Sustainable ICT Research

End User Computing

Schools & Colleges in England

info@px3.org.uk
www.px3.org.uk

A scientific research project report by the University of Warwick, sustainable ICT carbon footprint experts Px^3 and the United Kingdom Government's Department for Education.

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The University of Warwick computer science faculty Professor Rob Procter, Dr Justin Sutton-Parker and head of department Yulia Timofeeva. Px^3 Limited Dr Justin Sutton-Parker Department for Education (DfE) Chief Scientific Advisor Professor Russel Viner, DfE lead ICT advisors Jim Gardner and Chris Meaney, DfE ICT supporting advisors James Hatch, Steve Johnson and Craig Peppiatt, DfE Climate Change Unit David Wingate, DfE Digital Strategy Division Sofia Costa and Guy Paul, DfE Net Zero Accelerator Programme Sharon McHale, DfE DECBT Sustainability Team Gayle Boulton.

Research Lead
Dr Justin Sutton-Parker

Project Manager
Professor Rob Procter

Acknowledgements
The report was conceived by Dr Sutton-Parker with the intention of reducing UK schools and colleges ICT GHG emissions and costs to support the education sector's contribution to national net zero commitments. The University of Warwick has funded the research project to accelerate adoption of sustainable ICT strategies within the UK education sector. Px^3 has donated the use of its ICT carbon footprint calculation and strategy applications to ensure accuracy and to support the project and research timelines. The DfE has contributed resources to ensure secure data collection was feasible, to promote awareness of how sustainable ICT can drive climate action and to implement long term improvements to national ICT policies that drive responsible consumption. Global ICT companies, too many in number to list, are also thanked for access to test equipment and carbon footprint data. All participating schools and colleges are acknowledged and thanked; without them the project would not have been feasible. This includes Multi-Academy Trusts (MAT) Delta Academies Trust (Phil Thacker), Oasis Community Learning (Jessica Marshall) and United Learning (Emily Brunton) among others and special thanks to Blue Marble (John Edwards).

Foreword

Information technology offers a positive contribution to education as a tool for learning. However, with 16.1 million computer users in UK schools and colleges, the scale of IT carbon footprint, utility and procurement costs must be considered if this human-computer synergy is to become truly sustainable.

Data centres, both in-house and in the cloud, are arguably intangible to the people at the forefront of education, such as teachers, support staff and pupils. Therefore, drawing attention to the impact of tangible devices, such as desktops, laptops and tablets, may gain greater support for climate action driven by IT.

To begin the process, this research project determines the carbon footprint of end user computing devices within UK schools and colleges. Using this data, best practices sustainable IT strategies are modelled to show feasible reductions to IT-associated emissions, IT energy consumption, utility and procurement costs.

With the support of the University of Warwick and the Department for Education, the project is recognised as one of the largest sustainable IT research projects conducted to date. Equally, it is seen as a key step towards scientific validation for improved future sustainable IT policies within the UK education sector.

As such, it is my hope that if the findings resonate within the classrooms and offices of the UK's 25,000 schools and colleges, then end user computing will be validated as a climate action focus for established programmes already tackling the wider concept of greenhouse gas abatement in education.

Yours sincerely,

Dr Justin Sutton-Parker, Ph.D MBA

Chief Scientist, Px^3

Research Fellow, University of Warwick

Executive Overview

Information and communications technology (ICT) currently generates as much as 5% of all global greenhouse gas (GHG) emissions [1-4]. Research shows that in the United Kingdom (UK) public sector, barriers exist that prevent meaningful adoption and execution of sustainable ICT strategies [5]. The majority of stakeholders are unsure whether placing time and effort into sustainable ICT will produce meaningful carbon footprint reduction results [5]. They are also concerned that the time spent may increase costs and therefore reduce profit while focusing on policy compliance [5]. The doubt is caused by a lack of definite data against which to make decisions and to judge success [1, 5].

With over 16.1 million computer users, the English state funded education sector represents one of the world's largest end user computing communities.

Currently insufficient scientific data exists to validate forming national level sustainable ICT policies that may reduce the resulting supply chain and energy carbon footprint caused by procuring and using devices such as notebooks, tablets, desktops, monitors and displays.

To overcome the inertia and encourage policy forming, this research project works with the Department for Education (DfE) and 235 schools during a 12 month period to generate meaningful data relating to end user computing (EUC) device carbon footprint, e-waste, electricity consumption, utility and procurement costs.

The captured data is used to form a baseline for each type of establishment including primary, secondary and special educational needs and disabilities (SEND) schools plus colleges. Using scientifically validated tools, the research then models sustainable ICT strategies to validate feasible significant environmental and financial improvement.

It is found that extrapolated to a country level, the annual carbon footprint of EUC device ownership and use in the state education sector is 447 million kgCO_2e and requires 20.3 million trees to sequester the resulting carbon every year [7]. Nationally 6 million kg of e-waste is currently generated annually, equal to 400.6 million aluminium drinks cans. From an energy perspective, the EUC devices consume 239,813,471 kWh/y. This means that for schools and colleges in England, the entire output of 40 wind turbines is required [8]. Spending on end user computing procurement and use exceeds £1.2 billion, equivalent to employing 34,860 teachers [9].

When applied, the suggested sustainable ICT strategies reduce average annual carbon footprint by 57%. From a countrywide perspective, this would avoid 255,778,054 kgCO_2e of GHG emissions every year. Meaning, the state funded education sector could release 11,626,275 trees every year to sequester emissions from another source [7].

Doing so will also avoid 53% of potential e-waste meaning 3,201,713 kg no longer enters annual end of life services. That's equal to 213,447,545 soda cans never being made.

Energy consumption would fall by 14% avoiding 33,639,825 kWh/y of demand per year. Beyond reducing cost and scope 2 GHG emissions, the action would also relieve 6 wind turbines [8].

Finally, procurement and utility costs declined by 34% saving £407,407,833 each year. While the spend could be diverted to any necessary area, in context this is a sum sufficient to employ 11,983 additional teachers [9] during every twelve months of the proposed eight year change in strategy.

In conclusion, the research delivers scientific evidence that sustainable ICT strategies, such as lifespan extension and carbon footprint as a selection criterion, are effective at a local level. Because they deliver both financial and environmental benefits then theoretically, stakeholders with varying role based needs and interests will find reason to adopt the approach [5] despite preconceived barriers [5].

Pragmatically, it may be that only people minded to reduce environmental impact will seek out this research and perhaps diffusion will be slow regardless of the evident positive influence on general business operations. However, if translated to national policy by the DfE or the entire UK government, then the impact to the planet, profit and policy is undeniably meaningful.

Introduction

ICT 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].

Globally, the United Nations Sustainable Development Goal number 12, 'Responsible Consumption and Production', acts as a framework to help manufacturers and organisations producing, buying and using computers at scale to tackle ICT carbon footprint [10].

From a production perspective, manufacturing standards and regulations exist to ensure new computers are designed with carbon footprint reduction in mind. This includes energy efficiency thresholds and certifications [11-13] to influence the electricity consumed by an estimated 4.2 billion computer users every day. Plus, responsible raw material, hazardous substances use and manufacturing rules [14] designed to reduce the supply chain impact associated with over 700 million new personal computers produced and shipped every year.

From a consumption perspective, European policies exist to encourage large organisations to annually report and improve ICT related carbon footprint [15-17]. This includes scope 2 energy emissions and scope 3 supply chain emissions. Plus, in the public sector, policies exist to ensure carbon footprint is considered when buying replacement or new ICT equipment [18-20].

However, research shows that in the UK public sector, barriers exist that prevent meaningful adoption and execution of sustainable ICT strategies [5]. The majority of stakeholders are unsure whether placing time and effort into sustainable ICT will produce meaningful carbon footprint reduction results [5]. Plus they are concerned that the time spent may increase costs and therefore reduce profit while focusing on policy compliance [5]. The doubt is caused by a lack of definite data against which to make decisions and to judge success [1,5].

As an example, even when computer eco [21, 22] and energy [11] certification is introduced during ICT planning and purchase phases, mistakes can be easily made. This is because current standards and regulations have an arguably wide range when awarding computer energy efficiency and eco-certification [11, 21, 22]. Today the lowest carbon footprint notebook available generates just 88 kg CO_2e [23]. While the highest carbon footprint notebook generates 772 kg CO_2e [24]. Both devices are energy and eco-certified [11, 21, 22] yet the latter is 777% higher in GHG emissions.

That's almost 9 times worse for global warming which is driven by GHG emissions. Consequently, it's easy to see how ICT and procurement teams relying on eco and energy certification in isolation can inadvertently increase carbon footprint without realising.

However, research shows that when meaningful carbon footprint data is generated to accompany important guidance such as certifications, truly informed sustainable ICT strategies reduce carbon footprint and e-waste by 30% on average [1, . Additionally, the same strategies reduce ICT procurement and utility expenditure by one third, as buying cycles become less frequent and energy efficiency improves.

If every organisation on the planet adopted such approaches, then the 5% ICT carbon footprint currently experienced could diminish by 30% or more [25-28]. In the UK there are sectors that can contribute significantly to this positive change. As an example, the English state funded education sector has in excess of 16 million computer users and collectively represents one of the world's largest users of ICT [6]. In context, students, teachers and administrative staff represent 28% of all people living in England [29].

As noted, large organisations in Europe are already subject to ICT scope 2 (electricity) and scope 3 (supply chain) emissions reporting and improvement [15]. As an example, as part of capital goods owned, companies must detail the carbon footprint of computers [15]. Additionally, European Union directives require public sector organisations to only procure low carbon footprint ICT equipment [19].

In the UK, organisations are required to report scope 2 emissions as part of company reports [16, 17]. As these are high level, it is not required to detail what contribution ICT makes. However, as 10% of all commercial electricity is consumed by ICT [30] it is reasonable to suggest the same percentage of emissions could be applied. Similarly, there is no current requirement to report scope 3 emissions nor to specifically detail ICT supply chain emissions in the UK [16, 17].

From a public sector perspective, the UK government's Sustainable Technology Advice and Reporting (STAR) group does make significant efforts to drive sustainable ICT via the Greening Government ICT reports and strategic recommendations [31]. However, as this policy is not mandatory then, of their own admission, it is only government departments that make the effort to participate. During previous research projects and interaction with UK government departments [1, 28, 32], the inability to nationally diffuse and effectively execute sustainable ICT strategies is caused by a lack of valid data highlighting the positive outcomes associated with action.

To overcome the inertia and encourage diffusion at scale, this research project works with the DfE to generate meaningful data for the English state funded education sector. Involving schools and colleges across the country, EUC device asset data is collected to quantify the carbon footprint, e-waste, electricity consumption and cost of notebooks, desktops, tablets, monitors and displays in education. Using scientifically validated tools [7], the research generates a current average baseline and per capita value for primary, secondary and SEND schools plus colleges.

This data is then used to model feasible improvements delivered by sustainable ICT strategies. These specifically include extending devices lifespans and including carbon footprint as a selection criterion. The environmental and economic results are discussed at an individual school and college level from both a climate action and budget perspective. They are also extrapolated at a national level to document the impact to both sector and country net zero strategies [33-36].

The research findings are presented to the Department for Education with the purpose of validating new sustainable ICT procurement, use and reporting policies to be applied and adopted within the education sector nationally. By doing so, the opportunity to achieve responsible ICT consumption within the English state funded education sector is accelerated. Specifically, it is intended that the barrier of doubt as to whether sustainable ICT strategies are worth the time and effort [5] is overcome with new and meaningful information.

Methodology

The objective of this research project is three fold. Firstly, to determine a baseline for the annual carbon footprint, e-waste potential, electricity consumption, utility and estimated procurement costs associated with EUC device ownership and use in English schools and colleges. Secondly, to use the baseline results to model sustainable IT practices, such as lifespan extensions and introducing carbon footprint as a selection criterion, to demonstrate credible reductions that can be achieved for both the environmental and financial values. Thirdly, to present the findings to the Department for Education to act as scientific validation for improved future sustainable IT policies within the UK education sector.

To achieve the first objective, EUC asset and retention data is captured for 1% of English primary, secondary and special needs schools plus colleges [6]. Data captured at each school includes obfuscated computer asset details attributed to all end user computing classification devices.

This includes notebooks (including laptops, 2-in-1 notebooks, mobile workstations and mobile thin clients), desktop computers (including desktops, all-in-one desktops, workstations and thin clients, tablets and displays (including personal computer monitors and teaching displays).

The data is collected by ICT staff working at each school or college. In each case, consent to participate and to withdraw at any point from the research project is agreed. Following this, each participant is emailed an xls spreadsheet to populate either manually or using existing tools such as asset management or digital experience software. The column headings for each spreadsheet include device type (e.g. tablet), brand (e.g. Apple), model (e.g. iPad Air 2) and quantity.

Contextual data, such as school type (e.g. Primary), regional location (e.g. East of England) and the number of teachers, pupils and ancillary staff employed by the institute is also determined. This is used to examine trends by school type and/or location, plus to enable a computer to user ratio. To facilitate an examination of cost savings supporting sustainability strategies, an average cost per new device type is agreed with the DfE ICT advisors and applied when modelling feasible reductions to annual procurement costs caused by lifespan extension.

Once collected, the data is input into the online Px^3 computer carbon footprint calculation and reporting application platform [7]. The tool was initially developed during PhD research conducted at the University of Warwick computer science faculty. It is unique in the fact that each capability and function is validated by a corresponding published research paper meaning that the platform is validated by science.

The Px^3 platform consists of five key components including the Calculate, Compare and Change applications plus the EUC Baseline and EUC Strategy Report applications.

The Px^3 Calculate application automatically uploads each school or college asset data set via the structured xls spreadsheets. In each instance, the organisation's name and type is applied into two free type fields and location is selected by a drop down list. The selected location automatically applies electricity cost and a regional energy carbon intensity factor. A further drop down to identify the sector is also selected to enable energy consumption modelling using the cTEC approach [1]. In this instance, all schools and colleges are designated as 'Education Sector'.

Once loaded, two tables are produced. For the first table, the pre-set retention period drop downs available in the application are left blank. This means that when the subsequent first calculation occurs, the application's database will recognise the year of device production and automatically assign a retention period for each device model based upon age. This initial process enables the ages of devices by school (and college) type to be examined in the results section. The intention is to determine an average device age by type for schools and colleges and to examine if trends, such as excessively old equipment, emerge by region or organisation type.

The second table has the retention periods for devices by type (e.g. tablet) set to the average age determined by the first set of tables. This enables a direct comparison of all schools and colleges based upon the same retention period for each organisation type. Doing so enables an average results set to be created for each school type and college, plus a per capita value that enables schools and colleges to quickly compare results equivalently with other education sector organisations regardless of size.

This per capita value is referred to as the 'EUC volume of emissions ratio' and known as the EVER score. It is expressed by 1 device to the associated annual EUC emissions for a single year. An example would be 1:35 meaning that on average one EUC device generates 35 kgCO_2e annually.

Both tables include results for each organisation listed by unique device model and as a total for each entire EUC estate. The results include 1) Scope 3 supply chain GHG emissions (kgCO_2e); 2) Electricity consumption (kWh/y); 3) Electricity costs (£); 4) Scope 2 electricity used GHG emissions (kgCO_2e); 5) Annualised total carbon footprint (kgCO_2e); 6) Total lifespan carbon footprint (kgCO_2e); and 7) Potential E-waste (kg).

GHG emissions are reported in kilograms of carbon dioxide equivalent (kgCO_2e) as required by international GHG accounting protocol [36]. Electricity is reported in kilowatt hours per year (kWh/y) as per international computer efficiency measurement standards [37, 38]. Scope 2 use-phase emissions are calculated using carbon conversion factors determined by the location in which the device is most regularly used. Commercial electricity costs are based upon the cost per kWh for the selected location. E-waste represents the weight of each and all devices owned by the organisation. This is reported in kg as per international policy and frameworks.

Scope 3 GHG emissions values (production, transport and end of life treatment) are extracted directly from manufacturer published product carbon footprint reports generated in accordance with ISO 14040 [39], 14044 [40] and 14067 [41]. As such accuracy of the values are the responsibility of each manufacturer and the life cycle assessment (LCA) methodology used to generate greenhouse gas emissions values. Where a variable range of supply chain carbon footprint is published by the manufacturer, the mean value is used to represent each device.

The Px^3 product database is populated with over 5,000 EUC device records [7]. Each record is model specific and includes carbon footprint data, electricity consumption, eco-certification, approximate cost, year of manufacture, size and weight. If a product listed in any school or college asset file is not found or recognised within the database, an exception report is generated listing the products that could not be matched. Remedial action to ensure the product is accounted for includes 1) checking description accuracy, 2) creating a new product record and 3) using an average to represent the product.

Description accuracy can include misspelling, double words and using different words for a device, such as PC instead of desktop. The platform has inbuilt logic to overcome these scenarios and a second submission of data will either remedy the problem or invoke a next step. The next step will be to create a record for the product. This can be accomplished if manufacturer and certification data exists and overcome if it does not exist.

If the product precedes the date (2016) when ICT product carbon footprint life cycle assessment (LCA) began in earnest [1, 42] or if a specific manufacturer does not yet participate in product carbon footprint calculation and publication, two courses of action are taken. Firstly, in the case that a manufacturer does participate in LCA, yet the product has no published data, the supply chain data for a subsequent version (model) of the same product from the same manufacturer will be applied to the product. As energy certification records began in 1992 [1], the specific kWh for the actual device is applied to the database record. All other records will also be specific to the product including weight and year of manufacturer.

If no data is available, then an appropriate average record for the product determined by brand, device type, OS and size will be applied. In both cases the product description will be followed by '(E)' to denote that while categorised as 'accurate with confidence' this value is an estimate.

Scope 2 GHG emissions values (electricity consumed) are generated by multiplying the kWh/y of each device model by the carbon intensity conversion factor published by the UK government for 2024 [43]. The device specific electricity consumption (kWh/y) is determined by the commercial typical energy consumption (cTEC) value [1]. This value accounts for the increased active power draw caused when EUC devices are actively used by users [1, 44] as well as the low power modes (off, sleep, idle) measured by typical energy consumption (eTEC) Energy Star benchmark electricity consumption data [11]. This data is produced in accordance with IEC 62301 and 62623 standards [37, 38]. This approach is important to accuracy of electricity consumption, utility cost and concomitant scope 2 GHG emissions results as research shows that existing Energy Star eTEC results under-report electricity usage by a range of 30-108% due to the exclusion of active power draw during the benchmark tests [44].

Consequently, the Calculate results are scientifically validated as the most accurate available to date and meet criteria outlined within carbon footprint reporting protocol requiring that no GHG values should knowingly be under or over reported.

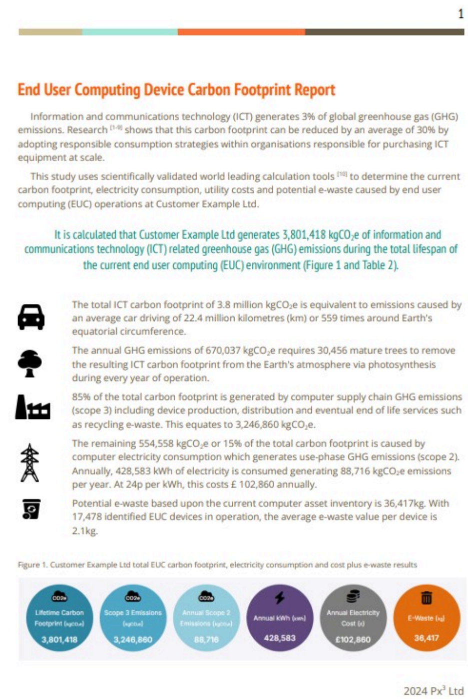
Further to the creation of the first two sets of Px^3 Calculate tables for all individual participating organisations, a third set of tables is created by grouping organisations by type (e.g. Primary) and region (e.g. East of England). For this the first set of tables that include device year of manufacture are used to enable examination of device age by school type and location.

Following this, a final series of four tables are generated by organisation type including primary, secondary and SEND schools plus colleges. For this exercise, the second set of tables are used that include the average age by device type. This is to enable creation of baseline data based upon the organisation type in order to facilitate an average by type of organisation to be generated.

Using the Px^3 application, baseline reports are generated for each individual school or college based upon the second (average age) set of results tables. This approach is taken because the baseline reports include annual and lifespan results. Therefore, each product included within an asset list must be accounted for across a substantiated lifetime. As an example, if a school has recently purchased 100 desktops, the age of these products in the first set of tables will appear as '1 year'. If this value was used for the baseline report, the results would attribute all supply chain data to one year and include just one year of use within the scope 2 results. Because it is already proven by the average retention periods revealed in table set 1, then this would not be representative of real life and would be subject to knowingly over and under reporting GHG emissions.

Each baseline report includes a summary page showing the total lifespan carbon footprint, annual carbon footprint by both scopes 2 and 3, annual electricity consumption and utility cost, plus annual e-waste. Subsequent pages include tables and graphs detailing an EUC device profile, EUC device carbon footprint, highest and lowest carbon footprint devices, annual supply chain & electricity EUC device carbon footprint, electricity consumption and cost, e-waste potential.

At this stage, all individual baseline reports are emailed to the relevant school or or college. This is undertaken to facilitate each organisation's understanding of their EUC carbon footprint. The intention of this is to support future action by each school or college, whether individually or via wider climate action schemes such as the Net Zero Accelerator, Let's Go Zero or Eco Schools [34-36]. Plus to assist participating schools to respond to the existing Greening Government ICT [20] policy, SECR reporting [17] or any future policies formed upon the findings of this research. The recommendation section of this research suggests a second research project to determine feedback and impact which are both not subject to this project.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End User Computing Device Carbon Footprint Report

Information and communications technology (ICT) generates 3% of global greenhouse gas (GHG) emissions. Research [1-9] shows that this carbon footprint can be reduced by an average of 30% by adopting responsible consumption strategies within organisations responsible for purchasing ICT equipment at scale.

This study uses scientifically validated world leading calculation tools [10] to determine the current carbon footprint, electricity consumption, utility costs and potential e-waste caused by end user computing (EUC) operations at Customer Example Ltd.

It is calculated that Customer Example Ltd generates 3,801,418 kgCO_2e of information and communications technology (ICT) related greenhouse gas (GHG) emissions during the total lifespan of the current end user computing (EUC) environment (Figure 1 and Table 2).

The total ICT carbon footprint of 3.8 million kgCO_2e is equivalent to emissions caused by an average car driving of 22.4 million kilometres (km) or 559 times around Earth's equatorial circumference.

The annual GHG emissions of 670,037 kgCO_2e requires 30,456 mature trees to remove the resulting ICT carbon footprint from the Earth's atmosphere via photosynthesis during every year of operation.

85% of the total carbon footprint is generated by computer supply chain GHG emissions (scope 3) including device production, distribution and eventual end of life services such as recycling e-waste. This equates to 3,246,860 kgCO_2e.

The remaining 554,558 kgCO_2e or 15% of the total carbon footprint is caused by computer electricity consumption which generates use-phase GHG emissions (scope 2). Annually, 428,583 kWh of electricity is consumed generating 88,716 kgCO_2e emissions per year. At 24p per kWh, this costs £ 102,860 annually.

Potential e-waste based upon the current computer asset inventory is 36,417kg. With 17,478 identified EUC devices in operation, the average e-waste value per device is 2.1kg.

Figure 1. Customer Example Ltd total EUC carbon footprint, electricity consumption and cost plus e-waste results

Lifetime Carbon Footprint (kgCO₂e) 3,801,418
Scope 3 Emissions (kgCO₂e) 3,246,860
Annual Scope 2 Emissions (kgCO₂e) 88,716
Annual kWh (kWh) 428,583
Annual Electricity Cost (£) £102,860
E-Waste (kg) 36,417

2024 Px[3] Ltd

The penultimate step of the data generation phase is to calculate an average for each school and college type based upon the including 1) number of computer users (including students and staff), 2) computer to user ratio, 3) number of devices by type, 4) carbon footprint by device type (scopes 2 and 3), 5) electricity consumption by device type, 6) potential e-waste and 7) an EVER metric. To achieve this the data generated by the second set of tables is used. This baseline information is represented and discussed at organisation type level within the results section of this research.

Finally, the four average baseline reports for primary, secondary and SEND schools plus colleges are input into the Px[3] Change application. This is undertaken to strategically model the influence of device lifespan extension and introducing carbon footprint as a selection criterion. In each case, a report is generated detailing reduction to carbon footprint, electricity consumption, e-waste, utility and procurement costs plus the EVER value. Again, this strategy outcome is represented and discussed at organisation type level within the results section of this research.

Having completed the data collection and information generation phase, the results section details all findings. Specifically, this includes four sections based upon organisation type (Primary, Secondary, SEND and Colleges) and details 1) Physical EUC Asset Profile, 2) Environmental and Energy Results by Device Type (categorised by mobile and static devices), 3) Average EUC Estate Carbon Footprint and Energy Baseline, 4) Sustainable EUC Strategy 1: Windows 10 EOL (lifespan extension), 5) Sustainable EUC Strategy 2: Device Lifespan Extension, 6) Sustainable EUC Strategy 3: Carbon Footprint as a Selection Criterion, 7) EUC Volume of Emissions Ratio (EVER).

The data tables, Px^3 Calculate and Change applications generate and supply all information required to facilitate the results with the exception of data required for the sustainable EUC strategy 3 'carbon footprint as a device selection criterion'. To achieve this, the Px^3 Compare application [45] is used to identify currently available products of the same type (e.g. desktop) and attribute (e.g. small form factor) that exhibit the lowest combined scope 2 (electricity) and scope 3 (supply chain) GHG emissions and therefore the lowest carbon footprint.

The Px^3 Compare application's primary function is to enable stakeholders responsible for EUC device selection and procurement to compare end user computing devices such as notebooks, desktops, tablets, smartphones and monitors by total carbon footprint, energy efficiency and supply chain emissions before purchasing products or during tender creations. However, in this instance it is used in conjunction with the Change application to supply low carbon footprint options to enable EUC strategy 3 calculations and results.

The research is completed with the summary, conclusions, limitations, recommendations and references sections.

The research time horizon is twelve months spanning July 2024 to June 2025 inclusive. Although it is noted that the research concept and strategy forming, grant funding application and resource gathering began in October 2023. The research asset data collection stage was undertaken between July 2024 and January 2025. Calculations conducted between January 2025 and April 2025 and the paper was written between April and early June 2025. The results were presented to the Department for Education at Westminster on 25th June 2025.

Results and Strategy Modelling

Overall, 235 schools participated in the research. Of the total, 157 were primary schools (67%), 2 combined primary and secondary schools (0.8%), 3 'all-through' schools offering primary, secondary and 6th form education (0.9%), 38 secondary schools (16%), 26 combined secondary and 6th form (11%), 7 SEND (3%) and 2 colleges (0.8%).

Currently, within England's state funded education sector there are 16,764 primary, 3,452 secondary, 1,050 SEND schools and 205 colleges [6]. Therefore, the research data sample is satisfactory and represents 1% of primary, 2% of secondary, 0.7% of SEND schools and 1% of colleges.

From a geographical perspective, data was collected from schools located in 8 of the 9 regions of England (89%). The North East was the only region not to participate in the study. At a county level, schools located in 28 of England's 46 counties (61%) are represented.

The research includes 134,169 computer users, made up from 121,226 students (90%) and 12,943 teaching, support and administrative staff (10%). A total of 142,615 EUC devices are measured including 124,194 computers (87%), 14,730 monitors (10%) and 3,691 (3%) displays. This creates an average ratio of 0.9 of one computer per user. Mobile type devices such as notebooks and tablets account for 87% of computers with static devices (such as desktops and AIO) accounting for the remaining 13%. The average age of static computers is 5 years, while monitors and displays are kept for 8 years.

The following sections detail this data, plus carbon footprint, e-waste, energy consumption, utility and procurement cost by each school type (primary, secondary and SEND) plus colleges.

In each example, a current baseline for an average school or college is calculated. This is then followed by modelling three sustainable ICT strategies designed to reduce carbon footprint, e-waste and associated costs. For each strategy reductions are detailed by value and percentage to show effectiveness. The annual average carbon footprint per device within schools and colleges is calculated to enable like for like comparison between establishments regardless of size or number of devices.

To demonstrate the wider impact of sustainable ICT strategies, results for each average school type and average college are extrapolated to a national level. For context, the carbon footprint results are expressed in standard accounting values plus analogous values including equivalent emissions from driving combustion engine vehicles or the number of trees required to remove the resulting carbon from Earth's atmosphere.

Where cost reductions are achieved, these are expressed in £GBP and for context, equated to the number of additional teachers that could be employed by using the annual financial savings.

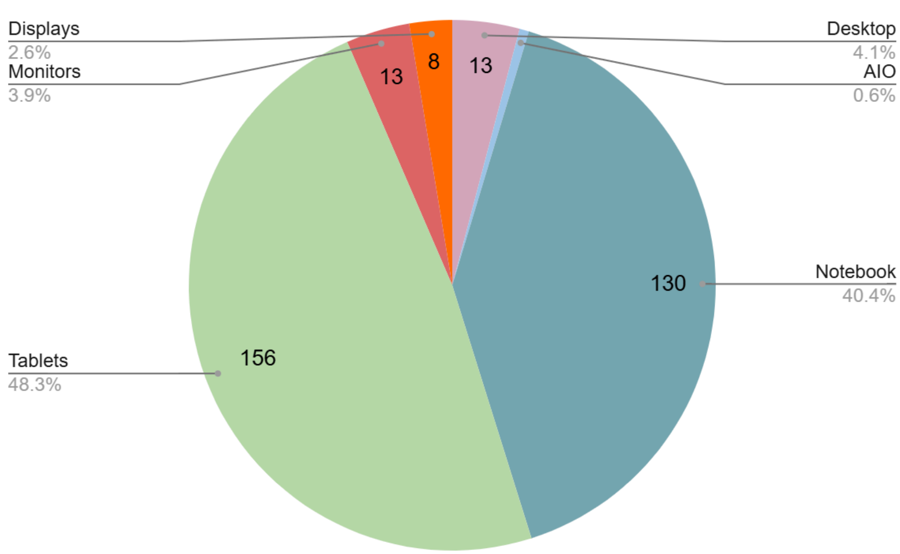
Primary Schools

Primary schools in England are typically for children aged 5 to 11, although some schools included in the research also include reception years for 4 year olds. Learning years include Year 1 (5-6 years of age) through to Year 6 (10-11 years of age). This therefore includes education Key Stage 1 (5-7 years of age) and Key Stage 2 (7 to 11 years of age). Only schools offering free education to students are included within the research meaning that private fee paying schools are not represented. The results are presented firstly as a physical representation of assets (e.g. type, size, OS, age) and secondly from a carbon footprint perspective (e.g. energy, supply chain and e-waste). The comprehensive approach enables an average baseline for a single primary school to be formed. This can then be subjected to sustainable ICT modelling strategies to show potential improvement. By doing so, the primary school 'before and after' results can be compared to average results for other school types (e.g. secondary) and extrapolated to represent a national current and potential impact. During the four month data collection period from October 2024 to January 2025, a total of 157 primary schools participated representing 67% of research participants. Eight of England's nine geographical regions are represented with the exception of the North East.

Primary Schools Physical EUC Asset Profile

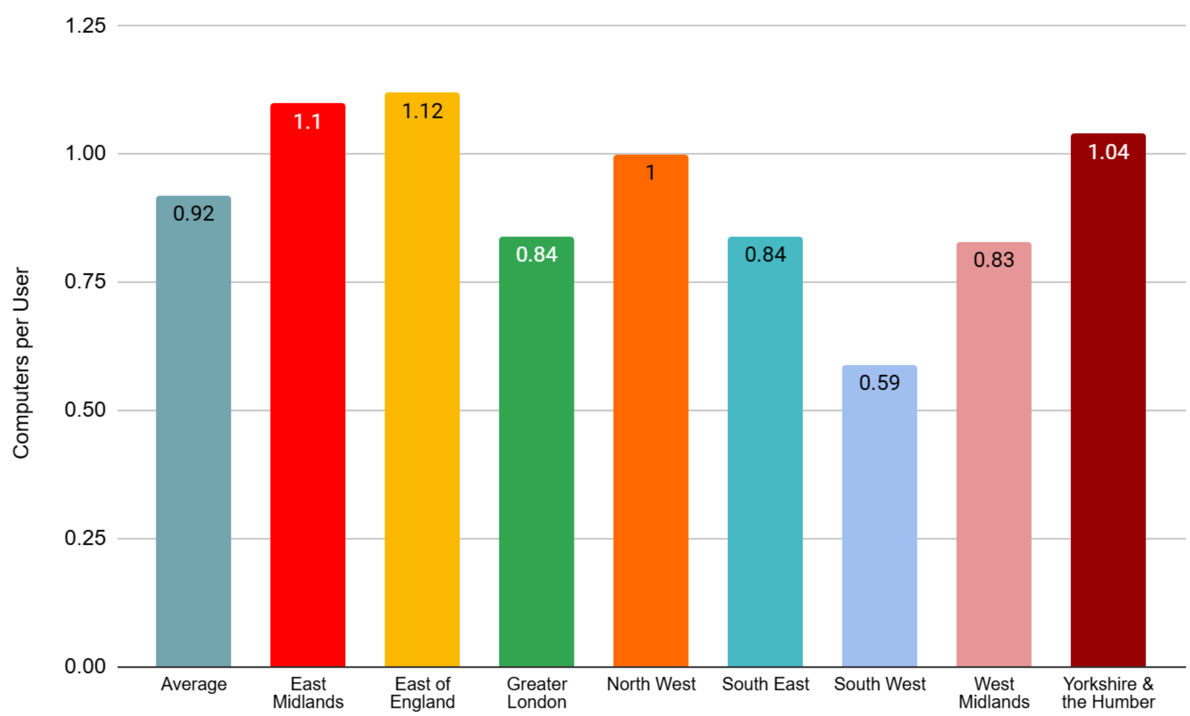
Data for over 51,000 EUC devices is captured, with 781 specific models of device from 55 brands identified. The data shows that an average primary school has 348 computer users. Of these, 309 are students (89%) and 39 (11%) staff. Each school has 322 EUC devices represented by 301 computers (94%), 13 monitors (4%) and 8 displays (2%) (Figure 1). This equates to an EUC asset list of 156 tablets (48%), 130 notebooks (40%), 13 desktops (4%) and monitors, 2 AIO desktops (0.6%), and 8 interactive displays (Figure 1).

Figure 1. Primary school average EUC device quantities by type



Therefore, the average ratio of computers to users is 0.9:1, meaning there is almost one computer available for every student. As shown in Figure 2, this ratio varies by region. The East of England has the highest mapping of 1:1, while the South West region has the lowest of 0.6:1 (Figure 2). The reason for this disparity is not within the scope of this research.

Figure 2. Primary school average EUC computer per student ratio by geographic region



In primary schools, 95% of computers are mobile devices (Figure 1, excluding displays and monitors). Specifically, tablets are the most popular at 52% of computers, followed by notebooks at 43%. The remaining 5% includes desktops (4%) and AIO integrated desktops (1%) (Figure 1). The most popular tablet size is a 10" screen (96.5%), followed by 7"-9" (3%) and less than 1% 12" and above. Tablets are predominantly Apple iPads (72%), followed by 27% Android variations, 0.5% ChromeOS and less than 0.2% Windows. From an operating system perspective, the results are relatively concurrent with global statistics in the fact that both iOS (Apple) and Android lead the market.

The most popular notebook size is 11" (68%), followed by 14" (11%) and 15" (11%), 16" (5%), 17" (4%) and 12" (1%). Overall, notebook operating system choice is predominantly ChromeOS (67%), followed by Microsoft Windows (32%), and MacOS (<1%). This is not concurrent with global PC operating system statistics showing that Windows has 72% market share and ChromeOS 2% [46]. Therefore, it is interesting to note that it is the 11" sized notebook causing the anomaly. Specifically, 90% of these small sized devices are ChromeOS. While sizes 12-17" are 82% Windows, 17% ChromeOS and 1% MacOS.

While not conclusive, the abundance of 11" notebooks suggests that budget is key to enabling students to have access to a computer in a cost effective manner. As an example, the most popular model in primary schools is a Lenovo 100e Chromebook, retailing at £200. While numerous variations of these size Chromebooks exist from several brands, versions of 11" Windows devices are limited and 45% more expensive. Similarly, the most popular tablet used by primary schools is the Apple iPad. This has a 10" screen and retails at between 35-85% higher in cost than the Chromebook. Therefore, from a cost perspective, the small Chromebooks are an affordable and fully functional computing alternative.

Desktop computers are predominantly small form factor (SFF) (76%), followed by ultra small form factor (USFF) (23%) and tower (1%). Microsoft's Windows operating system is the most popular, installed on 94% of desktops. This is followed by just over 5% ChromeOS and just under 5% for MacOS.

Integrated desktops (AIO) are predominantly 22" (54%), followed by 20-21" (29%) and 24" (17%). Similar to desktops, Windows is installed on 98% of all AIO, with ChromeOS and Apple's MacOS representing 1% each.

Displays refer to Interactive Displays for use within classrooms as teaching tools. The interactive displays range from 55-98". The most popular size interactive displays are 65" (58%), followed by 75" (36%), 55" (4%), 85" (1%) and 98" just under 1%. Android is the predominant operating system used with 99.9% install share. The remainder 0.1% being Windows used on Microsoft's Hub products.

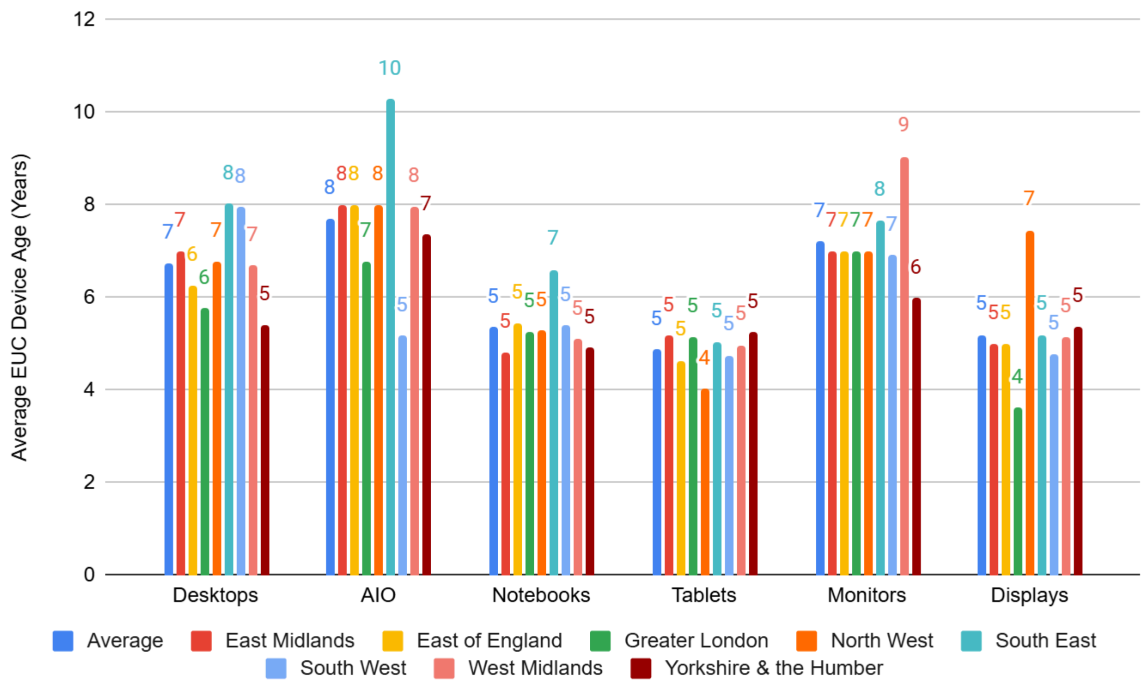
Monitors refer to computer user focused displays used as an external peripheral device in conjunction with a computer such as a desktop or notebook. The most popular size is 27" (32%), followed by 22" (25%), 23" (21%), 19" (10%), 24" (7%), 17" (2%), 14-16" (3%).

Equipment age differs by device type and varies by region. As shown in Figure 3, the desktop average age is 7 years, AIO 8 years, notebooks 5 years, tablets 5 years, monitors 7 years and displays 5 years. From a regional perspective, EUC devices are oldest in primary schools located in the South East. Specifically, desktops are 8 years, AIO 10 years, notebooks 7 years, tablets 5 years, monitors 8 years and displays 5.

Retaining EUC devices for longer periods is a positive strategy from both an environmental and cost perspective. This is because, on average, annual supply chain emissions and procurement costs are reduced as devices are purchased less often. However, certain device specifics, such as energy consumption efficiency and potential operating system obsolescence, will influence results as time passes. To enable a discussion on this subject (see sustainable strategies), Windows desktops, AIO and notebooks manufactured before 2018 are identified as a percentage of the primary school estate. This is because these devices cannot be upgraded to Windows 11 and therefore intervention will be required to avoid replacement. Similarly, monitors are categorised by age to enable an examination of improving energy efficiency during the past ten years for this device type.

