Sustainable IT Research

ChromeOS

Reducing End User Computing Carbon Footprint

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Executive Overview

Reducing GHG emissions caused by human activity is a growing priority for businesses and organisations across the globe. The change is driven in part by mandatory emissions reporting legislation and by an awareness and concern for global warming and ultimately climate change.

Information technology currently generates as much as 5% of all global greenhouse gas emissions [1-4]. Therefore, IT represents a significant GHG emissions source that can be meaningfully reduced with immediate and short term effect.

However, organisations perceive the adoption of sustainable IT as expensive and without significant environmental impact.

The objective of this research is to show how sustainable IT strategies with ChromeOS reduce cost and deliver meaningful reductions to an organisation's carbon footprint.

By applying lifespan extension and low carbon footprint device strategies enabled by ChromeOS to a typical end user computer environment, the results show that it is feasible to achieve a 50% reduction in device procurement costs, 73% reduction in utility costs, 68% carbon footprint abatement and 81% e-waste avoidance.

During the study time horizon, it is shown that the average 1,000 user environment can save as much as $636,654 in combined capital and operational expenditure.

In parallel, the same estate will avoid 476,984 kgCO_2e of GHG emissions. In context, to remove this amount of carbon from the atmosphere requires more than 21,000 trees and would take one entire year to complete the process. Additionally, 6,000 kg of cumulative e-waste is avoided.

Examined at scale, the research shows that by using ChromeOS Flex to avoid global disposal of computers unable to upgrade to Windows 11 [5], an estimated 62.4 million tons of replacement product GHG emissions is abated. This carbon footprint is larger than Ireland's entire annual GHG emissions [6] and would require over 1 billion tree seedlings grown for ten years [7] to remove this quantity of carbon from the atmosphere.

In this event, 1.4 million tons of e-waste is also avoided. This is equivalent to 6,250 times the weight of the Statue of Liberty.

In conclusion, the research finds that sustainable IT practices driven by ChromeOS support responsible consumption by improving economic and environmental outcomes.

Executive Summary

Increasing evidence of Climate Change means that nations are enacting legislation to reduce GHG emissions caused by human activity. As IT generates as much as 5% of global emissions [1-4], the sector is subject to specific policies designed to reduce IT carbon footprint within the supply chain and use-phase. Responsible production is being driven by international standards applied to raw material extraction, product design, manufacturing and life cycle assessment. While, responsible consumption is driven by new sustainable IT procurement policies and GHG reporting for both the use-phase (electricity) and supply chain.

As digitisation and increasing populations drive demand for ever increasing numbers of end user computing devices, the world must focus on two key strategies if IT's carbon footprint is to be meaningfully reduced. Firstly, selecting low carbon footprint devices at the point of purchase to reduce long term GHG emissions. Secondly, keeping devices for longer periods to reduce demand and support a circular economy.

The benefit of achieving both is not isolated to tackling GHG emissions and climate change. Purchasing low carbon footprint devices drives energy efficiency and reduces utility costs. Keeping devices for longer periods reduces procurement costs as replacement cycles become less often.

To show both the environmental and economic benefits of adopting sustainable IT practices, this research conducts several studies. Each study applies simple and incremental strategies that drive down the carbon footprint and costs of an average 1,000 user end user computing environment.

Research shows that ChromeOS products support and drive sustainable IT strategies, by being more energy efficient and capable of reducing both use-phase and supply chain emissions. Therefore, each incremental strategy is achieved with ChromeOS products and ChromeOS Flex software.

The first study extends device lifespans from an average of 5 years to a proposed 8 years using ChromeOS Flex. By doing this, an average 1,000 user environment saves 38% or $55,652 in annual device procurement costs. The same strategy reduces the annual carbon footprint by 31%, avoiding 26,714 kgCO_2e of GHG emissions. Plus, annual e-waste declines by 38% from 931kg to 582kg.

The study also examines the impact of Windows 10 EOL. It shows that disposal of devices unable to upgrade to Windows 11 [5] isn't the only option because continued use is possible with ChromeOS Flex. The specific European case study reveals that the region's education sector has an opportunity to avoid new device spend of €12.4 billion by upgrading affected devices with ChromeOS Flex. By doing so, a new device carbon footprint of 4.7 billion kgCO_2e and immediate e-waste 66.5 million kg can be avoided.

The second study shows how low carbon footprint ChromeOS devices such as Chromebooks and Chromeboxes significantly reduce GHG emissions and costs. As such, energy efficiency is improved by 49%, avoiding annual energy consumption of 24,094 kWh/y and saving $3,277 in utility costs for every year of operation.

Additionally, the total annual carbon footprint is reduced by 50%, avoiding 43,486 kgCO_2e of GHG emissions every year. Plus, as lighter weight devices are adopted, 58% and 537kg of e-waste is avoided annually.

The third study shows the impact of adopting a 100% mobile strategy by transitioning from a mixed device type environment to Chromebooks. Highlighting the considerable differences between desktop-monitor combinations and Chromebooks, annual hardware procurement costs reduce by 50%, saving $74,730 each year.

Similarly, as energy efficiency reaches a pinnacle with ChromeOS, annual utility cost becomes 73% lower than the initial baseline, saving $4,852 per year.

Coupled with the lower supply chain impact enabled by the Chromebooks, the annual carbon footprint reduces by 68%, avoiding 59,623 kgCO_2e. Additionally, e-waste is also reduced by 81%, meaning that for each year that passes, 756kg of e-waste is no longer introduced into the end of life services processing stream.

The research is summarised by calculating the cumulative benefits of adopting ChromeOS during an 8 year time horizon. It is shown that for the average 1,000 user environment, as much as $636,654 in combined procurement and utility costs can be saved.

From an environmental perspective, the outcome is equally rewarding. A cumulative reduction of 476,984 kgCO_2e is achievable during the 8 year period. To remove this amount of carbon from the atmosphere requires more than 21,000 trees and would take one entire year to complete the process.

In conclusion, sustainability is the principle of ensuring our current actions do not limit the economic, social, and environmental options of future generations. As shown by this research, this practice can be applied with relative ease to IT to significantly improve economic and environmental outcomes.

Therefore, it is reasonable to suggest that whatever your view is on climate change, sustainable IT practices are good for the planet and for profit, so why not try them today with ChromeOS?

Introduction

Today, computers influence every part of our lives. From food to furniture, if a product or service has been manufactured, produced or grown to meet human demand, then a computer will have been involved during the process.

With this in mind, it's perhaps unsurprising that information technology (IT) currently generates as much as 5% of all global greenhouse gas (GHG) emissions [1-4]. In context, this requires a forest the size of Canada and Greenland to remove the carbon from Earth's atmosphere via photosynthesis every single year [1].

The problem is recognised globally and because of this, manufacturing standards and regulations exist to ensure new computers are designed with carbon footprint reduction in mind. This includes energy efficiency thresholds and certifications to influence the electricity consumed by 4.2 billion computer users every day. Plus, responsible raw material, hazardous substances use and manufacturing rules designed to reduce the supply chain impact associated with over 700 million new personal computers produced and shipped every year.

However, current standards and regulations have an arguably wide range when awarding computer energy efficiency and eco-certification. As an example, today the lowest carbon footprint notebook available generates just 88 kg CO_2e [8-9]. While the highest carbon footprint notebook generates 772 kg CO_2e [9-10]. Both devices are energy and eco-certified yet the latter is 777% higher in GHG emissions. That's almost 9 times worse for global warming which is driven by GHG emissions.

As such, it's easy to see how our computer choices can positively or negatively influence ongoing IT carbon footprint and ultimately climate change without realising. We think we are doing the right thing by looking for eco-certificates but really we need to dive a little deeper. This is why the practice of 'sustainability' exists to encourage meaningful change.

The United Nations defines sustainability as the 'principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations' [11].

In the context of IT, simple changes to everyday actions will build a more sustainable future. Adding carbon footprint as a computer selection criteria during IT planning and procurement might influence all three sustainability focus areas.

For example, imagine a school buying low carbon footprint computers that consume less energy. For every year that passes, associated economic utility costs will be lower than expected, as will environmental GHG emissions generated by electricity consumption.

The carbon footprint generated by computers is caused by the supply chain (production, distribution and end of life services); plus computer use as electricity is consumed.

The issue of IT energy consumption is popular in business because IT is responsible for over 10% of commercial electricity use [12]. End user computing (EUC) devices such as laptops, desktops and tablets contribute significantly to this and therefore to use-phase (energy) GHG emissions and utility costs. Consequently, thousands of organisations in every sector are already examining the efficiency of EUC devices to reduce both expenditure and carbon footprint.

Scientific research shows that ChromeOS devices consume as much as 46% less energy consumption than comparable competitor computers [13]. Further research shows that at least 41% of this efficiency is attributed directly to the operating system itself [14]. While the additional reduction is enabled because components that require a lower power draw can be included in product designs when ChromeOS is present [14].

Therefore, it's no surprise that organisations are adopting new ChromeOS devices as an energy focused sustainable IT strategy.

In fact, existing studies show the positive impact in action. Within the hospitality sector, a hotel chain reduced PC energy consumption, cost and emissions by 26% [15]. A public sector organisation achieved a 38% reduction [16], and using ChromeOS for digital signage can reduce energy consumption in retail and commercial businesses by between 39-42% [17].

However, energy efficiency is just one part of the issue. On average, manufacturing and distribution accounts for approximately 75-85% of a device's total carbon footprint [18]. Therefore, selecting low carbon footprint devices in the first instance and keeping devices for longer periods also plays a vital role in sustainable IT practices.

Aside from the fact that the lowest carbon footprint device mentioned above is a Chromebook [8-9], retaining devices for just 4 years means that during a 12 year period, every user will receive 3 new computers. While increasing retention periods to 6 years, the users will only receive 2 new computers within the same time frame. Therefore, without much effort the IT carbon footprint and procurement costs can be reduced by 33%.

However, there are barriers to lifespan extension. A key driver for EUC devices replacement is operating system obsolescence. When forced to buy a new device when the hardware may still have a useful lifespan, the environmental impact can be significant. Scientific research shows that even if the new device is more energy efficient, it can take decades for the reduced use-phase energy emissions to compensate for the carbon footprint caused by manufacturing a new product [14].

Fortunately, ChromeOS Flex enables device extension for Windows and MacOS devices by replacing the old operating system and keeping the existing hardware. Effectively, notebooks and desktops destined for recycling become similar to Chromebooks and Chromeboxes. By doing so, the useful lifespan of the device is extended, demand for new devices is avoided and supply chain carbon footprint and procurement cost reductions are achieved [14-15]. Additionally, because ChromeOS improves EUC device energy efficiency [13], the existing computer that has been given a new lease of life, is most likely to use less energy and produce less use-phase emissions in the future [14].

To show the positive impact of ChromeOS on both economic and environmental metrics, the objective of this research is to apply lifespan extension and low carbon footprint device strategies to a typical 1,000 user EUC environment.

