions at 2,494 kgCO_2e (figure 7). If the scope 3 emissions for each device are 190 kgCO_2e, then the electricity GHG emissions contribution rises from 9% (figure 4) of the total product carbon footprint to 12%.

The Windows micro form factor desktop computer estate generates 42% more scope 2 emissions at 3,546 kgCO_2e. In this example, the use-phase emissions contribution to the total product carbon footprint therefore rises from 12% (figure 4) to 16%.

Consequently, scope 2 emissions abatement increases by 43% when compared to the business/education scenario, rising from 732 kgCO_2e to 1,052 kgCO_2e. This is equivalent to avoiding pollution caused by driving a petrol car for 3,830 miles.

As highlighted by the improved energy efficiency exhibited when transitioning from a Windows operating system to ChromeOS Flex, the newly transformed Intel NUC device scope 2 emissions are reduced by 21%, generating 2,819 kgCO_2e and causing the proportional contribution to the total product carbon footprint to decline to 13%.

Figure 7. Lifespan scope 2 GHG emissions (kgCO_2e) results for 3 devices in a retail environment



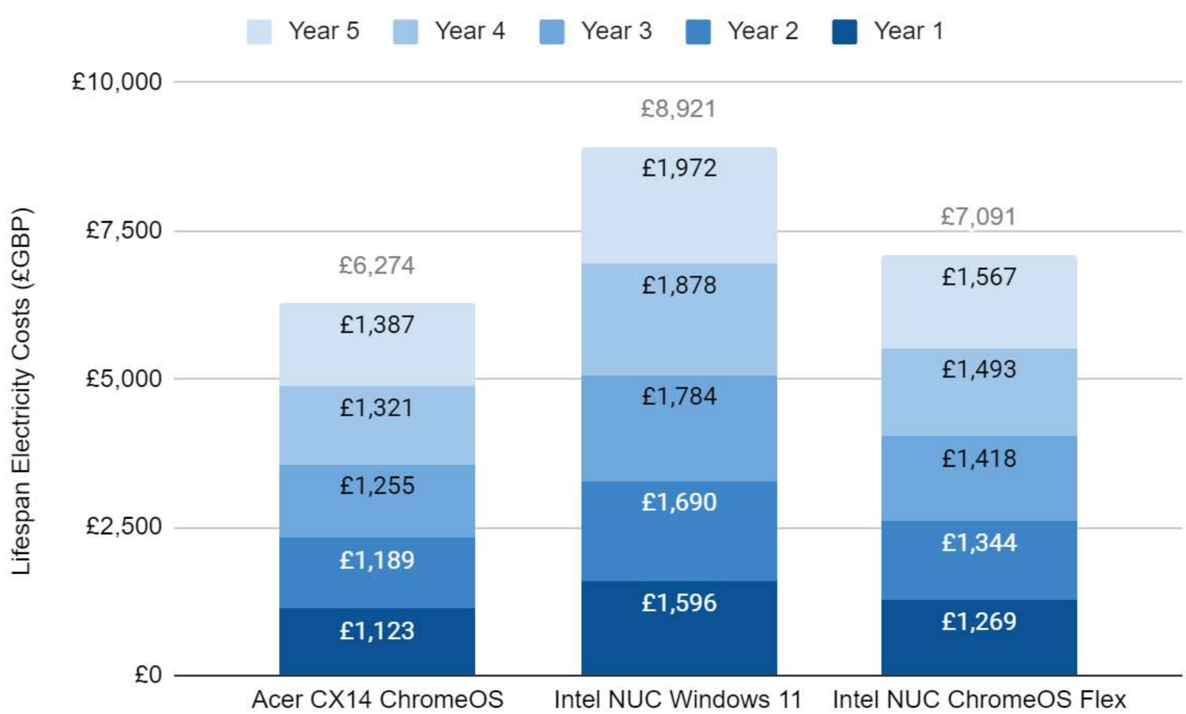
PROFIT: Utility Cost Reduction

Having determined that climate action potential is increased in a retail environment, so too is cost saving as higher electricity consumption reductions are realised.

Selecting an OEM Chromebox, utility expenditure for the 5-year period is £6,274. Due to the increase in electricity consumption associated with the Windows device the cost is 42% higher at £8,921. In this example, £2,641 is saved in total by selecting the more energy efficient ChromeOS device.

For existing Windows devices converted to ChromeOS Flex devices, the cost of electricity consumed is reduced 21% to £7,091, saving £1,830 (figure 8).

Figure 8. Lifespan electricity cost (£GBP) results for 3 devices in a retail environment



Summary

The results substantiate that similar desktop computers used for digital signage solutions are more energy efficient when installed with Google ChromeOS operating systems. The findings are congruent with existing research [8,10] and enable both utility cost reductions and climate action via responsible consumption.