Within English primary schools, 39% of Windows desktops, 70% of Windows AIO computers and 13% of Windows notebooks were manufactured during or before 2017. This means that based upon proportional representation of device types (Figure 1) and accounting for operating system popularity, 5 desktop computers, at least 1 AIO computer and 6 notebooks in an average primary school will not meet the Windows 11 upgrade criteria.

Figure 3. Primary school average EUC device age by type and geographic region



Monitors do not require operating systems and complex components such as central processing units (CPU), to function. Therefore, obsolescence is less frequent and it is common for the device type to be kept for longer periods than computers (Figure 3). The data reflects this with models identified that are as much as 20 years old with 26% of all monitors 8 years or older.

Specifically, 2% have been operational for 20 years, 6% between 15-19 years, 9% 10-14 years and 9% for 9 years. Summarising the profile results and accounting for all device types and type specific attributes, an average primary school EUC estate consists of the following device proportional representation:

- 156 tablets consisting of 112 Apple iPads, 42 Android, 1 ChromeOS and 1 Windows.
- 130 notebooks consisting of 87 Chromebooks, 42 Windows notebooks and 1 MacBook
- 13 desktops consisting of 11 Windows desktops, 1 Chromebox and 1 Mac Mini
- 13 monitors consisting of four 27", six 22-23", and three smaller than 22"
- 2 Windows AIO desktops
- 8 interactive displays including four 65", three 75" and one 55"

Primary School Environmental and Energy Results by Device Type

Environmental and financial results for the 51,382 EUC devices captured within the primary school data sample (including 781 models and 55 brands) are calculated at a specific model level to ensure maximum accuracy. The exception to this is that an average value for a device by type is applied to calculate annual procurement costs. Tablets are £499, notebooks £599, desktop and monitor combinations £998, AIO computers £799 and interactive displays £999. It is recognised that schools will have varying procurement prices although this average is constant throughout and therefore values and percentage reductions generated are comparable between strategies.

To generate the baseline metrics, the Px^3 Calculate application produces results for a) lifespan; b) annual electricity consumption; c) annual utility cost; d) concomitant scope 2 GHG emissions; e) scope 3 supply chain emissions (including production, transportation and EOL services); f) annualised total carbon footprint; g) lifetime carbon footprint; h) e-waste and i) procurement costs.

Using the model level results, averages are then calculated for each device type. These average device values are then used to create environmental impact and cost data associated with an average primary school as it is currently (the baseline) and then to model three proposed sustainable ICT strategies (the change). In each instance, a per capita value is generated to enable schools that vary in size to quickly estimate their own metrics by number of users/devices.

This per capita value is referred to as the 'EUC volume of emissions ratio' known as the EVER score. It is expressed by 1 device to the associated annual EUC emissions for a single year. An example would be 1:35 meaning that on average one EUC device generates 35 kgCO_2e annually.

Mobile Devices

Table 1 shows that the average tablet electricity consumption per year is 13.25 kWh/y. This generates 2.75 kgCO_2e of scope 2 use-phase GHG emissions for each year of operation. The results indicate that energy efficiency is influenced by the device operating system. On average, Android tablets consume -41% less than the mean at 7.8 kWh/y. This is followed by Google ChromeOS tablets (-37% at 8.3 kWh/y), Microsoft Windows (-5% 12.6 kWh/y) and finally Apple iOS (+16% at 15.4 kWh/y).

Tablet supply chain average emissions are 97 kgCO_2e meaning that the annual value is 19.40 kgCO_2e (Table 1). This value is influenced by size due to increased materials required for production and transportation impact as devices become larger and heavier. As an example, 7-8" tablets generate on average 31% less scope 3 GHG emissions at 77 kgCO_2e, while 12-13" tablets are 42% higher at 138 kgCO_2e.

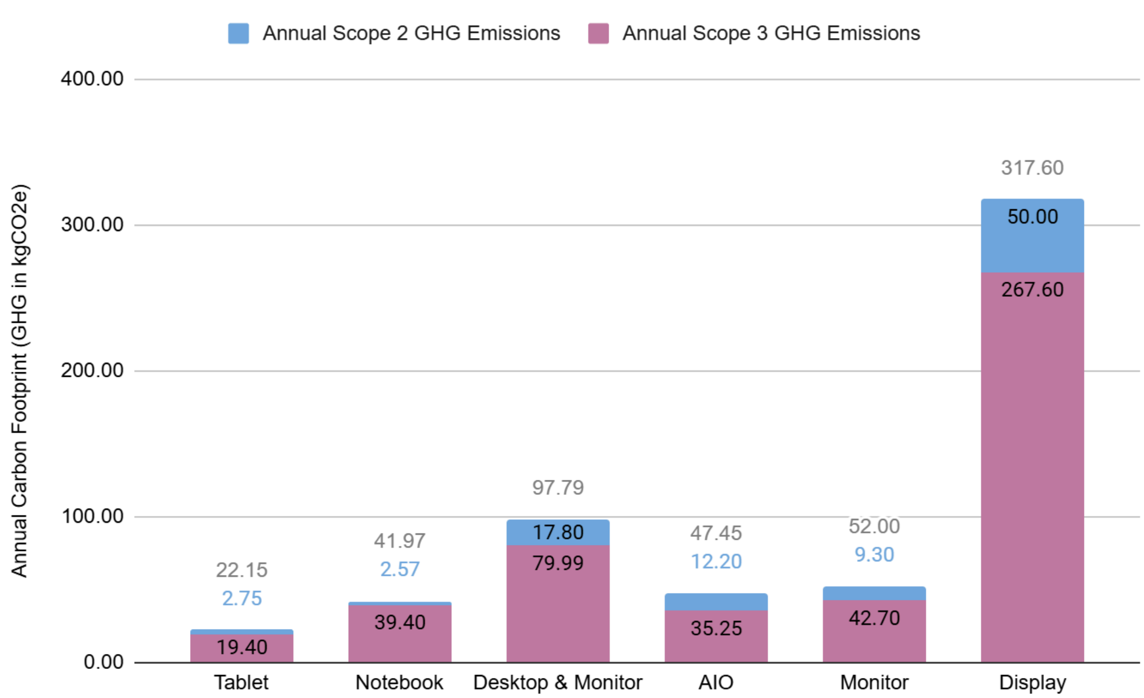
Table 1. Average primary school annual environmental and financial results by device type (one unit)

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	1	5	19.40	2.75	22.15	13.25	£4.11	£99.80	0.10
Notebook	1	5	39.40	2.57	41.97	12.40	£3.84	£119.80	0.30
Desktop & Monitor	1	7	79.99	17.80	97.79	86.00	£26.66	£142.60	1.24
AIO	1	8	35.25	12.20	47.45	59.00	£18.29	£99.80	1.04
Display	1	5	267.60	50.00	317.60	243.00	£75.33	£199.80	10.10

Figure 3 shows that on average tablets are kept for 5 years. Based upon this, the lifespan carbon footprint of a primary school tablet is 111 kgCO_2e, meaning tablets create 22.2 kgCO_2e annually (Figure 4). Therefore, supply chain emissions are responsible for 87% of the product carbon footprint and the use-phase of 13.75 kgCO_2e is responsible for 13%.

The average weight of a tablet is 0.48 kg and therefore the annualised e-waste potential is 0.10 kg per unit (Table 1).

Figure 4. Primary school average EUC device annual carbon footprint (GHG emissions kgCO_2e)



Average notebook annual electricity consumption is 12.4 kWh/y (Table 1), generating 2.57 kgCO_2e. Research shows that in most situations, tablets consume less electricity than notebooks. However, within primary schools, size and operating system preference are causing notebooks to consume 6% less energy than tablets (Table 1).

As previously noted, two thirds of notebooks are 11", which is only one inch larger than the average tablet. 90% of these smaller notebooks are installed with the ChromeOS operating system which research shows is more energy efficient than comparable operating systems . Examining the 11" Chromebooks in isolation shows that this notebook type consumes 8.89 kWh/y. This is 14% higher than Android tablets and 7% higher than the ChromeOS tablets. However, within primary schools, three quarters of tablets are Apple iPads consuming an average of 15.4 kWh/y. Therefore, the 11" Chromebooks are 42% more energy efficient than iPads which contributes to the unexpected outcome.

To further examine the effect of operating system choice, it is previously noted that in usual circumstances, the operating system share for notebooks would be approximately 72% Windows [46]. Examining Windows notebook in isolation shows that the average annual notebook electricity consumption is 19.29 kWh/y. This is 45% higher than the average tablet consumption and if Windows was the most prevalent operating system for primary school notebooks, the result would be congruent with expectation. As such, it is reasonable to suggest that the high proportion of small Chromebooks in operation within primary schools causes notebooks to, in this instance, prove more energy efficient than the average tablet computer.

The average notebook supply chain emissions value per unit is 197 kgCO_2e (Figure 4) creating an annual scope 3 emissions value of 39.4 kgCO_2e per unit (Table 1). While average notebook electricity consumption is below the tablet average, the scope 3 emissions are 77% higher.

Figure 3 shows that notebooks are retained for 5 years on average. Therefore, the lifespan carbon footprint for an average notebook in primary schools is 210 kgCO_2e, meaning notebooks create 42.1 kgCO_2e GHG emissions annually (Figure 4). As such, scope 3 emissions account for 94% of the overall product carbon footprint.

The average weight of a notebook is 1.51 kg and therefore the annualised e-waste potential is 0.3 kg per unit (Table 1).

Static Devices

Average annual desktop computer electricity consumption is 41 kWh/y per device (Table 1 shows the value combined with a monitor). This produces 8.5 kgCO_2e of scope 2 emissions for each year of operation (Table 1). It is notable that energy consumption differs based upon the age of the device. As an example, for desktops between 9-17 years the average annual value was 46% higher at 60 kWh/y. While desktops between 1-8 years of age consumed 37.4 kWh/y. This is 9% lower than the mean and 38% lower than the older desktops. The highest electricity consumption calculated was 145 kWh/y, generated by a 17 year old desktop model originally produced by Compaq.

Electricity consumption also differed considerably by desktop operating system and size. As an example, the average ChromeOS Chromebox devices proved the most efficient consuming an average of 13 kWh/y while MacOS desktops consume 17 kWh/y per unit. However, while this is 68% and 59% respectively lower than the mixed OS mean (Table 1), it is recognised that both Chromeboxes and Apple's Mac Mini are USFF and below the average age of devices. Specifically, Chromeboxes are on average 6 years old and Mac Mini's 5 years old.

As previously noted, 76% of desktops are SFF, 94% Windows and on average, 7 years old. Research shows that energy efficiency is affected by operating systems choice and low power components commonly found in modern devices [47]. It is therefore notable that newer Windows USFF desktops from brands such as Dell, HP and Lenovo that appear regularly in the school's assets do compare more favourably to the ChromeOS and MacOS devices. Specifically, this group of models reduced electricity consumption while running Windows 11 to an average of 14 kWh/y. This is 17% higher consumption than ChromeOS desktops and 12.5% lower than MacOS desktops. Consequently, the concept of ensuring energy efficiency is included as a selection criterion is evident within the data.

The average supply chain carbon footprint value for desktops is 261 kgCO_2e based upon SFF being the most popular format as noted. Therefore the annual scope 3 GHG emissions value is 37.29 kgCO_2e (Table 1 and Figure 4). Size does influence scope 3 emissions because more materials are required for larger devices and shipping emissions increase per computer. As an example, the average desktop tower format found in primary schools raised supply chain emissions 40% to 375 kgCO_2e. While, USFF devices are 16% lower at 224 kgCO_2e on average.

Based upon the 7 year average retention for desktops (Figure 3), the total lifespan carbon footprint of an average desktop in English primary schools is 321 kgCO_2e and therefore desktops create 45.8 kgCO_2e GHG emissions annually (Figure 4). Meaning that 81% of desktop computer carbon footprint is attributed to supply chain and 19% (60 kgCO_2e) to electricity consumption during use.

It is reasonable to suggest that for every desktop computer, a monitor will be required. Therefore, when presented as an EUC device the monitor carbon footprint and energy consumption must be coupled with the desktop.

An average monitor used in primary schools consumes 45 kWh/y (Table 1 combined with a desktop at 41 kWh/y). This generates 9.3 kgCO_2e scope 2 GHG emissions per year (Figure 4). Similar to desktops, device age influences energy efficiency due to technological improvement. As an example, 22" monitors older than 15" consume 82 kWh/y while the same sized monitors less than 5 years old consume 75% less electricity at 20 kWh/y on average.

Average primary school monitor supply chain emissions are 299 kgCO_2e per device and therefore 42.7 kgCO_2e annually (Figure 4). Similar to desktops, size influences this value due to materials and delivery impacts. As an example, large monitors such as 34" have an average scope 3 carbon footprint 35% higher at 404 $kgCO_2e$. While the most popular size of 27" is 12% higher at 337 $kgCO_2e$.

Based upon the 7 year average monitor retention period experienced in primary schools, the lifespan carbon footprint is 364 $kgCO_2e$, meaning monitors create 52 $kgCO_2e$ GHG emissions annually (Figure 4). Therefore, the supply chain accounts for 82% of the product carbon footprint and 18% (65 $kgCO_2e$) is caused by use.

When a monitor is coupled with a desktop computer, the lifespan carbon footprint per device pairing is 685 $kgCO_2e$ or 97.8 $kgCO_2e$ for each of the 7 years the device is in operation (Table 1 and Figure 4). Additionally, the average combined weight for a desktop (4.26 kg) and monitor (4.44 kg) is 8.7 kg. Therefore the annual potential e-waste is 1.24 kg (Table 1).

Integrated desktop average electricity consumption is 59 kWh/y (Table 1). This generates 12.2 $kgCO_2e$ per year (Table 1 and Figure 4). These device types are known as all-in-one (AIO) desktops as they include a monitor combined with a desktop computer in one integrated chassis. When compared to a desktop and monitor combination, the AIO device is 31% more energy efficient and therefore produces the same percentage less scope 2 emissions (see Table 1 and Figure 4).

Average AIO supply chain emissions are 282 $kgCO_2e$ per unit and therefore scope 3 emissions are 35.25 $kgCO_2e$ per year. AIO devices are similar to monitors in appearance. The majority of AIO used in primary schools are 22", while monitors are predominantly 27". Therefore it is congruent that AIO scope 3 emissions are 6% lower than the average monitor. However, supply chain emissions for the equivalent desktop and monitor combination are 560 $kgCO_2e$ (Table 1 and Figure 4). This means that an AIO device has on average, 50% less scope 3 emissions than a desktop/monitor equivalent (Table 1 and Figure 4).

Figure 3 shows that on average AIO devices are kept for 8 years. Therefore, the lifespan carbon footprint is 380 $kgCO_2e$. This means that the annual carbon footprint is 47.5 $kgCO_2e$ (Figure 4). In this example, the supply chain emissions are responsible for 74% of the product carbon footprint.

The average weight of an AIO device is 8.29 kg and therefore the annualised e-waste potential is 1.04 kg per unit (Table 1).

An average interactive display used in primary schools consumes 243 kWh/y of electricity annually (Table 1). This generates 50 $kgCO_2e$ per year (Table 1 and Figure 4). This value is significantly influenced by the device size due to the lit/active surface area increasing as devices become larger. As an example, 55" interactive displays consume 168 kWh/y on average, while an 86" version consumes 102% more electricity at 340 kWh/y.

The average scope 3 emissions for an interactive display are 1,338 $kgCO_2e$, therefore annual scope 3 emissions are 267.6 $kgCO_2e$ (Table 1 and Figure 4). Size also affects supply chain emissions due to significant increases in both material and transportation impact. As an example, average scope 3 emissions for a 55" display are 1,027 kgCO_2e while an 86" display is 64% higher at 1,681 kgCO_2e.

Figure 3 shows that the average retention period is 5 years. Therefore the average lifespan carbon footprint is 1,588 kgCO_2e meaning the annual carbon footprint is 318 kgCO_2e (Figure 4). As such, the supply chain is responsible for 84% and the use-phase is responsible for 16% of the product carbon footprint.

The average weight of an interactive display is 50.5 kg and therefore the annualised e-waste potential is 10.1 kg per unit (Table 1).

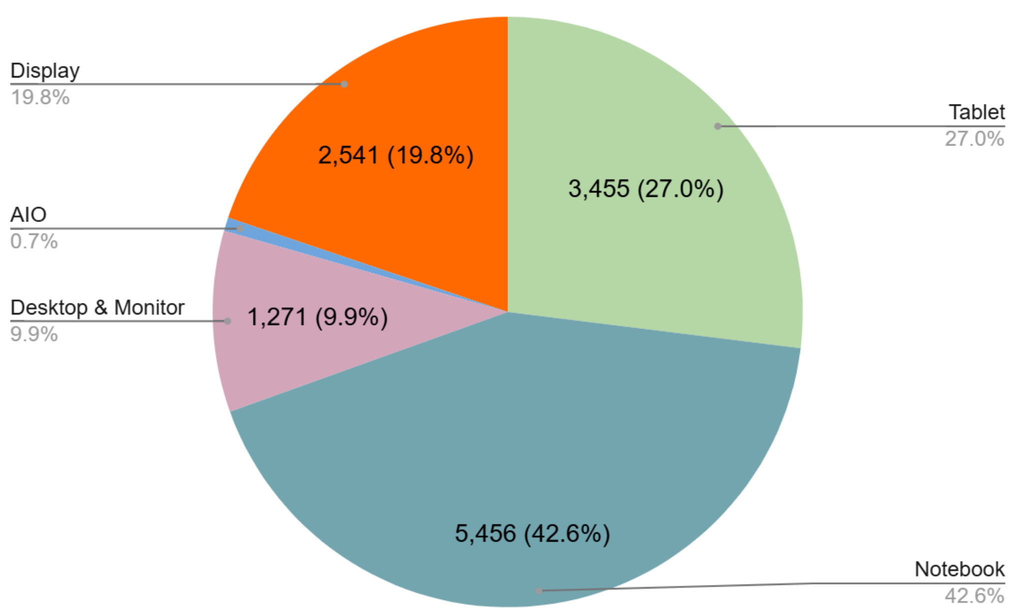
Average Primary School EUC Estate Carbon Footprint and Energy Baseline

Combining the proportional representation (Figure 1) of EUC devices within an average primary school and the carbon footprint by device type (Figure 4), the annual average carbon footprint for an entire EUC estate of 322 devices (Figure 1) is 12,835 kgCO_2e (Figure 5 and Table 2).

This is equivalent to emissions created by a combustion engine car travelling almost 76,000 km or almost twice around the Earth's circumference. In context, for one average primary school, 583 mature trees are required every year to remove this carbon from Earth's atmosphere.

Consequently, the per capita EVER ratio for an average primary school is 1:39, meaning that for every device owned, 39 kgCO_2e is generated annually. This requires 1.8 trees to sequester emissions.

Figure 5. Primary school average EUC device annual carbon footprint (kgCO_2e)



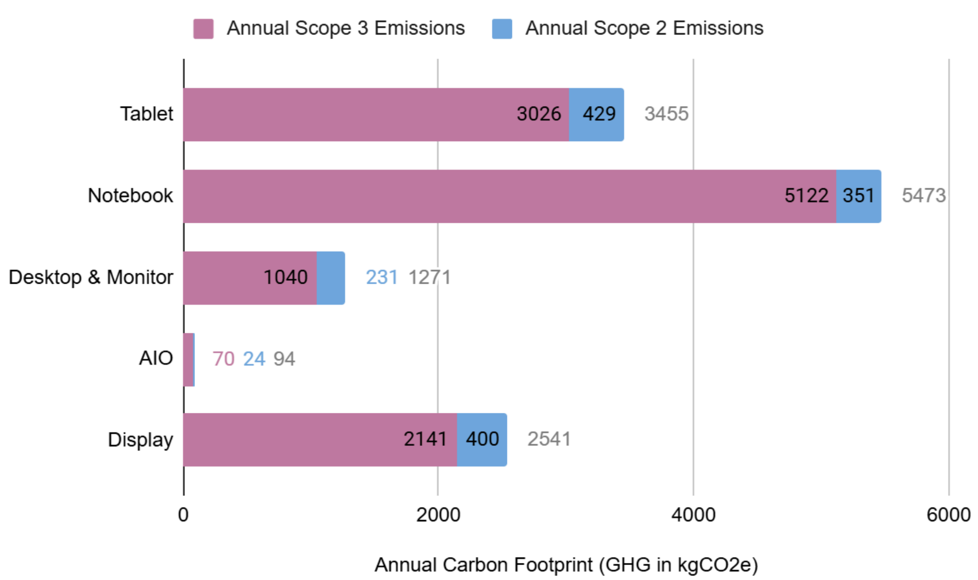
Tablets make up 48% of device quantities (Figure 1) although due to their low carbon footprint per unit (Figure 4) the contribution to annual GHG emissions is 27% (Figure 5). Comparatively, while displays represent only 2.6% of all devices (Figure 1), their high carbon footprint (Figure 4) per unit causes their contribution to the total impact to rise sevenfold to almost 20% (Figure 5).

Table 2. Average primary school EUC estate annual environmental and financial results

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	156	5	3,026	429	3,455	2,067	£641	£15,569	15.0
Notebook	130	5	5,122	351	5,473	1,612	£500	£15,574	39.3
Desktop & Monitor	13	7	1,040	231	1,271	1,118	£347	£1,853	16.2
AIO	2	8	70	24	94	118	£37	£200	2.1
Display	8	5	2,141	400	2,541	1,944	£603	£1,598	80.8
Total	**309**		**11,399**	**1,436**	**12,835**	**6,859**	**£2,126**	**£34,794**	**153.3**

As indicated by Figure 5 and 6 plus Table 2, display energy related emissions contribute significantly to annual scope 2 emissions. As an example, the 8 displays used in an average primary school (Figure 1) generate 28% of all scope 2 annual emissions (Table 2 and Figure 6), while the 156 tablets contribute 30% (Table 2 and Figure 6). As previously noted, a single display consumes 18 times more electricity than one tablet in one year (Table 1).

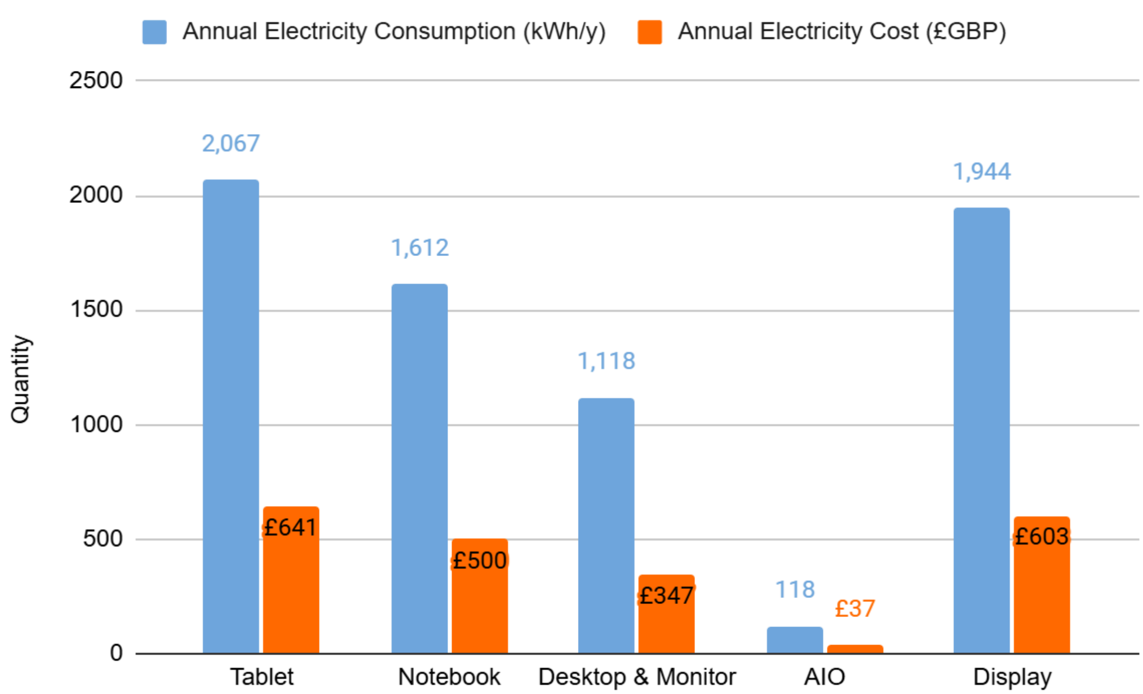
Figure 6. Primary school average EUC estate device annual carbon footprint ($kgCO_2e$) by GHG scope type



However, the impact of displays should be considered in the context of function. Specifically, it must be acknowledged that while a tablet can be used by one student or staff member at a time, displays are used for classroom / group learning. As the average class size is 27 pupils and 2 staff members would also be present, then the contribution of displays to both carbon footprint and electricity consumption is arguably rationalised.

Overall, supply chain emissions contribute 89% and 11,399 kgCO_2e annually (Figure 6). Meaning, that use-phase scope 2 emissions generate on average 11% and 1,436 kgCO_2e (Figure 6).

Figure 7. Primary school average EUC estate device annual electricity consumption (kWh/y) and cost (£GBP)



From a financial perspective, ICT operational factors including energy efficiency and retention periods will influence results. The first affects utility consumption and cost while the second determines annual device procurement costs.

In relation to energy efficiency, the average primary school EUC estate consumes 6,859 kWh/y of electricity (Table 2 and Figure 7) costing £2,126 per year (Table 2 and Figure 7). As before, while the fewest in number, 8 displays almost match 156 tablets in both consumption and cost (Figure 7). Specifically, tablets contribute to 30% (2,067 kWh/y) of EUC electricity consumption and cost (£641) followed by displays 28.5%, notebooks 23.5%, desktop and monitor combination 16.3%, and integrated computers 1.7% (Table 1 and Figure 7).

In isolation, electricity consumption for an average tablet costs £4.11 per year, £3.84 for a notebook, £26.66 for a desktop and monitor combination, £18.29 for an AIO device and £75.33 for an integrated display (Table 1 and Figure 8).

Dividing the average new hardware costs outlined (see above) by the varying average retention periods (Figure 3) produces an annual procurement cost by device type (Table 1). As such, annual capital expenditure for one tablet is £99.80, a notebook £119.80, a desktop and monitor combination £142.60, AIO £99.88 and a display £199.80 (Figure 8).

Figure 8 shows the combined cost of each device type per year for a single unit. The influence of high power draw required by certain device types on total annual cost is highlighted by displays. Specifically, utility cost (operational) represents 27% of annual expenditure, with capital cost being 73% (Figure 8). Comparatively, tablet electricity cost is just 4% (Figure 8). When placed into context of the entire primary school EUC estate, the capital cost of displays diminishes to one tenth of the tablets (Table 2 and Figure 9) due to fewer displays owned (Figure 1). However, the utility expenditure remains only 6% lower than all 156 tablets (Figure 9).

Figure 8. Primary School average EUC device annual electricity and procurement cost (£GBP) per unit

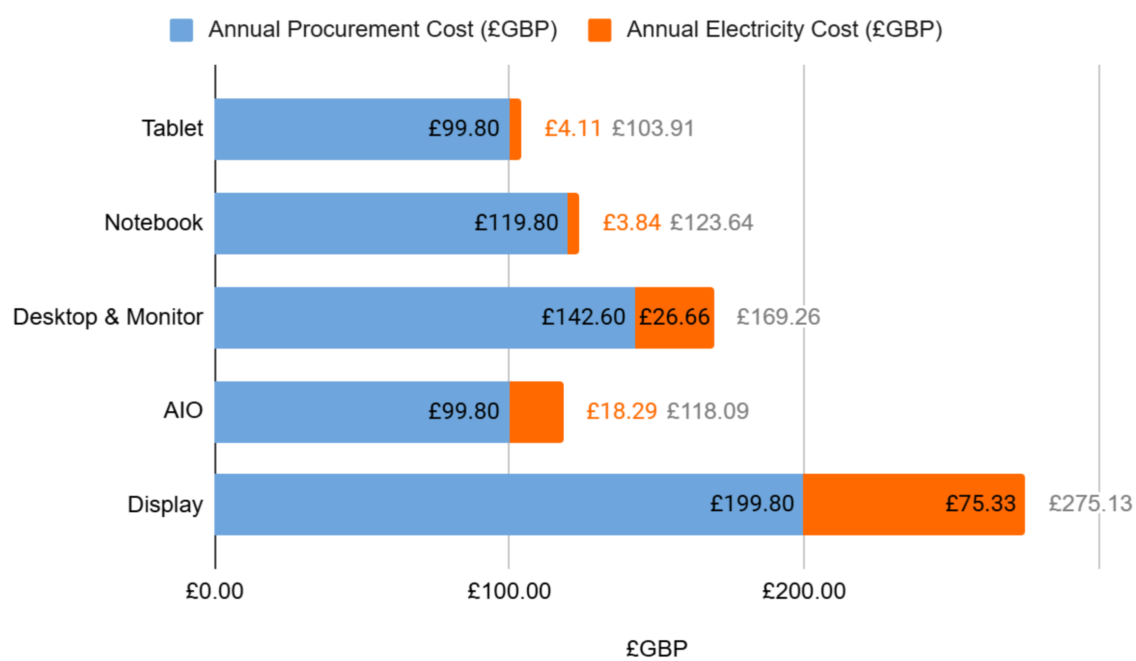
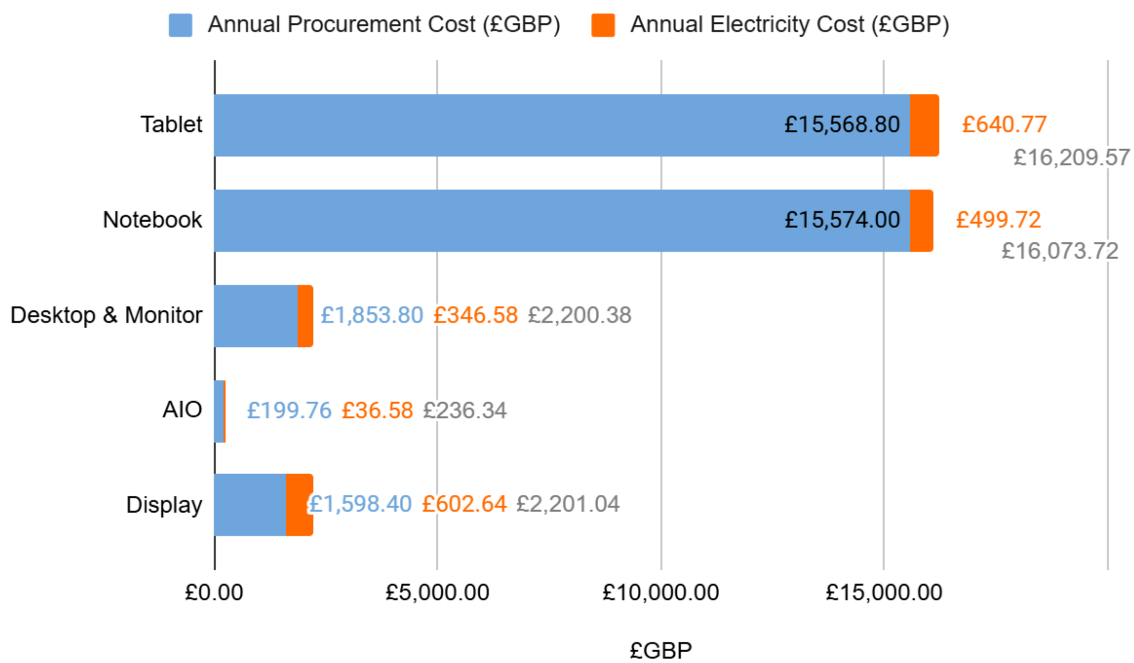


Table 2 and Figure 9 show that for an average primary school EUC estate, £36,920 will be spent on electricity (£2,126 and 6%) and device procurement (£34,794 and 94%). This means that with 322 devices, each will cost on average £114.69 to purchase and use (Figure 9).

Figure 9. Primary School average EUC estate annual electricity and procurement cost (£GBP)



Sustainable EUC Strategies in Primary Schools

To reduce short and long term carbon footprint and cost impact, three key sustainable strategies will generate differing results. The first is to address the impending replacement of devices affected by the Windows EOL event [48]. Secondly, extension of device lifespans to a uniform period of 8 years. Thirdly, introducing carbon footprint as a selection criterion for new devices.

Primary School Sustainable EUC Strategy 1: Windows 10 EOL

As noted, within an average English primary school, 39% of Windows desktops (5 devices), 70% of Windows AIO computers (1 device) and 13% of Windows notebooks (6 devices) were manufactured during or before 2017 and therefore will not meet the Windows 11 upgrade criteria [48].

For each primary school in England, this will generate 2,769 kgCO_2e of like for like new product supply chain GHG emissions and 38.65 kg of e-waste if the obsolete devices are replaced. It will also cost each school approximately £7,388 in procurement expenditure.

Currently, within England's state funded education sector there are 16,764 primary schools. Therefore, extrapolated to a country level the potential impact of finding no alternative strategy to replacement will generate 46,419,516 kgCO_2e of new product carbon footprint. This is equivalent to GHG emissions created by driving a combustion engine car

273.3 million km or 6,820 times around the world. This impact would require 2.1 million trees to sequester the resulting carbon from Earth's atmosphere.

Additionally, 648 tons of e-waste will be produced as the obsolete devices are sent for end of life services. In context, this is equivalent to 43.2 million aluminium soft drinks cans.

From a capital expenditure perspective, the cost to replace the devices will be in the region of £123.9 million unless alternative action is taken.

Research shows that Windows devices lifespan can be extended by replacing the existing operating system with Google's ChromeOS Flex. This operating system creates devices similar to Chromebooks in the case of notebooks and Chromeboxes for desktops and AIO devices.

The results show that ChromeOS is already highly popular within primary schools. As an example, 67% of notebooks are Chromebooks. Therefore, deploying ChromeOS Flex to devices affected by the Windows 10 EOL event offers a familiar alternative to replacement. Additionally, research shows that the operating system reduces electricity consumption by 19% when compared to Windows. A finding that is reflected in this research by the notebook electricity consumption value being lower than tablets (Table 1).

As such, considering ChromeOS Flex as a sustainable ICT strategy to overcome Windows 10 EOL will avoid all of the environmental and the majority of financial costs outlined above, plus reduce ongoing utility costs via improved energy efficiency.

From a cost perspective, if the new product cost was annualised across an extended lifespan of 8 years, the additional EUC procurement spend caused by the Windows EOL event is £15,481,554 annually. Using an average of £34,000 salary, this saving would enable 455 more teachers to be employed in the primary school sector during the coming decade.

Primary School Sustainable EUC Strategy 2: Device Lifespan Extension

Figure 3 shows that the lifespan of EUC equipment in primary schools varies from 5 years to 8 years depending upon device type. Research indicates that it is feasible for all devices to be retained for a uniform 8 years. This is due to operating systems being supported for longer periods by vendors and mechanical components, such as hard discs, now transitioned to solid state which improves mean time to failure (MTF) rates. These changes mean that when adopting retention policies that require all EUC devices to be retained for 8 years, annual supply chain carbon footprint, potential e-waste and capital costs reduce as devices are replaced less often.

Table 3 shows that lifespan extension in isolation will not improve energy related GHG emissions nor costs as the devices remain unchanged. However, from a supply chain and procurement cost perspective, significant reductions can be achieved with little effort.

The differing benefits of adopting a lifespan extension strategy depend upon device type. At a single device level, more expensive and higher carbon footprint devices will produce greater results in isolation. Figure 10 shows the influence of lifespan extension to 8 years upon annual supply chain emissions for each device type.

Table 3. Average primary school EUC estate annual environmental and financial results with lifespan extension to 8 years applied

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	156	8	1,892	429	2,321	2,067	£641	£9,731	9.4
Notebook	130	8	3,201	351	3,552	1,612	£500	£9,734	24.5
Desktop & Monitor	13	8	910	231	1,141	1,118	£347	£1,622	14.1
AIO	2	8	70	24	94	118	£37	£200	2.1
Display	8	8	1,338	400	1,738	1,944	£603	£999	50.5
Total	**309**		**7,411**	**1,436**	**8,846**	**6,859**	**£2,126**	**£22,285**	**100.6**

Unsurprisingly, AIO devices are unchanged as the average retention period in primary schools is already 8 years (Figure 3). Desktop and monitor combinations decline by 12.5% (10 $kgCO_2e$ per unit) reflecting the 1 year extension upon the already 7 year average (Figure 3). The highest percentage reduction of 37.5% is experienced in tablets, notebooks and displays that are currently kept for an average of 5 years (Figure 3). Specifically for each tablet 7.28 $kgCO_2e$ is avoided annually, for notebooks 14.78 $kgCO_2e$ and 100.35 $kgCO_2e$ each year for displays (Figure 10).

Applying the strategy to the entire average primary school EUC estate highlights the positive impact of lifespan extension at scale. With 156 tablets and 130 notebooks in use (Figure 1), the combined improvement exceeds the significant reduction achieved by displays at a single device level (Figure 10).

Specifically, Figure 11 shows that for each year that passes, 3,988 $kgCO_2e$ supply chain emissions are avoided. Tablets contribute to 28% of this reduction, notebooks 48%, desktops 3%, AIO 0% and displays 20%.

Consequently, the original total annual carbon footprint (including scope 2) is reduced by 31% from 12,835 $kgCO_2e$ (Table 2) to 8,846 $kgCO_2e$ (Table 3). While e-waste will reduce by 34.5% to 100.6 kg per year (Table 3).

The annually avoided emissions are equivalent to driving 23,480 km in a car and would require 181 mature trees to sequester.

Using this strategy, the EVER metric reduces from the current 1:39 ratio to 1:27. This means that by simply keeping devices for longer periods, 12 $kgCO_2e$ is avoided on average annually for each device owned.