The size of the environment is intentionally selected. If you have a business employing 5,000 users, simply multiply the results by 5. Similarly, if you have a business or organisation with 100 people, then divide the results by 10. As such, via the four studies, meaningful sustainable IT results are made available to all organisations regardless of size.

Specifically, this study includes EUC device carbon footprint (energy and supply chain), electricity consumption and cost, e-waste and procurement cost calculations for the following scenarios:

- An average existing 1,000 user environment
- The same 1,000 user environment with extended device lifespans facilitated by ChromeOS Flex
- A 1,000 user environment using 100% ChromeOS devices
- A 1,000 user environment using ChromeOS devices and a 100% mobile device strategy

However, before examining the findings, it's worth understanding how the data was produced. By doing so, you can be confident that the values generated are valid and represent what you may achieve by building a sustainable IT strategy with ChromeOS.

Methodology

All EUC device related metrics included in the examples are extracted from the scientifically validated Px^3 sustainable IT applications platform database [19]. The platform was developed during PhD research conducted at the University of Warwick computer science faculty.

It is designed to facilitate three specific activities. Firstly, to calculate a baseline carbon footprint, e-waste, electricity consumption and utility cost for all end user computing devices used by organisations in the commercial, public and third sectors. Secondly, to generate strategy reports showing by what percentage and value each baseline metric can be reduced via the adoption of sustainable IT practices. Thirdly, to enable end user computing devices to be compared by carbon footprint during procurement exercises; to ensure low carbon footprint devices are selected as part of an organisation's ongoing commitment to sustainable IT.

During the generation of each baseline report, a data set is created that shows the mixture of device types being used within each organisation. When combined, the data sets enable a comprehensive representation of an average end user computing environment to be formed.

Device types used are commonplace within every work environment including desktops, integrated desktops, thin clients and workstations; plus mobile devices such as notebooks and tablets. Not all business environments are the same with regards to what type of devices are in use. Therefore, average proportional representation of a typical 1,000 computer user environment by computer type and operating system are calculated. To achieve this, asset data of 3.2 million EUC devices captured during Px^3 carbon footprint reporting is used.

The metrics included in the studies are product carbon footprint (annual, total, use and manufacturing), e-waste, electricity consumption, plus utility and hardware procurement costs. All supply chain carbon footprint metrics are averaged by device type (e.g. desktop) and OS using the Px^3 database populated with over 10,000 model specific records [19]. Supply chain emissions are generated in accordance with ISO 14040, 14044 and 14067. Energy values use published typical energy consumption in accordance with IEC 62301 and

62623 standards plus cTEC [1] active use increases to reflect human to computer interaction. Concomitant use emissions are calculated using a global average carbon intensity conversion factor [19].

GHG emissions data for carbon footprint metrics are presented in kilograms of carbon dioxide equivalent (kgCO_2e) in accordance with international GHG accounting protocol. E-waste is calculated in kilograms (kg) and electricity consumption in kilowatt hours per year (kWh/y). Procurement and utility costs are based upon averages experienced globally and expressed in $ [19].

For the current environment impact calculations, device retention periods are set to an industry 5-years replacement average [1]. For lifespan extension, 100% ChromeOS and 100% mobile studies, this value is increased to 8-years to reflect the average replacement cycle across all sectors for ChromeOS devices experienced by Px^3 [19].

For the specific Windows 10 study, Px^3 EUC carbon footprint reports conducted within the last 12 months involving 500,000 devices across multiple sectors are used [19]. This approach is taken to identify the percentage of devices by device type and OS that will require replacement due to Windows 10 end of life (EOL) in October 2025 [5].

Specifically, the inability to upgrade to Windows 11 [5] is ultimately caused by the computer CPU model. From an Intel perspective, this means that any EUC device such as a notebook or desktop computer, must have a processor that is 8th generation or above. Considering this, it's reasonable to determine that computers manufactured before 2018 cannot be upgraded to Windows 11 [5]. To ensure legacy energy inefficiency is represented within the Windows 10 EOL study, an average energy consumption value by device type and OS for computers pre-2018 is calculated and applied [19].

Results

The results initially show annual carbon footprint, e-waste and cost values associated with an average 1,000 user EUC environment. This estate is then compared to three further potential sustainable IT strategies enabled by ChromeOS and designed to incrementally lessen environmental and cost impact as changes are made. In the model, the first action applied to the existing environment is to avoid the disposal of computers that cannot be transitioned to Windows 11 devices due to CPU incompatibility. By introducing ChromeOS Flex to achieve this, device lifespan extension becomes a reality for all existing Windows and MacOS devices. As such, lifespan averages shift from 5 years to 8 years.

The second strategy shows the positive influence of transitioning all desktop and notebook computers to similar type ChromeOS devices. Finally, the third strategy shows the planet and profit improvements delivered by transitioning to a 100% mobile ChromeOS device environment.

Average 1,000 user EUC Environment

The average 1,000 user environment consists of 56% static computers including desktops, thin clients, workstations and associated monitors plus integrated all-in-one desktops (Figure 1). The remaining 44% of devices consist of mobile devices such as notebooks and tablets (Figure 1). Operating system variations include Android, ChromeOS, iPadOS, MacOS, Windows and Linux based thin client operating systems.

Using proportional representation when conducting sustainable IT strategy modelling improves accuracy. Each device type has differing average carbon footprints due to several factors including size (requiring increased raw materials) and energy consumption. A desktop and monitor combination offer a similar operational experience to a notebook. However, from an environmental perspective the two approaches of static versus mobile produce different results.

Figure 2 shows both average energy consumption supply chain GHG emissions for three device types during a 5 year period. It is notable that the resulting lifespan carbon footprint of the desktop and monitor combination are 147% higher than that of a notebook (Figure 2). Due to fewer components, the AIO device, which is an integrated desktop and monitor solution, generates a carbon footprint 26% lower than the desktop and monitor combination (Figure 2). However, the AIO average GHG emissions are 84% higher than an average notebook (Figure 2).

Figure 1. Proportional representation by device type for an average 1,000 user EUC environment

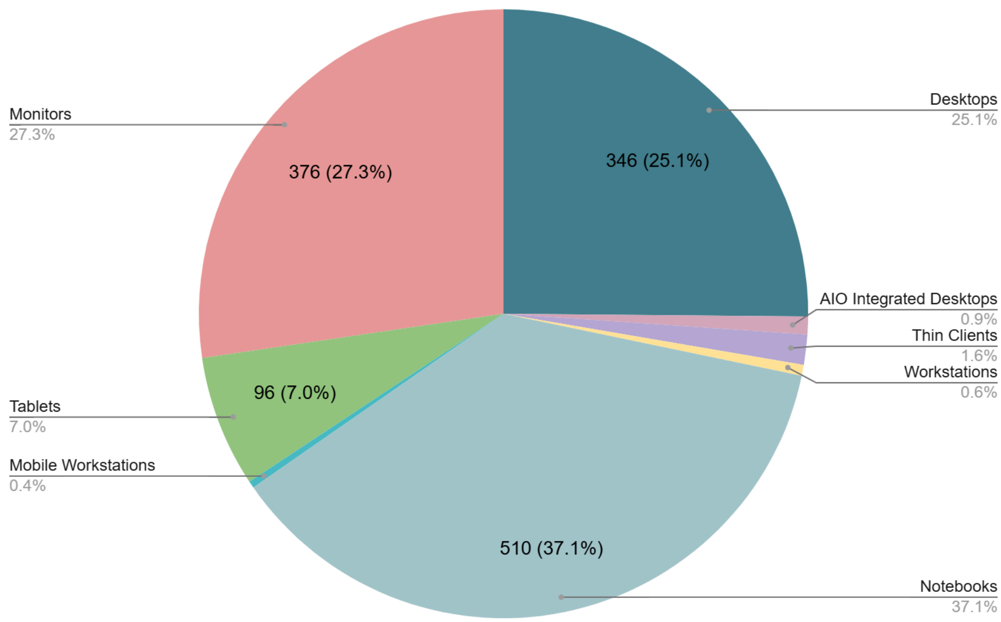
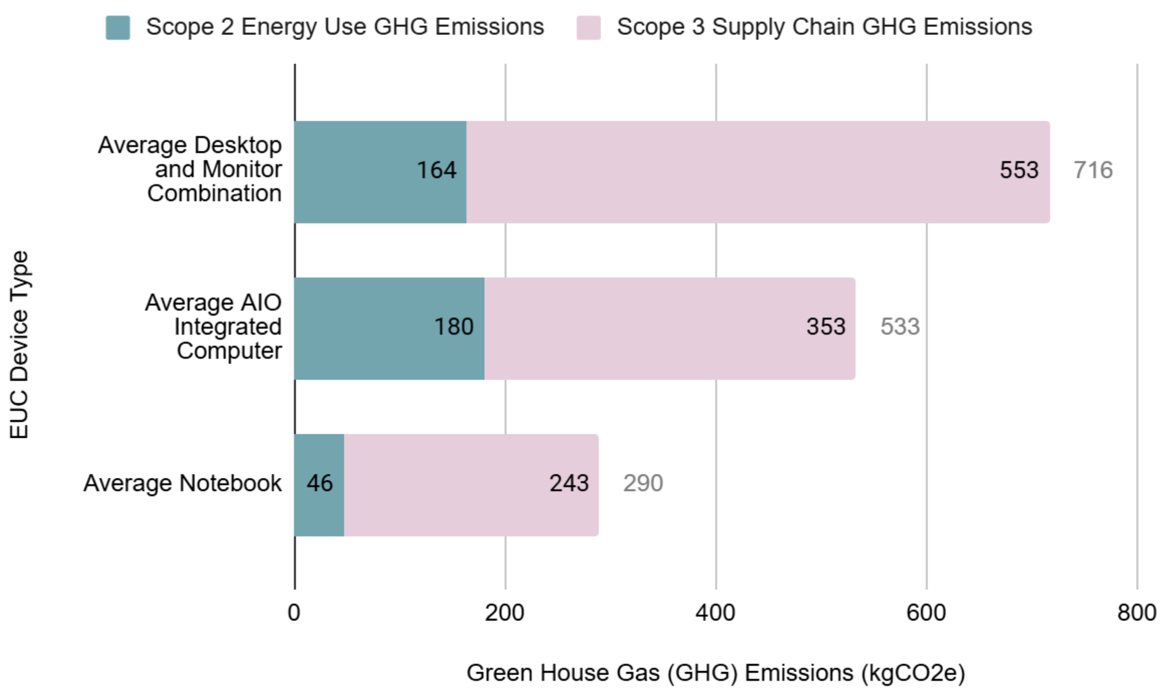


Figure 2. Average 5 year lifespan carbon footprint ($kgCO_2e$) for 3 device types

