# Carbon Emission Implications of ICT Re-use at the University of Edinburgh

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## *Executive Summary*

The University of Edinburgh Department for Social Responsibility and Sustainability is running a pilot project to reuse desktop PCs and monitors internally when they would otherwise be destined for the University's waste stream (for reuse or recycling elsewhere). The project has reused a total of 174 computers in this way, against a target of 100.

The benefit, in terms of carbon emissions avoided in the new computer supply chain, is significant. By extending the lifetime of a single computer and monitor from four years to six years, approximately 190 kg$CO_2$e of carbon emissions are avoided. Therefore, the pilot has achieved benefits of around 33,000 kg$CO_2$e, and the potential of the idea if fully incorporated into standard practice is conservatively estimated at 380,000 kg$CO_2$e per annum (equivalent to keeping more than 150 cars off the road).

The energy efficiency of new computers with respect to old computers is considered and discussed, and it is concluded that the benefit of continuing to use an old computer (i.e. making best use of the carbon invested in its creation) far exceeds the benefit from any potential energy efficiency gain from replacing it even under optimistic assumptions around improvements in energy efficiency.

## 1. Introduction

With financial support from Zero Waste Scotland, the University of Edinburgh Department for Social Responsibility and Sustainability is currently running a pilot PC re-use project. The objective of the pilot is to explore the challenges involved in reusing desktop computers[1] (PCs) that would otherwise have been rejected and replaced with new computers. Also, of course, the costs and benefits of the project need consideration. In this report, the primary focus is the cost-benefit equation in terms of carbon emissions.

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[1] The terms 'PC' and 'computer' are used interchangeably in this document, and refer to a desktop machine running a Microsoft Windows operating system. Energy and emissions data for the monitor /

## 1.1. Project Scope

The reuse pilot only takes in desktop Windows PCs at this stage, including peripherals (monitor, mouse, keyboard). Laptops, tablets, phones, etc. are excluded, and present an opportunity to expand the project following a successful pilot. The pilot target was to reuse 100 PCs in six months, and the final confirmed total is 174 PCs.

This report will consider the carbon costs and benefits from re-using PCs at the pilot project scale and the overall potential for the University if the project is expanded.

## 1.2. Baseline

Without the reuse project, when a PC user finishes with a computer – or a lab-full of computers – the computer is treated as 'waste', i.e. a problem to be dealt with. This presents an opportunity for external players – not-for-profit partners and waste contractors – that can themselves extract value from the computers through a combination of reuse (Remade in Edinburgh) and recycling (CCL North).

The University's computers join the waste stream for a variety of reasons, and at different ages. Some of the more technically demanding users change their PCs every year; some computer replacement events are led by capital projects (building refurbishments, reconfigurations, etc.), or the roll-out of new operating systems; and then there are the more typical planned replacement cycles (3 years for computer labs, and 4 or 5 years in other situations).

Typically, the University has over 12,000 PCs in use and reporting their status to the network, which allows energy consumption figures to be estimated. The total number of PCs owned by the University is thought to be considerably larger (in excess of 16,000), but for the purposes of this report the conservative figure of 12,000 is used. The rate of computer purchasing fluctuates significantly from year to year, but an average life of 4 years is assumed, resulting in the purchase of approximately 3000 machines per year and the disposal of a similar number. Reusing PCs should result in a reduction in the number of new machines purchased and old machines disposed of, thereby reducing costs and reducing the University's indirect responsibility for the carbon emissions associated with PC manufacture, distribution and recycling.

## 1.3. Re-use process

Following contact from the person with responsibility for the PCs through the Warp It system or a web link, PCs are transported to the reuse hub in the old nursery building at High School Yards: in most cases, this will be a journey of between approximately 200 metres and 3km (Kings Buildings) but potentially up to 10km (including the hospitals and Easter Bush), with several PCs on board.

The PC is opened up, cleaned, and inspected. A well-used PC will contain significant deposits of dust that need to be removed: this helps to keep the PC cool in operation, improving performance, efficiency and lifetime. The hard-drive is 'wiped' to a high standard of data security and the specification of the PC is inspected and minor upgrades made – if necessary - using parts cannibalised from other PCs (typically this would be just peripherals and any additional RAM that might be required to take the total to 8GB). The PCs are then claimed internally, and the computer is recommissioned by the new ‘owner’ who installs any operating system and software that is required.

### 1.4. Costs and Benefits of Reuse – embodied carbon, energy consumption, and end-of-life issues

A fundamental environmental trade-off exists at the heart of projects focussing on reuse of energy-using equipment, and the trade-off is explored in this report.

By prolonging the life of the computers, fewer computers need to be purchased: this reduces the demand that computer manufacturers must satisfy, and it is assumed that the manufacturers will reduce their demand on raw materials, transport, energy, etc., in line with this. Therefore the University’s choices result in a reduction of carbon emissions within its supply chain.

On the other hand, the delay in purchase of a new computer also usually represents a delay in taking an opportunity to swap an old machine for a (potentially) more energy-efficient replacement. Therefore there is a risk that a computer reuse project might cause the University’s own electricity demand – and therefore its scope 1 and 2 carbon emissions – to be higher than they otherwise would be. This argument is explored in Section 3.