Figure 10. Primary school average EUC annual supply chain reduction by device type (8 year retention policy)

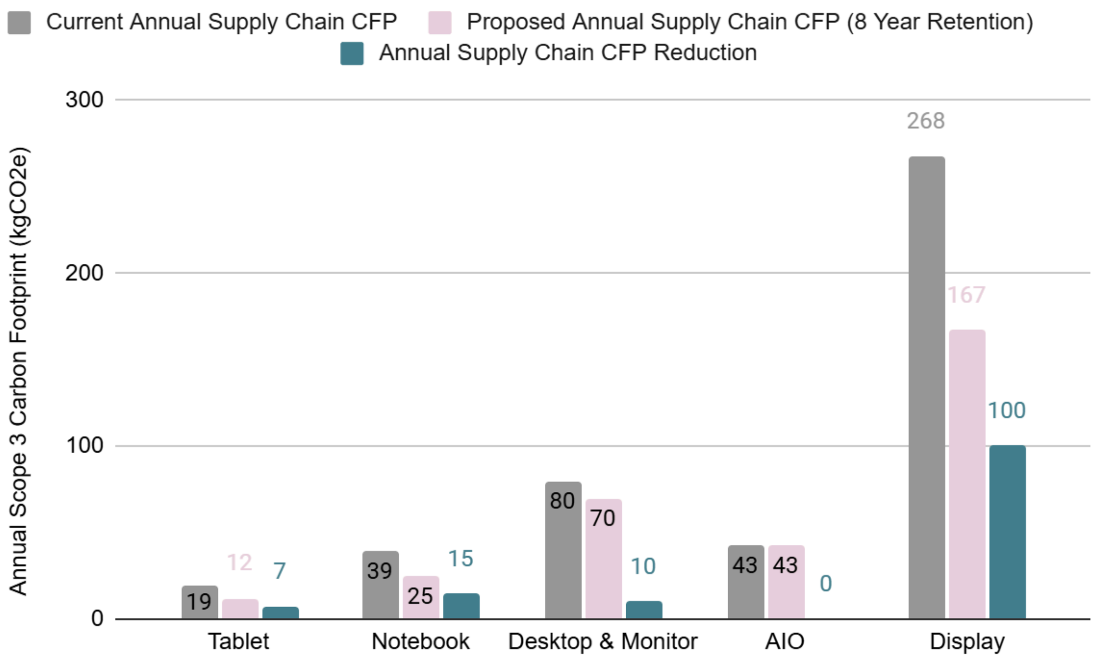
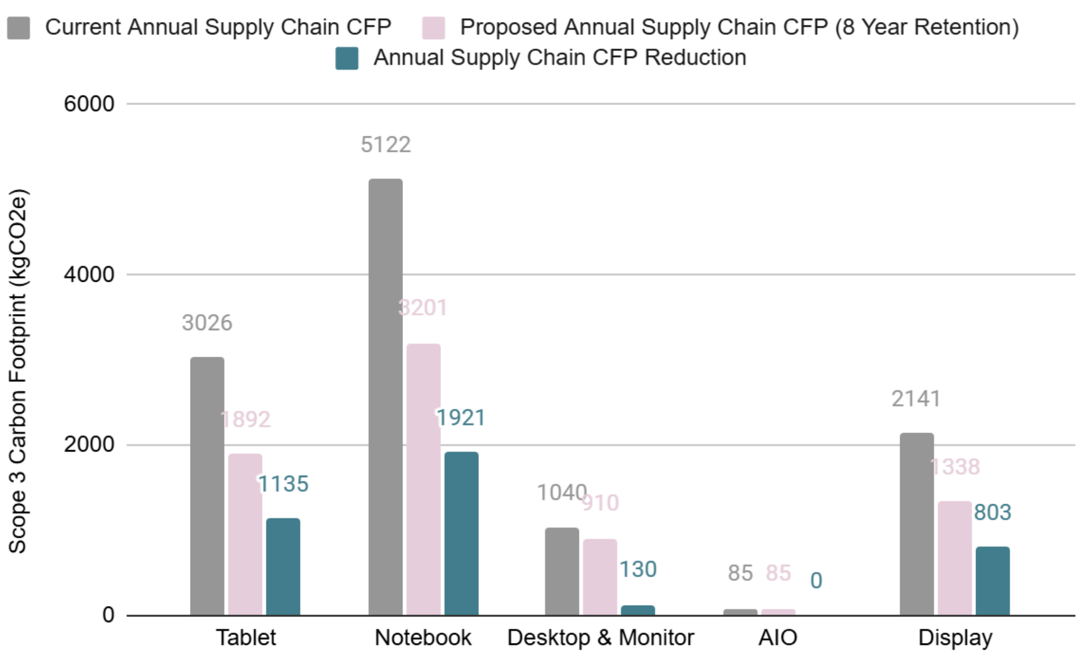
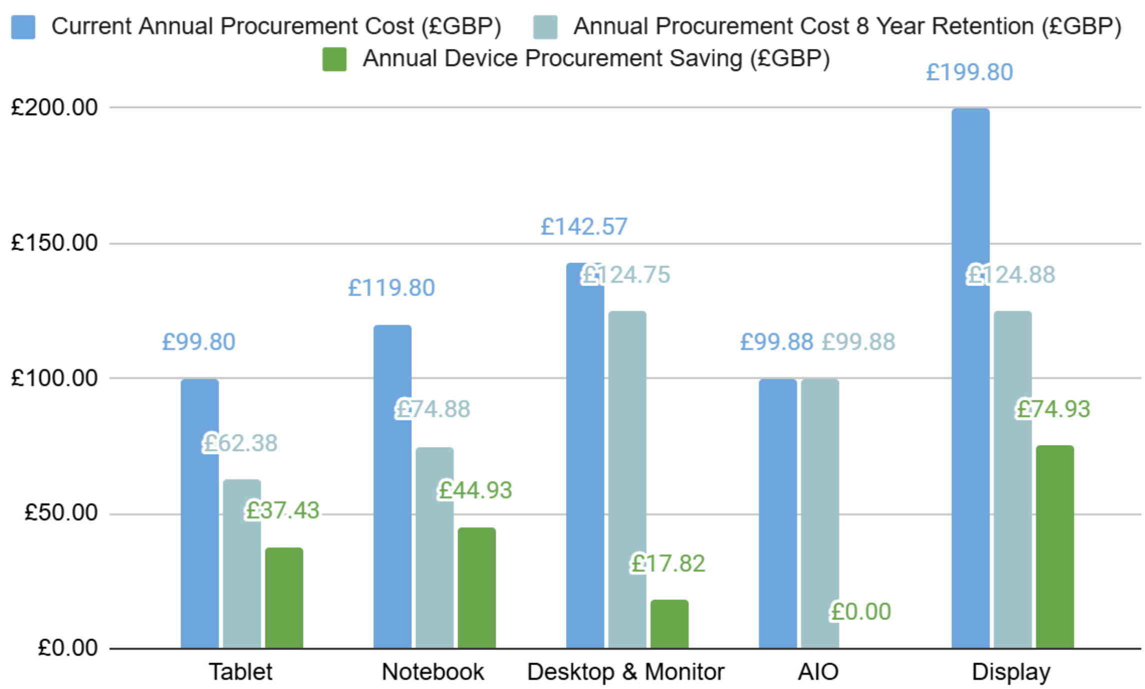


Figure 11. Primary school average EUC annual supply chain reduction for all assets (8 year retention policy)



Lifespan extension to 8 years will also deliver the same percentage reductions to annual procurement costs for each device type. This is because replacement cycles will occur less often and therefore device related capital expenditure will be reduced on an annual basis. Figure 12 shows that as before, AIO devices are unchanged due to the already being in place an 8 year retention period for this device type. While desktop and monitor combination reduce by 12.5% and £17.82 per unit annually. All devices previously retained for 5 years reduce in annual cost by 37.5%. Specifically, tablets reduce by £37.43 annually, notebooks by £44.93 and displays by £74.93.

Figure 12. Primary school average EUC annual procurement cost reduction by device type (8 year retention policy)



Applied to the entire average primary school EUC estate, Figure 13 shows that annual procurement costs reduce by 36% from £34,794 (Table 2) to 22,285 (Table 3). Meaning that each primary school extending device lifespans to a uniform 8 years, saves £12,510 per annum.

Similar to the Windows 10 EOL strategy, when applied at a country level the improvement to environmental and financial values within the primary school sector is significant. Specifically, if all schools adopted lifespan extension to 8 years 66,854,832 kgCO_2e of scope 3 supply chain GHG emissions would be avoided annually.

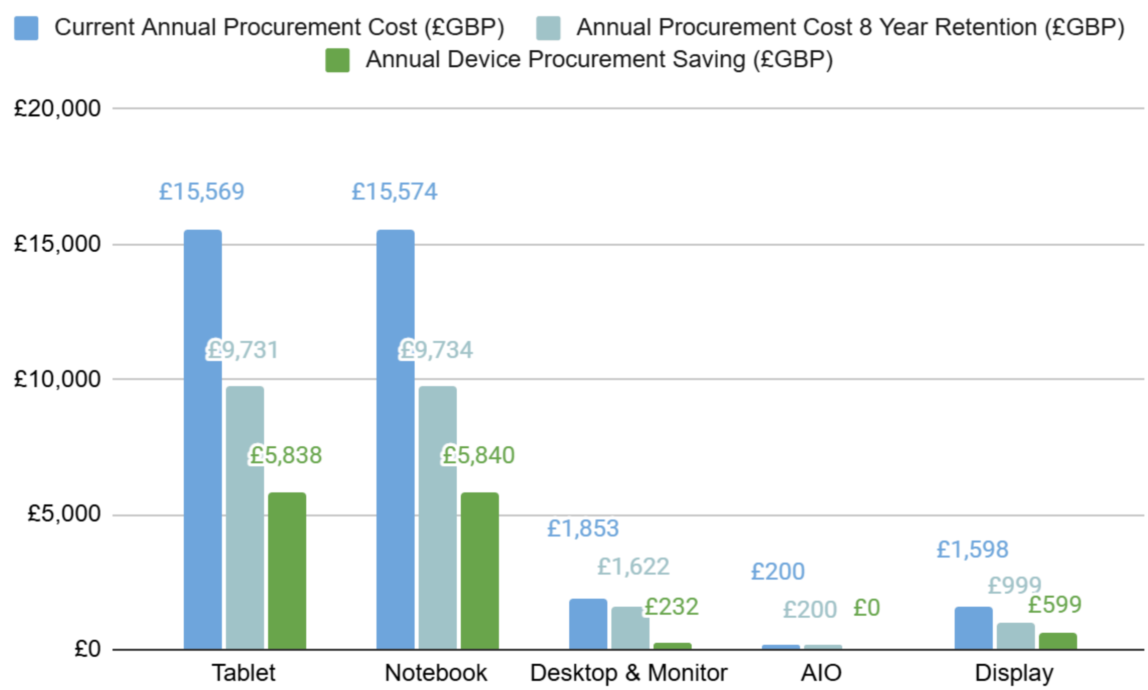
This is equivalent to driving a combustion engine car 393.6 million km or 9,822 times around Earth's equator. In context, over 3 million trees would be required every year to remove this carbon footprint from the atmosphere.

Additionally, 883,462 kg of potential e-waste would be avoided annually. This is equivalent to almost 59 million aluminium soda cans.

From a cost perspective, £209,717,640 in EUC device procurement expenditure would be avoided every year.

Using an average of £34,000 salary, this saving would enable 6,168 more teachers to be employed in the primary school sector.

Figure 13. Primary school average EUC annual procurement cost reduction for all assets (8 year retention policy)



Primary School Sustainable EUC Strategy 3: Carbon Footprint as a Selection Criterion

The carbon footprint of EUC devices differs both by type (Table 1 and Figure 6) and by model within the same device types. As previously noted, today the lowest carbon footprint notebook available generates just 88 kg CO_2e [23]. While the highest carbon footprint notebook generates 772 kg CO_2e [24]. Effectively both devices offer similar user experiences, 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 reasonable to suggest that it is easy to see how our computer choices can positively or negatively influence ongoing ICT carbon footprint and ultimately climate change without realising. Adding carbon footprint as a computer selection criteria during ICT planning and procurement will improve both environmental and financial results. In the first instance supply chain and use-phase emissions can be reduced and similarly utility costs can be lowered as devices prove to be more energy efficient.

Table 2 shows environmental and financial values for an average primary school that has not yet introduced uniform 8 year retention periods, nor carbon footprint as a selection criterion. As previously noted, the average primary school EUC estate currently generates 12,835 kgCO_2e in carbon footprint, produces 153 kg of e-waste, consumes 6,859 kWh of electricity, costs £2,126 in utility bills and £34,794 in procurement spend for every year of operation (Table 2). This creates an annual EVER per capita value of 1:39 and costs of £114.66 per device per year.

While, table 4 includes the procurement cost savings and supply chain reductions achieved in strategy 2 by adopting an 8 year lifespan extension strategy; it also shows the further reductions generated by the third strategy of including carbon footprint as a selection criterion.

In this example, the same device types are replaced with the lowest carbon footprint devices currently available. The model is not suggesting that schools should replace devices immediately and ahead of the end of their useful lifespan. It is an illustration of how long term transformation to low carbon footprint devices will improve annual metrics if devices are replaced after 8 years of use with low carbon footprint alternatives.

Table 4. Average primary school annual environmental and financial values following the implementation of strategy 2 (lifespan extension) and 3 (carbon footprint as a selection criterion.

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	156	8	1,131	431	1,562	2,081	£641	£9,731	10.4
Notebook	130	8	1,841	372	2,213	1,798	£554	£9,734	26
Desktop & Monitor	13	8	436	144	580	696	£215	£1,622	11
AIO	2	8	52	22	74	104	£32	£200	1.5
Display	8	8	851	253	1,104	1,224	£377	£999	32.63
Total	**309**		**4,311**	**1,222**	**5,533**	**5,903**	**£1,819**	**£22,285**	**82**

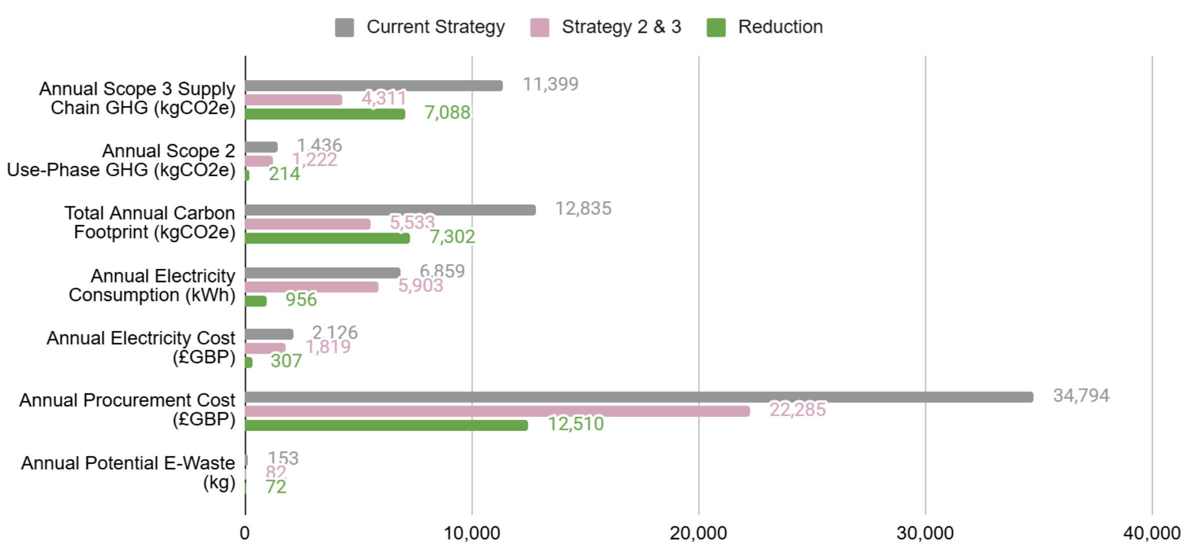
Strategy 2 (lifespan extension) contributes to a reduction of 3,988 kgCO_2e per year (Table 3 and Figure 11) when compared to the existing strategy. As noted, this reduces the original total annual carbon footprint by 31% from 12,835 kgCO_2e (Table 2) to 8,846 kgCO_2e (Table 3).

Table 4 shows that with the incremental introduction of carbon footprint as a device selection criterion, the annual carbon footprint is reduced by an additional 26% to 5,533 $kgCO_2e$. Additionally, annual e-waste declines by a total of 47% to 82 kg per year. Overall, the combination of increasing device lifespans and selecting the lowest carbon footprint devices has reduced annual EUC carbon footprint by 57%.

This means that an average primary school will reduce GHG emissions by 7,302 $kgCO_2e$ annually. This is equivalent to emissions generated by driving a combustion engine car almost 43,000 km or just over one journey around the Earth's equator. In context, the avoided emissions would otherwise require 331 trees to remove the carbon from Earth's atmosphere every year. The new annual carbon footprint reduces the original EVER metric from 1:39 to 1:17, meaning that on average each device owned generates just 17 $kgCO_2e$ per year.

Table 4 and Figure 14 show that the additional carbon footprint reductions are enabled by a reduction in both scope 3 supply chain and scope 2 energy emissions.

Figure 14. Primary school environmental and financial metrics comparing an average primary school current EUC strategy to results following implementation of lifespan extension to 8 years and carbon footprint as a device selection criterion



Comparatively, comparing the original strategy (Table 2) with the combined strategy of lifespan extension and low carbon footprint devices, tablets are 55% lower in annual carbon footprint, notebooks 59%, desktop and monitor combinations 54%, AIO devices 22% and interactive displays 57%. This created a scope 3 reduction of 7,088 $kgCO_2e$ and scope 2 reduction of 214 $kgCO_2e$ (Figure 14).

While the procurement cost savings reflect those of the lifespan extension strategy, a reduction in energy consumption of 956 kWh/y reduces utility costs by £307 (14%) to £1,819 per year.

Additionally, e-waste declines further to 82 kg per year which is a reduction of 54%.

Therefore, if it is feasible to avoid 7,302 kgCO_2e of EUC carbon footprint per primary school, then extrapolated to a country level if all primary schools adopted lifespan extension and introduced carbon footprint as a selection criterion then 122,410,728 kgCO_2e of GHG emissions could be avoided every year. This is equivalent to emissions generated by driving almost 721 million kilometres or 18,000 times around the world.

Additionally, 1.2 million kg of e-waste could be avoided annually. This is equivalent to 80.4 million aluminium soda cans.

And finally, as a saving of £12,817 can be achieved via reduced utility and procurement costs, then if all primary schools in England participated, a total cost saving of £214,864,188 could be made annually. In context, this saving is sufficient to employ 6,320 additional teachers every year.

Primary Schools EUC Volume of Emissions Ratio (EVER)

The results show that while primary schools offer a similar function, they differ significantly by staff and student size, device type choices, ratio of devices to computer users and therefore the number of devices in operation. To be able to examine how one primary school compares to another in relation to average EUC carbon footprint, then a ratio that remains constant must be determined.

For this reason the results include a metric called the 'EUC volume of emissions ratio' known as the EVER metric. It is expressed by 1 device to the associated annual EUC GHG emissions for a single year.

The concept of such metrics are already accepted and valued within ICT. As an example, Power Usage Effectiveness or PUE [49] is a metric used to determine how efficiently a data center uses energy regardless of size. Specifically, PUE is the ratio of the total energy consumed by a data centre to the energy used by the ICT equipment. Data centres with a PUE of 1.0 achieve optimum efficiency.

The results determine that for primary schools in England, the average EVER score is 1:39. This means that on average one EUC device generates 39 kgCO_2e annually.

When the lifespan extension strategy is applied this value reduces by 31% to 1:27. This means that by simply keeping devices for longer periods, 12 kgCO_2e is avoided on average annually for each device owned.

Adopting both the lifespan and carbon footprint as a selection criterion strategies reduces the EVER score by 57% when compared to the original strategy, resulting in 1:17. This means that for every year of operation, 17kgCO_2e are generated per device, while 22 kgCO_2e are avoided per device by implementing the two arguably simple strategies.

Figure 15 shows the EVER metric for each of the 157 primary schools included in the research data set. The results range from 1:19 for school 123, and rising by +379% to 1:91 for School 93. No pattern appears within the results by contextual conditions such as location. Therefore, to determine commonality between EVER results, equipment types are examined.

Table one shows that of all device types, tablets generate the lowest annual carbon footprint. Therefore, it is arguably unsurprising that primary schools with the highest proportion of tablets produce the lowest EVER metrics. As an example, schools 123, 22, 24, 32, 17, 21, 38, 92 and 124 have an EVER metric of between 1:19 and 1:21 (Figure 15) and the lowest EVER metric (Figure 16).

Figure 16 compares the percentage of tablets versus the EVER metric for primary schools with the lowest EVER metric and the highest. This shows that for schools achieving 1:19-21, between 86% and 93% of devices are tablets. Comparatively, for primary schools scoring an EVER metric of 1:67-91, between 0% and 11% of devices are tablets.

The deviations between the results in both the lowest and highest EVER ranges are caused by two factors already discussed. The first is the proportional representation of devices by device type. The second is the duration of retention and carbon footprint of each model. As an example, the school scoring the lowest EVER metric does not use interactive displays which generate the highest carbon footprint of all device types (Table 1). While for the remainder of the schools in the lower EVER range, notebooks make up the predominant remainder of devices used. As notebooks exhibit the second lowest carbon footprint by device type (Table 1), then mobile devices in favour of static devices such as desktop and monitor combinations are clearly assisting carbon footprint reduction.

Figure 1 shows that mobile computing already accounts for 89% of all primary school EUC devices. It is reasonable to suggest that a wholesale transition from static to mobile devices has already occurred. Therefore, from a strategy perspective for most schools, device lifespan extension and including carbon footprint as a selection criterion will help to reduce carbon footprint and associated EVER metrics.

However, as indicated by Figure 16, there are schools that continue to have a higher percentage of static computers such as desktops and AIO. As an example, school 93 (Figure 16) has 61% notebooks (mobile) and 39% static computers. Therefore, mobile computing adoption is 31% lower than the average.

These isolated cases should consider a transition to mobility and specifically tablets and low carbon footprint notebooks to improve EVER metrics. This would simply form part of the strategy to include carbon footprint when selecting devices for purchase. In this example, rather than comparing by device type, schools would compare at a computer level.

Figure 15. EUC Volume of Emissions Ratio (EVER) metrics for 157 primary schools

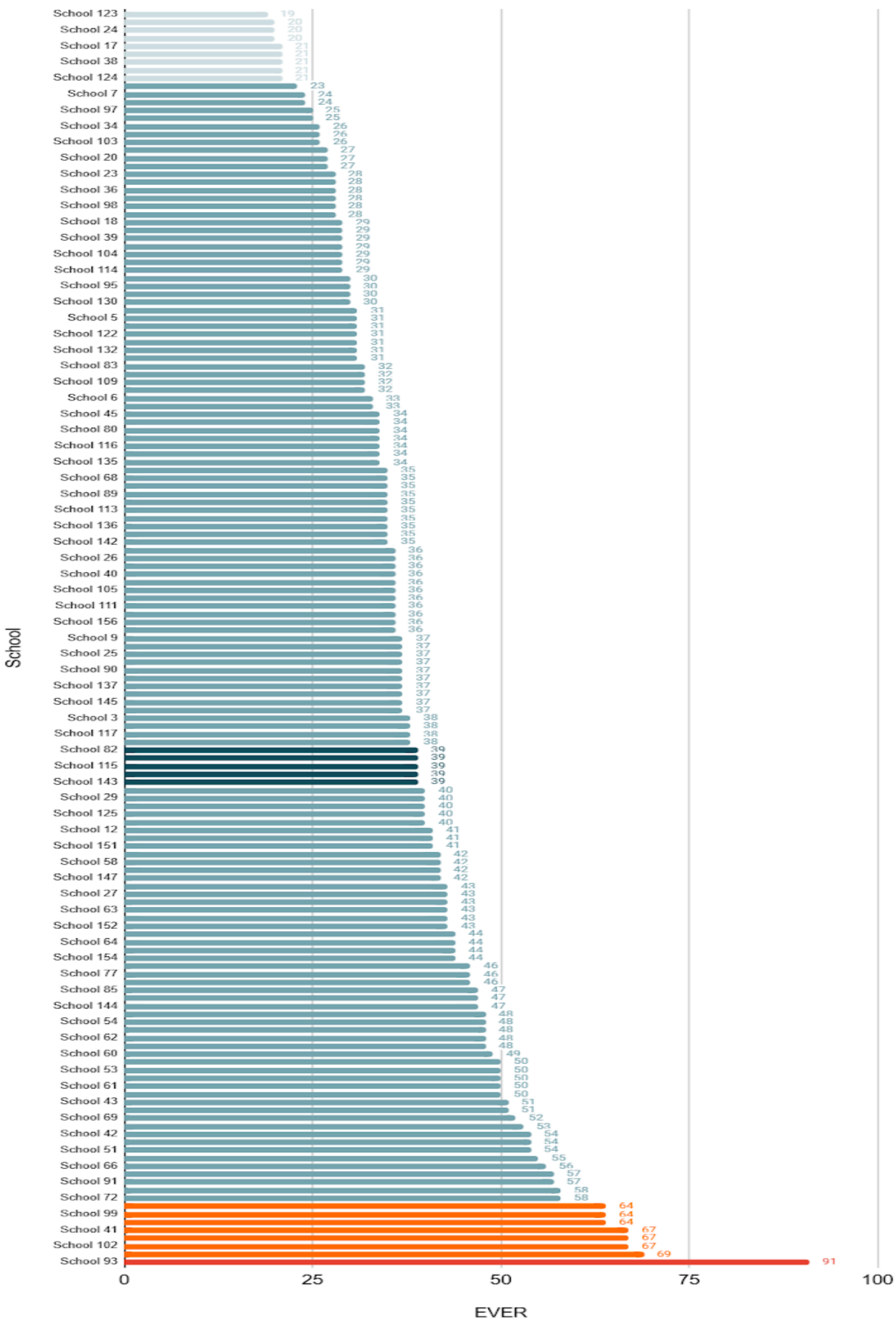
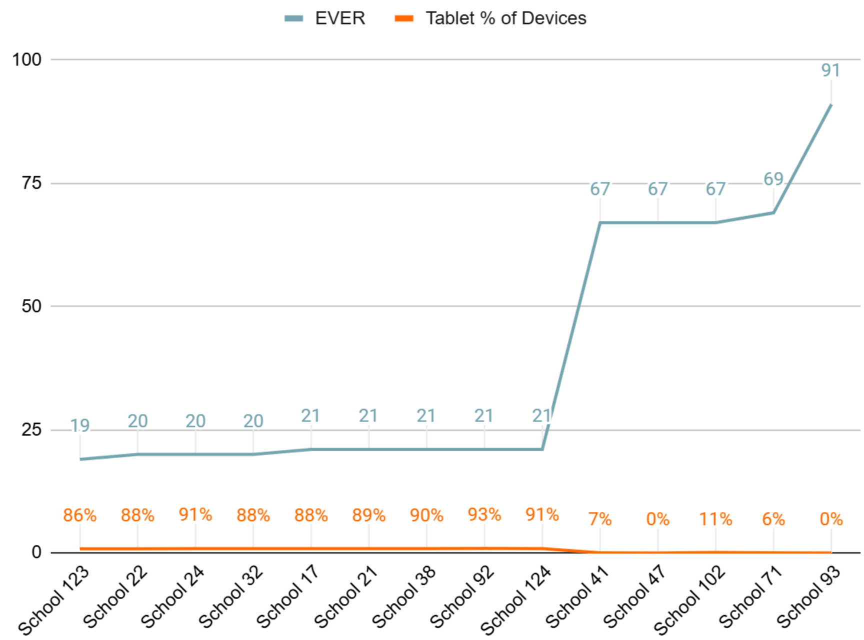


Figure 16. Highest and lowest EUC Volume of Emissions Ratio (EVER) metrics for primary schools versus percentage of tablets of all devices by school



To emphase the benefit of doing so, Figure 17 compares lowest available carbon footprint devices with the average examples captured during the research. In each instance, the value shown represents a combination of scope 2 and 3 emissions for 1 year when each device is kept for 8 years to ensure equivalent comparison.

Figure 17. New low carbon footprint mobile device annual carbon footprint versus existing static devices

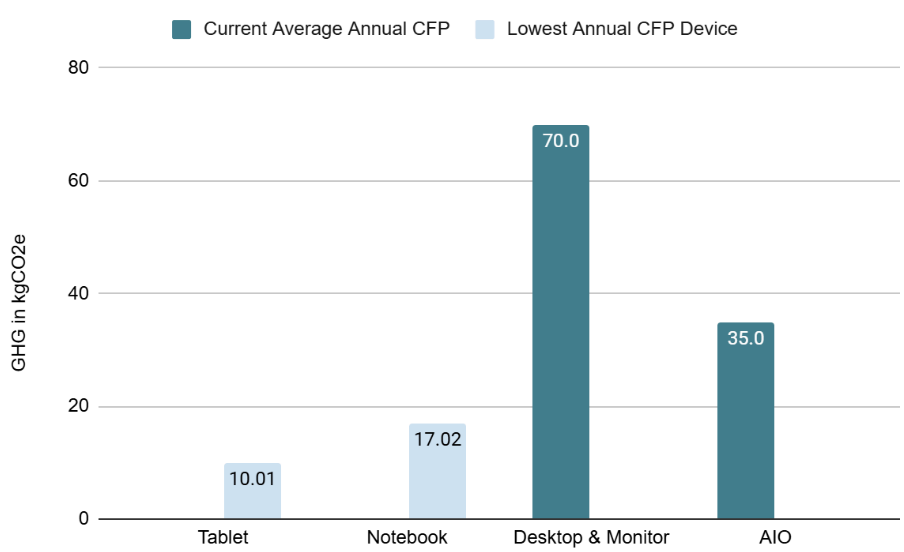


Figure 17 shows that transitioning from a desktop and monitor combination to a tablet can reduce annual GHG emissions by 86% per device (59.9 $kgCO_2e$). While this may be viable for many pupils as determined by the high percentage of tablets in primary schools (Figure 1), it is evident that notebooks remain popular too (Figure 1). Transitioning from the same desktop combination to a low carbon footprint reduces annual emissions by 76% (52.98 $kgCO_2e$) per device.

As such, when considering both environmental and financial metrics associated with primary school end user computing, stakeholders must include the following strategies:

- Lifespan extension
- Carbon footprint as a selection criterion
- Transition to mobile computing

As an average, by adopting sustainable EUC strategies within primary schools, both planet and profit metrics will improve. Specifically, doing so will reduce annual carbon footprint by 57%, e-waste by 54% and combined procurement and utility costs by 35%.

Secondary Schools

Secondary schools in England are typically for students aged 11-16, although in the context of this research some schools also offer primary schooling and/or offer 6th form education. For secondary only schools the learning years include Year 7-11. This therefore includes education Key Stage 3 (11-14 years of age) and Key Stage 4 (14 to 16 years of age). For schools offering 6th Form education, learning years also include Years 12-13 covering AS and A2 (16-18 years of age). Schools also including primary also include Key Stage 1-2 (5-11 years of age) as previously described. Only schools offering free education to students are included within the research meaning that private fee paying schools are not represented.

To reflect the primary school results, the secondary school results are presented firstly as a physical representation of assets (e.g. type, size, OS, age) and secondly from a carbon footprint perspective (e.g. energy, supply chain and e-waste). Again, this enables an average baseline for a single secondary school to be formed. This can then be subjected to sustainable ICT modelling strategies to show potential improvement. By doing so, the secondary school 'before and after' results can be compared to average results for other school types (e.g. primary) and extrapolated to represent a national current and potential impact. During the four month data collection period from October 2024 to January 2025, a total of 69 secondary schools participated representing 29% of research participants.

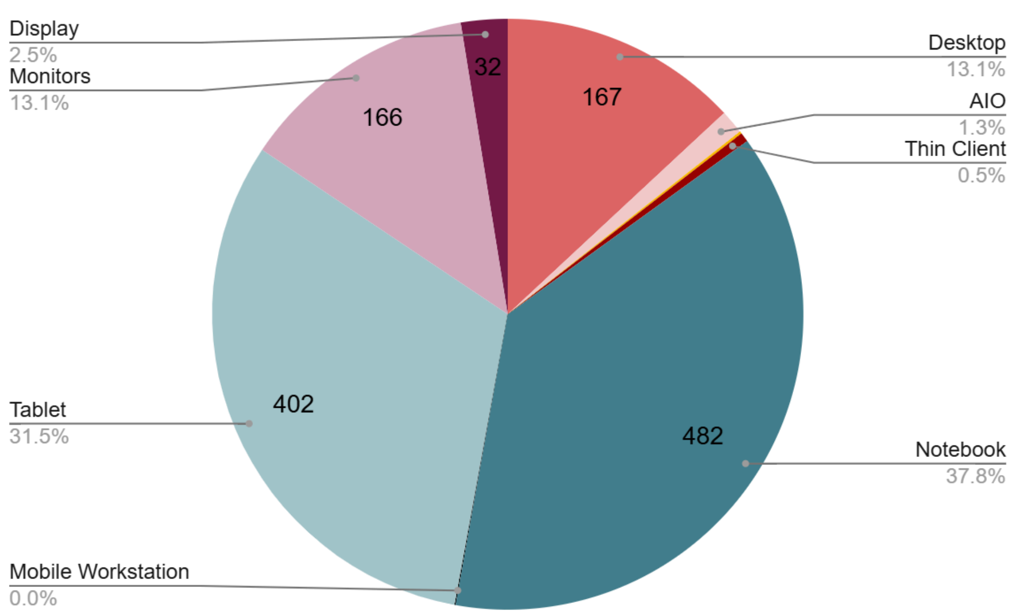
Similar to the primary schools, eight of England's nine geographical regions are represented with the exception of the North East.

Secondary Schools Physical EUC Asset Profile

Data for almost 88,000 EUC devices is captured, with 607 specific models of device from 53 brands identified. The data shows that an average secondary school has 1,091 computer users. In comparison, this is just over three times more than primary schools with 348 users on average. Of these, 999 are students (92%) and 92 staff (8%). Therefore, the proportion of students as computer users in secondary schools is 3% more than primary schools. Each secondary school has 1,274 EUC devices, represented by 1,075 computers (84%), 166 monitors (13%) and 32 displays (3%) (Figure 1). This equates to an EUC asset list of 482 notebooks (38%), 402 tablets (32%), 167 desktops (13%) and monitors, 17 AIO desktops (1.3%), 6 thin clients (0.5%), 2 workstations (0.15%), 1 mobile workstation (0.08%) and 32 interactive displays (2.5%) (Figure 18).

Mobile computing accounts for 82% of all computers (Figure 18). Compared to primary schools, this is proportionately 13% lower (Figure 1). This is because static computers increase in popularity from 4% to 13% for desktops and 0.6% to 1.3% for AIO devices. Also, thin clients and desktop workstations appear in secondary schools (0.65%) whereas they are absent in primary schools. Notebooks represent 45% of computers and tablets 37% (Figure 18). This is different to primary schools that on average have 52% tablets and 43% notebooks (Figure 1). As such, it is reasonable to suggest that as students become older, notebooks become the most popular device.

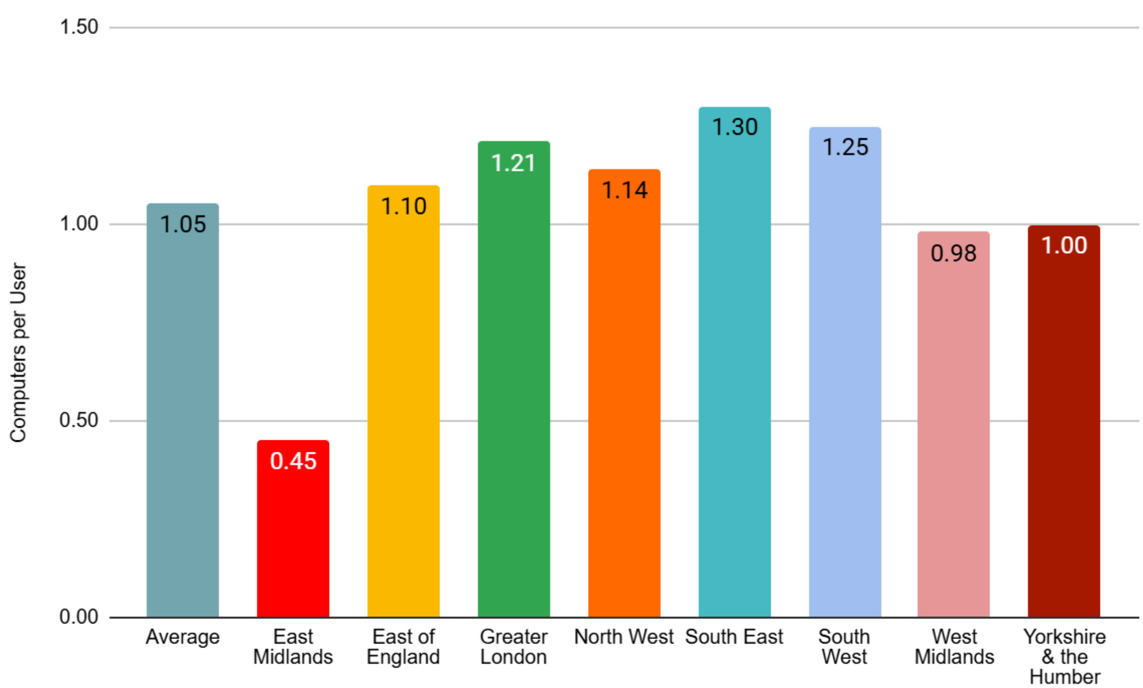
Figure 18. Secondary school average EUC device quantities by type



Therefore, the average ratio of computers to users is 1:1, meaning there is one computer available for every student. As shown in Figure 19, this ratio varies by region. The South East has the highest mapping of 1.3, while the East Midlands region has the lowest of 1 device for every 2 students. (Figure 19). The reason for this disparity is not within the scope of this research. However, the East Midlands region is represented by a single school and will therefore arguably create an anomaly. On examination, the school notes online that it is currently over subscribed by 27% which may account for the variation from the norm.

The average ratio of 1:1 is slightly higher than primary schools at 0.9 of a computer per user. The East of England, North West and Yorkshire and Humber are comparable in ratio for both primary and secondary (Figures 2 and 19). Notable differences occur in Greater London and the South East where computer availability rises from 0.8 computers per user to an average of 1.25 (Figures 2 and 19). Plus the South West rises from the previously lowest ratio of 0.6 computers per user in primary schools (Figure 2), to 1.25 in secondary (Figure 19).

Figure 19. Secondary school average EUC computer per student ratio by geographic region



The most popular notebook size in secondary schools is 11" (67%), followed by 14" (12%) and 15" (11%). This correlates with primary schools at 68%, 11% and 11% respectively. 9% of notebooks are 13", while less than 1% are 16". This differs from primary schools that have 9% of notebooks in the 16-17" category.

Overall, notebook operating system choice is predominantly ChromeOS (70.5%), followed by Microsoft Windows (29%), and MacOS (<1%). This closely matches the primary schools results and once again it is the 11" sized notebook causing the anomaly. Specifically, 92% of these small sized devices are ChromeOS compared to 90% in primary schools. While sizes 12-17" are 68% Windows, 32% ChromeOS and <1% MacOS. In this size category, Windows also has a 14% smaller notebook install base than primary schools (82%).

The results support the hypothesis that, as suggested previously, the abundance of 11" notebooks are due to budget and that from a cost perspective, the small Chromebooks are an affordable and fully functional computing alternative. The question was posed to the Department for Education and they agreed, highlighting that during the pandemic it was imperative to ensure computer to user ratios were elevated to as close as 1:1 as was feasible to enable home schooling. The 11" Chromebook proved both affordable and available, resulting in over 1 million units being distributed to English schools. The statement both supports economic viability as a driver plus the computer to user ratios of 0.9 in primary and 1 in secondary schools.

Unlike primary schools, a small percentage of devices are mobile workstations (0.08%). For these notebook devices, all are 15" in size and installed with Windows.

The most popular tablet size is a 10" screen (98%), followed by 7"-9" (1%) and 11" and above (1%). This correlates with the size distribution found in primary schools. Therefore, it is reasonable to suggest that screen sizes between 10-11" for both tablets and notebooks are deemed suitable for students.

Tablet OS install base in secondary schools is dominated by iPadOS with 91% of devices being iPads. This is 19% higher than in primary schools. This is followed by 8% Android meaning that the increase in iPadOS affects. Both Windows and ChromeOS have less than 0.5% share of tablet operating systems, similar to primary schools. As before, from an operating system perspective, the results are relatively concurrent with global statistics in the fact that both iOS (Apple) and Android lead the market.

Secondary school desktop computers are predominantly SFF (58%). In comparison to primary schools this is 18% lower. The reason is because USFF is 18% more popular at 41% of all desktops; while tower format dwindles in popularity at 1%. Microsoft's Windows operating system is the most popular, installed on 87% of desktops, although this is 7% lower than primary schools. This OS share is taken by ChromeOS at 12.5%. While MacOS represents less than 0.5% for desktops in schools.

Unlike primary schools a small percentage of desktop workstations (0.15%) and thin clients (0.5%) are used in secondary schools. All workstations were installed with Windows and 64% USFF, 23% SFF and 13% tower. This indicates that while tower formats used to be required to house large capacity hard drives, solid state high speed and capacity drives have enabled the most popular format to transition to the smallest of sizes. For thin clients, 100% of devices were Linux based and USFF.

Integrated desktops (AIO) in secondary schools are predominantly 22" (46%) which is 8% lower than primary schools. This is followed by 20-21" (29%), 24" (22%) and 27" (3%). The use of larger 27" and 5% increase in 24" account for the lower percentage of 22" devices when compared to primary schools. Similar to desktops, Windows is installed on 87% of all AIO and this is 5% less than in primary schools. This is due to Apple's MacOS representing 13% which is an increase of 12% share when compared to primary schools. ChromeOS did not appear in this category.

As noted, displays refer to Interactive Displays for use within classrooms as teaching tools and range from 55-98". In secondary schools, the most popular size interactive displays are 75" (68%), followed by 65" (27.5%), 85" (3.5%), 55" (0.9%) and 98" (0.1%). The main differences between secondary and primary school interactive displays are that 65" are more popular in primary schools (58%) than 75" (36%). For secondary schools the Android operating system is installed on 100% of devices, which correlates with primary school results.

As previously noted, monitors refer to computer user focused displays used as an external peripheral device in conjunction with a computer. The most popular size is 27" (47%), followed by 22" (20%), 19-20" (18%), 24" (9.5%), 23" (2.5%), 17" (<3%), 14-16" (0.1%). Sizing preferences are consistent with primary schools, although it is noted that 19" monitors constitute one in ten within secondary schools and almost absent in primary. These particular variants are mainly produced by Dell.