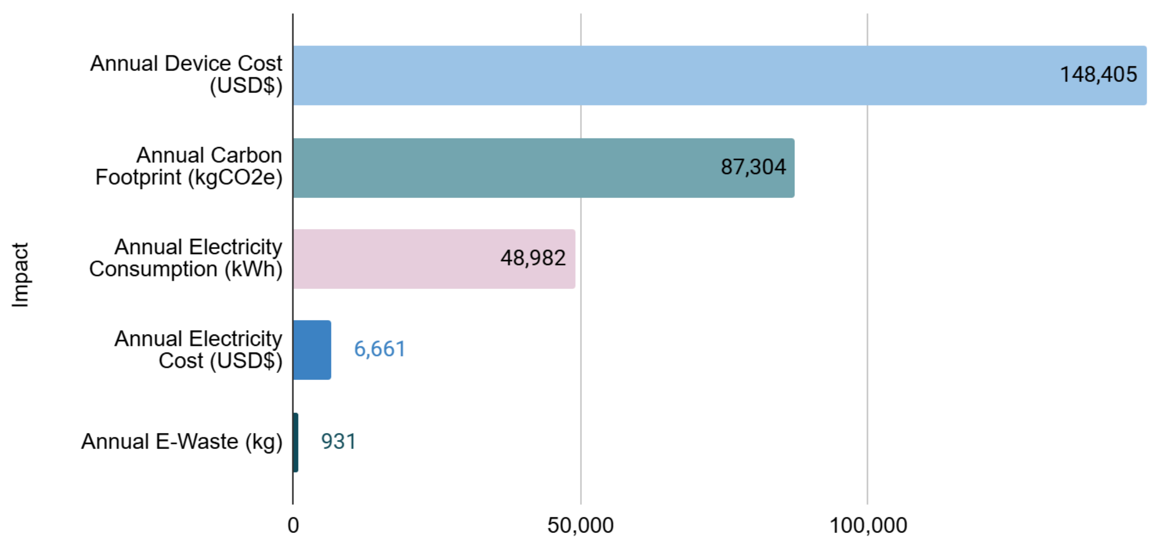


To enable an environmental and economic baseline to be created for the current EUC environment, carbon footprint, e-waste and cost values are calculated. To ensure the subsequent strategy modelling is comparable, cost metrics for both electricity per kWh and device procurement remain equivalent. As an example, a notebook represented within the device procurement costs has the same price per single unit applied throughout. Similarly, the carbon conversion factor used to determine GHG emissions generated by electricity consumption remains constant. As such, as change occurs in the subsequent studies, the only values that alter are energy consumption reduced by improving efficiency, supply chain impact and e-waste influenced by extended lifespans and alternative device types.

As previously noted, economic values are important to the success of sustainability strategies. Research shows that perceived cost is a barrier to adoption of sustainable IT strategies [12]. Therefore, if baselines and modelling show that in fact costs are reduced as sustainable action is taken, then support throughout organisations will grow because varying role based interests are satisfied among stakeholders. Simply put, ESG teams and CEOs responsible for GHG emissions reporting and improvement plus CFOs managing costs and profit will all benefit.

As figure 3 shows, the annual carbon footprint generated by an average 1,000 user EUC environment is 87,304 kgCO_2e. This volume of IT GHG emissions requires 3,968 mature trees every year to remove the carbon from the Earth's atmosphere via photosynthesis. Perhaps more surprising, is that during a 5 year period, the total IT carbon footprint of 436,520 kgCO_2e (5 x 148,405) is equivalent to emissions caused by an average car driving 2.6 million kilometres (km) or 64 times around Earth's equatorial circumference.

Figure 3. Annual environmental & Economic impact of an average 1,000 user EUC estate



79% of the total carbon footprint is generated by computer supply chain GHG emissions including device production, distribution and eventual end of life services such as recycling e-waste.

The remaining 21% of the total carbon footprint is caused by computer electricity consumption which generates use-phase GHG emissions.

Annually, 48,982 kWh of electricity is consumed (Figure 3) generating 18,319 kgCO_2e emissions per year (Figure 3). Using $0.14 per kWh to represent a global average price for commercial electricity, this generates a utility operational expenditure of $6,662 annually (Figure 3).

From a device procurement cost, the annualised capital expenditure value is $148,405 (Figure 3) for each year of the 5 year retention period. This creates an average annual cost of $108 per device based on 1,000 computers and 376 monitors.

Potential e-waste based upon the current computer asset inventory is 4,656kg for the lifespan of all devices and 931kg annually (Figure 3). Therefore, with 1,376 EUC devices in operation, the average e-waste value per device is 3.4kg.

The Influence of Computer Energy Efficiency by Location - a focus on APAC

The average 1,000 user environment example is based upon a global average (Figure 3). When examining specific localised values, supply chain emissions will remain relatively equivalent regardless of a company's location. However, electricity consumption will influence utility cost and use-phase (energy) GHG emissions.

Computer supply chain emissions remain equivalent for two reasons. Firstly, while representing between 75-85% of a device's carbon footprint [18], over 91% of this is attributed to raw materials and production [18]. As this impact occurs before the device is purchased, then the value remains unchanged regardless of the end user's location. Secondly, distribution emissions, which account for over 8% of supply chain emissions [18], are predominantly calculated as a global average by computer manufacturers [18]. Therefore, the location of the end user has little or no influence on supply chain results.

However, electricity experiences significant changes to both price and what is known as 'carbon intensity' depending on where the device is used [1]. Both price and use-phase GHG results are based upon how many kWh units of electrical energy are consumed by a device during its useful lifespan.

Price is an obvious influence and as an example, electricity in Texas (USA) costs approximately USD$0.09 per kWh unit. Comparatively, in the United Kingdom (UK), one kWh costs 335% more at USD$0.39 (£0.31). Therefore, the exact same amount of electricity used in Texas will cost over four times more in the UK.

Carbon intensity is calculated based upon how many grams of carbon exist per kWh when supplied by a specific electricity supply grid. This 'carbon intensity factor' is then multiplied by each kWh unit consumed to create use-phase GHG emissions values measured in $kgCO_2e$.

In smaller countries, electricity supply can be from a national grid or in larger countries there are multiple grids supplying different states and regions. The amount of carbon in each kWh depends upon the source used to generate electricity.

As an example, a renewable energy source, such as wind power, has a carbon intensity of between 5–8.2 grams of carbon dioxide (CO_2) emitted per kilowatt-hour (kWh) of electricity produced. As such, this is known as a low carbon energy supply.

Comparatively, electricity generated using fossil fuel has a high carbon intensity. Gas is approximately 500 grams per kWh; oil 650 grams and coal as much as 1,000 grams. Therefore, an electricity supply grid using coal to generate and supply electricity to businesses will generate over 120 times the amount of carbon as a wind generated supply grid.

Countries across the world are at differing stages of transitioning to renewable and, more importantly, low carbon energy sources. Therefore, location plays a key role in determining EUC device emissions. Figure 4 shows how the location of a business can significantly influence use-phase GHG emissions. Calculated to represent a 5 year use period, the region with the lowest electricity carbon intensity in the world (the Nordics) is compared to Asia and Oceania where electricity carbon intensity is higher.

The Nordics is a geographical and cultural region in Northern Europe. It includes countries such as Denmark, Finland, Iceland, Norway and Sweden. The region has already transitioned to predominantly low carbon electricity production. As an example, in Norway 98% of generation is renewable, of which hydro electric energy is 92% [20]. In context, hydro power is 97% less carbon intensive than electricity produced using coal.

Comparatively, the Asia Pacific region has transitioned to just over 23% of electricity produced from renewable sources [21]. Over half of all electricity production in the region is attributed to coal with a further 10% oil based [21]. Renewables are increasing, with hydro now accounting for 14% [21].

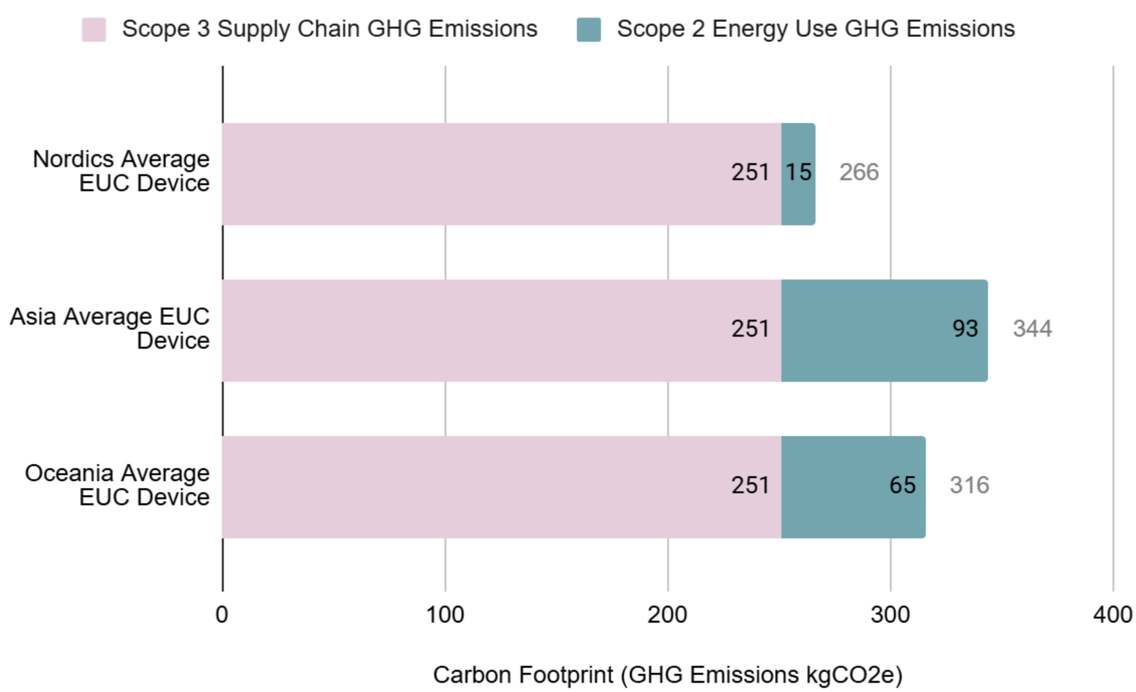
Figure 4 shows that in the Nordics region, during a 5 year lifespan, use-phase emissions account for 5.6% of an average EUC device's total carbon footprint. This means that supply chain emissions are responsible for the remaining 94.4%.

Whereas in Asia, the proportional contribution changes with electricity becoming responsible for 27% of the carbon footprint (Figure 4). This means that the supply chain emissions reduce to being responsible for 73% of the device total impact (Figure 4).

Consequently, when a device is used in Asia, even if the exact same amount of energy is consumed, use-phase emissions increase by 520% (Figure 4), causing the total lifespan carbon footprint increases by 29% when compared to a device used in the Nordics.