An argument might also be made that by holding on to older computers the University is denying external actors the opportunity to benefit from them, thereby ‘forcing’ them to buy new computers themselves. However, we cannot know the motivations of end-users of any computers that are reused externally, and whether they would otherwise have bought new, continued using their existing equipment, or done without. Furthermore, the decisions of those external actors are clearly not the University’s responsibility and can reasonably taken to be outside of the system under consideration. Therefore, for the purpose of this assessment, it is assumed that a reduction in new purchases by the University translates into an equivalent reduction in demand from the manufacturers.

In order to quantify the benefits of reuse across the University, consider the following basic and conservative scenario:

At the end of their four-year typical lifespan, half of the University’s ~12,000 computers are reused for a further two years and the other half would be taken out of service for a variety of reasons (which might include condition, faults, insufficient demand and the need for spare parts) to be cannibalised for parts and recycled.

After the system has had a few years to reach equilibrium the numbers would work out as follows:

- Computers taken out of service = 3600 p.a. (baseline was 3000)
- Computers processed and returned to service for two more years = 1200 p.a. (baseline was zero)
- 4-year old computers cannibalised / sent for recycling = 1200 p.a. (50%: baseline was 3000)
- 6-year old computers sent for recycling = 1200 p.a. (100%)
- Annual new purchases are reduced to 2400 (baseline was 3000, so 20% reduction).

The potential is, of course, better than this, because (a) 6 years is not a hard upper limit and (b) the decommissioning of the oldest computers would reduce the need to cannibalise computers after their first life, meaning that a higher proportion of the 4-year-old computers can be reused. Additionally, new parts – such as RAM – might be procured to reduce the proportion of 4-year old computers rejected to an absolute minimum.

# 2. PC & monitor carbon footprint – embodied carbon focus

## 2.1 Overview

Calculating the carbon footprint of something as complex as a computer is a long and involved process, far beyond the scope of this report. A computer consists of a great many parts from many suppliers, all with their own carbon footprint characteristics, and it is all but impossible to fully capture the necessary data. Therefore we rely here on the results of a small number of studies into the most relevant products.

Even calculating the carbon footprint of the operational phase of a computer's lifecycle is more complex than it first appears, as power demand varies with the intensity of CPU usage, and the relationship is a characteristic of the computer in question.

## 2.2 Examples

### *PCs*

The computer manufacturer Dell has published lifecycle studies on recent models.[2] Although the studies come from the manufacturer, there is not a strong case to distrust the findings, as there is little for Dell to gain by disguising the true carbon emissions associated with the manufacture and use of its products. In the absence of comparable data from competitors, customers are neither keen nor able to make their product selections on this basis: instead, the information is useful in supporting Dell in designing carbon out of the system in future iterations and in raising the level of debate on the subject.

As the typical PC used by the University is a small form factor business machine from HP or Dell, it is helpful that one of the few published studies on a PC lifecycle carbon footprint is Dell's own study of the **Dell Optiplex 9010 SFF** (pub. 2013).

Dell uses PAIA (Product Attribute to Impact Algorithm) which is a streamlined Life Cycle Analysis (LCA) tool developed by MIT's Materials System Laboratory[3] that estimates carbon and energy impact. Using this tool, the following lifecycle stages are considered.

The lifecycle carbon footprint is broken down into the following categories.

1. Manufacturing process – includes raw material capture (including recycled materials), processing, assembly, and everything between.

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[2] http://www.dell.com/learn/us/en/vn/corp-comm/environment_carbon_footprint_products All web links referenced accessed in June 2016.

[3] http://msl.mit.edu/projects/

2. Transport and distribution – everything that happens between the factory gate and the end user.
3. Use phase – energy demanded by the computer in use. The study assumes a 4-year life, in the USA (therefore using US emission factors), with a usage pattern based on the Energy Star Typical Energy Consumption (TEC) algorithm. 107 kWh p.a.
4. End of life – transport to recycling plant and energy demand at the plant. Recycling credits are not applied at this stage, to avoid double counting (the manufacturing process assumes a market mix of virgin and recycled materials).

There are some differences between the Dell scenario and the situation with the computers at the University. In particular:

1. Emissions from shipping and delivery to Edinburgh may be significantly different from the scenario analysed.
2. The carbon emission factor for electricity used in Edinburgh is different from that in the USA.
3. The University's average computer usage pattern might be significantly different from the TEC.

Of these, the second issue (carbon emission factor) is addressed in the carbon footprint data presented in Figure 1, but insufficient data was available to make corrections for the other items.