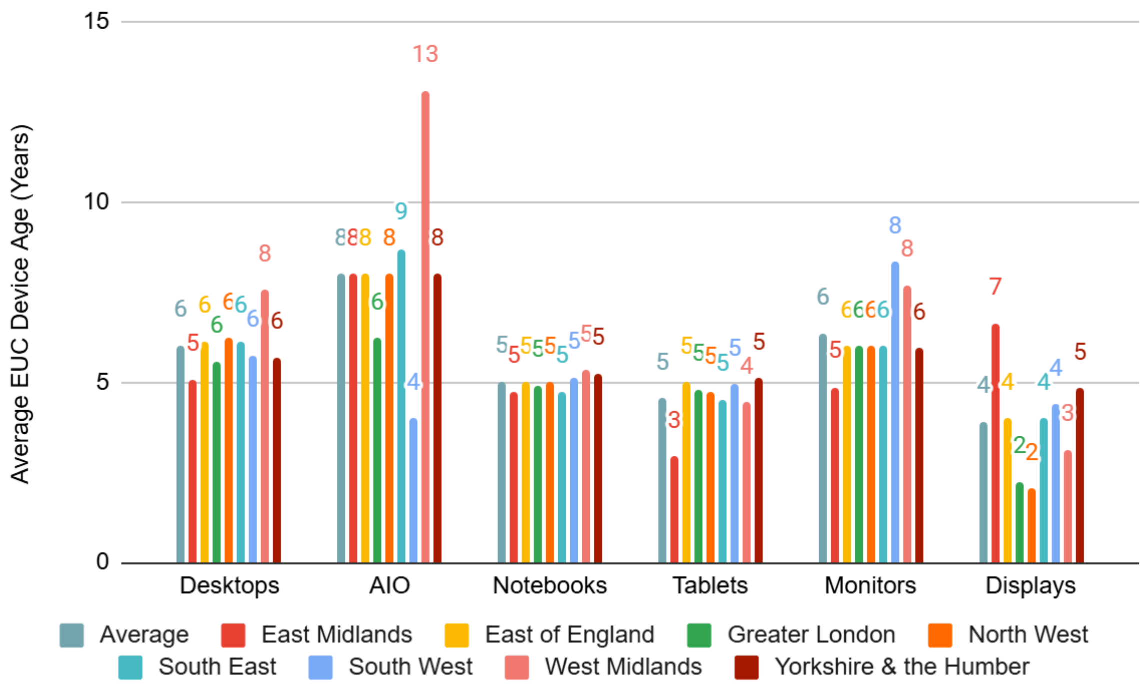
As would be expected and as highlighted in the primary school results, equipment age in secondary schools also differs by device type and varies by region. As shown in Figure 20, the desktop average age is 6 years, AIO 8 years, notebooks 5 years, tablets 5 years, monitors 6 years and displays 4 years. Desktops and monitors differ from the primary school results, with both being 1 year newer than the previous 7 year average age (Figures 3 and 20). Similarly, displays too are 1 year newer than the primary school average of 5 years (Figures 3 and 20).

From a regional perspective, there is no definitive location that has older equipment than others. However, obvious highlights of retaining devices for longer periods are evident in the West Midlands where desktops are retained for 8 years on average, AIO 13 years (63% higher than the average) and monitors 8 years (Figure 20). The area does however exhibit the second lowest retention period for tablets and displays 4 years (Figure 20).

The conclusive result for both data sets is that mobile devices including both notebooks and tablets are retained for 5 years and AIO for 8 years (Figures 3 and 20). Whereas, desktops and monitor combinations average between 6-7 years in schools (Figures 3 and 20). Interactive displays are a somewhat more recent addition to schools having transitioned from digital whiteboards often accompanied by projectors. As such, it is anticipated, although not yet proven, that interactive displays will be retained for similar periods to monitors in the future.

As highlighted by the primary school sustainability lifespan extension strategy modeling, retaining EUC devices for longer periods will reduce carbon footprint and cost. However, in relation to the impending EOL of Windows 10, the same issue is present in secondary schools.

Figure 20. Secondary School average EUC device age by type and geographic region



Within English secondary schools, 16% of Windows desktops, 60% of Windows AIO computers and 7% of Windows notebooks were manufactured during or before 2017. This means that based upon proportional representation of device types (Figure 18) and accounting for operating system popularity, 23 desktop computers, 9 AIO computers and 10 notebooks in an average secondary school will not meet the Windows 11 upgrade criteria.

In comparison to primary schools, the percentage of devices affected per school by Windows 10 EOL is far lower. As an example, the proportional percentage of desktops requiring Windows intervention in primary schools is 23% higher than secondary schools, AIO 10% higher and notebooks 6% higher (see primary schools section). However, as the number of these devices owned per average secondary school is far greater, then per school the replacement figure is higher in secondary schools. Specifically, for each secondary school 18 more desktops are affected, 8 more AIO and 4 more notebooks. Nationally, the impact comparison between school types is again influenced as five times more primary schools exist than secondary schools. The impact of this is outlined in the Windows 10 strategy below.

As previously noted, monitor obsolescence is less frequent and it is common for the device type to be kept for longer periods than computers (Figures 3 and 20). As an example, within secondary schools 13% of monitors were found to be 8 years and older with a limited number of models (1%) over 20 years old. Comparatively, the percentage monitors in primary schools 8 years or above were twice those of secondary schools at 26%. While research shows that supply chain emissions create 85% of EUC emissions, older monitors consume high levels of electricity compared to modern counterparts. As such, it is feasible that there is an inflection point at which monitors should be renewed to avoid excess scope 2 emissions contribution to the lifespan carbon footprint. Equally, electricity cost driven by old monitors may prove uneconomic and as such require intervention. This is discussed further below.

Summarising the profile results and accounting for all device types and type specific attributes, an average secondary school EUC estate consists of the following device proportional representation:

- 482 notebooks consisting of 340 Chromebooks, 140 Windows notebooks, 2 MacBooks
- 1 mobile workstation (Windows)
- 402 tablets consisting of 366 Apple iPads, 32 Android, 2 Windows and 2 ChromeOS
- 167 desktops consisting of 145 Windows desktops, 21 Chromeboxes and 1 Mac Mini
- 6 thin client desktops (Linux)
- 2 workstations (Windows)
- 17 AIO desktops consisting of 15 Windows and 2 Apple iMac
- 166 monitors consisting of seventy eight 27", thirty three 22", thirty 19-20", fifteen 24", four 23", five 17" and one 14-16"
- 32 interactive displays including twenty two 75", nine 65" and one 85"

Secondary School Environmental and Energy Results by Device Type

Environmental and financial results for the 87,902 EUC devices captured within the secondary school data sample (including 607 models and 53 brands) are calculated at a specific model level to ensure maximum accuracy. The exception to this is that an average value for a device by type is applied to calculate annual procurement costs as described previously.

In the same way data is calculated for primary schools, the model level results are used to generate averages for each device type. This enables a current average secondary school environmental impact and cost baseline, plus the subsequent three proposed sustainable ICT strategies. As before, an EVERY per capita value is generated in each instance.

Mobile Devices

Table 5 shows the average secondary notebook annual electricity consumption is 11.71 kWh/y generating 2.42 kgCO_2e. This is 5% lower than primary school average (Table 1) and driven by the higher percentage of ChromeOS notebooks found in secondary schools (70% versus 68%). Specifically, in secondary schools Chromebooks consume 8.9 kWh/y compared to the Windows average of 19.1 kWh/y and MacOS of 10.5 kWh/y per notebook. The results concur with existing research highlighting that, as previously noted, Chromebooks require less power draw when in active use.

The average notebook supply chain emissions value per unit is 195 $kgCO_2e$ (Figure 21) and concurs with the primary school results (Figure 4). This creates an annual scope 3 emissions value of 39 $kgCO_2e$ per unit (Table 5). Figure 20 shows that secondary school notebooks are retained for 5 years on average. Therefore, the lifespan carbon footprint for an average notebook is 207 $kgCO_2e$, meaning notebooks create 41.42 $kgCO_2e$ GHG emissions annually (Figure 21). In this instance, scope 3 emissions therefore account for 94% of the overall product carbon footprint (Figure 21).

The average weight of a notebook is 1.49 kg and therefore the annualised e-waste potential is 0.3 kg per unit (Table 5).

Mobile workstations are essentially a notebook but often with a higher than average component specification. In this instance, energy consumption per unit was equivalent to a standard Windows notebook average (19.1 kWh/y) producing 3.95 $kgCO_2e$ annually (Table 5). However, Table 5 shows supply chain emissions were 51% higher at 295 $kgCO_2e$ (59 $kgCO_2e$ annually), plus e-waste increased by 26% due to an average weight of 1.88 kg (0.38 kg annually). Overall, the mobile workstation average lifespan carbon footprint was 314.75 $kgCO_2e$ and 62.95 $kgCO_2e$ annually (Figure 21). Therefore, the supply chain accounts for 94% of the carbon footprint and the use-phase 6% (19.75 $kgCO_2e$). In context, the total footprint is 52% higher than an average standard secondary school notebook (Figure 21).

Average tablet electricity consumption in secondary schools per year is 14.64 kWh/y generating 3.03 $kgCO_2e$ (Table 5). This is 25% higher than the notebook average (Table 5). In the same way as for primary schools, the difference is driven by the majority of notebooks being a combination of small screen (11") Chromebooks that are high energy efficient. As an example, when compared to the Windows notebook average, energy consumption is 30% lower. When compared to the primary school tablet average of 13.25 kWh/y (Table 1), the secondary school average is 10% higher. This is driven by a 9% increase in iPad popularity in secondary schools. Specifically, the iPadOS devices have an average of 15.3 kWh/y in secondary schools which concurs with primary school results.

Secondary school tablet supply chain average emissions are 68 $kgCO_2e$ meaning that the annual value is 13.6 $kgCO_2e$ (Table 5). This is 30% lower than primary school averages (Table 1) and driven by the higher adoption of low supply chain carbon footprint iPads in secondary schools. Considering this, the fact that notebooks are, in this instance, more energy efficient than tablets, it is important from an environmental perspective to examine the entire lifespan carbon footprint of devices.

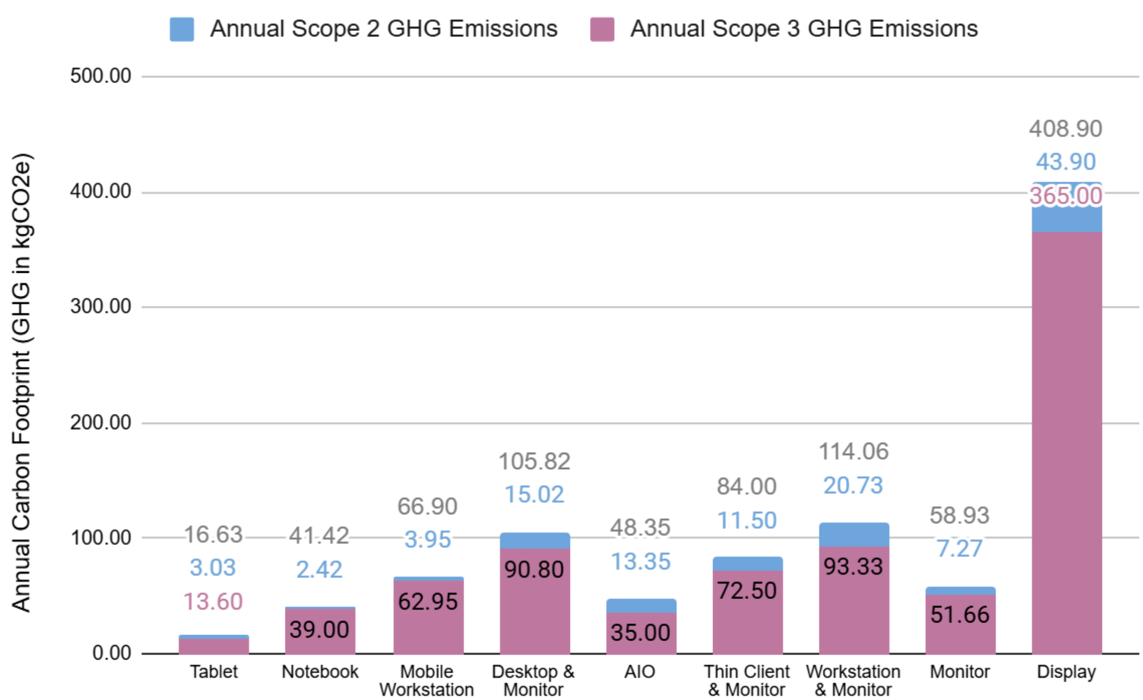
During 5 years of use, the lifespan carbon footprint of a secondary school tablet is 83 $kgCO_2e$, meaning tablets create 16.6 $kgCO_2e$ annually (Figure 21). Therefore, supply chain emissions are responsible for 82% of the product carbon footprint and the use-phase of 15.15 $kgCO_2e$ is responsible for 18% (Figure 21). When compared to the lifespan of a notebook during the same 5 year period (Table 5), the tablet has a 60% lower total carbon footprint. Therefore, despite tablets consuming more energy they generate two thirds less total lifespan emissions and therefore carbon footprint than a notebook.

The average weight of a tablet is 0.48 kg and therefore the annualised e-waste potential is 0.10 kg per unit (Table 5).

Table 5. Average secondary school annual environmental and financial results by device type (one unit)

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	1	5	13.60	3.03	16.63	14.64	£4.54	£99.80	0.10
Notebook	1	5	39.00	2.42	41.42	11.71	£3.63	£119.80	0.30
Mobile Workstation	1	5	62.95	3.95	66.90	19.10	£5.92	£119.80	0.38
Desktop & Monitor	1	6	90.80	15.02	105.82	72.50	£22.48	£166.33	1.50
AIO	1	8	35.00	13.35	48.35	64.50	£20.00	£99.80	1.04
Thin Client & Monitor	1	6	72.50	11.50	84.00	55.54	£17.22	£166.33	0.93
Workstation & Monitor	1	6	93.33	20.73	114.06	100.14	£31.04	£166.33	1.58
Display	1	4	365.00	43.90	408.90	212.00	£65.72	£249.75	12.94

Figure 21. Secondary school average EUC device annual carbon footprint (GHG emissions $kgCO_2e$)



Static Devices

Average annual desktop computer electricity consumption is 37.4 kWh/y per device (Table 5 shows the value combined with a monitor). This produces 7.75 kgCO_2e of scope 2 emissions for each year of operation (Table 5). This is 9% lower than primary school desktops (Table 1) and caused by two factors. Firstly, USFF sized desktops are 18% more popular in secondary schools and these devices are highly efficient, with an average energy consumption of 20.25 kWh/y. Secondly, Chromebox popularity is 7% greater in secondary schools. While these devices too are USFF, they also consume 68% less electricity than the desktop average at 11.72 kWh/y.

The average supply chain carbon footprint value for secondary school desktops is 235 kgCO_2e (Table 5). Due to the increased percentage of smaller USFF devices, this is 10% lower than the primary school desktop average (Table 1). The annual scope 3 GHG emissions value is 39.17 kgCO_2e (Table 5 and Figure 21). This is 5% higher than primary schools (Figure 4) due to the average lifespan in secondary schools being one year less (Figure 20), which increases annual supply chain values as devices are replaced more regularly. As such, despite the 10% improvement achieved in supply chain emissions per desktop unit, this is undone by shorter retention periods.

Based upon the 6 year average retention for desktops (Figure 20), the total lifespan carbon footprint of an average desktop in English secondary schools is 281.5 kgCO_2e, therefore desktops create 46.9 kgCO_2e per year. This is 2% higher than the annual average achieved in primary schools of 45.8 kgCO_2e GHG emissions (Figure 4). Meaning that 83% of desktop computer carbon footprint is attributed to supply chain and 17% (46.5 kgCO_2e) to electricity consumption during use.

An average secondary school monitor consumes 35.10 kWh/y generating 7.27 kgCO_2e (Figure 21 and Table 5). Considering that use patterns are similar between schools, it is arguably surprising that this is 22% lower than primary school average monitor energy consumption (Figure 4 and Table 1). Upon examination the issue is caused by the difference in age of monitors between the school types. In primary schools 26% of all monitors are between 9-20 years old, while in secondary schools this is only 11%. Specifically, the average power consumption for monitors 8 years or newer was found to be 45% less than the power consumed by monitors between 9-20 years.

While increasing the number of years a device is kept will decrease scope 3 annual supply chain emissions, it is recommended that schools be conscious of the ongoing influence older monitors have on electricity consumption and costs plus concomitant scope 2 emissions. However, as primary schools have just 13 monitors on average per school (Figure 1), then the additional cost of energy due to aged monitors is £39.89 per year. Comparably, replacing 3 (26% of all) monitors will add £171 in procurement costs to each year the new devices are owned (Table 1); far outweighing the additional utility cost.

Similarly, replacing the 3 old monitors will generate 128 kgCO_2e in new annual supply chain emissions across the coming 7 year retention period (Figure 4). As the incremental scope 2 emissions for the 3 old monitors is only 6 kgCO_2e then replacement makes no sense from an environmental perspective. Consequently, in line with the previous lifespan extension strategy findings, retaining existing equipment for the longest feasible period is indicated to be the most effective strategy.

Average secondary school monitor supply chain emissions are 310 kgCO_2e and therefore 51.66 kgCO_2e per year (Table 5). This is 21% higher in total due predominantly to the fact that primary schools keep monitors for one extra year on average (Figure 3). Based upon the 6 year average monitor retention period experienced in secondary schools (Figure 20), the lifespan carbon footprint is 354 kgCO_2e, creating 59 kgCO_2e of GHG emissions annually (Table 5). Again, due to the shorter retention period but improved efficiency, the difference to the primary school average reduces to 13%.

Therefore, when a monitor is coupled with a desktop computer, the lifespan carbon footprint per device pairing is 635.4 kgCO_2e or 105.90 kgCO_2e for each of the 6 years the device is in operation (Table 5 and Figure 21). Notably, despite efficiency and impact gains in supply chain and use-phase emissions in secondary schools, the annual value is 8% higher than primary schools (Table 1) due to the shorter retention period in secondary schools (Figure 20.

Additionally, the average combined weight for a desktop (4 kg) and monitor (5 kg) is 9 kg. While the secondary school desktops are lighter than the primary school devices (4.26 kg) due to their being predominantly USFF, the increase in adoption of 27" monitors from 32% in primary schools to 47% in secondary schools causes the combined weight to be relatively equal in both school types (Tables 1 and 5). In this instance the annual potential e-waste is 1.5 kg (Table 5).

Secondary school AIO average electricity consumption is 64.5 kWh/y (Table 5) and generates 13.35 kgCO_2e per year (Table 5 and Figure 21). This is 9% higher than primary schools (Table 1) because, as previously noted, larger screen sizes are more popular for AIO devices in secondary schools. When compared to the secondary school desktop and monitor combination, the AIO device is 11% more energy efficient and therefore produces the same percentage less scope 2 emissions (Table 5 and Figure 21).

Average AIO supply chain emissions are 280 kgCO_2e per unit and therefore scope 3 emissions are 35 kgCO_2e per year (Table 5). This is equal to the primary school results (Table 1) and 61% lower than when compared to supply chain emissions for the secondary school desktop and monitor combination (Table 5).

Figure 20 shows that on average AIO devices are kept for 8 years as is the case with primary schools. Therefore, the lifespan carbon footprint is 387 kgCO_2e (Figure 21). This means that the annual carbon footprint is 48.35 kgCO_2e (Table 5). In this example, the supply chain emissions are responsible for 72% of the product carbon footprint.

The average weight of an AIO device is 8.22 kg and therefore the annualised e-waste potential is 1.02 kg per unit (Table 5) and similar to primary schools (Table 1).

In secondary schools, thin client and workstation desktop computers also appear in small numbers (Figure 18). When coupled with a monitor, the thin clients consume 55.54 kWh/y and generate 11.50 kgCO_2e of annual scope 2 emissions (Table 5). This is 23% lower than the desktop average and 14% lower than the AIO average (Table 5). Therefore, thin clients offer an opportunity for schools to reduce both scope 2 emissions and utility costs. However, thin clients require additional data centre infrastructure to host virtual desktop instances. Where this data centre is situated must be considered. As an example, if it is an 'on premises' data centre located at the school, then the organisation will incur additional carbon footprint generation and electricity consumption. Whereas, if the virtual instance is located with a cloud provider, such as Windows 365, then the additional consumption and emissions may be the responsibility of the provider rather than the school.

Research shows that for one thin client virtual instance, an extra 30.7 kWh/y will be consumed in the data centre [50]. Consequently, if the data centre is on premises then the annual electricity consumption for the thin client solution rises to 86.24 kWh/y. This becomes 19% higher than a standard desktop solution and 34% higher than an AIO device (Table 5).

Scope 3 supply chain emissions for the average thin client when coupled with a monitor are 435 kgCO_2e and 72.5 kgCO_2e per year (Table 5). This is 20% lower than the equivalent desktop (Table 5) although, data centre supply chain values must be considered too. The impact of this depends upon the scale in numbers of thin client users. In practice, the more users, the lower the scope 3 emissions are per user as the datacentre hardware becomes fully utilised. Research shows that for 1,000 users, annual scope 3 emissions can be as low as 3.3 kgCO_2e per user in data centres [50]. However, the schools average desktop computer numbers indicate that only 190 thin client desktop users would be commonplace if a wholesale transition to thin clients (excluding mobile devices) occurred (Figure 18). As such, the scope 3 data centre attribute per user is more likely to be 17.40 kgCO_2e per year. This raises the total annual supply chain carbon footprint for a thin client solution to equal the desktop and monitor offering at 90 kgCO_2e.

Setting aside on premises data centre overheads, the total lifespan carbon footprint for an average thin client and monitor combination is 504 kgCO_2e and 84 kgCO_2e per year (Table 5). This is 21% lower than a desktop plus monitor and 74% higher than an AIO (Table 5). The average weight of a thin client device is 0.57 kg and when coupled with a monitor this rises to 5.57kg or 0.93 kg per year of potential e-waste (Table 5).

A secondary school workstation when coupled with a monitor consumes 100.14 kWh/y and generates 20.73 kgCO_2e (Table 5). This is 38% higher than a desktop plus monitor and 55% higher than an AIO device (Table 5). The increase is caused by workstations being designed for high performance computing and as such the components require increased power draw when active.

Combined workstation and monitor supply chain emissions are 560 kgCO_2e or 93.33 kgCO_2e per year (Table 5). This is 3% higher than the equivalent desktop solution (Table 5). The average weight is 9.45 kg, meaning that potential e-waste per year is 1.58 kg (Table 5).

An average secondary school interactive display consumes 212 kWh/y of electricity annually (Table 5). This generates 43.9 kgCO_2e per year (Table 5 and Figure 21). This is 13% lower than primary schools (Table 1) and arguably surprising because, as previously noted, secondary schools use a higher proportion of larger 75" displays; 68% compared to 36% in primary schools.

The reason for the reduced energy consumption is driven by 34% of the 75" secondary school displays being a model with a particularly low on-mode power draw of 75 Watts (W). As an example, the highest on-mode of all 75" integrated displays found in secondary schools is 108% higher at 156 W. While the average was 33% higher than the low power device at 100 W. As an average display consumes over 6 times the electricity of an average monitor, it is reasonable to suggest the on-mode power draw is an important metric to consider when selecting interactive displays.

The average scope 3 emissions for an interactive display are 1,460 $kgCO_2e$ (Figure 21). This is 9% higher than primary school (Figure 4), which is to be expected due to the higher proportion of larger displays in secondary schools as noted. The annual scope 3 emissions are 365 $kgCO_2e$ (Table 5 and Figure 21). This is 36% higher than the primary school equivalent average (Table 1); because displays are indicated to be kept for one year less in secondary schools (Figure 3 and 20).

Figure 20 shows that the average display retention period is 4 years in secondary school. Therefore, the average lifespan carbon footprint is 1,636 $kgCO_2e$ (Figure 21) meaning the annual carbon footprint is 409 $kgCO_2e$ (Figure 21). Consequently, the supply chain is responsible for 89% and the use-phase is responsible for 11% of the product carbon footprint.

The average weight of an interactive display is 51.77 kg and therefore the annualised e-waste potential is 12.94 kg per unit (Table 5).

Average Secondary School EUC Estate Carbon Footprint and Energy Baseline

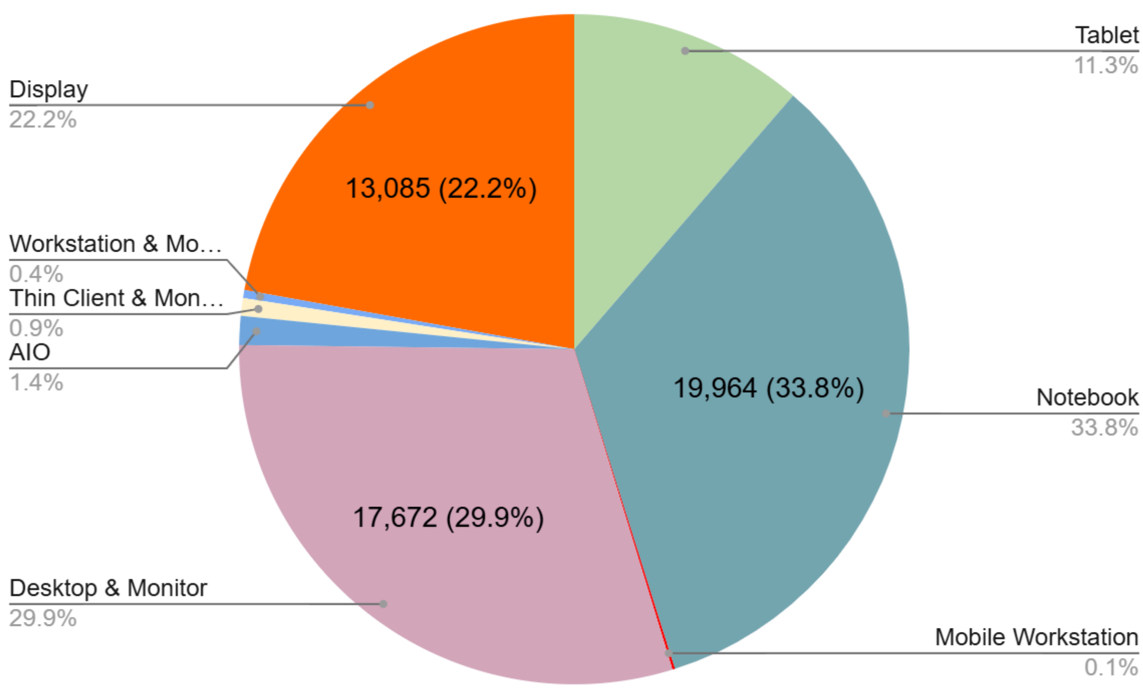
Combining the proportional representation (Figure 18) of EUC devices within an average secondary school and the carbon footprint by device type (Figure 22), the annual average carbon footprint for an entire EUC estate of 1,283 devices (Table 6 when monitors used in conjunction with static computers are included in the total) is 59,027 $kgCO_2e$ (Figure 22 and Table 6).

This is equivalent to emissions created by a combustion engine car travelling almost 347,544 km or almost nine times around the Earth's circumference. In context, for one average secondary school, 2,683 mature trees are required every year to remove this carbon from Earth's atmosphere.

Consequently, the per capita EVER ratio for an average secondary school is 1:46, meaning that for every device owned, 46 $kgCO_2e$ carbon footprint is generated annually. This requires 2 trees per year to sequester the carbon of each EUC device. The ratio is 18% higher than average primary schools and driven predominantly by the increase in desktop and monitor contribution to total annual emissions. Specifically, for primary schools 9.9% (Figure 5) of annual carbon footprint is caused by desktops, while for secondary schools this triples to almost 30% (Figure 22). This is simply because desktops appear in proportionally far higher quantities in secondary schools (167 units and 26% of total) than primary schools (13 units and 8% of total). Plus, as highlighted in table 1 and 5, a desktop and monitor combination is +536% higher than tablets which are the most common devices in primary schools (Figure 1).

The impact is highlighted by the fact that tablets make up 32% of secondary school device quantities (Figure 18), although due to their low carbon footprint per unit (Figure 21), the contribution to annual GHG emissions is 11.3% (Figure 22). Similar to primary schools, while displays represent only 2.5% of all secondary school devices (Figure 18), their high carbon footprint (Figure 21) per unit causes the contribution to the total impact to rise ninefold to almost 22% (Figure 22).

Figure 22. Secondary school average EUC device annual carbon footprint ($kgCO_2e$)

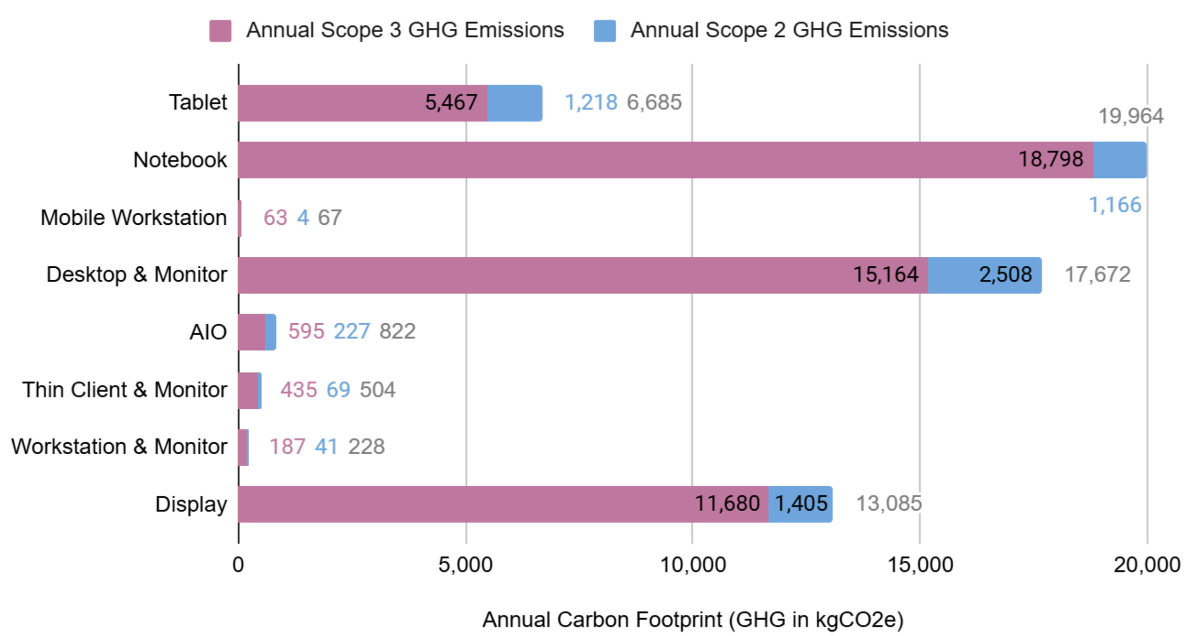


As indicated by Figure 22-23 and Table 6, display energy related emissions contribute significantly to annual scope 2 emissions. As an example, the 32 displays used in an average secondary school (Figure 18) generate 21% of all scope 2 annual emissions (Table 6 and Figure 23); while the 402 tablets contribute 18% (Table 6 and Figure 23). In secondary schools a single display consumes 14.5 times more electricity than one tablet in one year (Table 5). However, as discussed in the context of primary schools, the impact of displays should be considered in the context of a per pupil value. When in use, one display will be viewed by approximately 23 secondary school pupils and two staff. As such, annual electricity consumption becomes 8.48 kWh/y per user which is only 58% of electricity consumed by a single tablet (Table 5).

Table 6. Average Secondary school EUC estate annual environmental and financial results

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	402	5	5,467	1,218	6,685	5,885	£1,824.44	£40,120	38.6
Notebook	482	5	18,798	1,166	19,964	5,644	£1,749.71	£57,744	145.6
Mobile Workstation	1	5	63	4	67	19	£5.92	£120	0.4
Desktop & Monitor	167	6	15,164	2,508	17,672	12,108	£3,753.33	£27,778	250.5
AIO	17	8	595	227	822	1,097	£339.92	£1,698	17.6
Thin Client & Monitor	6	6	435	69	504	333	£103.30	£998	5.6
Workstation & Monitor	2	6	187	41	228	200	£62.09	£333	3.2
Display	32	4	11,680	1,405	13,085	6,784	£2,103.04	£7,992	414.1
Total	**1,109**		**52,388**	**6,639**	**59,027**	**32,070**	**£9,942**	**£136,781**	**875**

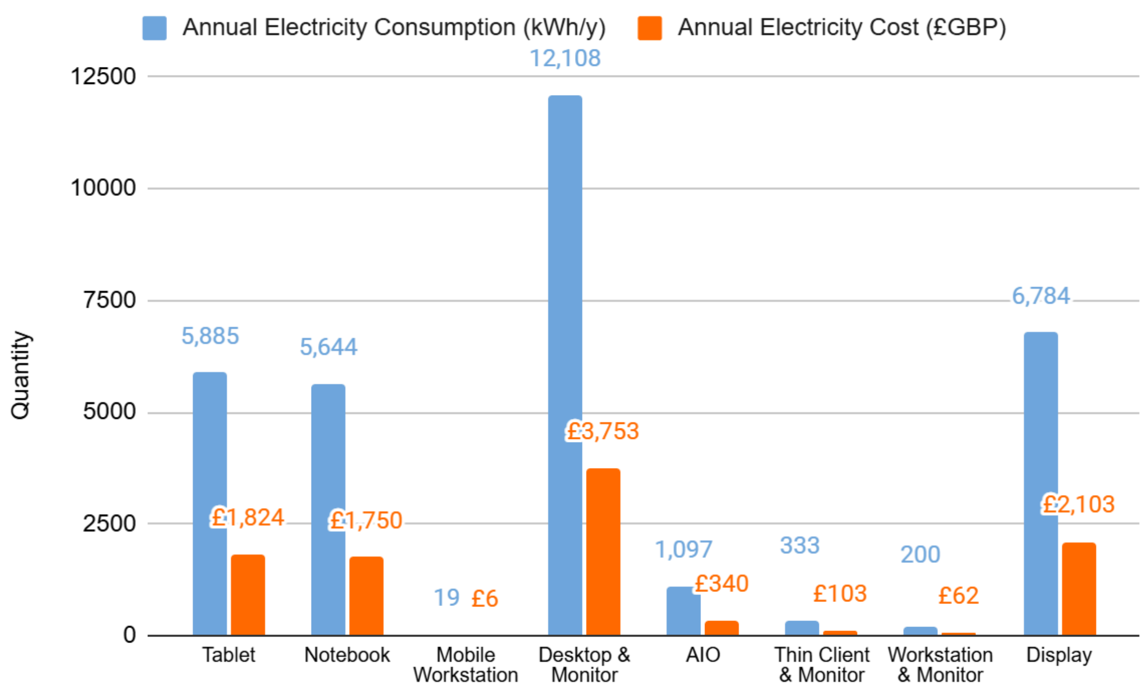
Figure 23. Secondary school average EUC estate device annual carbon footprint (kgCO_2e) by GHG scope type



Overall, secondary school EUC device supply chain emissions match the primary school percentage results by contributing 89% to the total (Figure 23). This means that use-phase scope 2 emissions generate on average 11% (Figure 23).

As previously noted, ICT operational factors, including device energy efficiency and school retention periods, will influence financial results. In relation to energy efficiency, the average secondary school EUC estate consumes 32,070 kWh/y of electricity (Table 6 and Figure 24), costing £9,942 per year (Table 6 and Figure 24). As secondary schools use almost four times more devices (Table 6) than primary schools (Table 2) due to school size, it is unsurprising that these values are 4.7% higher when compared. Although it is noted that the additional 0.7% is driven by the increase in percentage proportional representation of desktop and monitor combinations in secondary schools. Specifically, 4.1% of devices are desktops in primary schools (Figure 1) and 13.1% in secondary (Figure 18). Table 5 shows the difference in energy consumption for secondary schools tablets (14.64 kWh/y) and desktop/monitor combinations (72.50 kWh/y). Causing the utility cost per unit to rise from £4.54 (tablets) to £22.48 (desktops) per year (Table 5).

Figure 24. Secondary school average EUC estate device annual electricity consumption (kWh/y) and cost (£GBP)



Dividing the average new hardware costs outlined (see above) by the varying average retention periods discovered in secondary schools (Figure 20) produces an annual procurement cost by device type (Table 5). Figure 25 shows that this is equivalent to primary school results (Figure 8) where retention periods remain equivalent by device type. However, secondary schools keep both desktop style computers and displays for one year less than primary schools (Figure 3 and Figure 20). Therefore, annual procurement cost per unit increases by 16% to £166 (Figure 25) from £143 (Figure 8) and by 25% to £250 (Figure 25) from £200 (Figure 8) respectively.

Figure 25 shows the combined cost of each device type per year for a single unit. As the procurement costs are an applied average, it could be argued that a school may be able to purchase a desktop and monitor computer combination for a similar price to a notebook. However, considering notebooks offer a similar experience to desktops, it is notable that electricity cost for a desktop is +519% higher (£22.48 p.a.) than a single notebook (£3.63 p.a.) (Table 5 and Figure 25). As such, operational expenditure such as utility costs must be considered in the long term when function is similar between device types.

Figure 25. Secondary school average EUC device annual electricity and procurement cost (£GBP) per unit

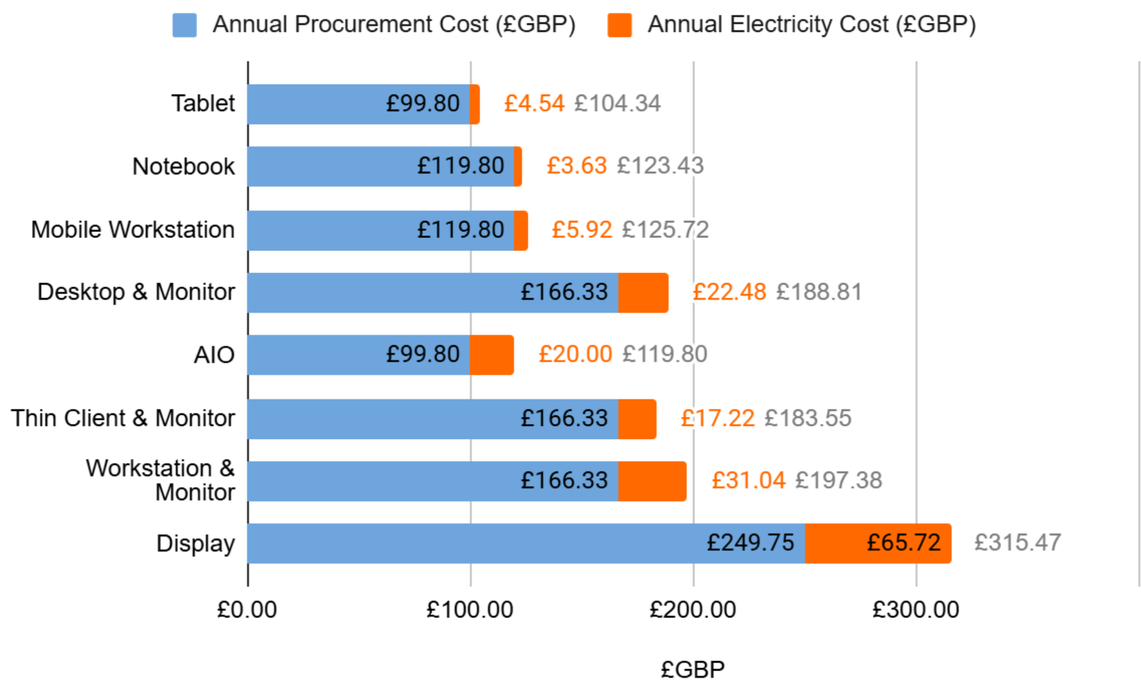


Table 6 and Figure 26 show that for an average secondary school EUC estate, £27,116

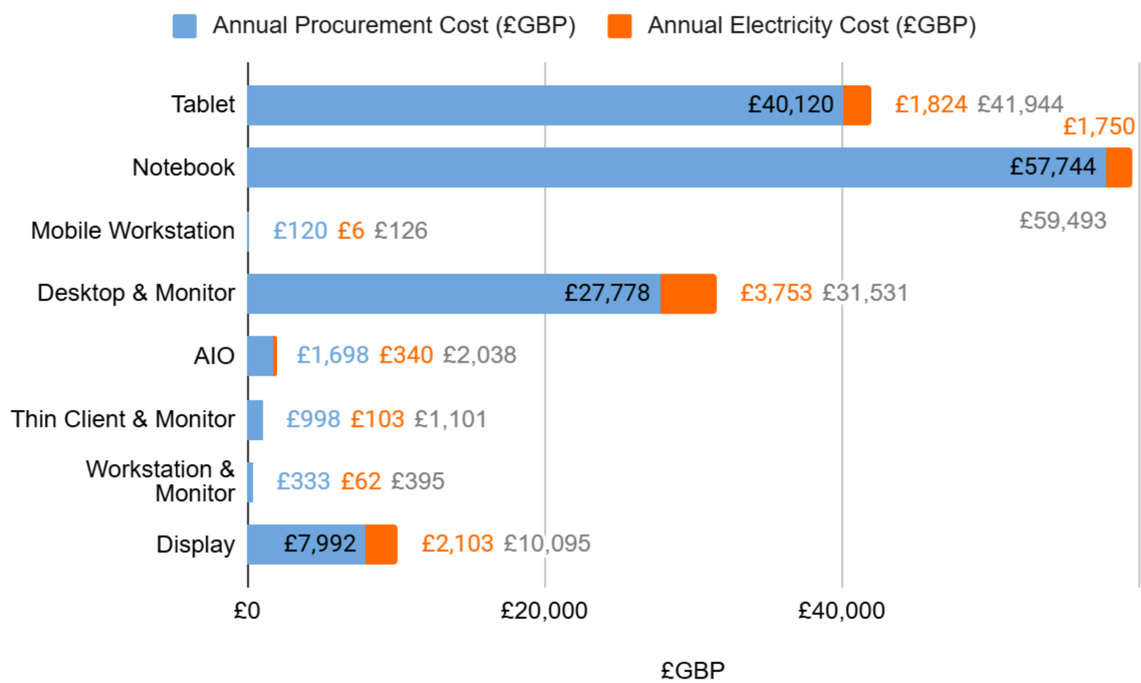
146,723 will be spent on combined electricity (£9,942 and 7%) and device procurement (£136,781 and 93%) annually. This means that with 1,283 devices in use in an average secondary school, each will cost on average £114.36 to purchase and use (Figure 26) per year.