This equates to an additional 78 $kgCO_2e$ on average per device and 107,328 $kgCO_2e$ for the average 1,000 user environment. In context, this amount of additional GHG emissions would require 975 more trees for every year of operation to remove the carbon from Earth's atmosphere.

Figure 4: Comparing EUC device use-phase GHG emissions and total carbon footprint by location of use



Devices used in Oceania cause use-phase GHG emissions to be 21% of the total carbon footprint, with supply chain emissions representing 79% (Figure 4). This represents a 333% increase when compared to use-phase emissions generated in the Nordics (Figure 4). Overall, the total carbon footprint has increased by 18% (Figure 4).

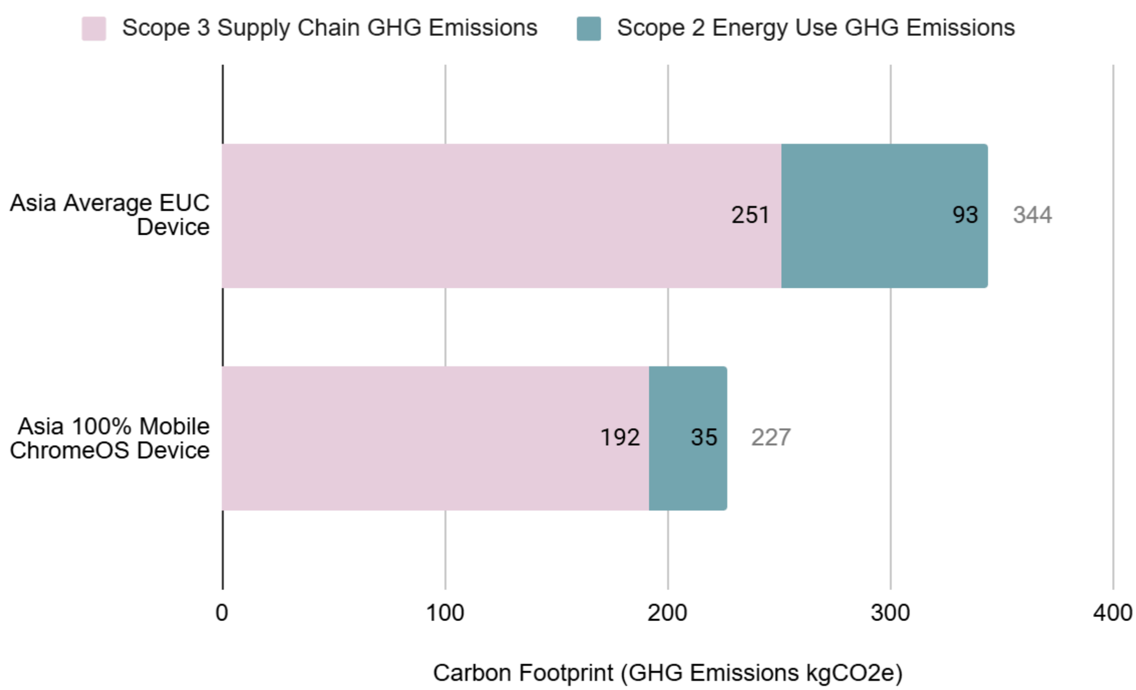
However, the fact that Oceania use-phase emissions are 30% lower than when the same amount of electricity is used in Asia (Figure 4) is, as noted, due to an increase in renewable energy adoption in Oceania.

As an example, in Australia, approximately 40% of electricity is produced by renewables [22]. This highlights that localised weather and topography plays a part in how a region implements low carbon energy production. While the Nordics utilises hydro electric production predominantly [20], Australia's topography and weather enables 32% of national renewable electricity to be produced by wind and solar [22].

'Sustainability Strategy 3' shown below (page 21), determines considerable reductions to electricity consumption, utility cost and use-phase emissions (Figure 10). This is achieved by transitioning from an average EUC environment, to a 100% mobile ChromeOS environment.

The same strategy highlights the significant impact when implemented in geographic locations experiencing high carbon electricity supply, such as Asia. Figure 5, compares the previous average device carbon footprint (Figure 4), with the 100% mobile ChromeOS strategy implemented in Asia.

Figure 5: Comparing EUC device use-phase GHG emissions and total carbon footprint by strategy



In this example, use-phase emissions are reduced by 62% (Figure 5) following the transition to Chromebooks from devices such as desktop and monitor combinations and notebooks. This avoids 58 kgCO_2e of use-phase emissions per device (Figure 5). Overall, the total device carbon footprint also reduces by 37% (Figure 5). This is achieved because of the reduced use-phase emissions and the Chromebook having an average supply chain impact of 192 kgCO_2e per device (Figure 5).

As companies and organisations become subject to mandatory GHG emissions reporting, the necessity to examine ways of reducing IT carbon footprint will increase in priority. As an example, in Europe, over 50,000 companies are already required by law [23] to report both use-phase and supply chain GHG emissions relating to capital goods such as IT.

In Asia Pacific, policies are heading in the same direction as they transition from voluntary sustainability and GHG reporting policies to mandatory requirements.

As an example, from January 2025, the Australian environmental accounting framework AASB S2 [24] mandates carbon emissions metrics and targets for large companies. In China, a mandatory environmental information disclosure system will be implemented in 2025 [25], meaning listed companies are required to publish sustainability reports. In Japan, a new Inaugural Sustainability Disclosure Standard [27] is being applied nationally which will enhance existing sustainability reporting requirements. Malaysia is in a period of public consultation to agree energy GHG emissions reporting for listed companies [27]. While Singapore already has in place legislation for sustainability related disclosure for large companies [28], as does Taiwan [29] and it is anticipated South Korea will follow suit shortly.

Consequently, within Asia Pacific where electricity carbon intensity remains high, device energy efficiency should be considered as an essential element of all sustainable IT strategies.

Sustainability Strategy 1: Lifespan Extension with ChromeOS

The following strategy examines the positive impact of extending the useful lifespan of existing end user computing devices. As previously noted, keeping devices for longer periods is vital to achieving successful sustainable IT strategies. Doing so not only reduces GHG emissions but also reduces procurement costs as computers are purchased less frequently.

The average 1,000 user baseline determines that 79% of the EUC device carbon footprint is caused by supply chain emissions proving it to be the dominant source of carbon footprint (Figure 2). Supply chain emissions include production (raw materials, materials and manufacturing), distribution (e.g. transport emissions) and end of life services impact such as recycling and disposal.

Research shows that on average the production phase contributes to 91% of the total average supply chain carbon footprint [18]. Furthermore, materials used for IT equipment represent as much as 95% of the production carbon footprint [18]. Therefore, it is reasonable to suggest that the materials that form the fabric of every EUC device must be safeguarded and used for as long as possible to reduce long term IT emissions.

In this lifespan extension strategy, ChromeOS Flex is used to avoid the disposal of 14% of devices determined to be unable to upgrade to Windows 11 [5]. This is relevant because in October 2025, Microsoft will no longer provide security updates or technical support for Windows 10 devices [5]. Meaning that devices not meeting the Windows 11 requirements [5] must be replaced or an alternative strategy sought.

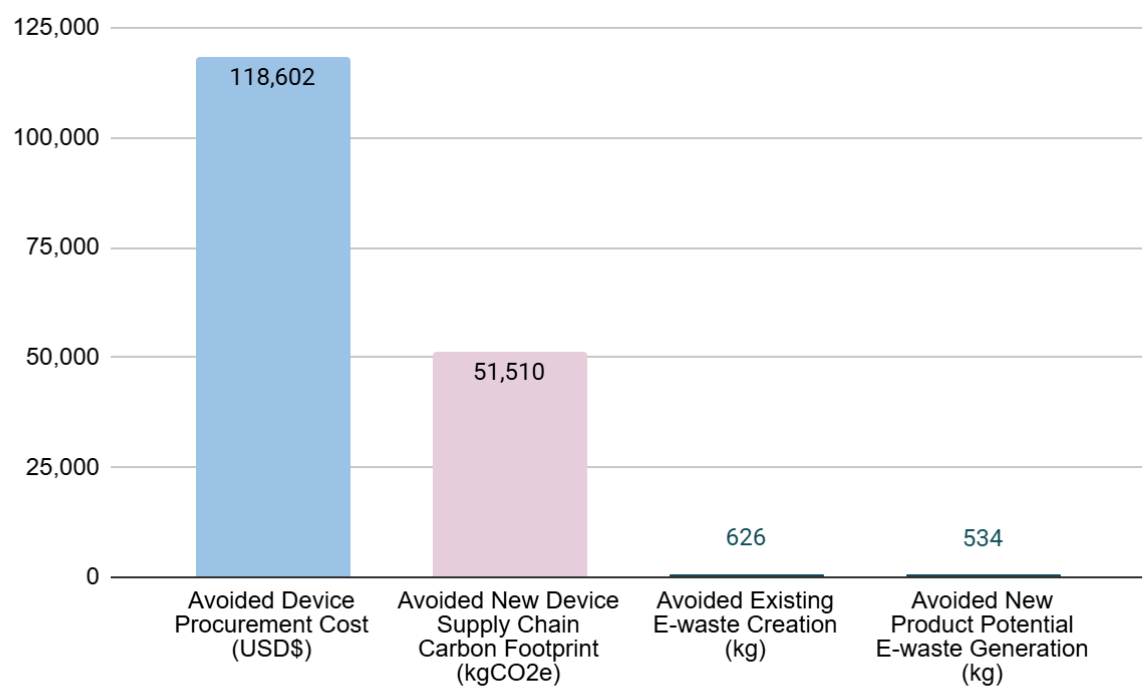
Specifically, 198 devices including 56 static and 142 mobile computers are converted from Windows 10 using ChromeOS Flex and an 8 year retention policy is set. The number of devices included in the model caters as much as 90% being capable of upgrading.

The remaining devices not subject to disposal due to operating system obsolescence are also transitioned to an 8 year policy. While ChromeOS Flex acts as an enabler to achieve extended lifespans, research shows that devices, such as monitors, already experience retention periods often stretching into 10 years [30]. Consequently, a uniform change to keeping devices for 3 years beyond the average 5 years is viable.

In relation to the 198 Windows 10 devices, figure 6 shows the total supply chain carbon footprint, e-waste and device procurement cost avoided by installing ChromeOS Flex. By not buying new devices, an average business can save approximately $120,000 (Figure 6) by extending the lifespan of Windows 10 devices with ChromeOS Flex.

Additionally, 51,510 kgCO_2e of new product supply chain carbon footprint is avoided entirely as the existing devices continue their useful lifespan. 626kg of existing e-waste does not enter the end of services processing chain and 534kg of potential new e-waste is avoided by demand for replacement computers becoming unnecessary.