Specifically, the OEM Windows 11 micro form factor desktop computer consumed between 39% and 42% more electricity than the OEM Chromebox when operating digital signage in a business/education and retail environment respectively.

The reason for the increase is predominantly caused by the operating system demanding more power draw when in the active state. This is highlighted by the

Chromebox requiring 6.55W compared to the Windows device requiring 9.6W when experiencing the same active workloads.

As the active state is not considered in existing typical energy consumption benchmarks, this significant percentage increase in electricity consumption would not be obvious to IT or procurement teams when selecting suitable computers for digital signage solutions. As an example, the published data suggests the Windows device consumes 3 kWh more electricity per year than the ChromeOS computer based upon the low power mode measurements.

As the test results substantiated, when the active state is included within the calculation, the consumption difference is as much as 14 kWh/y. As such, the difference between the two computers is actually 364% higher than suggested by the low power mode values.

Whilst the devices are similarly specified in size and components, research does indicate that energy efficiency is influenced by specifics such as central processing units, memory and hard drive types [3, 8]. Validation that the ChromeOS operating system is responsible for 50% of the energy consumption is achieved by transforming the Windows device into a ChromeOS Flex device.

By doing this, the device specification in both tests remains exact as only the operating system has changed. In this example, the active state power draw is reduced by 27% to 7.03W, delivering an overall electricity consumption reduction of between 16-21% depending on which environment the solution is used for.

From a planet perspective, the use case determining the impact of one hundred devices in both a business/education and retail setting defines that cumulative energy savings at scale enable meaningful climate action. Specifically, 732 kgCO_2e of emissions were avoided in a business/education environment and as much as 1,052 kgCO_2e when used in retail during a 5-year use-phase. While this is achieved by simply selecting the more energy efficient ChromeOS device, both scope 2 emissions and scope 3 supply chain emissions can also be influenced by transitioning to ChromeOS Flex.

As noted, the Windows computer energy efficiency improved after installation of ChromeOS Flex. This caused scope 2 GHG emissions to be reduced by 405 kgCO_2e in the business/education environment and 727 kgCO_2e in the retail setting. Had this transition occurred at the point when the Windows devices had reached the end of their 5-year life span it is feasible that with a new operating system, the devices could be kept for a further 3-years.

Each computer has a scope 3 emissions value of 190 kgCO_2e. Consequently, by extending the Windows device lifespan by a further 36 months, the annualised supply chain emissions reduce from 38 kgCO_2e per device to 24 kgCO_2e. As such, the overall scope

3 GHG emissions applied to the device lifespan are reduced by 37% as procurement cycles and new product requirements are displaced.

In the context of a one hundred device digital signage install base, the additional supply chain emissions abatement is 4,200 kgCO_2e generated by extending device lifespans with ChromeOS Flex. This is equivalent to preventing emissions caused by driving a petrol car for over 15,295 miles.

From a profit perspective, energy consumption reduction delivered by sustainable IT strategies is proven to be achievable and challenges the incorrect perception that adopting green IT adds to cost [16]. In the one hundred device example, utility costs are reduced by as much as £2,647 therefore supporting a justified business case to transition to ChromeOS devices.

While this is a definitive gain in relation to reducing operational expenditure, the concept of displacement strategies such as transitioning to ChromeOS Flex to extend device lifespans will also contribute to capital expenditure reduction.

As a simple example, assuming the Windows device's current cost is £400 the following is feasible. If kept for 5-years, the annualised cost of each unit is £80 per year. Should the device retention period be extended to 8-years then the annual cost reduces to £50. As such, because the procurement refresh cycle is displaced by 36 months, device capital expenditure is reduced by 37%. In the context of the one hundred device install base example, the total procurement cost saving applied to existing Windows computers by transitioning to ChromeOS Flex is £9,000.

Conclusions

As IT procurement and use legislation and policy [4] reaches beyond manufacturers and intensifies focus within consumer environments, commercial and public sector organisations must focus upon reducing the impact of high emissions sources such as end user computing [3]. As substantiated by the research, digital signage environments will benefit from both planet and profit perspectives by selecting ChromeOS devices that enable responsible consumption. Additionally, considering options such as replacement operating systems including ChromeOS Flex will both reduce scope 2 GHG emissions for existing devices and reduce scope 3 supply chain emissions by extending device useful lifespans.