Despite marginal differences in device type preference (Figures 1 and 18) and 12 months additional retention periods for displays and desktops (Figures 3 and 20), this value is almost identical to the primary school result (Figure 9). This is caused by mobile computers being responsible for the majority of devices in both instances (95% primary and 82% secondary) with the higher quantity of units of mobile devices in secondary schools (Figures 1 and 18) causing the overall average to correlate with primary schools.

Should the primary school unit proportional representation of device types (Figure 1) be applied to the secondary school annual monetary values (Table 6), the per unit price rises

2.5% to £117. This highlights that extended device retention periods and selecting energy efficient devices such as notebooks will reduce average procurement and utility costs.

Figure 26. Secondary school average EUC estate annual electricity and procurement cost (£GBP)



Sustainable EUC Strategies in Secondary Schools

To reduce short and long term carbon footprint and cost impact, three key sustainable strategies will generate differing results. The first is to address the impending replacement of devices affected by the Windows EOL event. Secondly, extension of device lifespans to a uniform period of 8 years. Thirdly, introducing carbon footprint as a selection criterion for new devices.

Secondary School Sustainable EUC Strategy 1: Windows 10 EOL

As noted, Within English secondary schools, 16% of Windows desktops, 60% of Windows AIO computers and 7% of Windows notebooks were manufactured during or before 2017. This means that based upon proportional representation of device types (Figure 18) and accounting for operating system popularity, 23 desktop computers, 9 AIO computers and 10 notebooks in an average secondary school will not meet the Windows 11 upgrade criteria [48].

For each secondary school in England, this will generate 9,875 $kgCO_2e$ of like for like new product supply chain GHG emissions and 181 kg of e-waste if the obsolete devices are replaced. It will also cost each school approximately £26,958 in procurement expenditure.

Currently, within England's state funded education sector there are 3,452 secondary schools. Therefore, extrapolated to a country level the potential impact of finding no alternative strategy to replacement will generate 34,088,500 $kgCO_2e$ of new product carbon footprint. This is equivalent to GHG emissions created by driving a combustion engine car 200.7 million km or just over 5,000 times around the world. This impact would require 1.55 million trees to sequester the resulting carbon from Earth's atmosphere.

Additionally, 624 tons of e-waste will be produced as the obsolete devices are sent for end of life services. In context, this is equivalent to 41.6 million aluminium soft drinks cans.

From a capital expenditure perspective, the cost to replace the devices will be in the region of £93 million unless alternative action is taken.

As previously noted in the primary school section, research shows that Windows devices lifespan can be extended by replacing the existing operating system with Google's ChromeOS Flex. Doing this creates devices similar to Chromeboxes and Chromebooks. Like primary schools, ChromeOS is already highly popular within secondary schools and installed on 70% of notebooks measured in this study. Therefore, deploying ChromeOS Flex to devices affected by the Windows 10 EOL event would most likely not meet with user resistance. Additionally, research shows that ChromeOS reduces electricity consumption by 19% when compared to Windows [47]. As such, with ChromeOS Flex it is feasible to entirely avoid new product supply chain GHG emissions, e-waste and procurement cost. Plus potentially lower ongoing utility costs.

In context, if the new product cost was annualised across an extended lifespan of 8 years, the additional annual EUC procurement spend caused by the Windows EOL event is £11,632,377 at a national level. Using an average teacher's salary, this saving would enable 342 more teachers to be employed in the secondary school sector during the coming decade.

The same preventative action in primary schools was calculated to enable 455 more teachers to be theoretically employed. Therefore, the combined feasible impact of avoiding disposal of devices with obsolete operating systems could enable a total of 797 additional teachers in primary and secondary education.

Secondary School Sustainable EUC Strategy 2: Device Lifespan Extension

Average lifespan of EUC equipment in secondary schools varies from 5 years to 8 years depending upon device type (Figure 20). Both the primary and secondary school assets included within this study show that it is feasible for all devices to be retained for a uniform

8 years. As an example, in both instances, AOI devices that include both a monitor and computer exhibit an average age of 8 years (Figures 3 and 20)

Consequently, as demonstrated in the primary school section, when the lifespan is uniformly extended to 8 years for all device types, both supply chain GHG emissions and annual procurement costs reduce simply because devices are purchased less often.

Table 7 shows that, as before, energy consumption, utility costs and concomitant scope 2 GHG emissions are not affected by lifespan extension strategies and remain identical to the current strategy. This is because the devices have not changed and therefore from an annual operating perspective these measurements will continue as before.

Table 7. Average secondary school EUC estate annual environmental and financial results with lifespan extension to 8 years applied

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	402	8	3,417	1,218	4,635	5,885	£1,824.44	£25,075	24.1
Notebook	482	8	11,749	1,166	12,915	5,644	£1,749.71	£36,090	91.0
Mobile Workstation	1	8	39	4	43	19	£5.92	£75	0.2
Desktop & Monitor	167	8	11,373	2,508	13,881	12,108	£3,753.33	£20,833	187.9
AIO	17	8	595	227	822	1,097	£339.92	£1,698	17.6
Thin Client & Monitor	6	8	326	69	395	333	£103.30	£749	4.2
Workstation & Monitor	2	8	140	41	181	200	£62.09	£250	2.4
Display	32	8	5,840	1,405	7,245	6,784	£2,103.04	£3,996	207.0
Total	**1,109**		**33,479**	**6,639**	**40,118**	**32,070**	**£9,942**	**£88,765**	**534**

However, from a supply chain and procurement cost perspective, any device previously kept for less than 8 years will be influenced by the extended lifespan. Unsurprisingly, in secondary schools AIO devices are unchanged as the average retention period is already 8 years (Table 7 and Figure 20). Comparatively, device types with shorter current retention periods cause annual supply chain GHG emissions to decline by 36% (Table 7). Displays show significant change, reducing in supply chain GHG emissions by 50% from 11,680 kgCO_2e (Table 6) to 5,840 kgCO_2e (Table 7). The improvement is driven by displays usually being retained for 4 years (Figure 20). Notebooks extend lifespan by 3 years, meaning that scope 3 emissions reduce by 38% from 18,798 kgCO_2e (Table 6) to 11,749 kgCO_2e (Table 7).

Applying the strategy to the entire average secondary school EUC estate highlights the positive impact of lifespan extension at scale. Specifically, Figure 28 shows that for each year that passes, 18,909 kgCO_2e supply chain emissions are avoided. Tablets contribute to 11% of this reduction, notebooks 37%, desktops 21%, AIO 0% and displays 31%.

Figure 27. Secondary school average EUC annual supply chain reduction by device type (8 year retention policy)

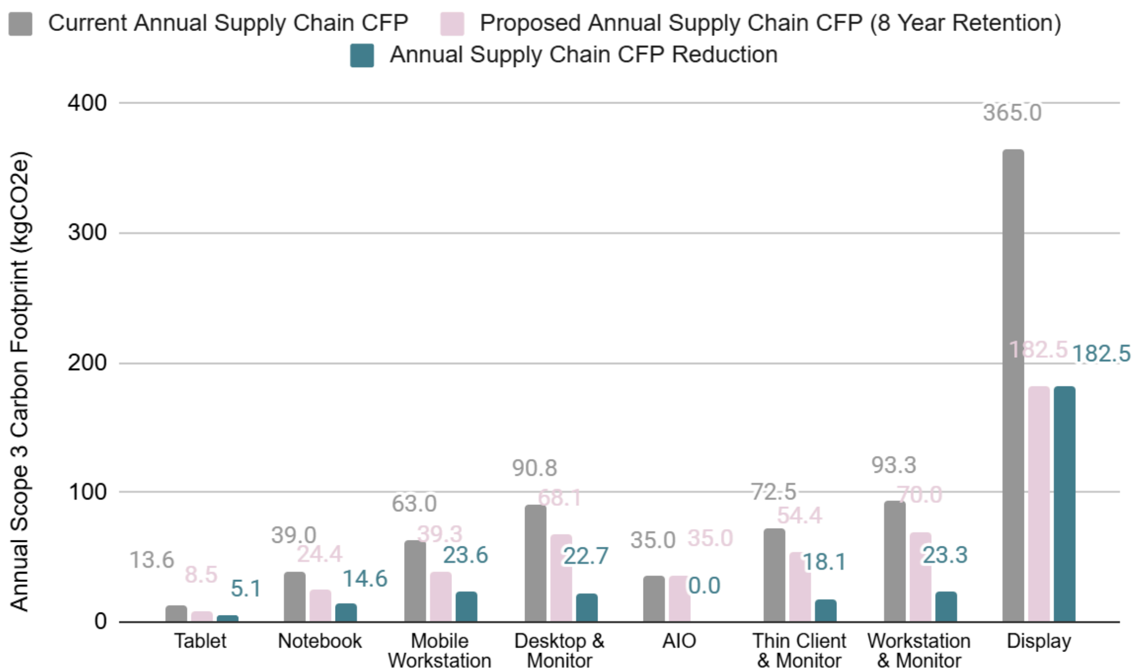
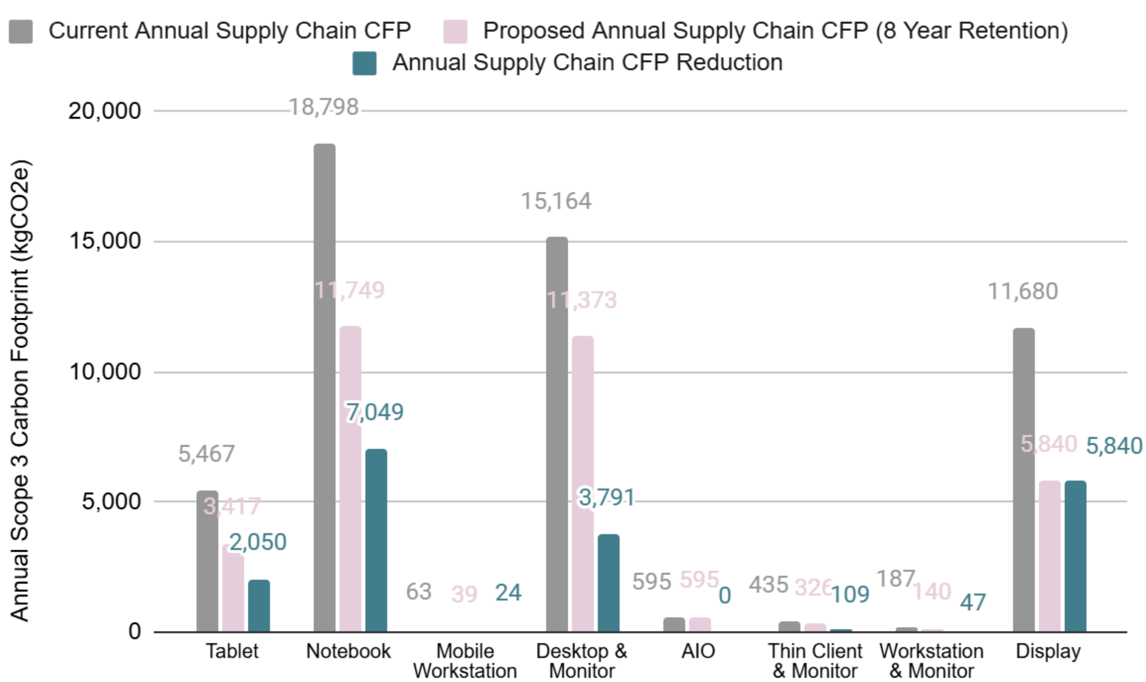


Figure 28. Secondary school average EUC annual supply chain reduction for all assets (8 year retention policy)

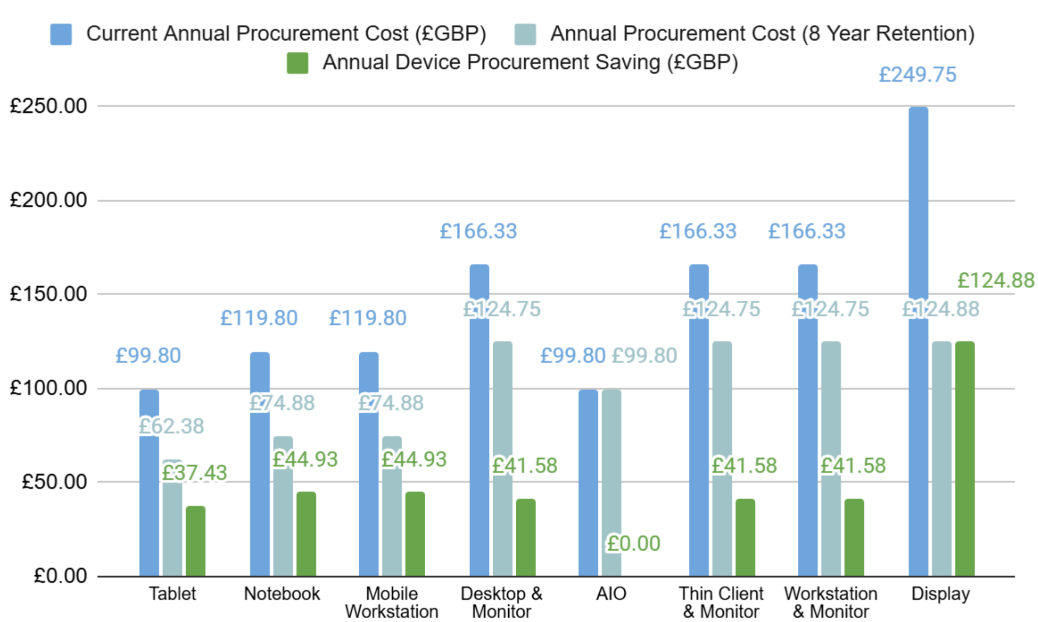


Consequently, the original total annual carbon footprint (including scope 2) is reduced by 32% from 59,027 $kgCO_2e$ (Table 6) to 40,118 $kgCO_2e$ (Table 7). As a percentage, this concurs with the primary school results of 31% (Table 3). While annual secondary school e-waste will reduce by 39% from 875 kg (Table 6) to 534 kg per year (Table 7).

The annually avoided GHG emissions of 18,909 $kgCO_2e$ are equivalent to driving 111,334 km in a car and would require 860 mature trees to sequester the carbon. Using this strategy, the EVER metric reduces from the current 1:46 ratio to 1:31. This means that by simply keeping devices for longer periods, 15 $kgCO_2e$ is avoided on average annually for each device owned.

Lifespan extension to 8 years will also deliver the same percentage reductions to annual procurement costs for each device type as highlighted by the primary school results (Table 3). This is because replacement cycles will occur less often and therefore device related capital expenditure will be reduced on an annual basis. Figure 29 shows that as before, AIO devices are unchanged due to the already being in place an 8 year retention period for this device type. While desktop and monitor combination reduce by 25% and £41.58 (Figure 29) having transitioned from a 6 year to 8 year retention period. This is twice the impact caused in primary schools (Figure 12) of 12.5% and £17.82 per unit annually, because desktops are retained for 7 years already. All devices previously retained for 5 years reduce in annual cost by 37.5%. Specifically, tablets reduce by £37.43 annually and notebooks by £44.93 in line with the primary school reductions (Figure 12). Displays exhibited a 50% decline in cost from £249.75 to £124.88 (Figure 29). This exceeds the reduction of 37.5% and £74.93 per year experienced in primary schools (Figure 12). This is because primary schools keep displays for one year longer than secondary schools as discussed.

Figure 29. Secondary school average EUC annual procurement cost reduction by device type (8 year retention policy)



Applied to the entire average secondary school EUC estate, Figure 30 shows that annual procurement costs reduce by 35% from £136,781 (Table 6) to £88,765 (Table 7). Meaning that each secondary school extending device lifespans to a uniform 8 years, saves £48,016 per annum.

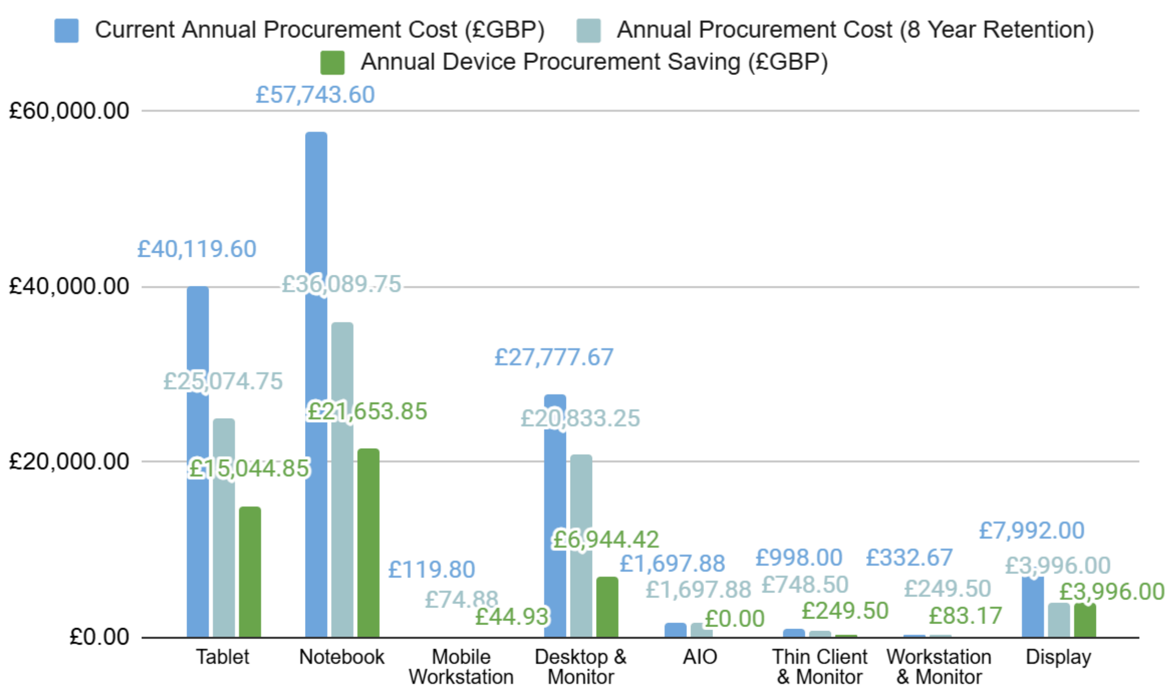
Similar to the Windows 10 EOL strategy, when applied at a country level the improvement to environmental and financial values within the secondary school sector is significant. Specifically, if all schools adopted lifespan extension to 8 years 65,275,150 $kgCO_2e$ of scope 3 supply chain GHG emissions would be avoided annually.

This is equivalent to driving a combustion engine car 384.3 million km or 9,590 times around Earth's equator. In context, just under 3 million trees would be required every year to remove this carbon footprint from the atmosphere.

Additionally, 1,177,308 kg of potential e-waste would be avoided annually. This is equivalent to almost 78.5 million aluminium soda cans.

From a cost perspective, £165,753,677 in EUC device procurement expenditure would be avoided every year. This avoided cost could be used to employ 4,875 additional teachers each year. When added to the primary school equivalent, then 11,043 more teaching staff could be employed in the primary and secondary state funded education sector.

Figure 30. Secondary school average EUC annual procurement cost reduction for all assets (8 year retention policy)



Secondary School Sustainable EUC Strategy 3: Carbon Footprint as a Selection Criterion

As demonstrated in the primary school sections (Table 1 and Figure 6), the carbon footprint of EUC devices differs both by type and by model within the same device types. The previous example used a notebook that was both eco and energy certified but had a carbon footprint 777% higher in GHG emissions than a similar low carbon footprint version. Therefore, introducing carbon footprint as a selection criterion is essential when procuring new devices if long term emissions, energy consumption and utility cost is a focus.

Table 6 shows environmental and financial values for an average secondary school that has not yet introduced uniform 8 year retention periods, nor carbon footprint as a selection criterion. As previously noted, the average secondary school EUC estate currently generates 59,027 kgCO_2e in carbon footprint, produces 875 kg of e-waste, consumes 32,070 kWh of electricity, costs £9,942 in utility bills and £136,781 in procurement spend for every year of operation (Table 6). This creates an annual EVER per capita value of 1:46 and costs of £114.36 per device per year.

Table 8 includes the procurement cost savings and supply chain reductions achieved in strategy 2 by adopting an 8 year lifespan extension (Table 7). However, it also shows the incremental reductions to carbon footprint, energy consumption and cost plus e-waste generated by the 3rd strategy of including carbon footprint as a selection criterion.

Following the same strategy as used for primary schools, the same device types are replaced with the lowest carbon footprint devices currently available. The model is not suggesting that schools should replace devices immediately and ahead of the end of their useful lifespan. It is an illustration of how long term transformation to low carbon footprint devices will improve annual metrics if devices are replaced after 8 years of use with low carbon footprint alternatives.

Table 8. Average secondary annual environmental and financial values following the implementation of strategy 2 (lifespan extension) and 3 (carbon footprint as a selection criterion).

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	402	8	2,915	1,206	4,121	5,226	£1,620.06	£25,075	26.6
Notebook	482	8	6,825	1,446	8,271	6,748	£2,091.88	£36,090	96.4
Mobile Workstation	1	8	21	3	24	13	£4.03	£75	0.2
Desktop & Monitor	167	8	5,606	1,837	7,443	9,018	£2,795.58	£20,833	141.7
AIO	17	8	439	187	626	884	£274.04	£1,698	12.4
Thin Client & Monitor	6	8	190	66	256	318	£98.58	£749	5.0
Workstation & Monitor	2	8	92	34	126	168	£52.08	£250	2.2
Display	32	8	3,405	1,024	4,429	4,896	£1,517.76	£3,996	130.3
Total	**1,109**		**19,491**	**5,803**	**25,294**	**27,271**	**£8,454**	**£88,765**	**415**

Strategy 2 (lifespan extension) contributes to a reduction of 18,909 $kgCO_2e$ per year (Table 7 and Figure 29) when compared to the current strategy (Table 6). As noted, the original total annual carbon footprint (including scope 2) is reduced by 32% from 59,027 $kgCO_2e$ (Table 6) to 40,118 $kgCO_2e$ (Table 7).

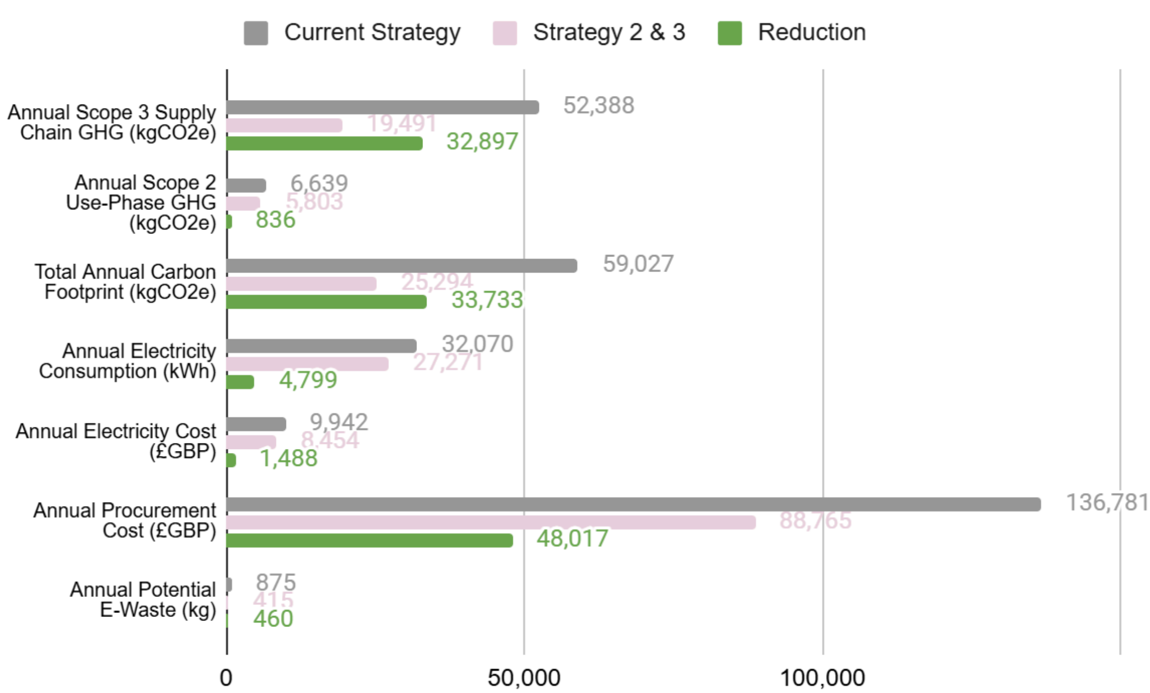
Table 8 shows that with the incremental introduction of carbon footprint as a device selection criterion, the annual carbon footprint causes the total reduction from the current strategy to rise to 57%. The additional 26% reduces the annual carbon footprint to 25,294 $kgCO_2e$ (Table 8), and e-waste to 415 kg per annum (Table 8). This is 53% less than the current strategy (Figure 31)

This means that an average secondary school will reduce GHG emissions by 33,733 $kgCO_2e$ annually (Figure 30). This is equivalent to emissions generated by driving a combustion engine car almost 199,000 km or 5 times around the Earth's equator. In context, the avoided emissions would otherwise require 1,533 trees to remove the carbon from Earth's atmosphere every year.

The new annual carbon footprint reduces the original EVER metric from 1:46 to 1:20, meaning that on average each device owned generates just 20 $kgCO_2e$ per year.

Table 8 and Figure 31 show that the additional carbon footprint reductions are enabled by a reduction in both scope 3 supply chain and scope 2 energy emissions.

Figure 31. Secondary school environmental and financial metrics comparing an average primary school current EUC strategy to results following implementation of lifespan extension to 8 years and carbon footprint as a device selection criterion



Comparing the original strategy (Table 6) with the combined strategy of lifespan extension and low carbon footprint devices (Table 8), tablets are 38% lower in annual carbon footprint, notebooks 59%, desktop and monitor combinations 58%, AIO devices 24% and interactive displays 66%. This is driven by scope 3 supply chain emissions declining by 63% (Figure 31) and scope 2 use-phase emissions by 13% as newer devices become more energy efficient (Figure 31).

The procurement cost savings shown in Figure 31 reflect those achieved by the lifespan extension strategy. However, due to improved energy efficiency, a reduction in energy consumption of 4,799 kWh/y reduces utility costs by £1,488 (15%) to £8,454 per year (Figure 31).

Figure 31 shows that 33,733 kgCO_2e of EUC carbon footprint can be avoided every year in an average secondary school. Therefore if all 3,452 secondary schools in England adopted device lifespan extension and introduced carbon footprint as a selection criterion, then 116,446,316 kgCO_2e of GHG emissions could be avoided every year. This is equivalent to emissions generated by driving almost 686 million kilometres or 17,100 times around the world.

Additionally, 1.6 million kg of e-waste could be avoided annually. This is equivalent to almost 106 million aluminium soda cans.

And finally, as a combined saving of £49,505 can be achieved via reduced utility and procurement costs, then if all secondary schools in England participated, a total cost saving of £170,891,260 could be made annually. In context, this saving is sufficient to employ 5,026 additional teachers every year. This brings the total of combined primary and secondary school possible teacher funding scenarios to 11,346 if strategies 2 and 3 became a reality.

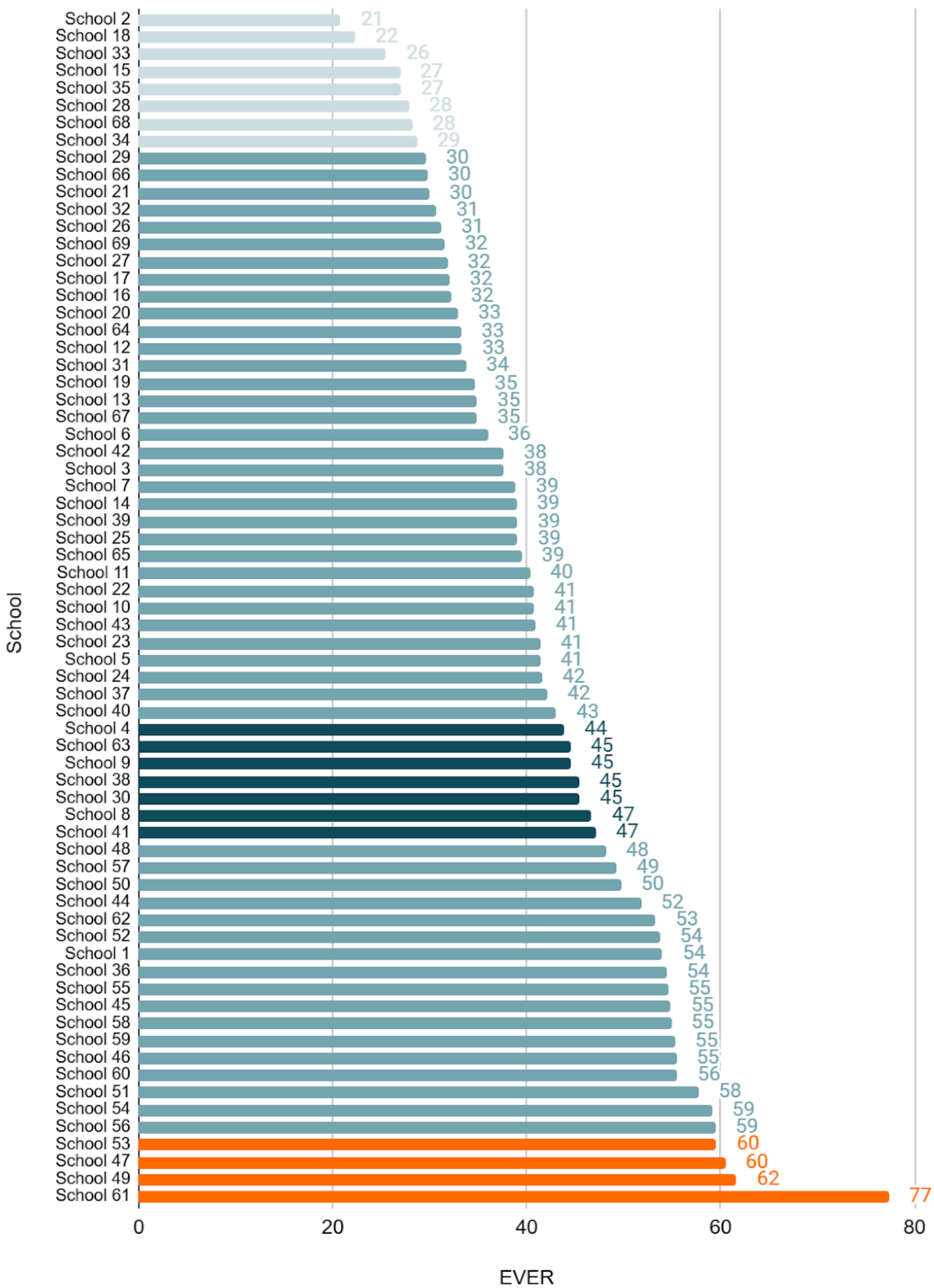
Secondary Schools EUC Volume of Emissions Ratio (EVER)

The results show that while secondary schools offer a similar function from one establishment to the next, they differ significantly by staff and student size, device type choices, ratio of devices to computer users and therefore the number of devices in operation. To be able to examine how one secondary school compares to another in relation to average EUC carbon footprint, then a ratio that remains constant must be determined. This is represented by the 'EUC volume of emissions ratio' known as the EVER metric. As noted, it is expressed by 1 device to the associated annual EUC GHG emissions for a single year.

The results determine that for secondary schools in England, the average EVER score is 1:46. This means that on average one EUC device generates 46 kgCO_2e annually.

When the lifespan extension strategy is applied this value reduces by 32% to 1:31. This means that by simply keeping devices for longer periods, 15 kgCO_2e is avoided on average annually for each device owned.

Figure 32. EUC Volume of Emissions Ratio (EVER) metrics for 69 secondary schools



Adopting both the lifespan and carbon footprint as a selection criterion strategies reduces the EVER score by 57% when compared to the original strategy, resulting in 1:20. This means that for every year of operation, 20 kgCO_2e are generated per device, while 26 kgCO_2e are avoided per device by implementing the two arguably simple strategies.

Figure 32 shows the EVER metric for each of the 69 secondary schools included in the research data set. The results range from 1:21 for school 2, and rising by +238% to 1:71 for School 61.Similar to primary schools (Figure 15), no pattern appears within the results by contextual conditions such as location. Therefore, as before to determine commonality between EVER results, equipment types are examined.

Tables 1-8 show that of all device types, tablets generate the lowest annual carbon footprint. Therefore, it is arguably unsurprising that primary schools with the highest proportion of tablets produced the lowest EVER metrics (Figure 16). In relation to secondary schools, the influence of tablet computers appeared again. As an example, at the two extremes, school 2 (EVER 1:21) had 83% tablets when compared to total devices, while school 61 (EVER 1:71) had just 2.5%.

As before, the deviations between the results in both the lowest and highest EVER ranges are caused by retention periods and which devices are most popular. As a rule, schools selecting predominantly mobile computing devices are achieving the best EVER ratios. This is simply because the carbon footprint of these device types can reduce GHG emissions by as much as 86% (Figure 17) when comparing a tablet with a desktop and monitor combination. While this may not suit secondary schools to the same percentage adoptions as primary schools where tablets are more popular (Figures 1 and 18), notebooks offer a feasible 76% reduction (Figure 17) and are therefore appealing from a sustainability perspective.

As such, to echo the primary school results, when considering both environmental and financial metrics associated with secondary school end user computing, stakeholders must include the following strategies:

- Lifespan extension
- Carbon footprint as a selection criterion
- Transition to mobile computing

On average, by adopting sustainable ICT strategies in secondary schools, both associated planet and profit metrics will improve. Specifically, doing so will reduce annual carbon footprint by 57%, e-waste by 53% and procurement and utility costs by 34%.

Special Educational Needs and Disabilities (SEND) Schools

Special Educational Needs and Disabilities (SEND) schools in England are typically for students aged between 0-25 who are in education or training and have a learning difficulty and/or disability that requires special educational provision.

Using the same approach as the primary and secondary school data, SEND are presented firstly as a physical representation of assets (e.g. type, size, OS, age) and secondly from a carbon footprint perspective (e.g. energy, supply chain and e-waste). As before, this enables an average baseline for a single SEND school to be formed. This can then be subjected to sustainable ICT modelling strategies to show potential improvement to create 'before and after' results plus extrapolation to represent a national current and potential impact.

During the data collection period, 7 SEND schools participated representing 3% of research participants and 0.7% of all SEND schools in England [6]. Due to the smaller quantity of schools, five of England's nine geographical regions are represented. This includes East of England, Greater London, South East, South West plus Yorkshire and the Humber.

SEND School Physical EUC Asset Profile

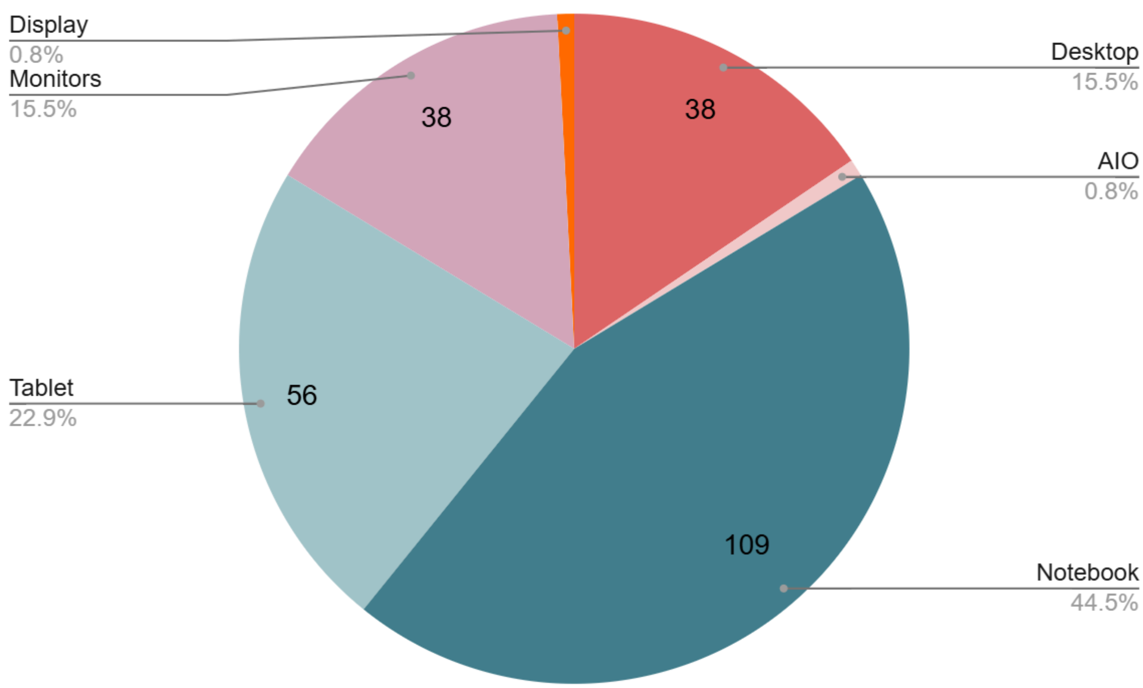
Data for 1,870 EUC devices is captured, with 70 specific models of device from 11 brands identified. The data shows that an average SEND school has 151 computer users. In comparison, this is 43% of the size of a primary school and 14% of an average secondary school.

Of these, 130 are students (86%) and 21 staff (14%). Therefore, the proportion of students as computer users in SEND schools is 3% lower than primary schools and 6% lower than secondary schools. Each SEND has an average of 245 devices, represented by 205 computers (84%), 38 monitors (15%) and 2 displays (1%). Compared to both primary and secondary schools, the mix is similar.

This equates to an EUC asset list of 109 notebooks (45%), 56 tablets (23%), 38 desktops (16%) and monitors, 2 AIO desktops (<1%), and 2 interactive displays (<1%) (Figure 33). The proportional representation of notebooks is between 5-7% higher than previous results (Figures 1 and 18). While tablets are 9-25% lower than primary and secondary schools (Figures 1 and 18). The main reason is that desktop style devices are 10% higher than in primary schools and 3% higher than in secondary schools. As such, mobile computing accounts for 68% in SEND schools (Figure 33) compared to 95% in primary schools and 82% in secondary (Figures 1 and 18).

With 205 computers available per school, there are 1.3 computers per user. This exceeds both primary schools at 0.9:1 and secondary school at 1:1 (Figure 34). Greater London has the highest mapping of 1.8, double that of primary schools in the region and 40% higher than secondary schools (Figures 2 and 19). While the South West region has the lowest of 1:1 (Figure 34). A ranking reflected in the primary school results of 0.6 computers per user in primary schools (Figure 2) and 20% lower than 1.25 in secondary schools in the region (Figure 19).

Figure 33. SEND school average EUC device quantities by type

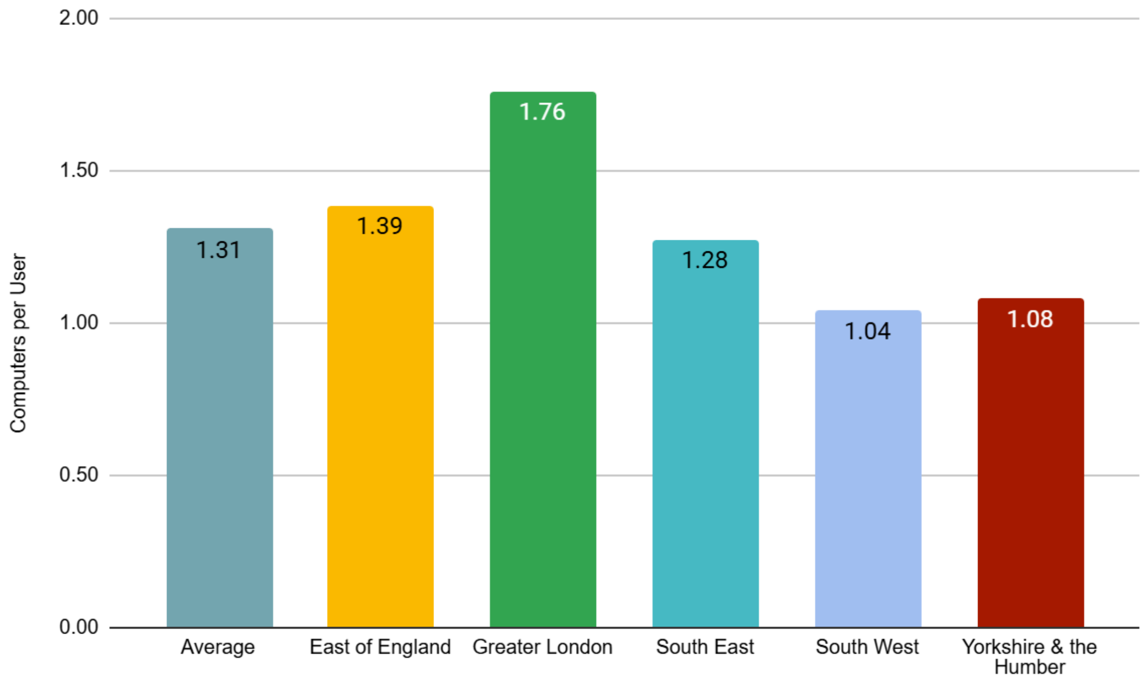


Concurring with primary and secondary school results, the most popular notebook size in SEND schools is 11" (63%), followed by 14" (20%), 15" (10%) and 13" 7%. Once again, notebook operating system choice is predominantly ChromeOS (78%) and Microsoft Windows (22%). The notable exception was the absence of any MacOS notebooks. The high percentage of ChromeOS install base is driven by the 11" devices which in this instance were 100% Chromebooks. This is 8-10% higher than the primary and secondary school results.