Figure 6. Economic and environmental values avoided via Windows 10 device lifespan extension using ChromeOS Flex



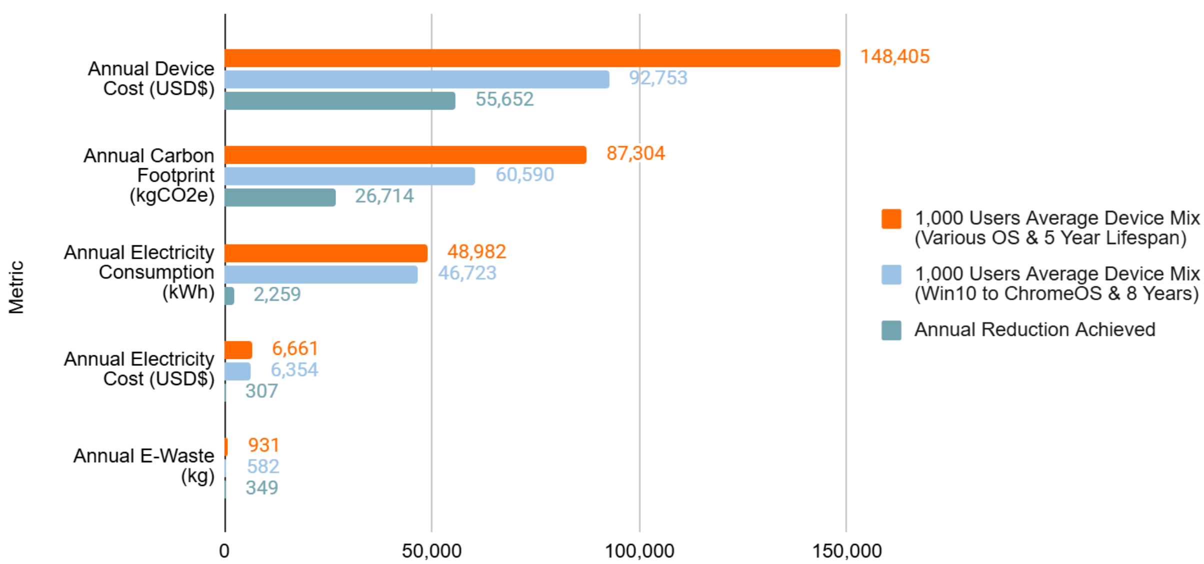
Upgrading to ChromeOS Flex, rather than replacing Windows 10 devices, avoids substantial and immediate economic and environmental impact (Figure 6). In the longer term, applying the same 8 year retention strategy will increase periods between device procurement cycles by 3 years. This means that annual procurement costs, supply chain carbon footprints and e-waste will decline by approximately 40% depending upon device types present within each estate.

Figure 7 shows that buying new devices less often reflects this and reduces the annualised procurement cost by 38% from $148,405 to $92,753. This generates a yearly capital expenditure saving of $55,652 (Figure 7).

The same strategy reduces the annual carbon footprint by 31% from 87,304 kgCO_2e to 60,590 kgCO_2e and avoids 26,714 kgCO_2e (Figure 7) of GHG emissions. In context, this environmental improvement is equivalent to reducing the number of trees required to remove annual carbon from the atmosphere by 1,176 from 3,968 to 2,792. That's more than one tree per user, by making one simple change.

Extending retention periods and reducing new product demand causes the annual e-waste value for an average 1,000 user environment to decline by 38% from 931kg to 582kg (Figure 7). This avoids 349kg of e-waste for every year the devices are kept.

Figure 7. Comparing annual metrics for an average 1,000 user EUC environment before and after Windows 10 device transformation and retention policy change from 5 to 8 years



One area that will not usually be positively influenced by lifespan extension in isolation is electricity consumption, utility cost and use-phase GHG emissions. This is because unlike spreading procurement cost and supply chain emissions across longer periods, computers will continue to consume energy every year if they remain in operation. The easiest way to conceptualise this is thinking of the computer as a car and the electricity as the fuel. You may not change the car but more fuel will be consumed and exhaust emissions created based on how much you use it and how long you keep it.

A simple example is that an average desktop and monitor kept for a total of 5 years will generate a total lifespan carbon footprint of 716 kgCO_2e (Figure 2). In total 164 kgCO_2e (23%) attributed to 60 months of energy consumption (Figure 2). This creates 110 kgCO_2e of annualised supply chain emissions because the device's supply chain carbon footprint is 553 kgCO_2e. Whereas, annual use-phase energy emissions are 32.8 kgCO_2e.

The same device kept for 8 years will generate a total lifespan carbon footprint of 815 kgCO_2e; with 262 kgCO_2e (32%) attributed to 96 months of energy consumption. While it may seem as though the carbon footprint has increased by 13% this is not the case if the impact is calculated on an annual basis.

When kept for 8 years, the annualised supply chain emissions decline by 37% to 69 kgCO_2e per year. Whereas annual use-phase energy emissions remain constant at 32.8 kgCO_2e.

However, research shows that ChromeOS Flex can influence electricity consumption and therefore cost and use-phase emissions [13-15]. Research also shows that when installed on existing devices, energy consumption is reduced by 19% [14]. Consequently, in this lifespan extension strategy, because of the Windows 10 device transformation using ChromeOS Flex, electricity consumption declines by 5%. Annually, 2,259 kWh of electricity is avoided meaning a saving of $307 in utility costs per device and 845 kgCO_2e of use-phase emissions (Figure 7).

Windows 10 End of Life - Focus on Europe

Europe is one of the most advanced regions in relation to adopting legislation that ensures organisations calculate and report both energy and supply chain IT GHG emissions.

As an example, in 2019, The European Green Deal [31] was proposed to reduce environmental impact in the region. Among several key abatement focus areas, reducing GHG emissions from European businesses is imperative if the goal of becoming the first climate neutral continent by 2050 is to be achieved [31].

To facilitate participation, the Corporate Sustainability Reporting Directive (CSRD) came into effect in 2024 [23]. As previously noted, over 50,000 organisations in Europe must report energy consumption and supply chain GHG emissions in annual reports from 2025. This includes GHG emissions from IT, because the equipment consumes electricity and forms part of the supply chain as capital goods procured [23].

In the public sector, increasingly specific policies are already in place to set standards for both procurement and reporting. In the European Union (EU), the 'Green public procurement criteria for computers, monitors, tablets and smartphones' policy has been active since 2020 [32]. It is designed to drive sustainable practices in procurement including assessing product carbon footprint, feasible product lifetime, energy consumption, hazardous substances, and end-of-life management.

Similarly, the United Kingdom (UK) government's forerunner policy 'Greening Government IT Strategy' was first published in 2011 [33]. The initial concept was to recognise the impact of IT used by 6.2 million public sector workers. In particular, the report was designed in part to address use phase energy GHG emissions reporting required by the existing Companies Act [34]. Proposing similar changes to IT strategies as the EU green procurement policy, updated versions of the report continue to be published annually.

Notably, in 2022 and in preparation for CSRD, research data [35] was included for the first time highlighting the IT supply chain carbon footprint of government departments [36]. As the emissions quantity (718.7m $kgCO_2e$) was vast [35-36], the government recommended including supply chain IT GHG data in future reports [36].

As part of the ongoing focus, a subsequent research project was conducted to determine the EUC device carbon footprint of English schools and colleges [30]. Considered one of the world's largest sustainable IT research projects to date [30], the results focus on encouraging sustainable IT strategies among 16 million students, teachers and workers.

The research findings deliver many key sustainable IT policy recommendations [30]. This includes an urgent requirement to address the impending Windows 10 end of life event in October 2025.

As described previously, operating system obsolescence is on average causing 14% of EUC devices globally to face replacement due to not being upgradable to Windows 11 [5].

However, in sectors such as education, the impact is far greater. Due to limited budgets, devices are kept by schools on average between 6-8 years depending on type [30]. As this retention period is as much as 60% longer than in the commercial sector, then a greater number of computers are affected by Windows 10 EOL.

Specifically, research shows [30] that 51% of Windows desktop computers, 73% of Windows all-in-one computers and 52% of Windows notebooks in the English state funded education sector will not meet the Windows 11 upgrade criterion [5]. The key issue is that, while memory and storage drive capacities can be increased and in some instances the Trusted Platform Module (TPM) can be updated, these devices contain CPU models that do not meet the upgrade criteria.

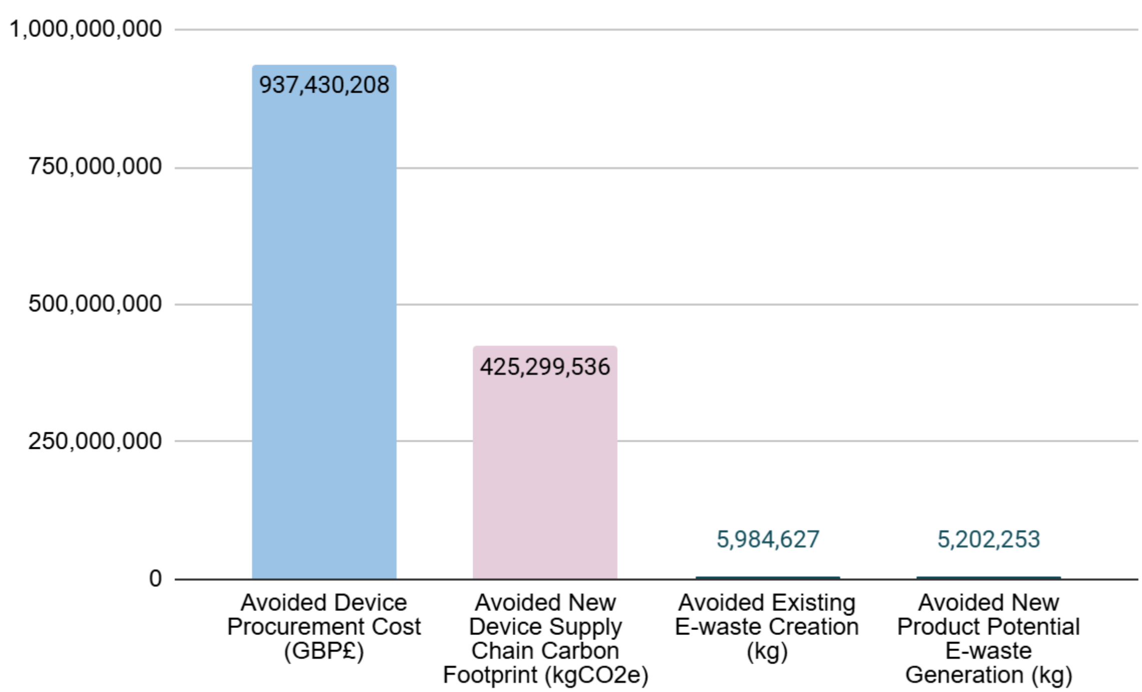
Consequently, this means that almost 1.6 million computers will require disposal unless an alternative strategy is taken to expand the lifespan [30]. As such, it is clear that the UK's Department for Education has the opportunity to avoid disposal by recommending upgrading these devices with ChromeOS Flex.