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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About Px[3]

Px[3] is an award winning research focused IT consulting organisation specialising in sustainability and specifically the reduction of GHG emissions created by the way people work today. Our unique services enable global IT manufacturers, software vendors, cloud computing service providers, technology distributors, value added resellers plus commercial and public sector organisations to plan for and adopt sustainable IT that is good for the planet, people and productivity – hence our name. The DUPA process, Px[3] framework, cTEC methodology, Dynamic Carbon Footprint and Silent Sole certification name and icon are copyright of Px[3] Ltd. All practices were developed during PhD research conducted under the supervision of the University of Warwick Computer and Urban Science faculty and the Warwick Business Schools Sustainability and Business faculty.

The United Nations notes, 'The Global Goals can only be met if we work together. International investments & support is needed to ensure innovative technological development. To build a better world, we need to be supportive, empathetic, inventive, passionate, and above all, cooperative.' For information technology to drive SDG 13 Climate Action then SDG 17 Partnership for the goals is essential. Without cooperation we cannot achieve SDG12 Responsible Consumption and Production. At Px[3] our ethos reflects this. When asking IT stakeholders to rank the importance of climate change from 1-10, the average response is '9'. Whilst this identifies a passion for action, many organisations don't feel equipped to make the bridge between IT & climate action.

We empathise with this complex problem and use innovation to reveal that 'Great IT can also be Green IT'

To support responsible production, we conduct scientific research measuring the environmental impact of products & services produced by global technology companies. The rationale being that these organisations enable 4.2bn computer users to be productive or enjoy digital content. From a responsible consumption perspective, we help these companies to produce material explaining why their offerings meet SDG12 criteria. We also work in partnership and directly with their customers globally to drive behavioural changes that reduce IT supply chain, use-phase & end of life treatment emissions. As an example, our applications and consultants assist companies to select computers with the lowest carbon footprint, to measure their current IT carbon footprint and to realise potential sustainable IT strategies that enable positive change & ultimately GHG emissions abatement. This may be as simple as keeping devices for longer periods to reduce demand for the 460m new end user computing devices produced annually.

Such change is what ultimately drives SDG 13 Climate action. We've measured and advised people using almost 5m computers to date. As a result, as each year passes companies reduce their environmental footprint caused by IT.

We are achieving our goal to cumulatively abate 10,000,000 kgCO_2e of GHG emissions every year via the diffusion of sustainable IT. In fact, as a result of empathy, support, innovation and cooperation, by 2035, carbon requiring the photosynthesis of 250,000 acres of forest will no longer enter our atmosphere. In context, that's a forest equivalent to 3.9m tennis courts.

We cannot do this without embracing SDG 17 partnership for the goals. If our passion isn't shared by manufacturers, vendors and customers then our research and consulting will not be adopted and diffused. And that's why Px[3] considers SDG 17 to be the binding element that enables us all to realise our ultimate goal of Climate Action. As such, we collectively thank our current and prospective ecosystem of companies that utilise Px[3] services to create a more sustainable future.

About the Author

Dr. Justin Sutton-Parker specialises in computer science and specifically information communications technology (ICT) carbon footprint, life cycle assessment and greenhouse gas (GHG) emissions reduction.

As a Research Fellow with the University of Warwick and founder of research and consulting organisation Px3, Dr. Justin leads global ICT GHG impact research projects and publishes papers in prominent scientific journals. The findings advance and influence global ICT manufacturing, procurement and user behaviours designed to reduce the carbon footprint of ICT. Doing so supports United Nations (UN) SDG 12 'responsible consumption and production' and ultimately SDG 13, 'climate action' via the diffusion of sustainable ICT.

Many of the world's largest ICT, eco-certification companies and governments use Dr. Justin's research to scientifically substantiate international sustainable ICT strategies.

Accredited with advances within the field of sustainable ICT, including commercial computing typical energy (cTEC) consumption calculation, plus the invention of world first science based sustainable ICT carbon footprint calculation, pre-procurement and strategy modelling applications platform, Dr. Justin's research has been nominated for awards including The Earth Shot Prize.

A regular international public speaker, Dr. Justin participates in numerous mainstream media publications, videos and podcasts and is the sustainable ICT editor for the world's leading ethics and sustainability magazine My Green Pod, producing special editions distributed at UN COP sessions.

Dr. Justin specifically promotes the adoption of 4 simple steps to achieving a lower ICT carbon footprint. These include:

- selecting low carbon footprint devices and keeping them for longer periods
- selecting green data centres
- adopting increased remote working strategies to reduce commuting emissions
- reducing e-waste via displacement and circular economy strategies.

Contact: https://www.linkedin.com/in/justin-sutton-parker-514b48/ or via www.px3.org.uk and www.drjustin.co.uk

Px³ Ltd

The Surrey Technology Centre

40 Occam Road

The Surrey Research Park

Guildford

Surrey GU2 7YG

United Kingdom

www.px3.org.uk