The most popular tablet size is a 10" screen (99%), followed by 11" and 12" (<0.5% each). This correlates with size popularity in both primary and secondary schools. While MacBooks were missing from the notebook assets, the tablets proved to be 73% iPadOS (iPads), 26% Android and Windows and ChromeOS achieving 0.5% each. This is identical to primary schools and 18% less iPadOS install base than in secondary schools at 91%.

SEND school desktops mirror secondary school choices with SFF making up 57% of the units. USFF forms the balance of devices (43%). However, unlike primary and secondary schools that have a 94% and 87% Microsoft desktop operating system average, Windows appears on 59% of SEND desktops. The difference is that Chromeboxes represent 41% while Mac Mini is less than 1%.

Figure 34. SEND school average EUC computer per student ratio by geographic region



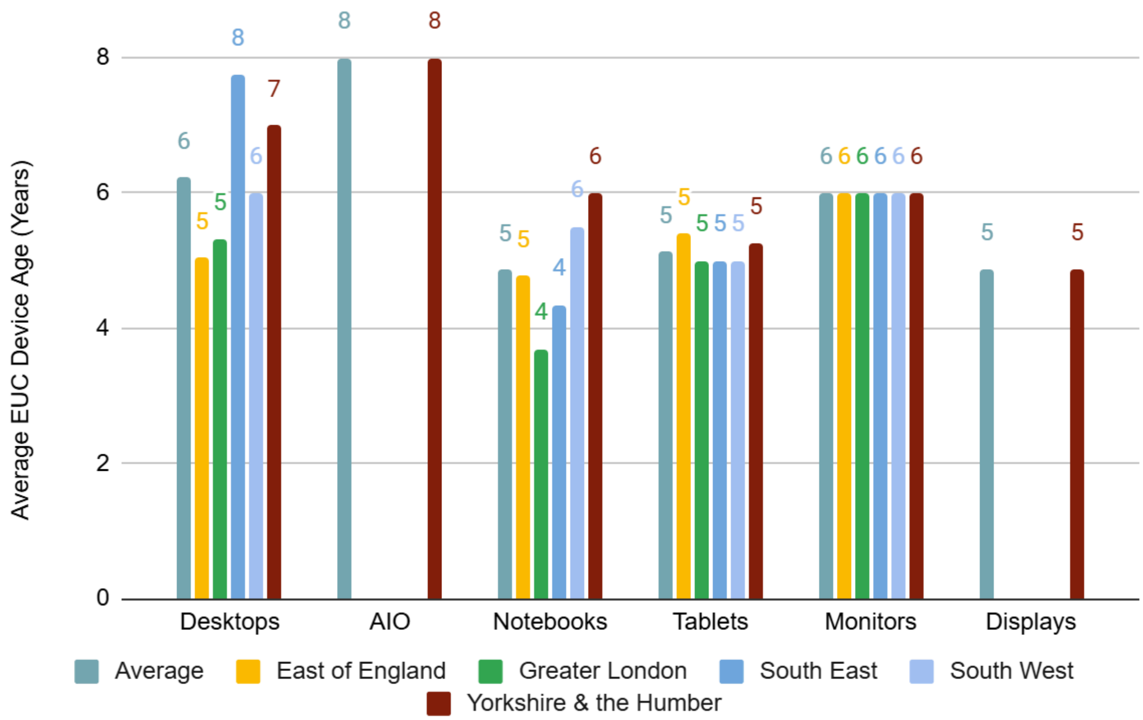
Integrated desktops (AIO) included in the SEND data sample are 100% 22" and all Windows. The difference being that the other two school types also included 20-21", 24" and 27" variations. This is followed by 20-21" (29%), 24" (22%) and 27" (3%). Similar to primary schools, no MacOS devices were present, which is different to secondary schools where 13% of AIO are manufactured by Apple.

In SEND schools, the most popular size interactive displays are 55" (58%), 65" (31%) and 75" (1%). This is not the same as primary schools preferring 65" (58%) and secondary school 75" (68%). Once again, the Android operating system is installed on 100% of devices, which correlates with primary and secondary school results.

As previously noted, monitors refer to computer user focused displays used as an external peripheral device in conjunction with a computer. In this instance no monitor sizes were included with the asset registry data for SEND schools and therefore sizing feedback cannot be applied.

Figure 35 shows that notebook and tablet average age match the 5 year results of both primary and secondary schools (Figures 3 and 20). Desktop and monitors match the 6 years discovered in secondary schools (Figure 20) and one year less than 7 years at primary schools (Figure 3). Both AIO and display age were difficult to credibly calculate due to these being reported by SEND schools in only the Yorkshire and the Humber region (Figure 35). In this limited state, AIO devices were congruent with other schools at 8 years (Figures 3, 20 and 35) while displays were 1 year older than primary (Figure 3) and 2 years older than secondary (Figure 20) at 5 years on average (Figure 35). As monitor data was missing, it is assumed that for all regions the age matches that of desktops at 6 years (Figure 35). This decision is based on both the primary and secondary schools desktop average ages matching monitors in each instance (Figures 3 and 20).

Figure 35. SEND school average EUC device age by type and geographic region



Similar to primary and secondary schools, any Windows AIO, desktops, and notebooks manufactured during or before 2017 will not meet the Windows 11 upgrade criteria and will require intervention before October 2025. For SEND schools, this equates to 6% of Windows desktops (1 device), 19% of Windows notebooks (5 devices) and 100% of Windows AIO computers (2 devices). The percentage of desktops requiring intervention is particularly low considering it is found to be 39% in primary and 16% in secondary. The data again highlights that AIO devices are at high risk, with replacement results for all school types being between 60-100%. While the percentage of SEND Windows notebooks that may not be upgradable are in between secondary (7%) and primary (13%).

Summarising the profile results and accounting for all device types and type specific attributes, an average SEND school EUC estate consists of the following device proportional representation:

- 109 notebooks consisting of 85 Chromebooks, 24 Windows notebooks
- 56 tablets consisting of 41 Apple iPads, 15 Android devices
- 38 desktops consisting of 22 Windows desktops, 15 Chromeboxes and 1 Mac Mini
- 2 AIO desktops (Windows)
- 38 monitors
- 2 interactive displays including one 55" and one 65"

Environmental and Energy Results by Device Type

Environmental, financial and EVER results for the 1,870 EUC devices captured within the SEND school data sample (including 70 models and 11 brands) are calculated in the same manner used for primary and secondary schools.

Mobile Devices

Table 9 shows the average SEND notebook annual electricity consumption is 11.29 kWh/y generating 2.33 kgCO_2e. This is equivalent to secondary (Table 5) and 5% lower than primary school average (Table 1). This is driven by the higher percentage of ChromeOS notebooks found in SEND schools (78% versus 68-70%) plus the fact that all 11" devices are Chromebooks. Similar to secondary school, SEND Chromebooks consume 8.9 kWh/y compared to the Windows average of 19.6 kWh/y. The results once again substantiate existing research highlighting that, as previously noted, Chromebooks require less power draw when in active use.

The average notebook supply chain emissions value per unit is 191 kgCO_2e (Table 9) **a**nd concurs with both primary and secondary school results (Tables 1 and 5). This creates an annual scope 3 emissions value of 38.20 kgCO_2e per unit (Table 9). Therefore, the lifespan carbon footprint for an average SEND notebook is 202.65 kgCO_2e, meaning notebooks create 40.53 kgCO_2e GHG emissions annually (Table 9). Scope 3 emissions therefore account for 94% of the overall product carbon footprint. The average weight of a SEND notebook is 1.46 kg and therefore the annualised e-waste potential is 0.29 kg per unit (Table 9).

The average tablet electricity consumption per year is 14.77 kWh/y generating 3.06 kgCO_2e. Once again this is 30% higher than the notebook average. In the same way as for primary and secondary schools, the difference is driven by the majority of notebooks being a combination of small screen (11") Chromebooks that are high energy efficient. As an example, when compared to the SEND Windows notebook average, energy consumption is 25% lower. While equivalent to secondary school tablet energy consumption (Table 5), this is 11% higher than the primary school tablet average (Table 1). This is again driven by iPad popularity in SEND and an average iPadOS device energy consumption of 17.3 kWh/y which is 13% higher than the iPad models in both primary and secondary schools.

Secondary school tablet supply chain average emissions are 75 $kgCO_2e$ meaning that the annual value is 15 $kgCO_2e$ (Table 1). This is 23% lower than primary school tablet average (Table 1) and 10% higher than secondary school results (Table 5). The difference between the three is purely driven by model choice which substantiates the introduction of carbon footprint as a selection criterion.

During 5 years of use, the lifespan carbon footprint of a SEND school tablet is 90.3 $kgCO_2e$, meaning tablets create 18.06 $kgCO_2e$ annually (Table 9). Therefore, supply chain emissions are responsible for 83% of the product carbon footprint and the use-phase 17%. As before, when compared to the lifespan of a notebook during the same 5 year period, the tablet has a 55% lower total carbon footprint. Therefore, despite tablets consuming more energy in this example, they generate over one half less emissions than a notebook.

The average weight of a tablet is 0.48 kg and therefore the annualised e-waste potential is 0.10 kg per unit (Table 9)

Table 9. Average SEND school annual environmental and financial results by device type (one unit)

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	1	5	15.00	3.06	18.06	14.77	£4.58	£99.80	0.10
Notebook	1	5	38.20	2.33	40.53	11.29	£3.50	£119.80	0.29
Desktop & Monitor	1	6	80.91	13.80	94.71	66.65	£20.66	£166.33	1.25
AIO	1	8	35.25	12.94	48.19	62.50	£19.38	£99.88	1.08
Display	1	5	233.60	29.13	262.73	140.73	£43.63	£199.80	7.20

Static Devices

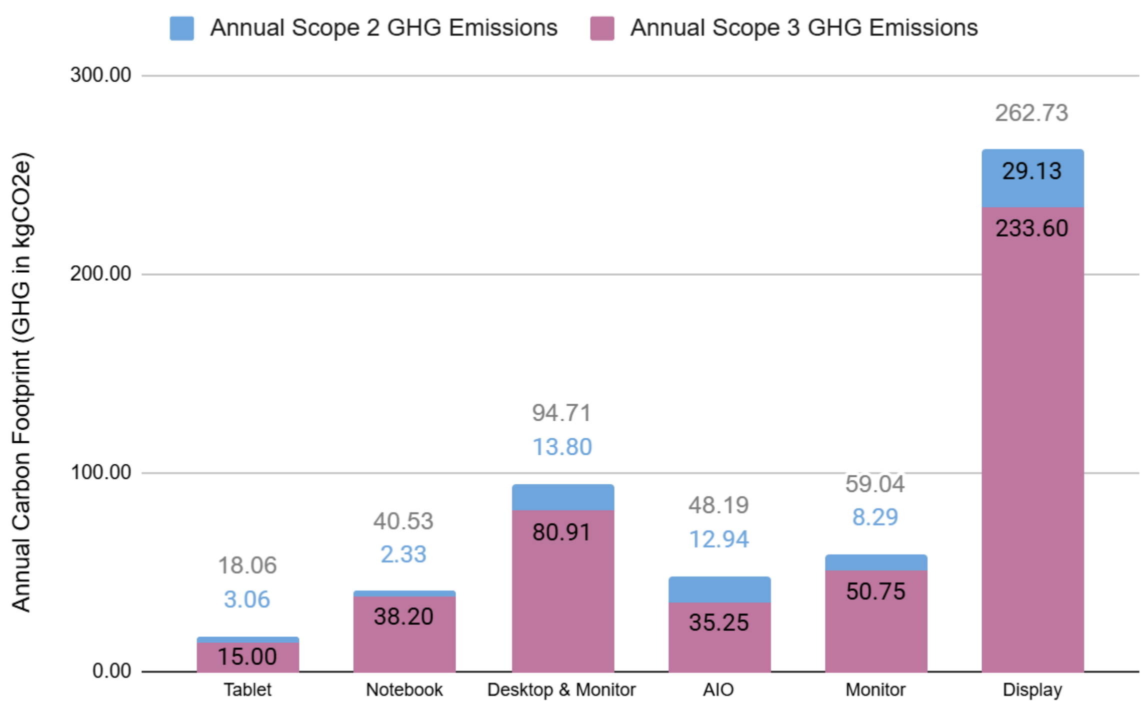
Average SEND school annual desktop computer electricity consumption is 26.6 kWh/y and generates 5.5 $kgCO_2e$ scope 2 emissions (Table 9 as part of the monitor combination). This is 35% and 29% lower than the primary and secondary school desktop averages (Tables 1 and 5). The result is driven by SEND schools having Chromeboxes as 41% of desktops compared to 6% in primary schools and 13% in secondary. As an example, the SEND Chromeboxes consume 11.4 kWh/y compared to the Windows desktops at over 3 times higher at 37.13 kWh/y.

The average supply chain carbon footprint value for desktops is 181 $kgCO_2e$. This is 31% and 23% lower than primary and secondary school equivalents (Tables 1 and 5). The reason is a high quantity of a Dell micro size Windows desktop with an incredibly low supply chain carbon footprint. The outcome once again highlights that even when faced with increased energy consumption relating to Windows devices, selecting a device with low scope 3 emissions is essential.

Based upon the 6 year average retention for desktops (Figure 35), the total lifespan carbon footprint of an average desktop in English SEND schools is 214 $kgCO_2e$. Therefore desktops create 35.67 $kgCO_2e$ per year. The average weight is 2.74 kg due to the micro device and as such, annual e-waste potential is 0.46 kg.

As no monitor data was available an average of the primary school and secondary school results (tables 1 and 5) is used. Specifically, 40.05 kWh/y generating 8.29 $kgCO_2e$ of scope 2 emissions (Table 9). Plus 304.5 $kgCO_2e$ of supply chain emissions, annualised to 50.75 $kgCO_2e$ (Table 9). The average weight is 4.72 kg and 0.79 kg per year.

Figure 36. SEND school average EUC device annual carbon footprint (GHG emissions $kgCO_2e$)



Consequently, as shown in Table 9, a combined desktop and monitor consumes 66.65 kWh/y of electricity, causing 13.8 $kgCO_2e$ of scope 2 concomitant emissions. The supply chain value is 485.5 $kgCO_2e$ in total, generating 80.91 $kgCO_2e$ per year and the annual e-waste potential is 1.25 kg.

The SEND school integrated desktop average electricity consumption is 62.5 kWh/y (Table 9) and generates 12.94 $kgCO_2e$ per year (Table 9). This is in between both the primary (59 kWh/y) (Table 1) and secondary (64.5 kWh/y) (Table 5) results and driven by the single 22" screen size used in SEND schools which is in between the 20-27" ranges used in other school types.

Average AIO supply chain emissions are 282 $kgCO_2e$ per unit and therefore scope 3 emissions are 35.25 $kgCO_2e$ per year. This is equal to the primary school results and 49% lower than when compared to supply chain emissions for the SEND school desktop and monitor combination. Considering that an AIO is effectively the same solution and therefore experience, this should be considered when examining desktop options.

Figure 35 indicates that SEND school AIO devices are kept for 8 years matching primary and secondary schools results. sc as is the case with primary schools. Therefore, the lifespan carbon footprint is 385.52 kgCO_2e and 48.19 kgCO_2e per year (Table 9). In this example, the supply chain emissions are responsible for 73% of the product carbon footprint.

The average weight of an AIO device is 8.6 kg and therefore the annualised e-waste potential is 1.08 kg per unit (Table 9) and similar to primary and secondary schools.

An average secondary school interactive display consumes 140.73 kWh/y of electricity annually (Table 9) and generates 29.13 kgCO_2e per year (Table 9). This is 42% lower than the primary school average (Table 1) and 34% lower than the secondary school average (Table 5). The fact that SEND schools use predominantly 55" displays compared to 65" in primary and 75" in secondary, highlights that increasing screen size influences power consumption significantly.

The average scope 3 emissions for an interactive display are 1,168 kgCO_2e and 233.60 kgCO_2e per year (Table 9). This is 8% lower than display averages in primary schools and 20% lower than secondary schools. Again, this is driven by additional size requiring more materials and impacting shipping emissions due to volume and weight.

Figure 35 shows that the average retention period is 5 years. Therefore the average lifespan carbon footprint is 1,314 kgCO_2e meaning the annual carbon footprint is 263 kgCO_2e (Figure 4). Consequently, the supply chain is responsible for 89% and the use-phase is responsible for 11% of the product carbon footprint.

The average weight of an interactive display is 36.01 kg and therefore the annualised e-waste potential is 7.2 kg per unit (Table 9).

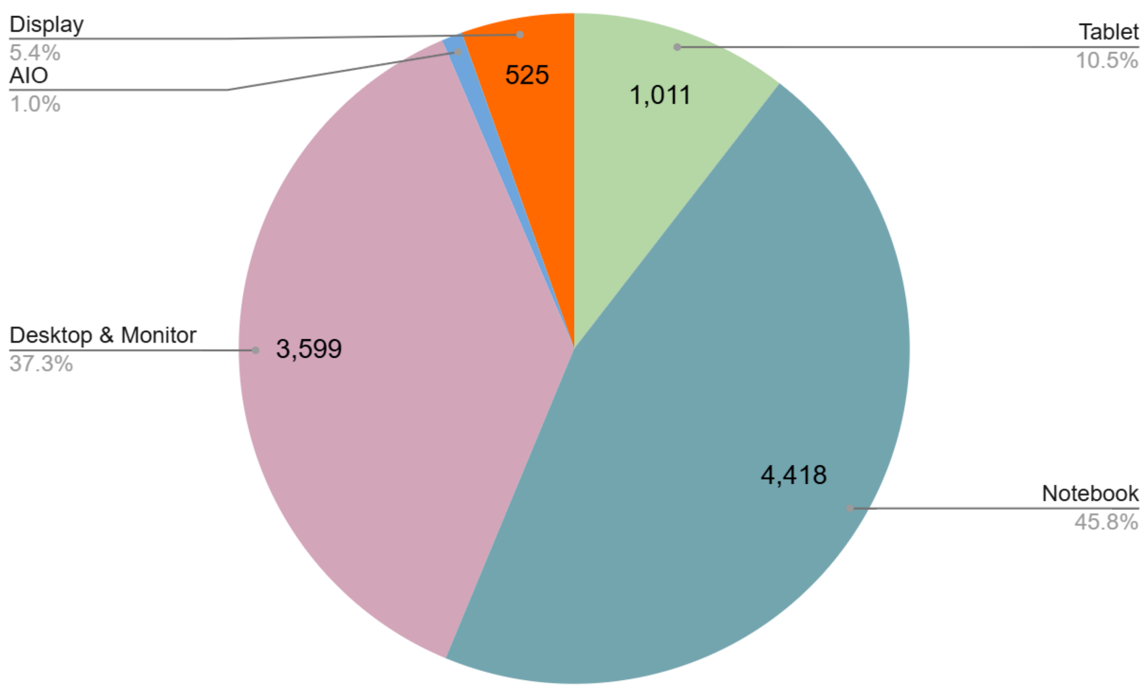
Average SEND School EUC Estate Carbon Footprint and Energy Baseline

Combining the proportional representation (Figure 33) of EUC devices within an average SEND school and the carbon footprint by device type (Figure 36), the annual average carbon footprint for an entire EUC estate of 245 devices (Table 10 when monitors used in conjunction with static computers are included in the total) is 9,650 kgCO_2e (Figure 36 and Table 10).

This is equivalent to emissions created by a combustion engine car travelling almost 56,818 km or 1.4 times around the Earth's circumference. In context, for one average SEND school, 439 mature trees are required every year to remove this carbon from Earth's atmosphere.

Consequently, the per capita EVER ratio for an average SEND school is 1:39, meaning that for every device owned, 39 kgCO_2e carbon footprint is generated annually. This requires 2 trees per year to sequester the carbon of each EUC device. The ratio is equal to average primary schools (1:39) and 15% lower than secondary schools (1:46). The equivalence to primary schools is achieved despite a higher GHG contribution from desktops and monitors in SEND schools of 37% (Table 10) versus 10% (Table 2). This is because displays are fewer in quantity per SEND schools at 2 units (Table 10) versus 8 units (Table 2) and therefore contributing just 5.4% of annual carbon footprint (Figure 37). While the display contribution to GHG emissions in primary schools is 20% (Figure 5).

Figure 37. SEND school average EUC device annual carbon footprint (kgCO_2e)



Similar to both primary (Figure 5) and secondary schools (Figure 22), it is notable that while tablets account for 23% of all devices, the resulting carbon footprint is 10.5% of the total (Figure 36%). Therefore once again, from a single device unit per contribution to GHG emissions perspective, displays contribute the highest carbon footprint (Tables 2, 6 and 10).

Overall, SEND school EUC device supply chain emissions match both primary (Figure 6) and secondary (Figure 23) school percentage results by contributing 89% to the total (Figure 36). This means that use-phase scope 2 emissions generate on average 11% (Figure 38). Therefore it is reasonable to find that these percentage values of supply chain versus use-phase contribution to EUC product life cycle carbon footprint are valid for all schools.

As previously noted in both the primary and secondary schools sections, ICT operational factors, including device energy efficiency and school retention periods, will influence financial results.

In relation to energy efficiency, the average SEND school EUC estate consumes 4,997 kWh/y (Table 10). Based upon an average SEND school having 245 devices, this produces a per device consumption of 20 kWh/y. For primary schools with 322 devices, this is 1% higher at 21.30 kWh/y per device (Table 2). While secondary schools with 1,283 devices, this is 25% higher at 24.99 kWh/y. The increase in average device electricity consumption among schools is predominantly driven by a balance of what type of devices prove most popular by school type.

Table 10. Average SEND school EUC estate annual environmental and financial results

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	56	5	840	171	1,011	827	£256.41	£5,589	5.4
Notebook	109	5	4,164	254	4,418	1,231	£381.49	£13,058	31.8
Desktop & Monitor	38	6	3,075	524	3,599	2,533	£785.14	£6,321	47.5
AIO	2	8	71	26	96	125	£38.75	£200	2.2
Display	2	5	467	58	525	281	£87.25	£400	14.4
Total	**207**		**8,616**	**1,034**	**9,650**	**4,997**	**£1,549**	**£25,567**	**101**

Figure 38. SEND school average EUC estate device annual carbon footprint (kgCO_2e) by GHG scope type

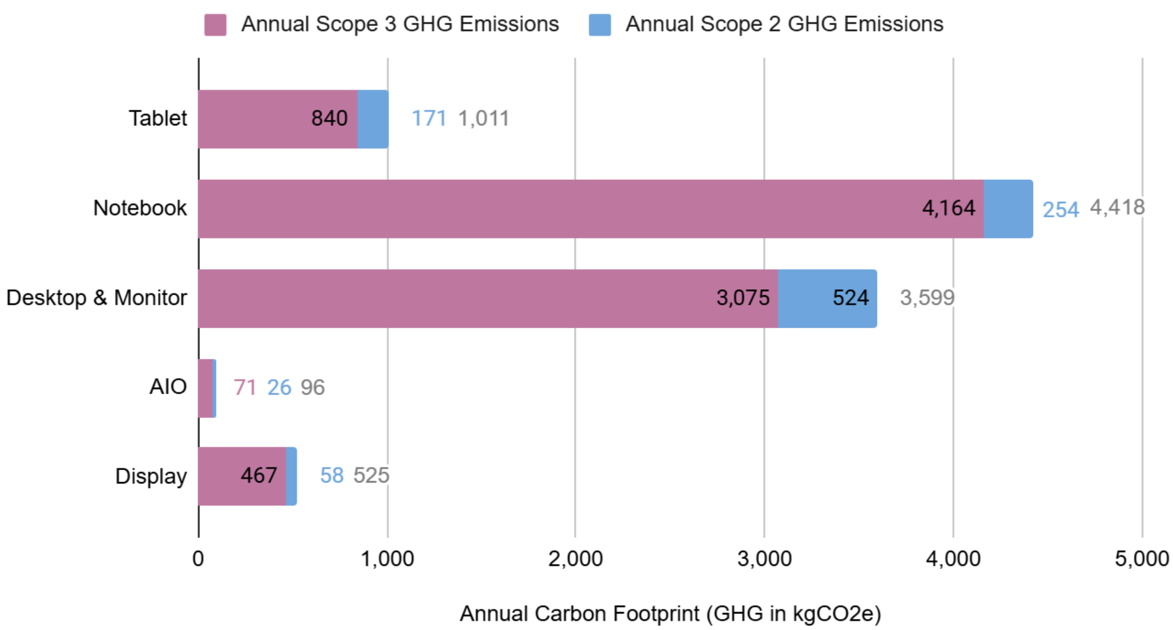
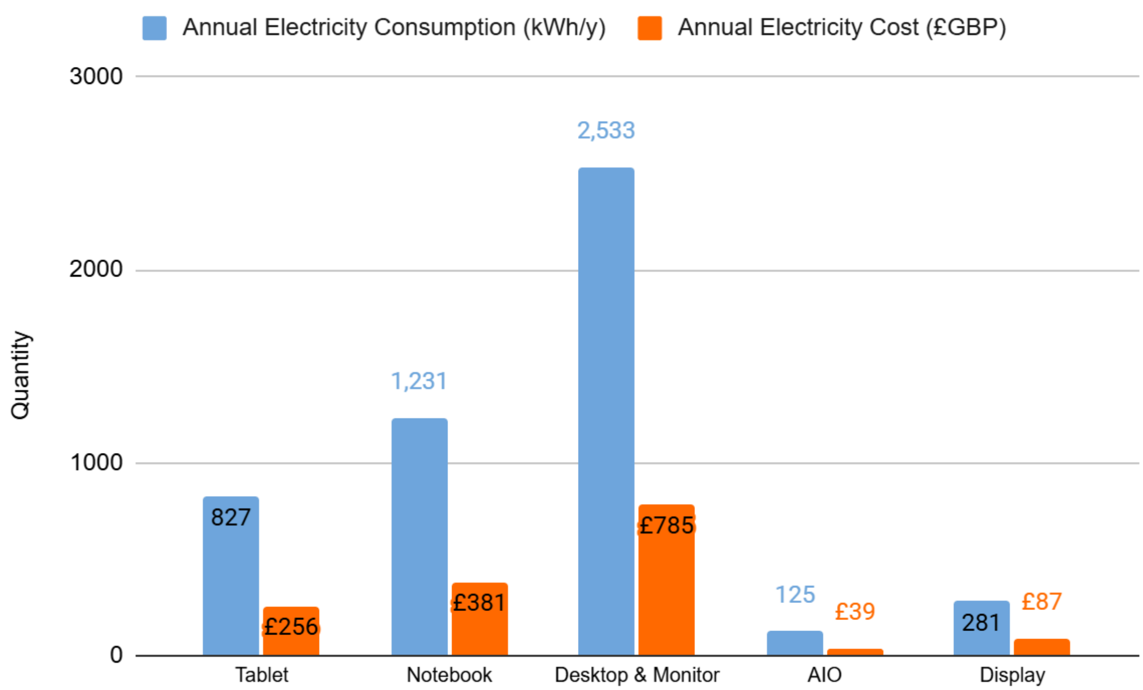


Figure 39. SEND school average EUC estate device annual electricity consumption (kWh/y) and cost (£GBP)



As an example, high energy consumption devices are more popular in secondary schools. Specifically, desktops represent 4.1% of all devices in primary schools (Figure 1), 13.1% in secondary (Figure 18) and 15.5% in SEND schools (Figure 33). Additionally, displays represent 2.6% in primary (Figure 1), 2.5% in secondary (Figure 18) and 0.8% SEND schools represent 0.8% (Figure 33). Therefore, as secondary schools have on average +298% and +523% more devices than primary and SEND schools respectively, changes to display and desktop proportional representation will have an influence on energy consumption.

Dividing the average new hardware costs by the varying average retention periods discovered in SEND schools (Figure 35) produces an annual procurement cost by device type (Table 10). Figure 38 shows that this is equivalent to primary and secondary school results (Figures 8 and 25) when retention periods remain equivalent by device type.

Table 10 and Figure 40 show that for an average SEND school EUC estate, £27,116 will be spent on combined electricity (£1,549 and 6%) and device procurement (£25,567 and 94%) annually. This means that with 245 devices in use in an average SEND school, each will cost on average £110.68 to purchase and use (Figure 41) per year. This is 4% lower than both primary schools at £114.69 per device (Figure 9) and secondary schools at £114.36 (Figure 26). The variation is caused by the blend of device type choices as previously discussed plus differing retention periods between school types.

Figure 40. SEND school average EUC device annual electricity and procurement cost (£GBP) per unit

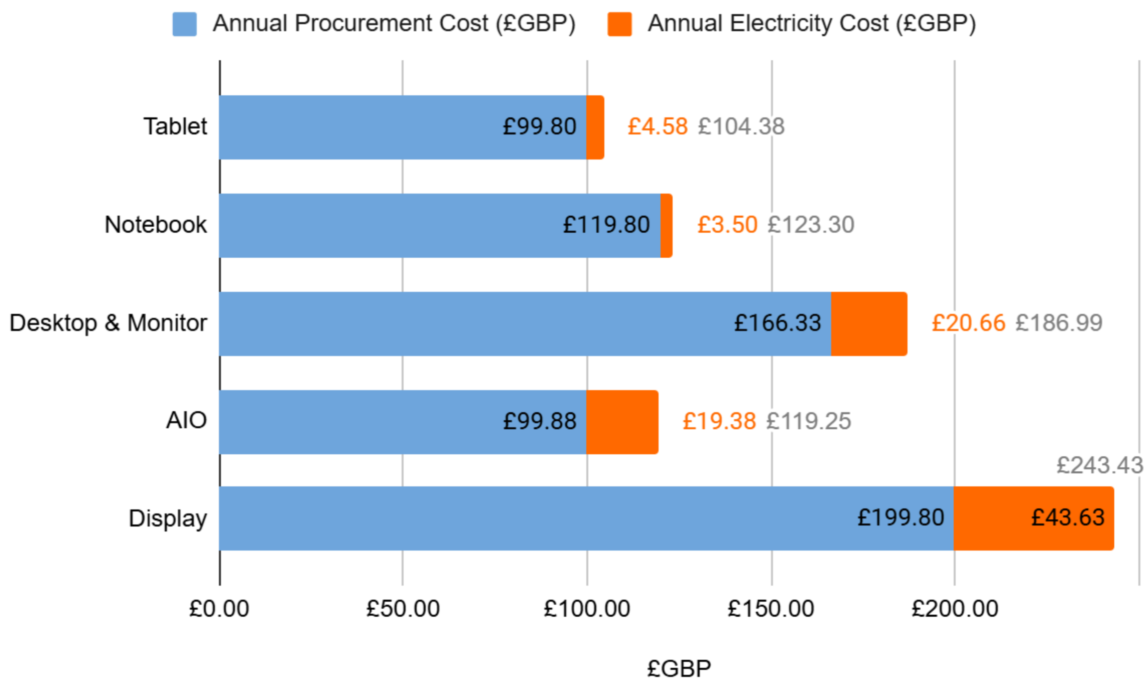
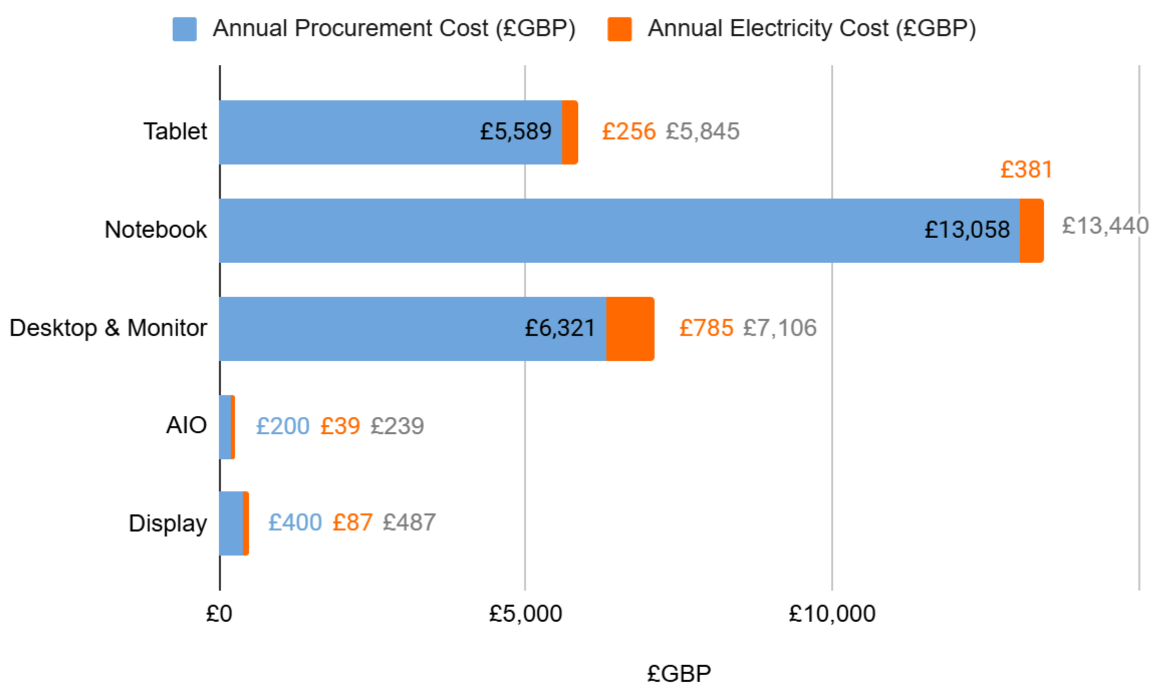


Figure 41. SEND school average EUC estate annual electricity and procurement cost (£GBP)



Sustainable ICT Strategies in SEND Schools

Similar to primary and secondary schools, to reduce short and long term carbon footprint and cost impact, three key sustainable strategies will generate differing results. The first is to address the impending replacement of devices affected by the Windows EOL event [48]. Secondly, extension of device lifespans to a uniform period of 8 years. Thirdly, introducing carbon footprint as a selection criterion for new devices.

SEND School Sustainable EUC Strategy 1: Windows 10 EOL

As previously noted, within English SEND schools, 6% of Windows desktops (1 device), 19% of Windows notebooks (5 devices) and 100% of Windows AIO computers (2 devices) will not meet the Windows 11 upgrade criteria when Windows 10 becomes EOL.

Based upon the data in Table 10, this means for each SEND school in England, 2,004 kgCO_2e of like for like new product supply chain GHG emissions and 32 kg of e-waste will be generated. Replacement of the affected device will also cost each school approximately £5,591 in procurement expenditure.

Currently, within England's state funded education sector there are 1,050 SEND schools. Therefore, extrapolated to a country level the potential impact of finding no alternative strategy to replacement will generate 2,104,200 kgCO_2e of new product carbon footprint. This is equivalent to GHG emissions created by driving a combustion engine car 12.4 million km or just over 309 times around the world. This impact would require almost 96 thousand trees to sequester the resulting carbon from Earth's atmosphere.

Additionally, 33.6 tons of e-waste will be produced as the obsolete devices are sent for end of life services. In context, this is equivalent to 2.2 million aluminium soft drinks cans.

From a capital expenditure perspective, the cost to replace the devices will be in the region of £5,870,550 unless alternative action is taken.

As previously noted in the primary and secondary school sections, research shows that Windows devices lifespan can be extended by replacing the existing operating system with Google's ChromeOS Flex. Doing so creates devices similar to Chromeboxes and Chromebooks. SEND schools have a high percentage of both desktops (41%) and notebooks (78%) using ChromeOS as an operating system already. Therefore, deploying ChromeOS Flex to devices affected by the Windows 10 EOL event would most likely not meet with user resistance.

In context, if the new product cost was annualised across an extended lifespan of 8 years, the additional annual EUC procurement spend caused by the Windows EOL event is £733,819 at a national level. Using an average teacher's salary, this saving would enable 22 more teachers to be employed in the SEND school sector during the coming decade.

The same preventative action in primary and secondary schools was calculated to enable 797 more teachers to be theoretically employed. Therefore, the combined feasible impact of avoiding disposal of devices due to Windows 10 EOL is 819 across all schools in England.

SEND School Sustainable EUC Strategy 2: Device Lifespan Extension

Similar to primary and secondary schools (Figures 3 and 20), the average lifespan of EUC equipment in SEND schools varies from 5 years to 8 years depending upon device type (Figure 35). All results indicate that it is feasible for all devices to be retained for a uniform 8 years. As previously demonstrated, when doing so both supply chain GHG emissions and annual procurement costs reduce simply because devices are purchased less often.

Table 11 shows that while annual energy consumption, utility costs and concomitant scope 2 GHG emissions remain unaffected, supply chain emissions reduce by 33% from 8,616 kgCO_2e (Table 10) to 5,796 kgCO_2e (Table 11). The percentage reduction concurs with both primary and secondary school. Plus, this simple change in strategy avoids 2,820 kgCO_2e per year and would otherwise require 128 mature trees to remove the carbon from Earth's atmosphere.