In a sector with spending constraints, the economic benefit of doing so is considerable. Specifically, new hardware costs of £937.4 million (Figure 8) could be avoided entirely.

From an environmental impact and compliance reporting aspect, continuing with existing devices will generate positive results too. Over 425 million kgCO_2e of supply chain carbon footprint would also be avoided as new product demand and procurement is deferred (Figure 8).

In context, this is equivalent to avoiding emissions generated by driving a combustion engine car 2.5 billion km or 62.5 thousand times around the world. Considering the UK government supports reforestation as part of its national net zero programme, it is notable that it would require 19.3 million trees one year to remove the resulting carbon from the atmosphere.

Figure 8: Economic and environmental impact avoided by upgrading Windows 10 devices in the English education sector to ChromeOS Flex



Additionally, e-waste is an increasing focus for Europe as regulations to create a circular economy expand. As part of the Green Deal and inline with the EU's 2050 Climate Neutrality Goal [37], the Circular Economy Action Plan [38] is now active. Driven by a 100% increase in electronic products entering the market in the last decade [39], the strategy is based upon the UN SDG 12 to achieve 'responsible consumption and production' [40] among its citizens.

Specifically, the framework notes that IT equipment continues to be one of the fastest growing waste streams in the EU with less than 40% being recycled [38].

Citing that two thirds of Europeans would be happy to keep devices for longer if performance was not impaired [38], the policy outlines a 'Circular Electronics Initiative' [38]. Notably, this includes a focus on IT as a priority sector for implementing the ‘right to repair’, including a right to update obsolete software [38].

Clearly, the Windows 10 EOL event [5] falls directly into this category, with the right to upgrade to ChromeOS Flex being imperative to the success of an emerging circular IT economy.

In the same theme, Figure 8 shows that 11.2 million kg of existing and new potential e-waste waiting to be created in the UK education sector, can be avoided. In context, this amount of e-waste is just over the weight of the Eiffel Tower in Paris.

With almost 100 million students enrolled in education in Europe [41], the economic and environmental value of ChromeOS Flex in the context of Windows 10 EOL, is potentially exponential. Considering that England represents 9% of enrolled students [42], it is feasible that the values demonstrated in Figure 8 may increase by over ten times if extrapolated across Europe.

In this instance, it is feasible that by upgrading to ChromeOS Flex, the European education sector could avoid a new device spend of €12.4 billion, a new carbon footprint of 4.7 billion kgCO_2e and immediate e-waste creation weighing 66.5 million kg. From the latter perspective, this is over 1% of the entire continent's annual e-waste quantity [38] and certainly a meaningful contribution to the pursuit of a circular economy and the overall Green Deal [31].

Sustainability Strategy 2: Low Carbon Footprint Devices with ChromeOS

The initial lifespan extension strategy offers a valuable insight into the importance of keeping devices for longer periods. To take this a step further and improve economic and environmental outcomes, organisations must introduce carbon footprint as a criterion when selecting new EUC devices.

The introduction notes that in many organisations, 'sustainability' as a selection criterion is active and growing in popularity. However, sustainability as a criterion does not yet include carbon footprint. Instead, it focuses upon energy efficiency, hazardous materials and ethical supply chains.

While this is undoubtedly positive, as noted previously, devices that meet eco-certification criteria can and do vary widely in carbon footprint due to the thresholds set. The example used in the introduction shows that one notebook was almost 9 times worse for global warming compared to another; yet both products had been awarded energy and eco-certification. Therefore, by not including carbon footprint as a selection criterion, organisations are potentially not achieving their IT sustainability goals.

The lowest carbon footprint device used in the example is a Chromebook. This is perhaps not surprising as research shows that ChromeOS devices consume as much as 46% less energy consumption than comparable competitor computers [13].

However, the average 1,000 user EUC baseline metrics and the lifespan extension strategy both show that supply chain emissions account for between 65-80% on average. As such, it is reasonable to suggest that a truly low carbon EUC device must be both highly energy efficient and exhibit low supply chain emissions when compared to similar products.

To show how introducing carbon footprint as a selection criterion positively influences both environmental and economic results, strategy 2 proposes eventual replacement of all devices to ChromeOS computers. To ensure valid comparability, the device types revealed in the average 1,000 user environment (Figure 1) are retained. For example, if a computer is a desktop in the baseline scenario, it will be replaced with a Chromebox while notebooks will be replaced by Chromebooks. For tablets and monitors, these products remain the same.

As carbon footprint and energy consumption averages for devices by type and operating system have been used for the initial average 1,000 user environment, the same approach is applied to the proposed 100% ChromeOS environment. Consequently, after examining the carbon footprint of over 5,000 unique EUC device models [9], an average for Chromeboxes and Chromebooks is generated. Taking this approach ensures that the results are comparable to the baseline results on a like for like basis.

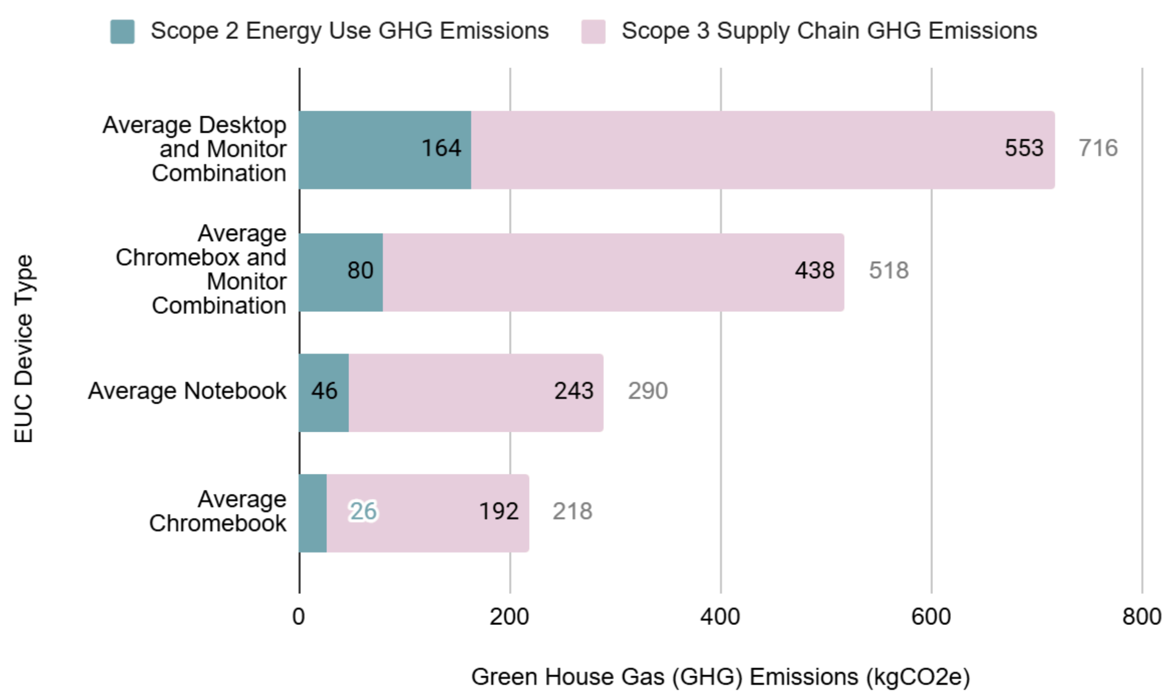
Figure 6 shows that when compared to an average desktop and monitor combination, the average Chromebox solution is 28% lower in carbon footprint across the same 5 year retention period. As the monitor remains constant, the reduction is driven by the Chromebox supply chain average carbon footprint being 42% lower than the average desktop. Plus the average Chromebox energy consumption and concomitant use-phase emissions being 51% lower than the average desktop.

While the ChromeOS operating system is shown by research to require less energy consumption than competitive operating systems [13], the significant reduction in total carbon footprint is also enhanced by the ultra small form factor (USFF) used for most

Chromeboxes. As an example, standard desktop PCs are available in sizes ranging from USFF to Tower form. Data shows that as weight increases with size, so too does the carbon footprint [19]. This is because more materials are used during production for tower formats. Plus higher transportation GHG emissions are applicable as fewer products can be shipped per consignment [19].

Examining the mobile computer averages, the average reduction in total carbon footprint delivered by the Chromebook is 25% (Figure 9). Specifically, energy efficiency drives a 43% reduction in use-phase GHG emissions (Figure 9), while supply chain emissions create a 21% reduction (Figure 9).

Figure 9. Comparing average desktop and notebook computer carbon footprint averages with equivalent average ChromeOS computers



Transitioning all of the existing 389 static computers and 515 notebooks represented in the average 1,000 user environment (Figure 1) to the same number of equivalent Chromeboxes and Chromebooks delivers further improvements to the economic and environmental metrics.

Figure 10 shows that the new strategy delivers the same cost reduction as the lifespan extension strategy of $55,652 per year.

The result is because hypothetical device costs are equivalent by type to enable direct comparison in each strategy. Plus, the lifespan period has already been extended from 5 years to 8 years meaning that the annual costs of the same device types cannot be further reduced by procurement cycle frequency changes. As such, this outcome is to be expected.

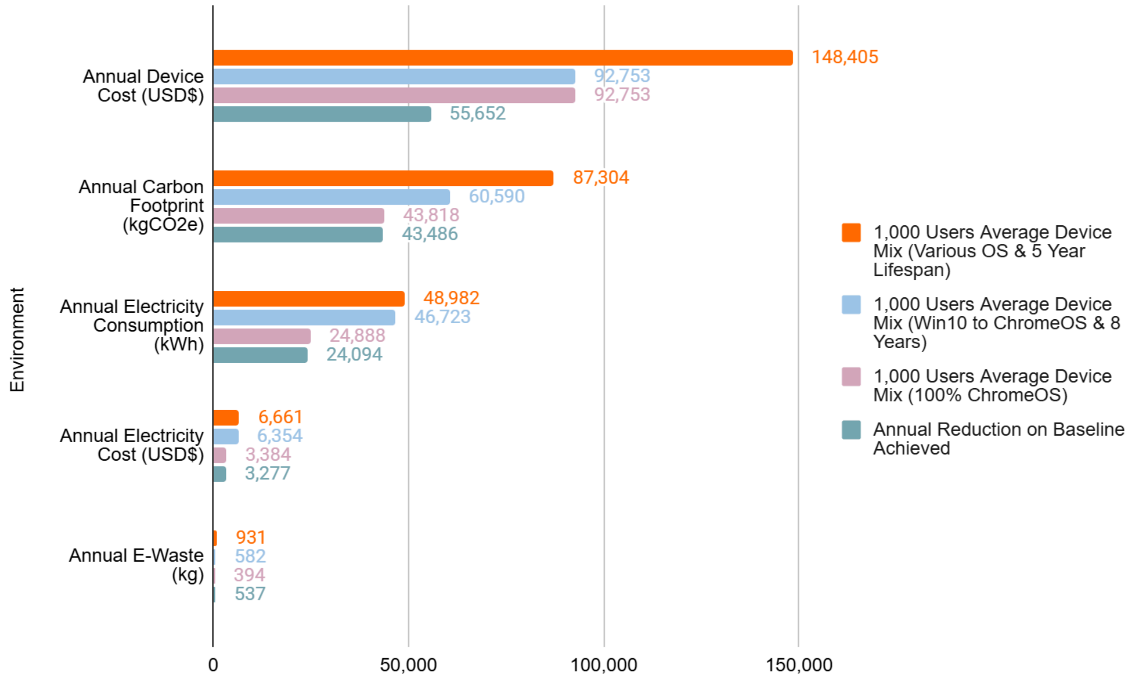
However, from a cost influence perspective, energy efficiency is improved across the estate by 49% compared to the original average 1,000 user environment (Figure 10). Specifically, annual energy consumption is reduced from 48,982 kWh/y to 24,888 kWh/y. This avoids using 24,094 kWh/y and reduces utility costs by $3,277 for every year of operation (Figure 10).