Further to extending the lifespan, tablets contribute to 11% of this reduction, notebooks 55%, desktops 27%, AIO 0% and displays 6%. The reason for the lack of improvement from AIO devices is because they are already kept for 8 years on average, whereas comparatively notebooks represent the highest number of devices (Table 11) and are currently only kept for 5 years (Figure 35)

Table 11. Average SEND school EUC estate annual environmental and financial results with lifespan extension to 8 years applied

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	56	8	525	171	696	827	£256.41	£3,493	3.4
Notebook	109	8	2,602	254	2,856	1,231	£381.49	£8,161	19.9
Desktop & Monitor	38	8	2,306	524	2,830	2,533	£785.14	£4,741	35.6
AIO	2	8	71	26	96	125	£38.75	£200	2.2
Display	2	8	292	58	350	281	£87.25	£250	9.0
Total	**207**		**5,796**	**1,034**	**6,830**	**4,997**	**£1,549**	**£16,844**	**70**

Figure 42. SEND school average EUC annual supply chain reduction by device type (8 year retention policy)

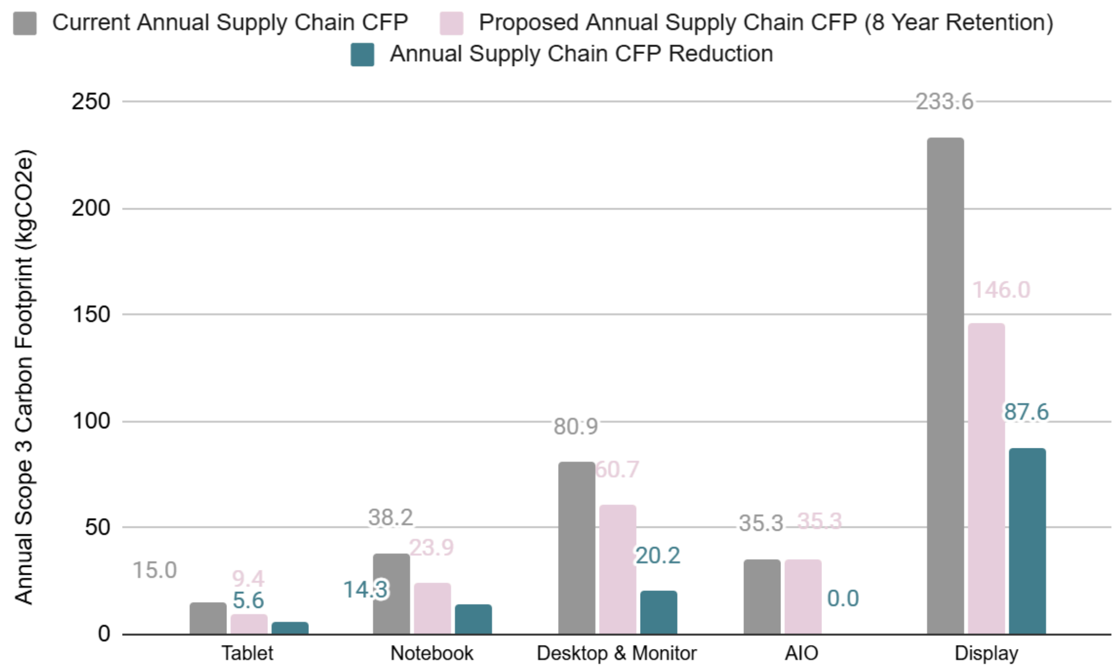
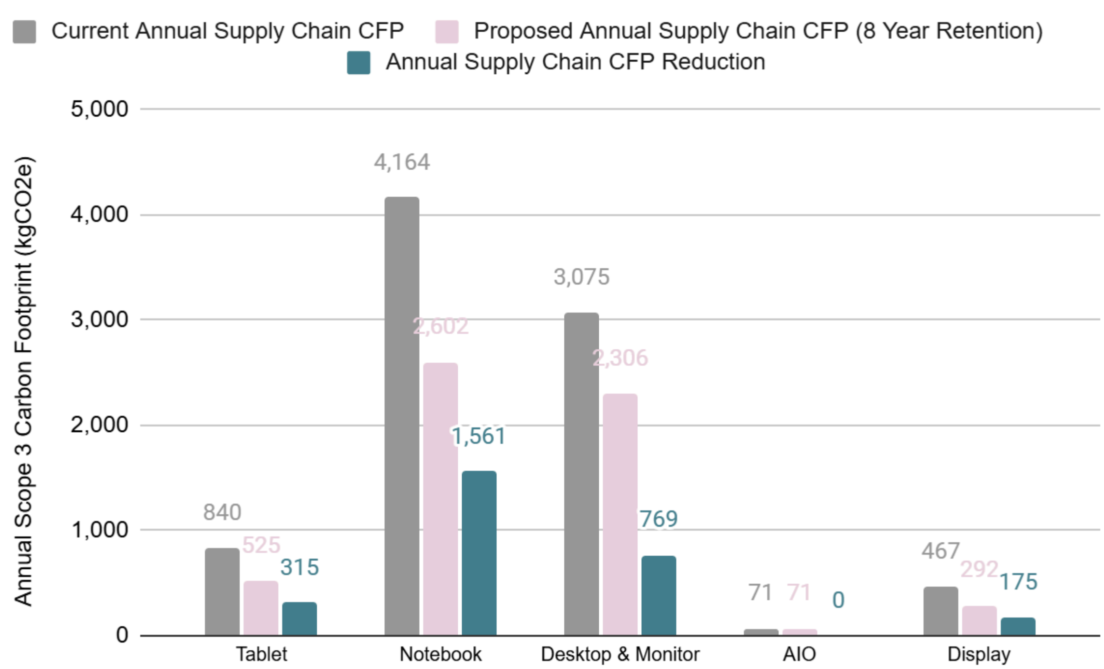


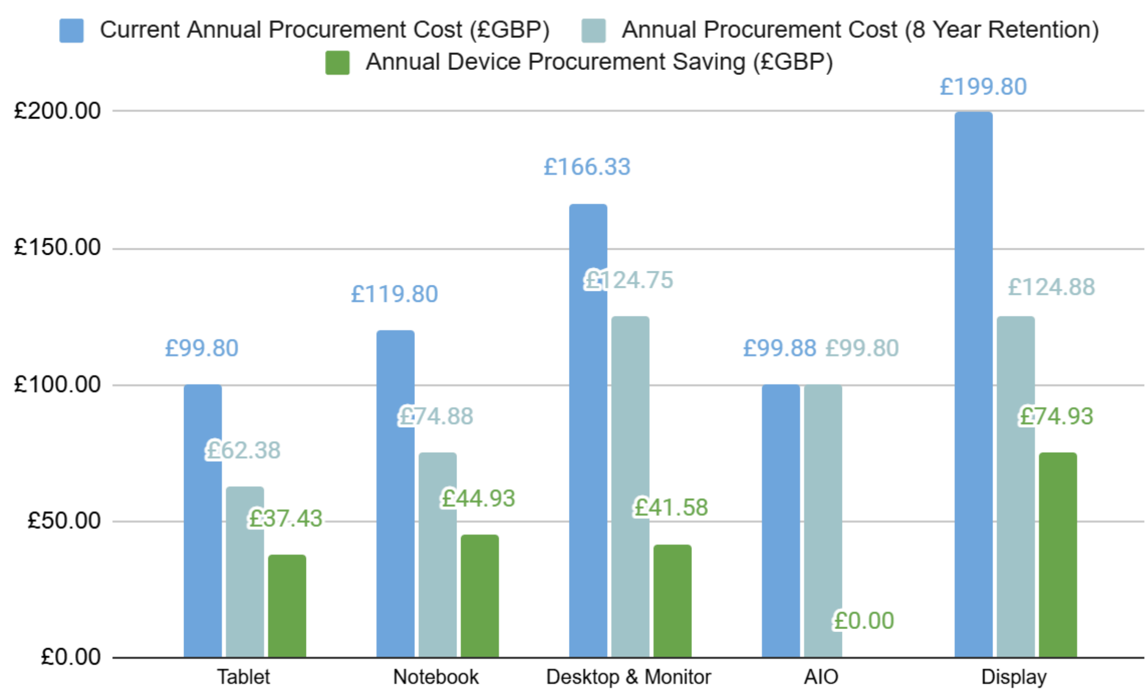
Figure 43. SEND school average EUC annual supply chain reduction for all assets (8 year retention policy)



Using this strategy, the SEND school EVER metric reduces from the current 1:39 ratio to 1:28. This means that by simply keeping devices for longer periods, 11 $kgCO_2e$ is avoided on average annually for each device owned.

From an annual procurement perspective Figure 44 shows that while AIO devices remain unaffected, desktop and monitor combination reduce by 25% and £41.58 (Figure 44) having transitioned from a 6 year to 8 year retention period. This is equivalent to secondary schools with the same average retention period and twice the impact caused in primary schools (Figure 12) of 12.5% and £17.82 per unit annually, because desktops are retained for 7 years already. All devices previously retained for 5 years reduce in annual cost by 37.5%. Specifically, tablets reduce by £37.43 annually and notebooks by £44.93 in line with the primary and secondary school reductions (Figures 12 and 29). Displays exhibited a 37.5% and £74.93 reduction annually (Figure 42). This is equivalent to primary schools (Figure 12) and lower than secondary schools at 50% decline in cost from £249.75 to £124.88 (Figure 29). This is because secondary schools keep displays for one year less than primary and SEND schools.

Figure 44. SEND school average EUC annual procurement cost reduction by device type (8 year retention policy)



Applied to the entire average SEND school EUC estate, Figure 45 shows that annual procurement costs reduce by 34% from £25,567 (Table 11) to £16,844 (Table 7). Meaning that each SEND school extending device lifespans to a uniform 8 years, saves £8,723 per annum.

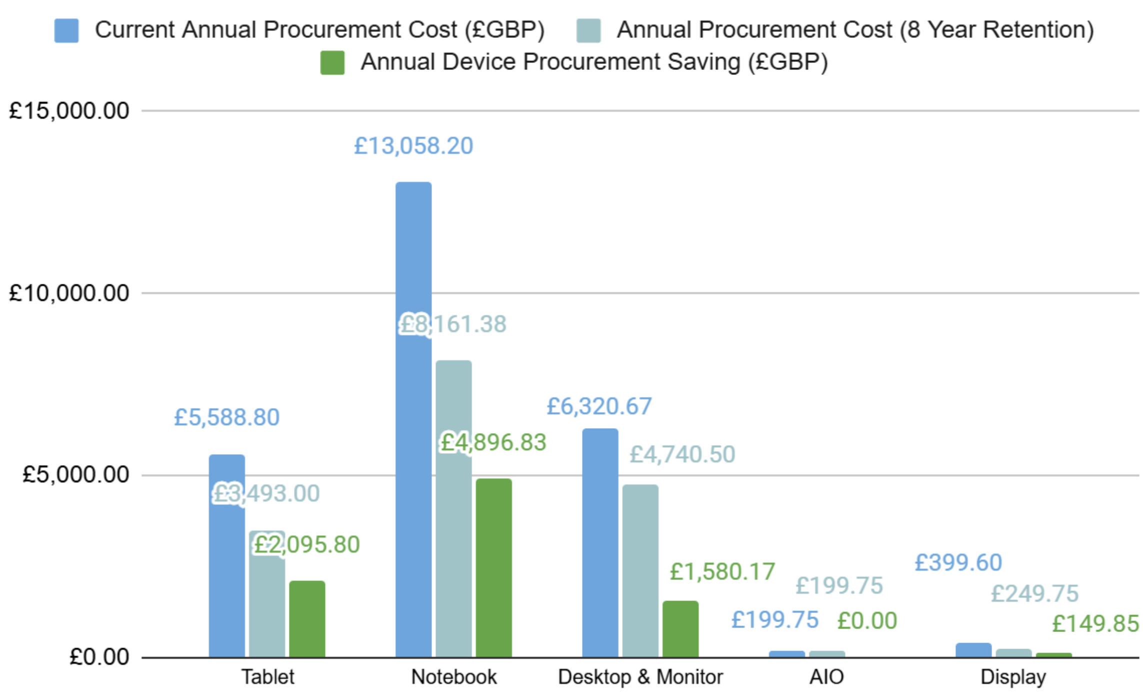
Similar to the Windows 10 EOL strategy, when applied at a country level the improvement to environmental and financial values within the SEND school sector is significant. Specifically, if all schools adopted lifespan extension to 8 years 2,961,000 kgCO_2e of scope 3 supply chain GHG emissions would be avoided annually.

This is equivalent to emissions created by driving a combustion engine car 17.4 million km or 435 times around Earth's equator. In context, 134,590 trees would be required every year to remove this carbon footprint from the atmosphere.

Additionally, 32,550 kg of potential e-waste would be avoided annually. This is equivalent to almost 2.17 million aluminium soda cans.

From a cost perspective, £9,159,150 in EUC device procurement expenditure would be avoided every year. This avoided cost could be used to employ 269 additional teachers each year. When added to the primary and secondary school equivalent, then 11,312 more teaching staff could be employed in the state funded schools sector.

Figure 45. SEND school average EUC annual procurement cost reduction for all assets (8 year retention policy)



SEND School Sustainable ICT Strategy 3: Carbon Footprint as a Selection Criterion

As previously noted, an average SEND school EUC estate currently generates 9,650 kgCO_2e in carbon footprint, produces 101 kg of e-waste, consumes 4,997 kWh of electricity, costs £1,549 in utility bills and £25,567 in procurement spend for every year of operation (Table 10). This creates an annual EVER per capita value of 1:39 and costs of £110.68 per device per year (Table 10).

The primary and secondary school results show that introducing carbon footprint as a selection criterion together with lifespan extension, will reduce annual GHG emissions by an incremental 26% (Figure 14 and 31). Table 12 shows that in SEND schools this is 22%.

Specifically, the current annual carbon footprint is reduced by a total of 54% to 4,488 kgCO_2e. This is achieved by reducing supply chain emissions by 60% from 8,616 kgCO_2e (Table 10) to 3,489 kgCO_2e (Table 12 and Figure 46). Plus scope 2 use-phase emissions by 3.4% from 1,034 kgCO_2e (Table 10) to 999 kgCO_2e (Table 12 and Figure 46).

Comparing the original strategy (Table 10), the change causes tablets to be 43% lower in annual carbon footprint, notebooks 58%, desktop and monitor combinations 53%, AIO devices 24% and interactive displays 47%.

In total, annually avoided emissions are 5,162 kgCO_2e and equivalent to emissions generated by driving a combustion engine car over 30,000 km and would otherwise 234 trees to remove the carbon from Earth's atmosphere every year. The new annual carbon footprint reduces the original EVER metric from 1:39 to 1:18, meaning that on average each device owned generates just 21 kgCO_2e per year.

Table 12. Average SEND annual environmental and financial values following the implementation of strategy 2 (lifespan extension) and 3 (carbon footprint as a selection criterion).

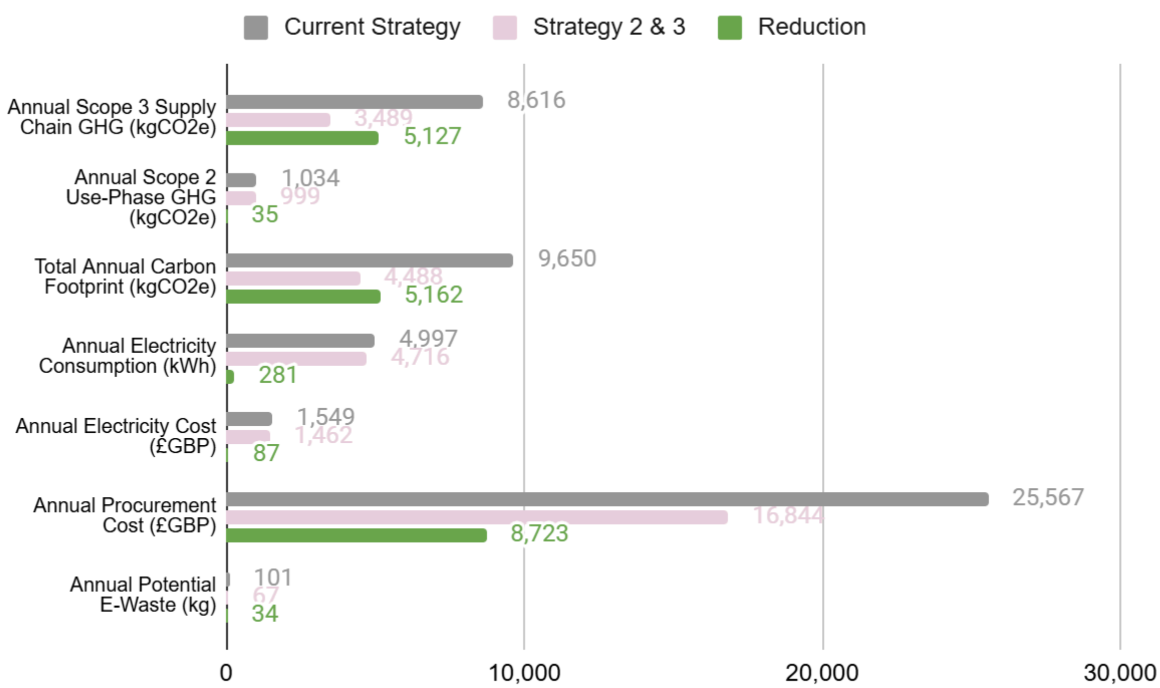
	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	56	8	406	168	574	728	£225.68	£3,493	3.7
Notebook	109	8	1,543	327	1,870	1,526	£473.06	£8,161	21.8
Desktop & Monitor	38	8	1,276	418	1,694	2,052	£636.12	£4,741	32.3
AIO	2	8	52	22	74	104	£32.24	£200	1.5
Display	2	8	213	64	277	306	£94.86	£250	8.1
Total	**207**		**3,489**	**999**	**4,488**	**4,716**	**£1,462**	**£16,844**	**67**

Figure 46 reflects the procurement savings achieved in the lifespan extension strategy (Figure 45). However, due to improved energy efficiency, a reduction in energy consumption of 281 kWh/y reduces utility costs by 6% and £87 annually (Figure 46).

Nationally, the total avoided SEND school EUC emissions would equal 5,420,100 kgCO_2e per year. This is equivalent to emissions generated by driving almost 32 million kilometres or 796 times around the world. Additionally, 35,700 kg of e-waste could be avoided annually. This is equivalent to almost 2.4 million aluminium soda cans.

And finally, as a combined saving of £8,810 per SEND school can be achieved via reduced utility and procurement costs, then if all SEND schools in England participated, a total cost saving of £9,250,500 could be made annually. In context, this saving is sufficient to employ 272 additional teachers every year. This brings the total to 11,618 additional teachers across all schools if strategies 2 and 3 became a reality.

Figure 46. SEND school environmental and financial metrics comparing an average primary school current EUC strategy to results following implementation of lifespan extension to 8 years and carbon footprint as a device selection criterion



SEND Schools EUC Volume of Emissions Ratio (EVER)

As with the primary and secondary schools data, the EVER metric is used to determine average annual GHG emissions per device ratio for all schools to enable comparison. Using the current strategies, the ratio is 1:39 for primary and SEND schools and 1:46 for secondary schools. When strategies 2 and 3 are applied this reduces to a feasible 1:17 in primary, 1:18 in SEND, 1:20 for secondary schools.

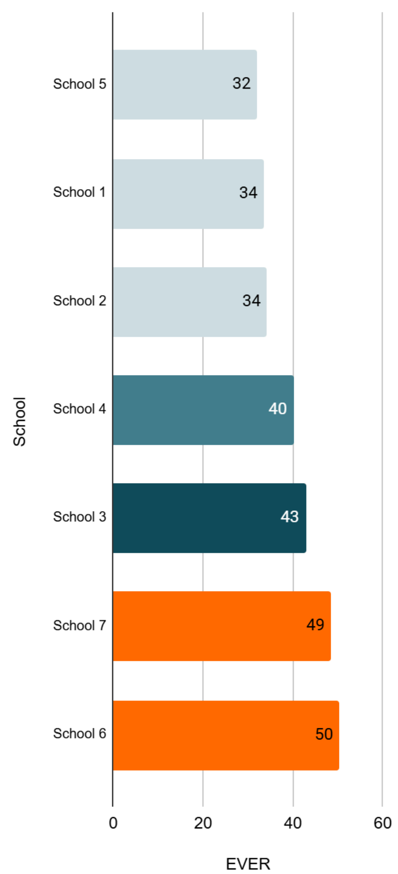
Figure 47 shows the EVER metric for each of the 7 SEND schools included in the research data set. The results range from 1:32 for school 5 and rise by 56% to 1:50 for school 6. In this example, the disparity is driven by the simple fact that school 2 doesn't use interactive displays while they form 8% of devices. As before, it is therefore clear that as anticipated, device type proportional representation and ultimately choice, will influence carbon footprint.

As such, to echo the primary and secondary school results, when considering both environmental and financial metrics associated with SEND school end user computing, stakeholders must include the following strategies:

- Lifespan extension
- Carbon footprint as a selection criterion
- Transition to mobile computing

On average, by adopting sustainable ICT strategies in SEND schools, both associated planet and profit metrics will improve. Specifically, doing so will reduce annual carbon footprint by 54%, e-waste by 33% and procurement and utility costs by 33%.

Figure 47. EUC Volume of Emissions Ratio (EVER) metrics for 7 SEND schools



Colleges

For this research, the colleges section excludes sixth form secondary school education establishments as they are included in the secondary school results. Instead, the criterion for Colleges is that they only operate as a 6th form college with students generally aged between 16-18. Although no student age limit is implied.

Within the data set collected this includes just two colleges based in the East of England and the South East. Therefore, while the results are presented in a similar, although more concise way to the schools sections, the results must be read as typical for only these two establishments. This is because although the sample represents 1% of all 6th form only colleges in England [6], two data sets cannot be considered as adequate to draw conclusion upon all 217 colleges in the sector [6].

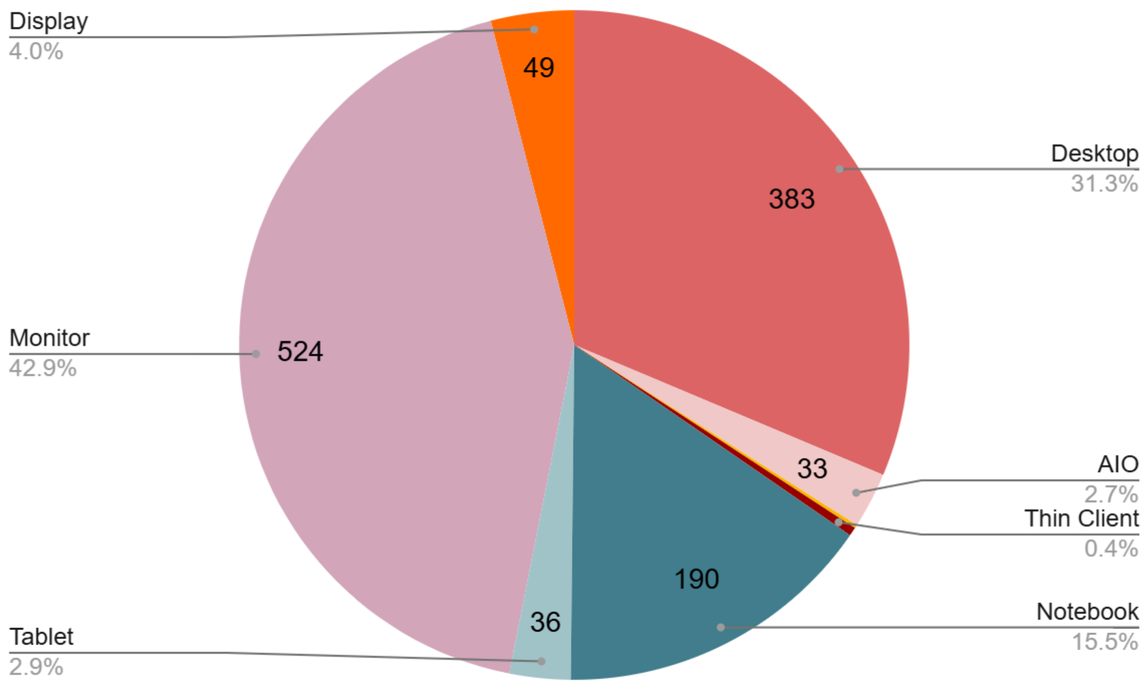
Colleges EUC Asset, Environmental and Financial Profile

Data for 2,444 EUC devices is captured, with 54 specific models of device from 21 brands identified. The data shows that an average college has 1,625 computer users. In comparison, this is 49% larger than an average secondary school. Of these, 1,480 are students (91%) and 145 staff (9%), resembling the same user ratio as a secondary school. Each college has an average of 1,222 devices, represented by 649 computers (53%), 524 monitors (43%) and 49 displays (4%) (Figure 48). Compared to both schools, the mix is far greater in relation to monitors which range between 4-13% (Figures 1, 18 and 33). This is because additional monitors are in operation in colleges to be connected to devices brought into the college by students. In this instance 'bring your own devices' BYOD are not included within the scope of the research and are therefore not accounted for. The rationale for this is that the colleges have no ability to influence device choice nor retention for the BYOD computers.

This equates to an EUC asset list of 190 notebooks (16%), 36 tablets (3%), 383 desktops (31%), 33 AIO (<3%), 2 workstations (<0.5%), 5 thin clients (<0.5%), 524 monitors (43%) and 49 (4%) displays (Figure 48). This suggests that 19% of college computing is via mobile devices. However, considering that primary, secondary and SEND schools exhibit between 68-95% mobile computing devices (Figures 1, 18 and 33), the assumption is that the shortfall in mobile devices is due to BYOD not being accounted for.

Because of this the ratio of devices per user will prove invalid in the context of creating a realist view of device availability. Specifically, with 649 computers and 1,625 users, the data indicates there is 0.4 of one computer per user. Considering that all schools range from 0.9 to 1.3 then this is once again considered misleading.

Figure 48. College average EUC device quantities by type



Mobile Devices

Average notebook age is 4 years (Table 13); one year less than all schools. Unlike schools that are mainly populated with 11" devices (63-68%), colleges favour 14" (42%), followed by 15% (34%), 13" (23%) and 16" (1%). From an OS perspective, Windows is installed on 99% of devices with 1% MacOS. This is different to schools that have between 67-78% Chromebooks. Of the Windows notebooks, 6% were manufactured during or before, meaning that 11 college notebooks will not meet the Windows 11 upgrade criteria.

Notebook OS and size influences energy consumption, with the average being 18.69 kWh/y (Table 13), costing £5.86 per year and causing 3.87 kgCO_2e scope 2 emissions annually. This is 58% higher than the average school's notebook value of 11.8 kWh/y (Tables 1, 5, 9). College notebook supply chain emissions per unit are 240 kgCO_2e and 60 kgCO_2e (Table 13) annualised across the 4 year retention period. Due to the increased screen size, this is 24% higher than the 194 kgCO_2e experienced in schools (Tables 1, 5, 9). Lifespan e-waste is elevated due to increased weight of 1.75 kg compared to 1.5 kg in schools. Therefore, annualised notebook e-waste is 0.44 kg (Table 13). Procurement per unit is also 25% higher, simply because of the lower retention period, resulting in £149.75 per year versus £119.80 in schools (Tables 1, 5, 9).

Tablets are kept for just 2 years which is incongruent with schools that uniformly apply 5 years (Figures 3, 20, 35). The OS mix is also very different with 90% Windows. The remaining 10% are iPads, compared to schools' iPad install base of between 72-81% of all tablets.

However, the Microsoft Surface Pro devices in this instance produce a lower overall tablet energy consumption of 10.83 kWh/y. Costing £3.36 per year and creating 2.24 $kgCO_2e$ of scope 2 emissions. This is 24% lower than the 14.18 kWh/y average in schools (Tables 1, 5, 9). Similar to schools, the most popular size is 10" and the average supply chain value is 93 $kgCO_2e$ annualised to 46.5 $kgCO_2e$ (Table 13). This is 16% higher than the schools average (Tables 1, 5, 9) suggesting that iPads in general have a lower scope 3 value than comparative brands. Average tablet weight in colleges is 0.56 and comparable with schools, although due to the short retention period annual e-waste is 0.28 kg (Table 13) compared to 0.1 kg (Tables 1, 5, 9). While the 2 year retention period could simply be associated with a wholesale refresh in both colleges, this does increase the annual procurement value from £99.80 experienced in schools (Tables 1, 5, 9) to £249.50 (Table 13).

Static Devices

Desktops are kept for 5 years (Table 13) with sizes relatively evenly spread between USFF (55%) and SFF (45%). This is 2 years less than primary schools (Table 1) and 1 year less than secondary and SEND schools (Tables 5 and 9). Energy consumption is 31 kWh/y, causing 6.4 $kgCO_2e$ of use-phase emissions and costing £9.61 (Table 13). This is 11% lower than the schools average and driven by high quantities of Dell Micro desktops that proved highly energy efficient.

Supply chain emissions average is 191 $kgCO_2e$ and annualised to 38.2 $kgCO_2e$ (Table 13). This is 15.5% lower than the schools average (Tables 1, 5 and 9) of 226 $kgCO_2e$. This is again due to the low manufacturing carbon footprint of the same Dell Micro desktop. Procurement costs per year are elevated when compared to schools due to the shorter retention period. Specifically for colleges it is £119.80 (Table 13). The average desktop weight is 3.2 kg resulting in 0.64 of potential annual e-waste (Table 13).

8.8% of Windows desktops are produced before 2018. Considering that 81% of desktops are Windows (9% MacOS), this means that 27 desktops will not meet the Windows 11 upgrade criteria.

Similar to secondary schools, thin client computers are present in colleges. The average age is 3 years and all are USFF. Energy consumption is 23.44 kWh/y and as before this does not account for data centre electricity overhead. This costs £7.27 per year and generates 4.85 $kgCO_2e$ per year (Table 13). Scope 3 emissions are 129.8 $kgCO_2e$ annualised to 43.27 $kgCO_2e$ while the weight is 1.67 and annualised to 0.56 kg of potential e-waste annually (Table 13). Due to the relatively short retention period, annualised procurement costs are £199.67 per unit (Table 13).

Workstations are also present in small numbers. These devices are kept for 5 years on average and are all tower format. Due to the increased size and nature of their function, the workstations consume +334% more energy than desktops at 134.5 kWh/y; generating 27.84 $kgCO_2e$ in scope 2 emissions and costing £41.70 per year in utility spend (Table 13). Because of the tower format, supply chain emissions are +137% more than desktops at 453.5 $kgCO_2e$ and annualised to 90.70 $kgCO_2e$ (Table 13). Weight too is increased by +267% to 11.75 kg and creates 2.35 kg of potential e-waste annually (Table 13). While procurement costs are £119.80 per year (Table 13). All Workstations are Windows with 50%

manufactured before 2018, meaning 1 device will require intervention when Windows 10 becomes EOL [48].

AIO devices are once again 8 years old on average, which concurs with schools (Tables 1, 5 and 9). Electricity consumption is 42.12 kWh/y generating 8.72 kgCO_2e (Table 13) and costs £13.06 per year. This is 44% lower than the schools average 63.38 kWh/y (Tables 1, 5 and 9). OS choice is evenly split between MacOS (44%) and Windows (56%) and the efficiency of the specific model choices is driving the reduction. Supply chain emissions are 273.5 kgCO_2e and annualised to 34.19 kgCO_2e (Table 13) which concurs with school results (Tables 1, 5, 9). Procurement costs per unit are £99.88 per year and e-waste is 7.22 kg annualised to 0.90 kg and inline with schools. The data set shows that all Windows AIO are manufactured before 2018, and therefore 18 devices will not meet the Windows 11 update criteria.

Monitors are kept for 5 years which correlates with desktop average age (Table 13). Unlike schools that prefer 27" monitors, 22" proved most popular at 67% of all screens. This was followed by 27" (27%), 5% 24" and 1% 32". Electricity consumption was reduced significantly by 34% at 26.5 kWh/y (costing £8.22 and generating 5.49 kgCO_2e) (Table 13) when compared to the schools average of 40 kWh/y (Tables 1, 5 and 9). This is driven by the 22" devices proving to be one third more energy efficient. However, a common detraction associated with 22" monitors caused the supply chain value overall to be 10% higher at 330 kgCO_2e and annualised to 66 kgCO_2e (Table 13) when compared to the school average of 304.5 kgCO_2e (Tables 1, 5, and 9). E-waste is 5 kg, annualised to 1 kg, while procurement costs are £79.80 per year (Table 13).

Table 13. Average college annual environmental and financial results by device type (one unit)

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	1	2	46.50	2.24	48.74	10.83	£3.36	£249.50	0.28
Notebook	1	4	60.00	3.87	63.87	18.90	£5.86	£149.75	0.44
Monitor	1	5	66.00	5.49	71.49	26.50	£8.22	£79.80	1.00
Desktop	1	5	38.20	6.40	44.60	31.00	£9.61	£119.80	0.64
AIO	1	8	34.19	8.72	42.91	42.12	£13.06	£99.88	0.90
Thin Client	1	3	43.27	4.85	48.12	23.44	£7.27	£199.67	0.56
Workstation	1	5	90.70	27.84	118.54	134.50	£41.70	£119.80	2.35
Display	1	5	307.40	49.78	357.18	240.50	£74.56	£199.80	13.34

The most popular display size in colleges is 86" (87%) followed by 75" (13%) which is different to all schools' preferences ranging between 55-75". Consequently, electricity consumption is 21% higher than the school average of 198.58 kWh/y (Tables 1, 5 and 9). At 240.5 kWh/y this costs £74.56 in utility expenditure and generates 49.78 kgCO_2e per year (Table 13). Supply chain emissions are 1,537 kgCO_2e and annualised to 307.4 kgCO_2e (Table

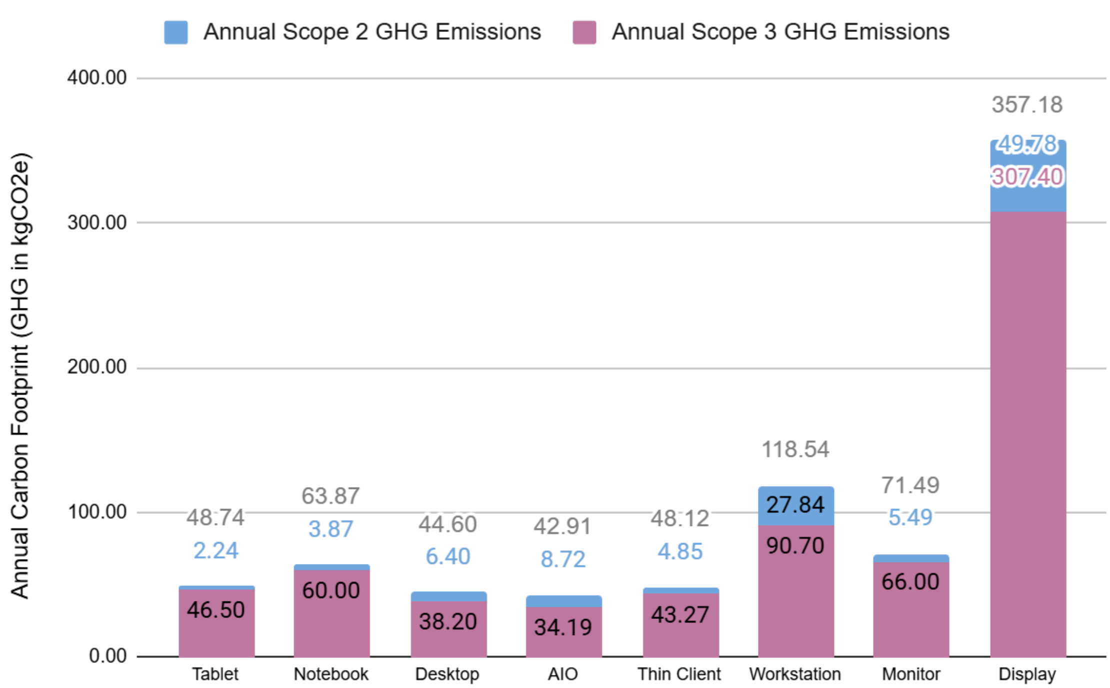
13). Due to the increased size, this is 16% higher than the school average of 264.4 $kgCO_2e$ (Tables 1, 5 and 9). The average weight is 66.69 kg, annualised to 13.34 kg of potential e-waste (Table 13). This is 45% higher than the school average of 9.22 kg (Tables 1, 5 and 9) and substantiates the need to consider product physical size in relation to e-waste.

In this instance, between the two colleges, both sets of displays were relatively new with an average age of 2 years. Because of the limited college data this does not indicate a trend for retention periods and therefore the schools average of 5 years is applied. The assumption is made to ensure that the improvements created by the sustainable ICT strategies are not inflated by extending lifespans beyond what is a more realistic retention period. As such, annual procurement cost is inline with schools at £199.80 (Table 13).

Summarising the profile results and accounting for all device types and type specific attributes, an average college EUC estate consists of the following device proportional representation:

- 190 notebooks consisting of 188 Windows notebooks, 2 MacBooks
- 36 tablets consisting of 32 Microsoft Surface and 4 Apple iPads
- 383 desktops consisting of 310 Windows desktops and 73 Mac Mini
- 5 Thin Clients desktops (Linux)
- 33 AIO desktops 18 Windows and 15 iMac
- 2 Workstation desktops (Windows)
- 524 monitors
- 49 interactive displays including forty three 86" and six 75"

Figure 49. College average EUC device annual carbon footprint (GHG emissions $kgCO_2e$)



Average College EUC Estate Carbon Footprint and Energy Baseline

As with schools, college proportional representation (Figure 48) of EUC devices combined with carbon footprint by device type (Figure 49), enables the annual average carbon footprint for an entire college EUC estate of 1,222 (Table 14) to be calculated. The annual carbon footprint is 87,828 kgCO_2e (Table 14) and equivalent to emissions created by a combustion engine car travelling 517,121 km or almost 13 times around the Earth's circumference. In context, for one average college, 1,932 mature trees are required every year to remove this carbon from Earth's atmosphere.

Consequently, the per capita EVER ratio for an average college is 1:72, meaning that for every device owned, 72 kgCO_2e carbon footprint is generated annually. This requires 3 trees per year to sequester the carbon of each EUC device. The ratio is 75% higher than the school average of 1:41.

The significance is simply driven by the fact that without considering BYOD, only 19% of college devices are mobile (Figure 48) while in schools this value ranges from 68-95% (Figures 1, 18 and 33). Therefore, as previously noted, to generate a valid EVER value for colleges, BYOD computers should be surveyed.

Figure 50. College average EUC device annual carbon footprint (kgCO_2e)

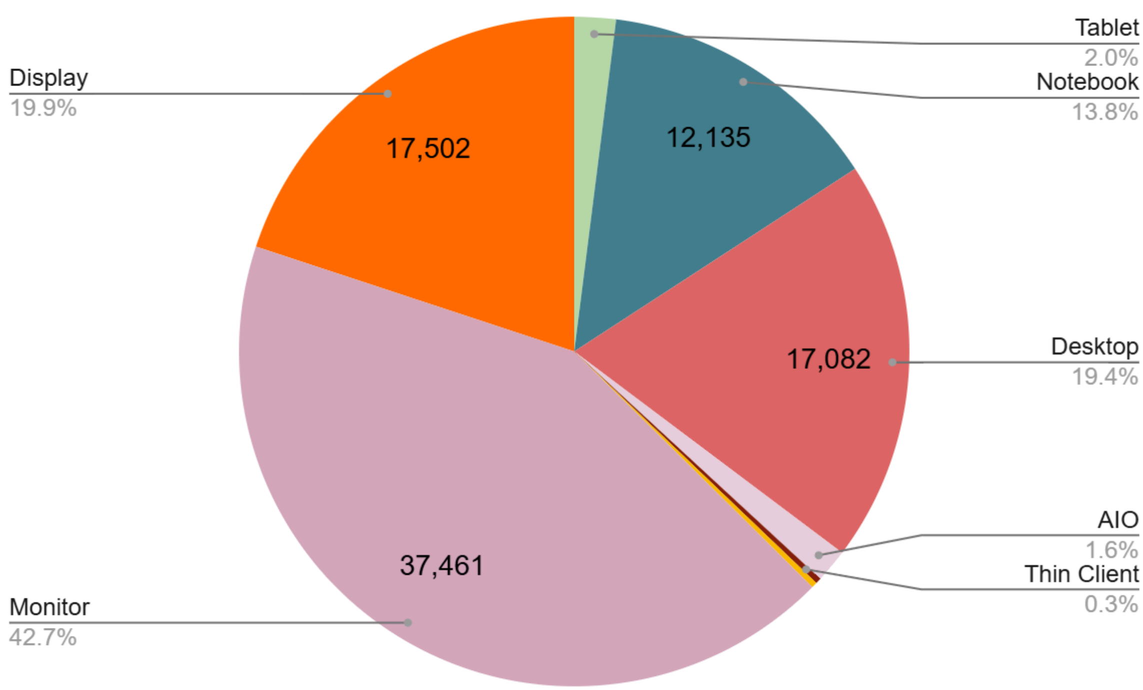
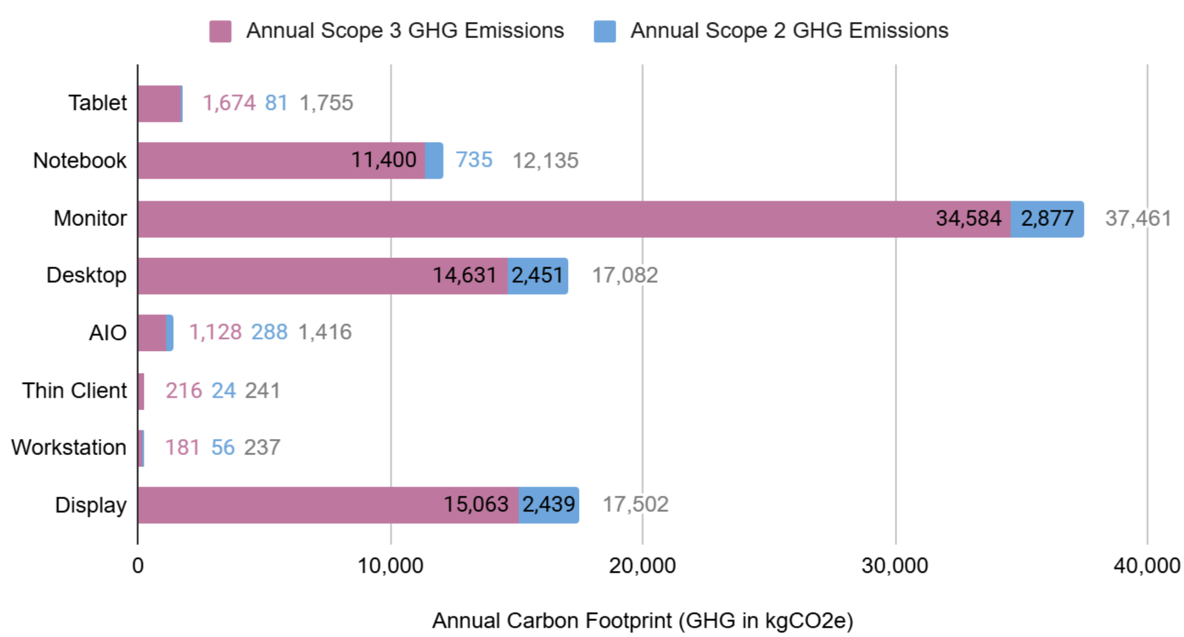


Table 14. Average college EUC estate annual environmental and financial results

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	36	2	1,674	81	1,755	390	£120.86	£8,982	10.1
Notebook	190	4	11,400	735	12,135	3,591	£1,113.21	£28,453	83.6
Monitor	524	5	34,584	2,877	37,461	13,886	£4,304.66	£41,815	524.0
Desktop	383	5	14,631	2,451	17,082	11,873	£3,680.63	£45,883	245.1
AIO	33	8	1,128	288	1,416	1,390	£430.89	£3,296	29.7
Thin Client	5	3	216	24	241	117	£36.33	£998	2.8
Workstation	2	5	181	56	237	269	£83.39	£240	4.7
Display	49	5	15,063	2,439	17,502	11,785	£3,653.20	£9,790	653.7
Total	**1,222**		**78,877**	**8,951**	**87,828**	**43,301**	**£13,423**	**£139,457**	**1,554**

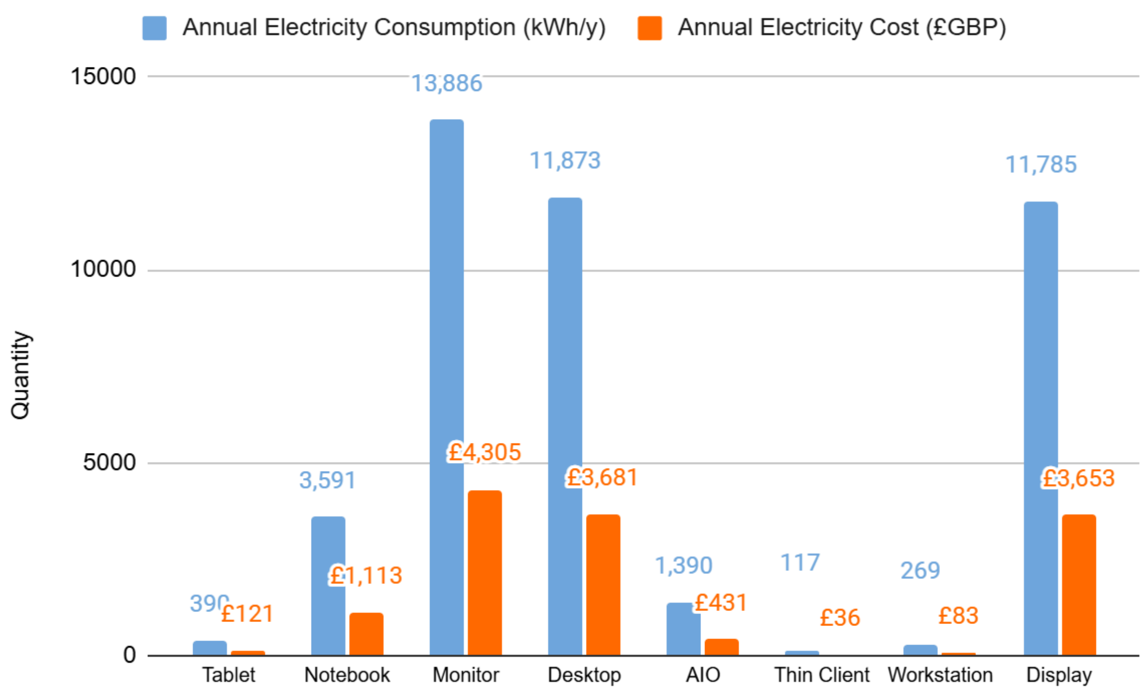
Figure 51 shows the carbon footprint of EUC devices for each year of use. For colleges supply chain emissions are responsible for 89% on average and supply chain emissions 11%. This is concurrent with the school findings (Tables 1, 5 and 9). While conclusive, it is noted that this is specific to the UK due to the carbon intensity of English electricity grid supply. Therefore, if applied in other countries this must be accounted for.

Figure 51. College average EUC estate device annual carbon footprint (kgCO_2e) by GHG scope type



In relation to energy efficiency, the average college EUC estate consumes 43,301 kWh/y (Table 14). Based upon an average college having 1,222 devices, this produces a per device consumption of 35.4 kWh/y. This is 60% higher than the school average of 22.1 kWh/y (Tables 1, 5, 9) and is driven by the previously noted low percentage of mobile devices which consume less energy than static devices (Tables 1, 5, 9 and 13). This influences the per unit utility cost, producing an equivalently increased value of £10.98 per annum (Figure 52).

Figure 52. College average EUC estate device annual electricity consumption (kWh/y) and cost (£GBP)



Dividing the average new hardware costs by the varying average retention periods discovered in colleges (Table 13) produces an annual procurement cost by device type (Table 13). Figure 53 shows that this is equivalent to school results (Figures 8, 25 and 40) when retention periods remain equivalent by device type. However, in this example, because tablets were on average only 2 years old within the limited data set, this causes an increased annual procurement cost of £252.86 (Figure 53). This is a +153% increase on the school average annual procurement cost of £99.80 (Figures 8, 25 and 40), simply due to the differing retention period. It is suggested that had the colleges data been more expansive then this margin would have narrowed as older devices were identified.

Figure 53. College average EUC device annual electricity and procurement cost (£GBP) per unit

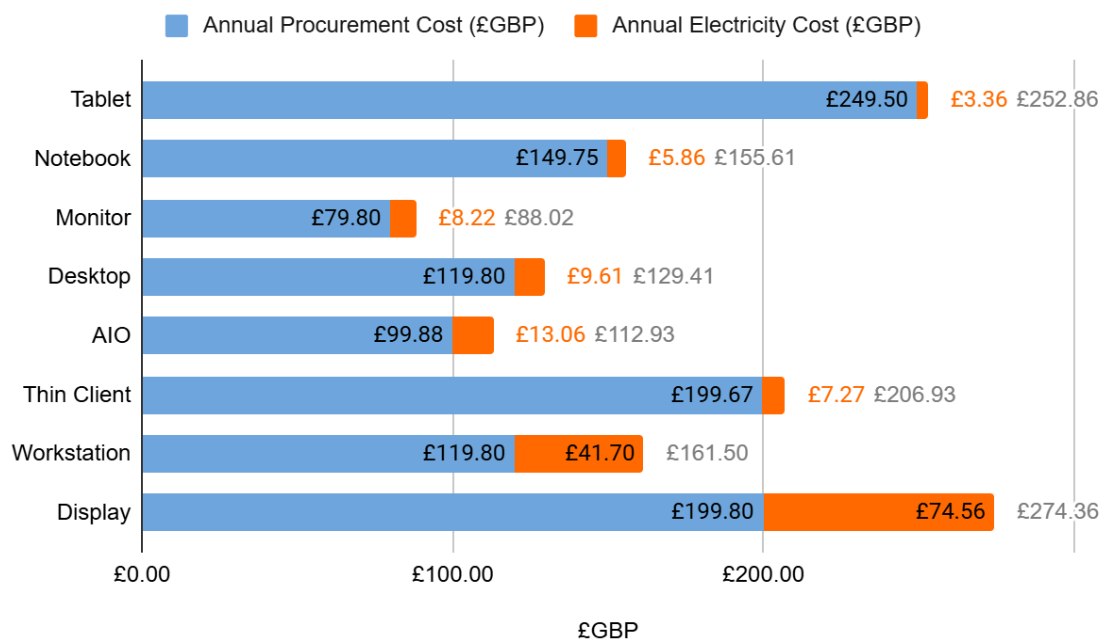
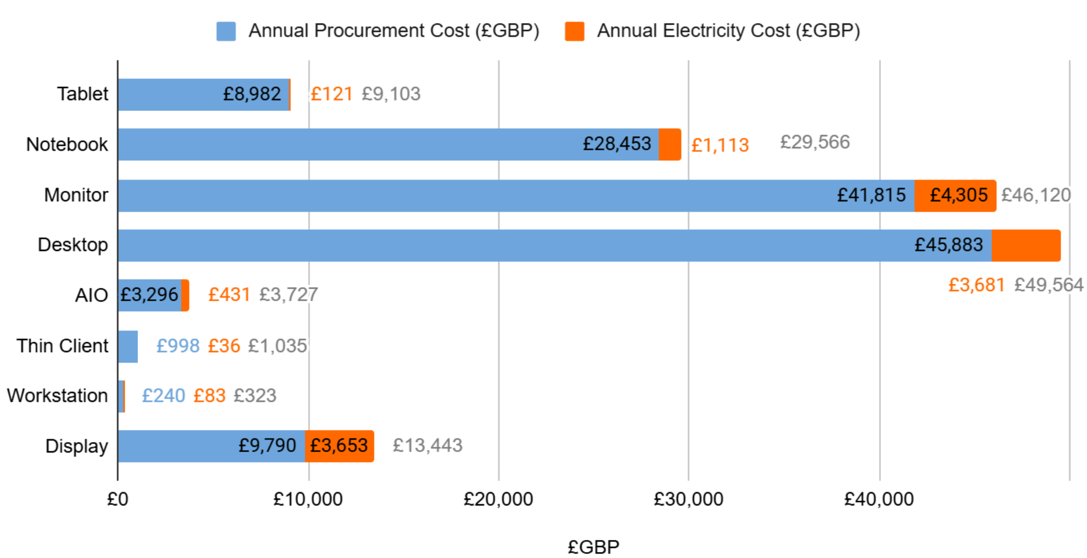


Table 14 and Figure 54 show that for an average college EUC estate, £152,880 will be spent on combined electricity (£13,423 and 9%) and device procurement (£139,457 and 81%) annually. This means that with 1,222 devices in use in an average college, each will cost on average £125.10 (Figure 54) per year. This is 10% higher than the school average of £113.24 (Figures 9, 26 and 41) and again caused by the perceived low adoption of mobile devices.

Figure 54. College average EUC estate annual electricity and procurement cost (£GBP)



Sustainable ICT Strategies in Colleges

Similar to schools, to reduce short and long term carbon footprint and cost impact, three key sustainable strategies will generate differing results in colleges. The first is to address the impending replacement of devices affected by the Windows EOL event [48]. Secondly, extension of device lifespans to a uniform period of 8 years. Thirdly, introducing carbon footprint as a selection criterion for new devices.

College Sustainable EUC Strategy 1: Windows 10 EOL

As previously noted, in the two colleges, 8.8% of Windows desktops (27 devices), 6% of Windows notebooks (11 devices), 100% of Windows AIO (18 devices) and 50% of Windows Workstations (1 device) will not meet the Windows 11 upgrade criteria when Windows 10 becomes EOL [48].

Based upon the data in Table 13, this means for each college in England, 13,174 kgCO_2e of like for like new product supply chain GHG emissions and 247 kg of e-waste will be generated. Replacement of the affected device will also cost each college approximately £37,743 in procurement expenditure.

Currently, within England's state funded education sector there are 205 colleges. Therefore, extrapolated to a country level the potential impact of finding no alternative strategy to replacement will generate 2,700,670 kgCO_2e of new product carbon footprint. This is equivalent to GHG emissions created by driving a combustion engine car 15.9 million km or almost over 398 times around the world. This impact would require almost 122 thousand trees to sequester the resulting carbon from Earth's atmosphere.

Additionally, 50.6 tons of e-waste will be produced as the obsolete devices are sent for end of life services. In context, this is equivalent to almost 3.4 million aluminium soft drinks cans.

From a capital expenditure perspective, the cost to replace the devices will be in the region of £7,737,315 unless alternative action is taken.

As previously noted in the school sections, research shows that Windows devices lifespan can be extended by replacing the existing operating system with Google's ChromeOS Flex to create devices similar to Chromeboxes and Chromebooks. In this example, colleges show very little ChromeOS operating systems in place, although the data sample is limited. As such, using ChromeOS Flex may require user acceptance.

In context, if the new product cost was annualised across an extended lifespan of 8 years, the additional annual EUC procurement spend caused by the Windows EOL event is

£967,164 at a national level. Using an average teacher's salary, this saving would enable 28 more teachers to be employed in the college sector during the coming decade.

The same preventative action in schools was cumulatively calculated to enable 819 more teachers to be theoretically employed. Therefore, the combined feasible impact of avoiding disposal of devices due to Windows 10 EOL rises to 847 across the state education sector in England.

College Sustainable EUC Strategy 2: Device Lifespan Extension

Similar to schools (Figures 3, 20 and 35), the average lifespan of EUC equipment in colleges varies from 5 years to 8 years depending upon device type (Table 13). All results indicate that it is feasible for all devices to be retained for a uniform 8 years. This is because numerous examples appear in the data set showing all device types in operation for 8 years or longer. As previously demonstrated, when extending lifespans uniformly, both supply chain GHG emissions and annual procurement costs reduce simply because devices are purchased less often.

Table 15 shows that while annual energy consumption, utility costs and concomitant scope 2 GHG emissions remain unaffected, supply chain emissions reduce by 40% from 78,877 kgCO_2e (Table 14) to 47,615 kgCO_2e (Table 15). The percentage reduction is 7% higher than schools (Tables 3, 7 and 11) because original retention periods for all college devices, with the exception of AIO, are shorter. The college extended lifespan strategy avoids 31,262 kgCO_2e per year and would otherwise require 1,421 mature trees to remove the carbon from Earth's atmosphere.

Further to extending the lifespan, tablet carbon footprint reduces by 72%, notebooks by 47%, desktops 32%, AIO 0%, thin clients 56%, workstations 29%, monitors 35% and displays 32% (figure 52). The reason for the lack of improvement from AIO devices is because they are already kept for 8 years on average, whereas all other devices differ as previously noted.

This causes annual e-waste to decline by 38% from 1,554 kg to 967 kg, avoiding 587 kg per year.

Using this strategy, the college EVER metric reduces from the current 1:72 ratio to 1:46. This means that by simply keeping devices for longer periods, 26 kgCO_2e is avoided on average annually for each device owned.

Figure 57 shows that while AIO devices remain unaffected, all other device types experience annual procurement reduction as the device cost is annualised across an increased number of years. Obviously, as the device costs are assumed equal between schools and colleges (see methodology) then the 8 year lifespan delivers similar single device costs (Tables 3, 7, 11 and 15).

Table 15. Average College EUC estate annual environmental and financial results with lifespan extension to 8 years applied

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	36	8	419	81	499	390	£120.86	£2,246	2.5
Notebook	190	8	5,700	735	6,435	3,591	£1,113.21	£14,226	41.8
Monitor	524	8	21,615	2,877	24,492	13,886	£4,304.66	£26,135	327.5
Desktop	383	8	9,144	2,451	11,595	11,873	£3,680.63	£28,677	153.2
AIO	33	8	1,128	288	1,416	1,390	£430.89	£3,296	29.7
Thin Client	5	8	81	24	105	117	£36.33	£374	1.1
Workstation	2	8	113	56	169	269	£83.39	£150	2.9
Display	49	8	9,414	2,439	11,853	11,785	£3,653.20	£6,119	408.5
Total	**1,222**		**47,615**	**8,951**	**56,565**	**43,301**	**£13,423**	**£81,222**	**967**

Figure 55. College average EUC annual supply chain reduction by device type (8 year retention policy)

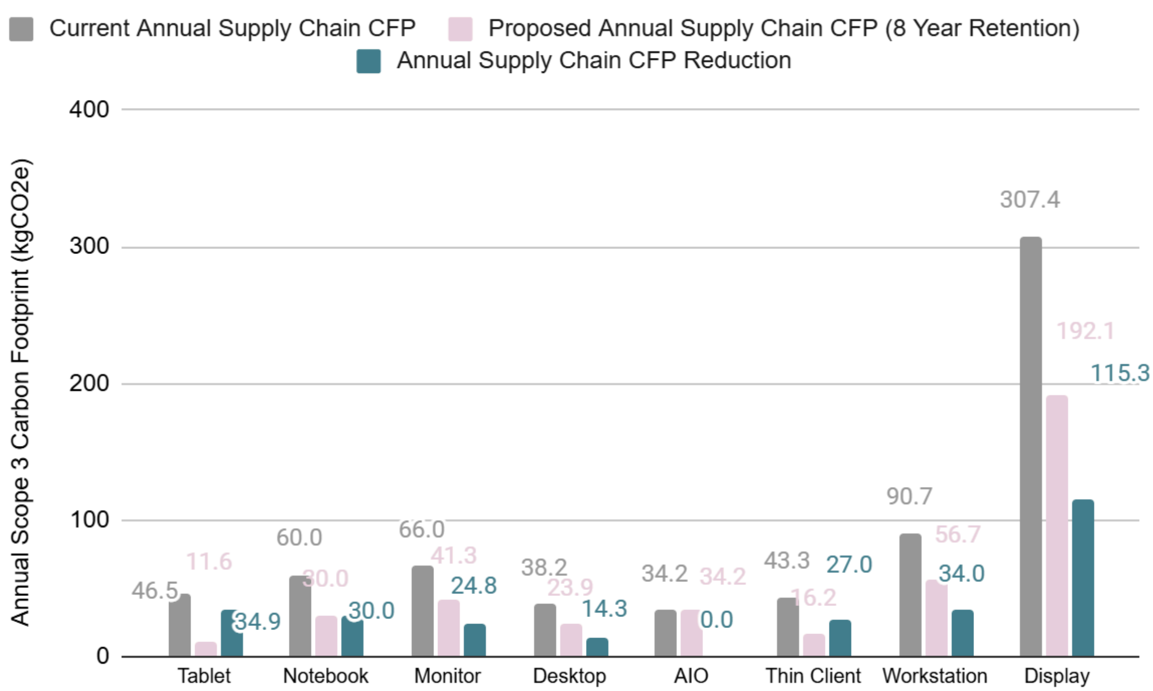


Figure 56. College average EUC annual supply chain reduction for all assets (8 year retention policy)

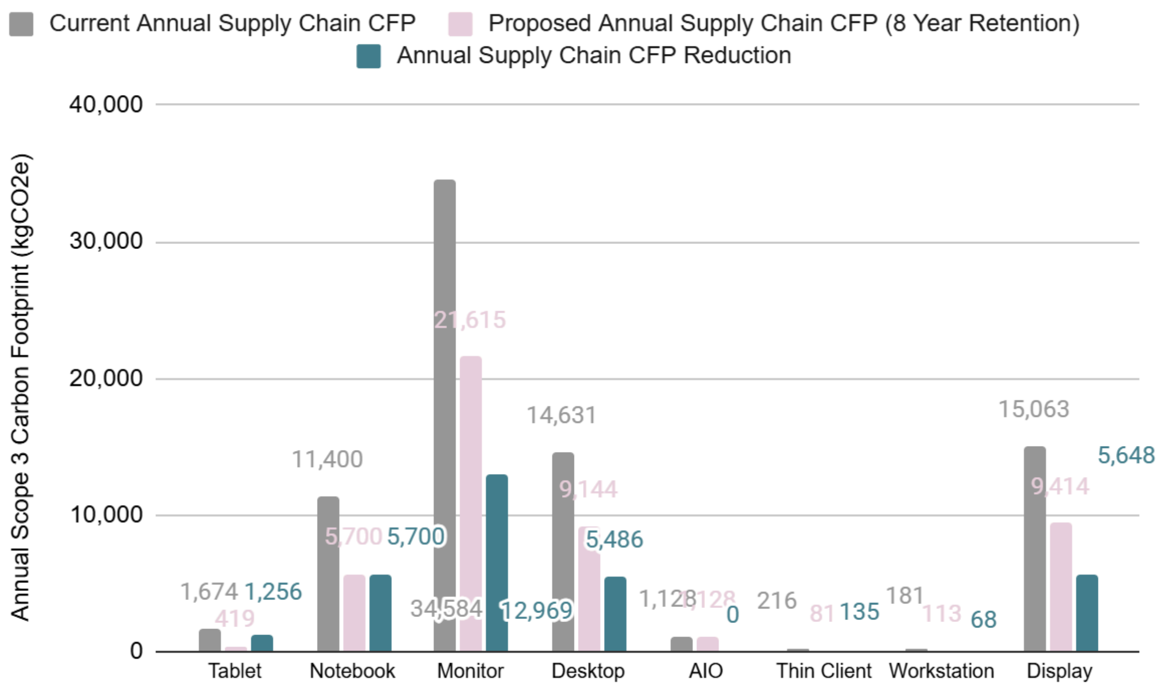
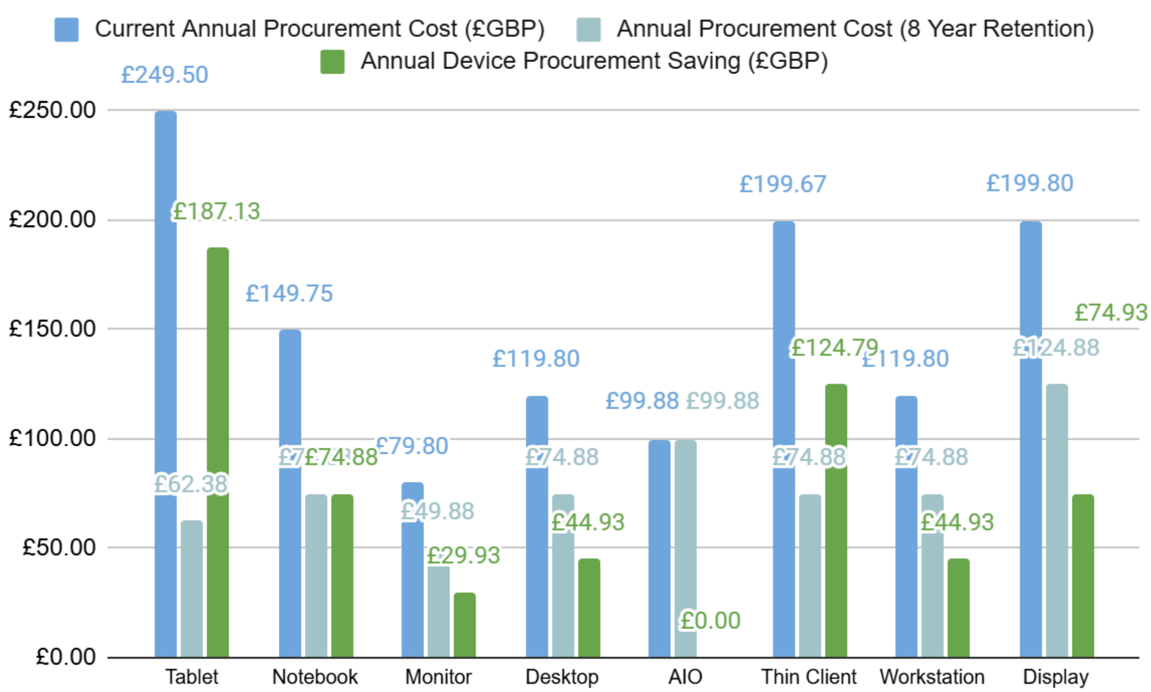


Figure 57. College average EUC annual procurement cost reduction by device type (8 year retention policy)



Applied to the entire average college EUC estate, Figure 58 shows that annual procurement costs reduce by 42% from £139,457 (Table 14) to £81,222 (Table 15). Meaning that each college extending device lifespans to a uniform 8 years, saves £58,235 per annum.

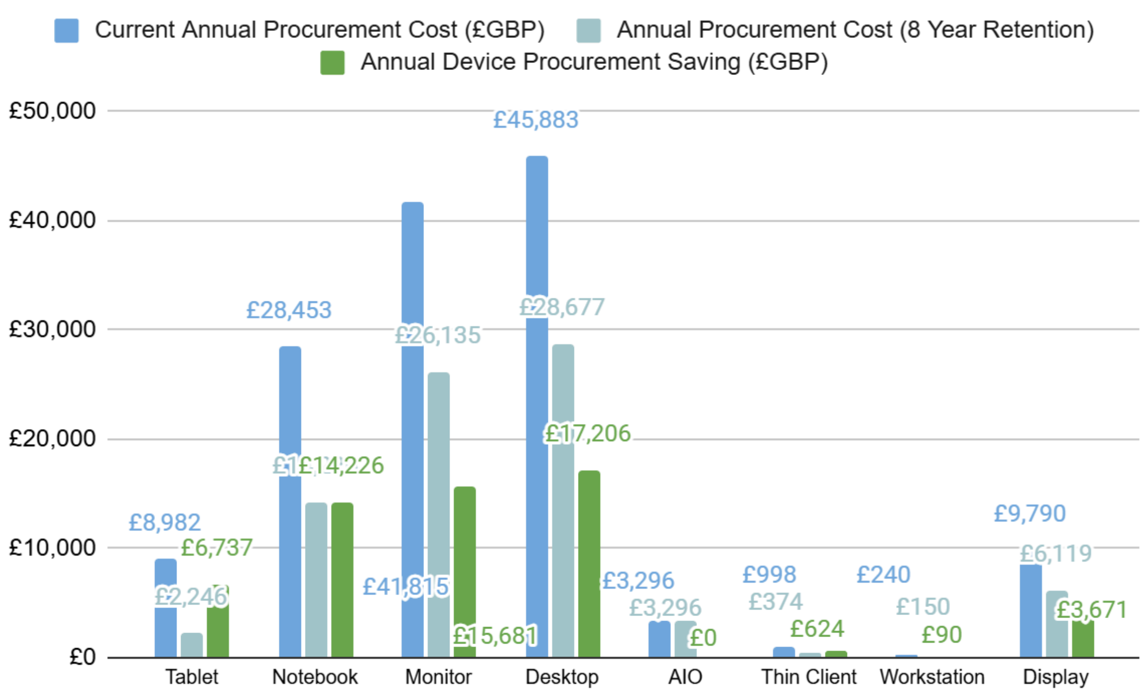
Similar to the Windows 10 EOL strategy, when applied at a country level the improvement to environmental and financial values within the college sector is significant. Specifically, if all colleges adopted lifespan extension to 8 years 6,408,710 kgCO_2e of scope 3 supply chain GHG emissions would be avoided annually.

This is equivalent to emissions created by driving a combustion engine car 37.7 million km or 941 times around Earth's equator. In context, 291,305 trees would be required every year to remove this carbon footprint from the atmosphere.

Additionally, 120,335 kg of potential e-waste would be avoided annually. This is equivalent to almost 8 million aluminium soda cans.

From a cost perspective, £11,938,175 in EUC device procurement expenditure would be avoided every year. This avoided cost could be used to employ 351 additional teachers each year. When added to the cumulative schools value, then 11,663 more teaching staff could be employed in the state funded education sector.

Figure 58. College average EUC annual procurement cost reduction for all assets (8 year retention policy)



College Sustainable ICT Strategy 3: Carbon Footprint as a Selection Criterion

As previously noted, an average college EUC estate currently generates 87,828 kgCO_2e in carbon footprint, produces 1,554 kg of e-waste, consumes 43,301 kWh of electricity, costs £13,423 in utility bills and £139,457 in procurement spend for every year of operation (Table 14). This creates an annual EVER per capita value of 1:72 and costs of £125.10 per device per year (Table 14).

The school results show that by introducing carbon footprint as a selection criterion as an addition to lifespan extension, will reduce annual GHG emissions by an incremental value of between 22-26% (Figure 14, 31 and 46).

For colleges this incremental value is 28% (Tables 14, 15 and 16). Specifically, the current annual carbon footprint is reduced by a total of 64% to 31,726 kgCO_2e. This is achieved by reducing supply chain emissions by 69% from 78,877 kgCO_2e (Table 14) to 24,279 kgCO_2e (Table 16). Plus scope 2 use-phase emissions by 7% from 8,951 kgCO_2e (Table 14) to 7,447 kgCO_2e (Table 16).

Comparing the original strategy (Table 14), the change causes tablets to be 79% lower in annual carbon footprint, notebooks 73%, desktops 45%, AIO devices 14%, thin clients 53%, workstations 64%, monitors 72% and interactive displays 61%.

In all, annually avoided emissions are 56,102 kgCO_2e and equivalent to emissions generated by driving a combustion engine car over 330,000 km and would otherwise require 2,550 trees to remove the carbon from Earth's atmosphere every year. The new annual carbon footprint reduces the original EVER metric from 1:72 to 1:26, meaning that on average each device owned generates just 26 kgCO_2e per year.

Table 16. Average College annual environmental and financial values following the implementation of strategy 2 (lifespan extension) and 3 (carbon footprint as a selection criterion).

	Unit	Average Age (Years)	Annual Scope 3 Supply Chain GHG (kgCO2e)	Annual Scope 2 Use-Phase GHG (kgCO2e)	Total Annual Carbon Footprint (kgCO2e)	Annual Electricity Consumption (kWh)	Annual Electricity Cost (£GBP)	Annual Procurement Cost (£GBP)	Annual Potential E-Waste (kg)
Tablet	36	8	261	108	369	468	£145.08	£2,246	2.0
Notebook	190	8	2,684	570	3,254	2,660	£824.60	£14,226	34.4
Monitor	524	8	8,384	2,096	10,480	9,956	£3,086.36	£26,135	327.5
Desktop	383	8	6,750	2,681	9,431	13,405	£4,155.55	£28,677	82.8
AIO	33	8	850	363	1,213	1,716	£531.96	£3,296	24.1
Thin Client	5	8	78	35	113	170	£52.70	£374	1.0
Workstation	2	8	60	26	86	130	£40.30	£150	0.7
Display	49	8	5,212	1,568	6,780	7,497	£2,324.07	£6,119	199.6
Total	**1,222**		**24,279**	**7,447**	**31,726**	**36,002**	**£11,161**	**£81,222**	**672**

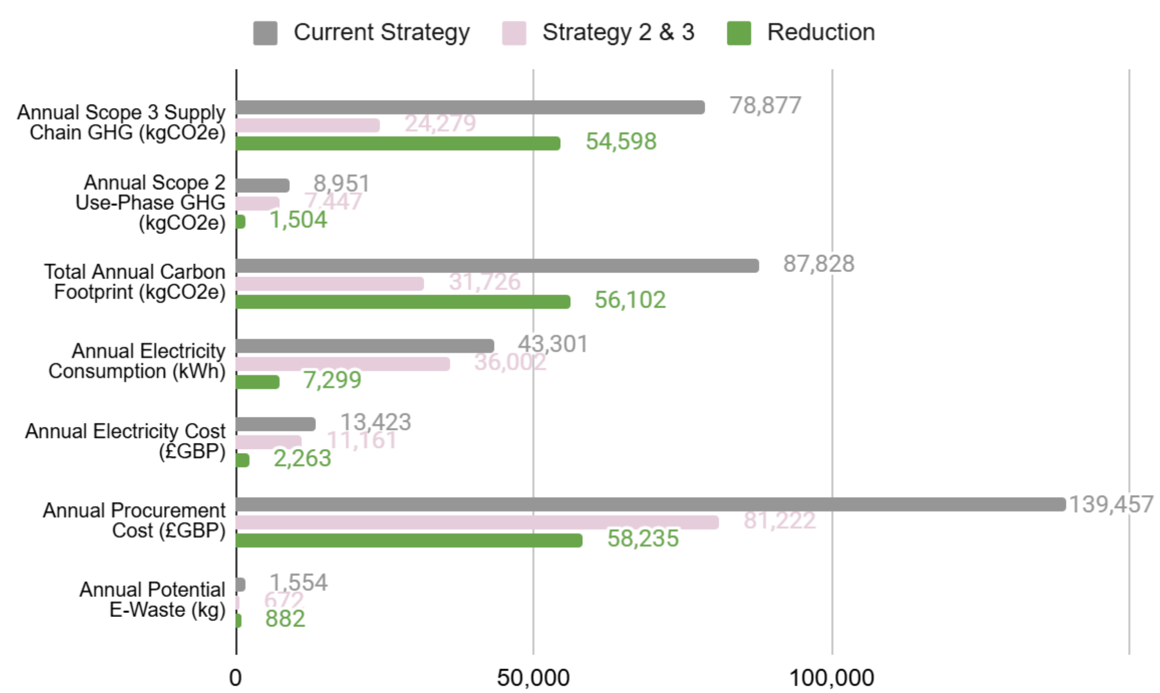
Figure 59 reflects the procurement savings achieved in the college lifespan extension strategy (Figure 58). However, due to improved energy efficiency, a reduction in energy consumption of 7,299 kWh/y reduces utility costs by 7% and £2,263 annually (Figure 59).

Nationally, the total avoided college EUC emissions would equal 11,500,910 kgCO_2e per year. This is equivalent to emissions generated by driving almost 67.7 million km or 1,690 times around the world.

Additionally, for each college 882kg of e-waste can be avoided annually. At a national level this equates to 180,810 kg. This is equivalent to almost 12 million aluminium soda cans.

And finally, as a combined saving of £60,497 per college can be achieved via reduced utility and procurement costs, then if all colleges in England participated, a total cost saving of £12,401,885 could be made annually. In context, this saving is sufficient to employ 365 additional teachers every year. This brings the total to 11,983 additional teachers across the state education sector in England if strategies 2 and 3 became a reality.

Figure 59. College environmental and financial metrics comparing an average primary school current EUC strategy to results following implementation of lifespan extension to 8 years and carbon footprint as a device selection criterion



College EUC Volume of Emissions Ratio (EVER)

As with the schools data, the EVER metric is used to determine average annual GHG emissions per device ratio. However, as the data set is limited to two colleges, the average result of 1:72 offers little comparison between colleges as both are equal. It is notable that after both sustainable ICT strategies are applied, this reduces to 1:26. Meaning for every device owned, 46 kgCO_2e is avoided annually.

As such, to echo the school results, when considering both environmental and financial metrics associated with college end user computing, stakeholders must include the following strategies:

- Lifespan extension
- Carbon footprint as a selection criterion
- Transition to mobile computing

On average, by adopting sustainable ICT strategies in colleges, both associated planet and profit metrics will improve. Specifically, doing so will reduce annual carbon footprint by 64%, e-waste by 57% and procurement and utility costs by 60%.

Summary and Conclusions

The results show that annually, end user computing devices in the education sector currently generate a significant carbon footprint and e-waste potential, consume high amounts of electricity and incur substantial costs via utility and procurement spend.

As previously noted, for every year of operation an average primary school EUC estate currently generates 12,835 kgCO_2e in carbon footprint, produces 153 kg of e-waste, consumes 6,859 kWh of electricity, costs £2,126 in utility bills and £34,794 in procurement spend for every year of operation (Table 2). This creates an annual EVER per capita value of 1:39 and costs of £114.66 per device per year (Table 2).

Comparatively, an average secondary school generates 59,027 kgCO_2e in carbon footprint, produces 875 kg of e-waste, consumes 32,070 kWh of electricity, costs £9,942 in utility bills and £136,781 in procurement spend for every year of operation (Table 6). This creates an annual EVER per capita value of 1:46 and costs of £114.36 per device per year.

While an average SEND school EUC estate currently generates 9,650 kgCO_2e in carbon footprint, produces 101 kg of e-waste, consumes 4,997 kWh of electricity, costs £1,549 in utility bills and £25,567 in procurement spend for every year of operation (Table 10). This creates an annual EVER per capita value of 1:39 and costs of £110.68 per device per year (Table 10).

Finally, an average college EUC estate currently generates 87,828 kgCO_2e in carbon footprint, produces 1,554 kg of e-waste, consumes 43,301 kWh of electricity, costs £13,423 in utility bills and £139,457 in procurement spend for every year of operation (Table 14). This creates an annual EVER per capita value of 1:72 and costs of £125.10 per device per year (Table 14).

Currently, within England's state funded education sector there are 16,764 primary, 3,452 secondary, 1,050 SEND schools and 205 colleges. Extrapolated to a country level, this means the annual carbon footprint of EUC device ownership and use is 447,064,384 kgCO_2e.

Depending on your point of view, it is arguably concerning that these GHG emissions require 20,321,108 trees every year to remove the resulting carbon from Earth's atmosphere. In context, this means that state education sector end user computers, such as notebooks, tablets and monitors, rely on almost 2% of England's entire woodland for climate action.

The yearly carbon footprint is equal to emissions created by a combustion car driving 2.63 billion km. That's six return journeys from Earth to Mars.

The potential e-waste generated by EUC devices in education is equally worrying. The results show that nationally 6,010,012 kg is currently generated each year as devices are disposed of. This is equivalent to amassing 400,667,467 aluminium drinks cans.

From an energy perspective, the devices consume 239,813,471 kWh/y. This means that for schools and colleges in England, the entire output of 40 wind turbines is required [8].

While research shows that not all stakeholders responsible for ICT operations focus on climate related issues such as carbon footprint, e-waste and energy demand [5], it's reasonable to suggest that all organisations focus upon cost and ultimately profit to remain viable.

At a country level, the research finds that English state funded schools and colleges spend a cumulative £1,185,226,876 on end user computing device procurement and use every year. That's equivalent to employing 34,860 teachers, and as such if costs could be reduced then surely the will to reduce environmental impact would follow.

The results show that end user computing devices including tablets, notebooks, desktops, AIO, monitors and displays are kept for varying periods of time. The data reveals that it is feasible to keep devices that have common components such as a screen and computer for 8 years. Specifically, in all instances integrated desktops are on average 8 years old and remain operational (Figures 3, 20, 35 and Table 14). Therefore, the same retention policy can be applied to other devices that exhibit currently shorter retention periods.

The results show that implementing a lifespan extension strategy reduces annual carbon footprint, e-waste and procurement costs as devices are replaced less often.

The data also shows that due to the diverse range of supply chain and use-phase emissions across similar device types, schools and colleges are not yet focusing upon including carbon footprint as a selection criterion. While pockets of low carbon footprint devices are noted in the results, implementing a policy that requires IT and procurement teams to compare carbon footprint before purchase is shown to reduce annual GHG emissions, energy consumption, cost and e-waste.

Specifically, it is found that by adopting these strategies in primary schools, annual carbon footprint can be reduced by 57%, e-waste by 54%, energy consumption by 6% and costs by 35% (Table 4).

Similarly, in secondary schools, annual carbon footprint will reduce by 57%, e-waste by 53%, energy consumption by 15% and procurement and utility costs by 34% (Table 8).

In SEND schools, annual carbon footprint can be reduced by 54%, e-waste by 33%, energy consumption by 6% and procurement and utility costs by 33% (Table 12).

Finally, for colleges annual carbon footprint can decline by 64%, e-waste by 57%, energy consumption by 7% and procurement and utility costs by 60% (Table 16).

Therefore, by creating a scientifically valid baseline and modelling sustainable ICT strategies, it is proven to be feasible to reduce on average carbon footprint by 57%. From a countrywide perspective, this would avoid 255,778,054 kgCO_2e of GHG emissions every year. Meaning, the state funded education sector could release 11,626,275 trees every year to sequester emissions from another source.

Doing so will also avoid 53% of potential e-waste meaning 3,201,713 kg no longer enters annual end of life services. That's equal to 213,447,545 soda cans never being made.

Energy consumption would fall by 14% avoiding 33,639,825 kWh/y of demand per year. Beyond reducing cost and scope 2 GHG emissions, the action would also relieve 6 wind turbines [8].

Finally, procurement and utility costs would decline by 34% saving £407,407,833 each year. While the spend could be diverted to any necessary area, in context this is a sum sufficient to employ 11,983 additional teachers during every year of the proposed 8 change in strategy.

In conclusion, the research delivers scientific evidence that strategies such as lifespan extension and carbon footprint as a selection criterion are effective at a local level. Because they deliver both financial and environmental benefits then theoretically, stakeholders with varying role based needs and interests will find reason to adopt the approach.

Pragmatically, it may be that only people minded to reduce environmental impact will seek out this research and perhaps diffusion will be slow regardless of the evident positive influence of general business operations. However, if translated to national policy by the Department of Education, then the impact to the planet, profit and policy is undeniably meaningful.

Recommendations and Limitations

The research creates valid scientific data that enables sustainable ICT policies to be formed by the Department of Education. It is recommended that the policies include standard practices such as ensuring equipment has undergone eco and energy certification and that it is manufactured by companies participating in product lifecycle assessment. However, to be meaningful such policies must include lifespan extension to 8 years and carbon footprint as a selection criterion. While the former has been proven in this research the latter is also easily attainable using available tools that overcome misleading data included in manufacturer carbon footprint reports relating to energy and concomitant scope 2 emissions.

It is recommended that the videos that accompany this research be used to promote the concepts and a second research project be undertaken to gain feedback and likelihood of impact and adoption.

From a limitations perspective it is noted that while this research analysed a large subject group and an even larger number of specific devices, the results may differ from organisation to organisation. As such, in line with existing legislation, schools and colleges should be encouraged to baseline their own EUC environments and model appropriate strategies. Tools are available to ensure this can be achieved quickly, easily and with accuracy.

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Figures and Tables

Px3 Ltd

The Surrey Technology Centre

40 Occam Road

The Surrey Research Park

Guildford

Surrey

GU2 7YG

United Kingdom

www.px3.org.uk

info@px3.org.uk

University of Warwick

Computer Science Department

Coventry

Warwickshire

CV4 7AL

United Kingdom

https://warwick.ac.uk/about/contact/

Department for Education

Sanctuary Buildings,

Great Smith Street,

London,

SW1P 3BT

United Kingdom

https://www.gov.uk/contact-dfe