Consequently, the total annual carbon footprint is reduced by 50% from 87,304 kgCO_2e in the original 1,000 average environment, to 43,818 kgCO_2e. This means that 43,486 kgCO_2e of GHG emissions is avoided every year (Figure 10).

In context, this reduces the number of trees required to sequester the carbon from the atmosphere from 3,968 to 1,992. This means that the burden caused by the newly proposed 100% ChromeOS environment requires 1,976 fewer trees; or almost 2 trees per user.

In line with the carbon footprint reduction, e-waste also declines by 58% as lighter weight devices are adopted. Specifically, the e-waste value declines from 931kg per year to 394kg avoiding 537kg annually (Figure 10).

Figure 10. Comparing annual metrics for an average 1,000 user EUC environment to a 100% ChromeOS environment and retention policy change from 5 to 8 years



Sustainability Strategy 3: 100% Mobile with ChromeOS

Figure 9 shows the significant difference between selecting a device that, without exception, requires an external monitor (such as a desktop) and selecting a mobile device such as a notebook. As an example, an average Chromebook is 70% lower in lifespan carbon footprint than an average desktop and monitor combination (Figure 9). While the Chromebox and monitor combination reduces the gap between static and mobile devices to 42% (Figure 9), the continued necessity of a monitor will reduce the meaningful impact of all sustainable IT strategies.

To show this influence, all devices within the average 1,000 user EUC device environment are transitioned to a 100% mobile strategy using Chromebooks. As before, average supply chain and energy GHG emissions are applied to the Chromebook values to avoid focusing on individual models or manufacturer results. Additionally, the 8 year retention period is assumed. As this is a 100% mobile strategy, the tablets remain unchanged and all monitors are removed from calculations.

Figure 11. Comparing annual metrics for an average 1,000 user EUC environment to a 100% mobile ChromeOS environment and retention policy change from 5 to 8 years

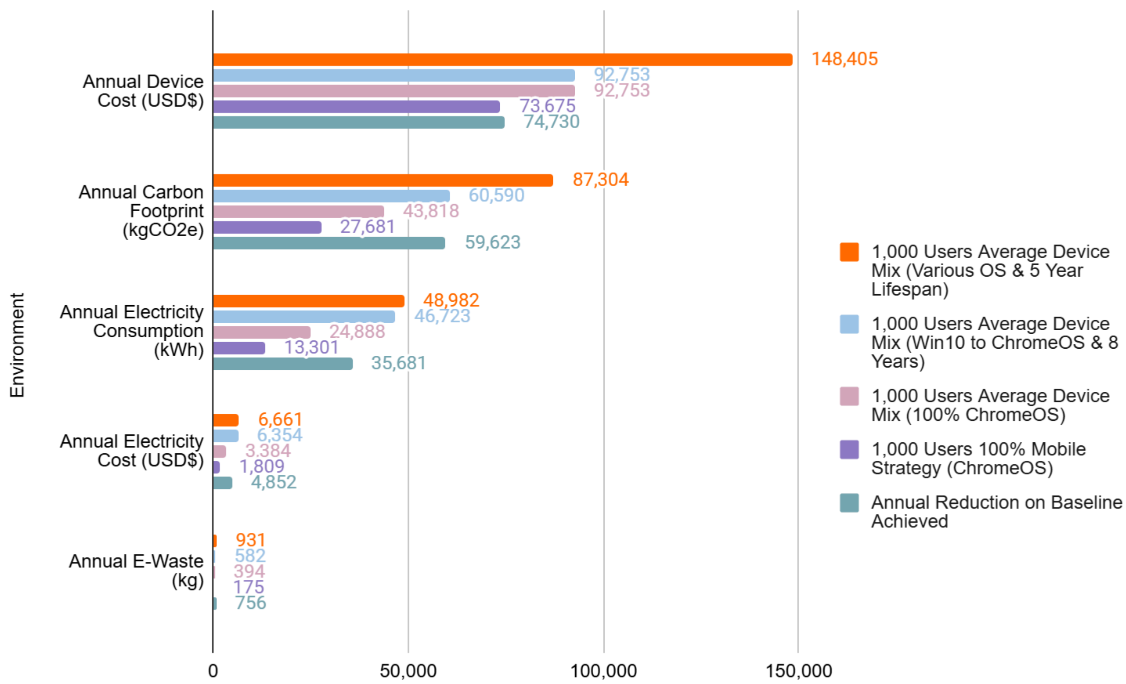


Figure 11 shows that in the 100% mobile ChromeOS strategy, annual device procurement costs are reduced when compared to the baseline, lifespan extension and ChromeOS strategies. This is because unlike the two prior strategies, monitors and AIO devices (that have a higher average purchase price than notebooks) no longer form part of the estate.

Specifically, when compared to the original 1,000 user environment, the lifespan extension and move to 100% mobile ChromeOS devices reduces annual hardware procurement costs by 50% from $148,405 to $73,675 (Figure 11). This generates a capital expenditure saving of $74,730 each year (Figure 11).

In this final example, annual utility cost is 73% lower than the initial baseline (Figure 11). Now costing $1,809, down from $6,661, the new strategy saves $4,852 per year (Figure 11).

The improvement in energy efficiency delivered by the Chromebooks coupled with the lower supply chain impact (Figures 5 and 9) significantly reduces annual carbon footprint values too. Compared to the average 1,000 user environment, annual GHG emissions decline by 68% from 87,304 $kgCO_2e$ to 27,681 $kgCO_2e$ (Figure 11).

In context, the annual carbon footprint reduction of 59,623 $kgCO_2e$ (Figure 11) means that 2,710 fewer trees are required every year to remove the resulting carbon for Earth's atmosphere. That's approaching 3 trees per user.

Finally, e-waste is also reduced by 81% when compared to the original EUC device environment (Figure 11). With new lighter weight mobile computers in place, the average device weight declines from 3.38kg to 1.4kg. This means that for each year that passes, 756kg of e-waste is no longer introduced into the end of life services processing stream (Figure 11).

Summary

The three sustainable IT strategies enabled by ChromeOS deliver meaningful improvement to the economic and environmental metrics determined in the average 1,000 user EUC environment baseline study (Figure 2).

The final strategy reaches a pinnacle (Figure 11), with ChromeOS delivering a 50% reduction in device procurement costs, 73% reduction in utility costs, 68% carbon footprint abatement and 81% e-waste avoidance (Figure 11).

Throughout, the research calculates the positive impact to the planet and profit on an annual basis. Revealing the results of the proposed changes across the entire 8 years reveals the true impact of following the same path or taking action to drive responsible IT consumption.

Figure 12 cumulatively plots and compares the combined annual electricity and device procurement cost differences between the average 1,000 user EUC environment baseline and the 3 proposed sustainability strategies.

As shown, by year 8 the average 1,000 user environment costs a total of $1,240,526. This is because procurement cycles have remained at 5 year intervals and energy consumption has remained unchanged and unchallenged.

Comparatively, at the other end of the spectrum, the 100% mobile and Chromebook strategy saves the organisation $636,654 in combined capital and operational expenditure. By transitioning to 8 year retention periods and energy efficient devices, the organisation saves $637 per user.

Figure 12. Comparing cost metrics between an average 1,000 user EUC environment and 3 ChromeOS sustainable IT strategies during an 8 year time horizon

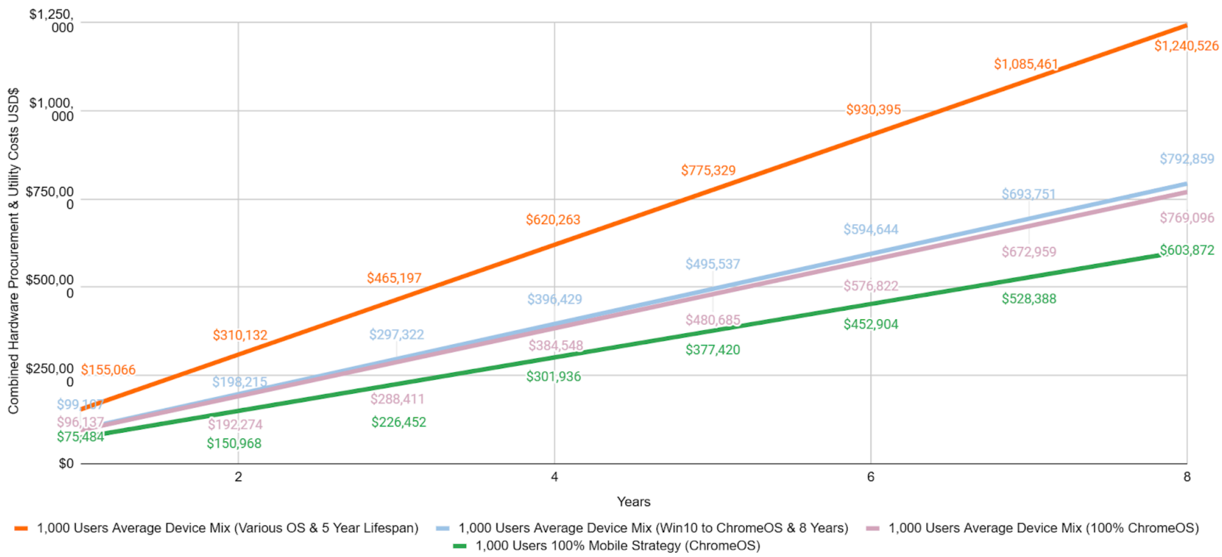


Figure 13 cumulatively plots and compares the carbon footprint between the baseline and the ChromeOS strategies. By year 8, the average 1,000 user environment has generated 698,432 kgCO_2e of GHG emissions.

In context this is equivalent to exhaust pipe emissions caused by driving 4.1 million km in an average combustion engine car. That's a distance equal to 104 times around the Earth's circumference.

Comparatively, the lowest carbon footprint 100% Chromebook strategy reduces this impact by 476,984 kgCO_2e during the 8 year period (Figure 13).

To appreciate the magnitude of this value, to remove this amount of carbon from the atmosphere requires more than 21,000 trees and would take one entire year to complete the process. Per capita, the new strategy avoids 477 kgCO_2e per user during the device retention period.

Similarly, cumulative e-waste shown in figure 14, reveals that in the original baseline this value reaches 7,450kg. By transitioning to a Chromebook environment and keeping devices for an additional 3 years, this value declines to 1,403kg. As such, by following the sustainability pathway 6,047kg or over 6kg per user has been avoided.

Figure 13. Comparing carbon footprint metrics between an average 1,000 user EUC environment and 3 ChromeOS sustainable IT strategies during an 8 year time horizon

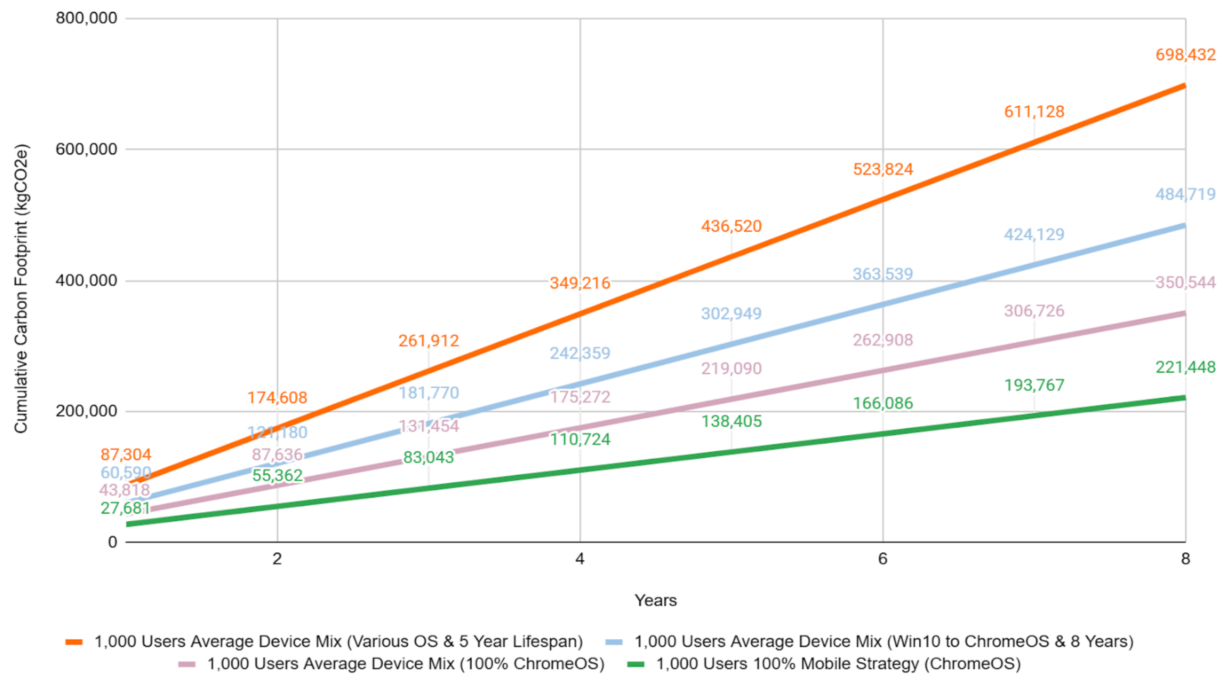
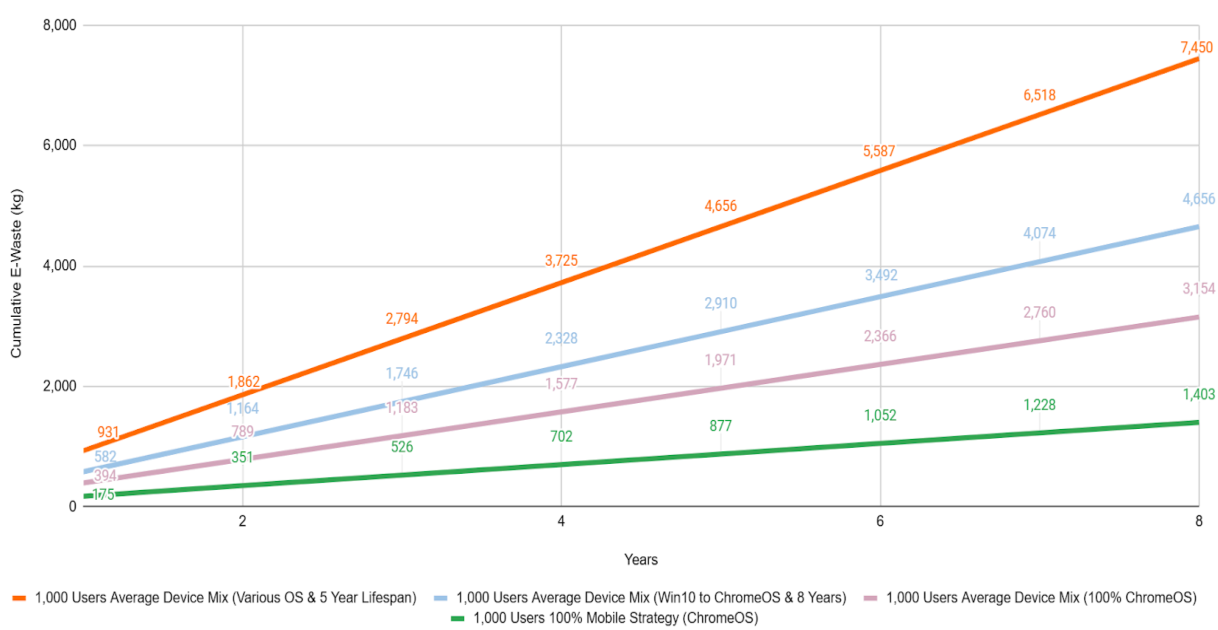


Figure 14. Comparing e-waste metrics between an average 1,000 user EUC environment and 3 ChromeOS sustainable IT strategies during an 8 year time horizon



Conclusion

Reducing GHG emissions caused by human activity is a growing priority for businesses and organisations across the globe. The change is driven in part by legislation, such as the Corporate Sustainability Reporting Directive (CSRD) [23] that requires over 50,000 organisations to report and reduce emissions; and by clear evidence of climate change including 2023 being the first 12 month period to experience a consistent 1.5°C rise in temperature [43].

While the annual percentage increase of GHG emissions has slowed, global levels continue to rise overall [43]. Consequently, to avoid passing the 1.5°C point permanently, the net result of human activity measured in GHG emissions must become zero by 2030 [43].

Achieving 'net zero' involves two key outcomes. Firstly, a 45% reduction in global GHG emissions generation via sustainable lower carbon alternatives such as renewable energy and electrified transport. Secondly, growth in natural (e.g. reforestation) and mechanical carbon capture processes to remove the remaining 55% [43].

2030 is nearly upon us. Evidence indicates that insufficient policies and plans plus infrastructure, economic and political complexities and spiralling consumer demand will create barriers to achieving the net zero goal [43].

Considering this, it's reasonable to suggest that we have two choices. Do nothing or adopt the practice of sustainability and turn our attention to significant GHG emissions sources that can be meaningfully reduced with immediate and short term effect.

This study shows that within every 1,000 user EUC environment, GHG emissions can be reduced by as much as 68% (Figure 13). As IT generates 5% of global GHG emissions, the sector represents a significant opportunity for climate action now.

At scale, the collective impact of sustainable IT will be significant. As an example, reports suggest 240,000,000 computers will be disposed of due to the impending Windows 10 end of life event [44]. This research determines that 14% of devices are affected in business and as such this vast disposal estimation is perceived as credible. After all, there are over 4.2 billion internet users on Earth. While many will access via smartphones and not all will own a computer, it only takes half of the users to own one personal computer and the disposal quantity is exceeded.

Theoretically, if each Windows 10 disposal was avoided by using ChromeOS Flex to create Chromebooks or Chromeboxes, then an estimated 62.4 million tons of replacement product GHG emissions (Figure 9 extrapolated) would be avoided.

The abatement is larger than Ireland's entire annual GHG emissions [6]. In an analogous context, it would require over 1 billion tree seedlings grown for ten years to remove this quantity of carbon from the atmosphere [7].

From an immediate and potential e-waste perspective, the impact is obviously vast too. Not only does 758,400 tons of computer waste enter the end of life services process (Figure 9 extrapolated) immediately, a further 648,000 tons enters circulation due to new product demand. Combined, the e-waste is equivalent to 6,250 times the weight of the Statue of Liberty.

In conclusion, sustainability is the principle of ensuring our current actions do not limit the economic, social, and environmental options of future generations. As shown by this research, this practice can be applied with relative ease to IT to significantly improve economic and environmental outcomes. Therefore, it is reasonable to conclude that whatever your view is on climate change, sustainable IT practices are good for the planet and for profit, so why not try them today with ChromeOS?

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About Px^3

A scientific IT carbon footprint report by sustainable IT experts Px^3.

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Founded in 2013, Px^3 is a world leading sustainable IT research and consulting organisation. Working globally for leading IT manufacturers, eco certification labels, governments, commercial, public and third sector organisations, our aim is to drive climate action via the adoption of sustainable IT.

This is achieved by combining our research and consulting skills with our unique sustainable IT applications platform. The Px^3 sustainable IT cloud-based applications platform is the only solution of its kind in the world to be validated by science.

Already being used by organisations responsible for millions of computer users, the platform was researched, developed and peer reviewed during PhD research conducted at the world leading University of Warwick Computer Science Faculty. Consequently, the data produced is compliant with GHG accounting protocols, international Life Cycle Analysis (LCA) and electronic equipment energy testing standards and sustainable procurement legislation.

The Px^3 applications platform enables organisations to create baseline IT carbon footprint and energy consumption baseline reports. Then to model strategic policy changes such as selecting low carbon footprint devices and extending device lifespans to significantly reduce IT GHG use phase and supply chain emissions, e-waste, electricity consumption, utility and procurement costs.

Research Lead

The author of this report, Dr Justin Sutton-Parker, holds a PhD in computer science in the field of sustainable IT and a MBA in sustainability. As Chief Scientist for Px^3 and a Research Fellow for the University of Warwick, Dr Sutton-Parker's findings advance and influence global IT manufacturing, procurement, eco-certification, changes in national government policy and user behaviours designed to reduce the carbon footprint of IT.

Dr Sutton-Parker is widely published in scientific journals, public media, a regular public speaker and responsible for the first dedicated sustainable IT magazine series distributed at the UN COP sessions.

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