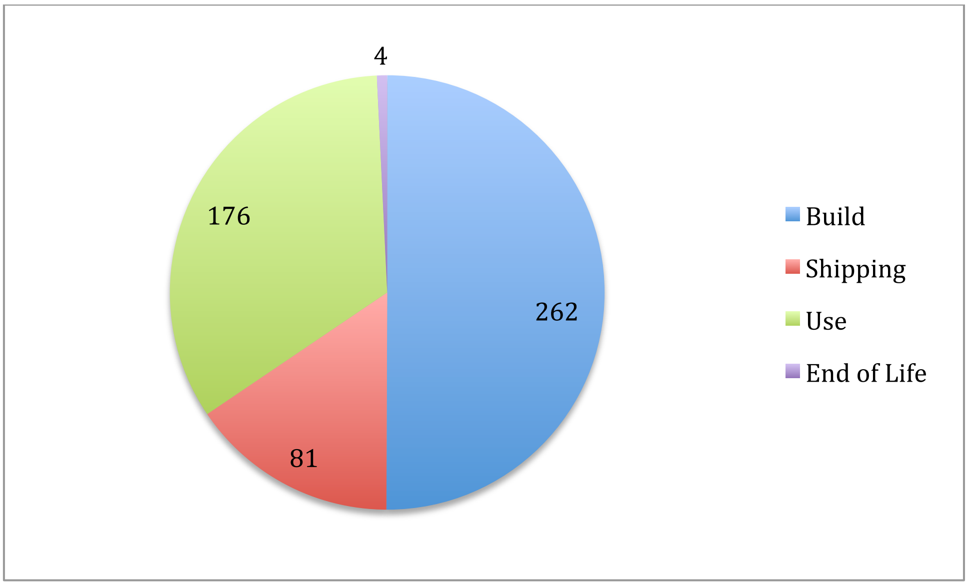

Figure 1 – the Dell Optiplex 9010 SFF life cycle carbon emissions. Units are $kgCO_2e$, and the total is 523 $kgCO_2e$ using – for the use phase – the grid emissions factor currently applicable in the UK, not the figure for the USA used at the time of the study (the total figure published by Dell is 667 $kgCO_2e$, using older US-specific grid emission factor[4]).

Of the build emissions, the 'mainboard and other boards' constitute 80%, with optical drive and hard drive 4% each, and power supply 5%. The chassis makes up most of the remainder. This is consistent with other information and commentary that indicates that the printed

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[4] UK grid emission factor used here is the most recent DEFRA guidance for corporate reporting – 0.412 $kgCO_2e/kWh$. This is on a decreasing trajectory at the moment, as coal power stations are decommissioned in favour of gas-fired and renewable generation.

circuit boards (including CPU) are responsible for the overwhelming majority of the embodied carbon at the factory gate. It follows, therefore, that if new parts (such as power supplies, hard drives, optical drives, cases, etc.) have to be bought in order to reuse a computer, the carbon emissions reductions will be largely retained, even if the cost benefits are significantly diminished.

In an earlier study (2010), Fujitsu published[5] a life cycle assessment / carbon footprint of the **Fujitsu ESPRIMO E9900 Desktop PC**, with support from external partners, the Bavarian bifa environmental institute and the Fraunhofer Institute for Reliability and Microintegration. The results are broadly in line with those for the Dell Optiplex 9010 (about the same for product build and distribution combined): for a computer used in the UK, the total figure is around 530 kg$CO_2$e[6], mainly split between use (about 190kg over 4 years, with a TEC of 114kWh p.a.) and product build (about 300kg).

### Monitors

Dell has also provided information on its **E1912H – 19-inch business display** (2013). A similar method and assumptions have been used, although numbers are approximate as they are read off a graph. Manufacturing and distribution accounts for around 90 of the 213kg$CO_2$e total, with the 4-year use phase (calculated using an unspecified European emission factor) dominating the rest. Scaling this up to the 21-inch screens used by the University, using an approximation based on a methodology suggested by Teehan and Kandlikar[7], suggests that the emissions for manufacturing and distribution would be approximately 120 kg$CO_2$e.

As an aside, is worth pointing out that Teehan and Kandlikar – through their studies of embodied GHG emissions of various products from around 2009/10 – found a surprisingly strong linear relationship between total product mass and embodied carbon across different ICT product categories. The relationship they suggested was 27g $CO_2$e / g of product. A good fit was also obtained when considering the masses of three different key elements of products separately (PCB, display, and battery). Example embodied carbon footprints reported in that paper include:

- A Samsung 21.5inch LCD monitor – 168kg$CO_2$e +/- approx. 65
- Desktop Optiplex 780 tower (2010) – 164kg$CO_2$e +/- approx. 30 (broadly in line with Dell's own analysis of the same machine – a point also noted by the authors).

In all, there appears to be a reasonable level of consistency in the carbon emission figures mentioned for both PCs and monitors, although the sample of machines analysed is still very low. Such consistency is to be expected: different manufacturers come up with similar solutions, and assemble their products from sub-assemblies produced to similar specifications (the main printed circuit board / CPU in particular, which is responsible for so much of the embodied carbon).

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[5] http://sp.ts.fujitsu.com/dmsp/Publications/public/wp-LCA-PCF-ESPRIMO-E9900.pdf

[6] Making the same emission factor correction as for the Dell.

[7] Comparing Embodied Greenhouse Gas Emissions of Modern Computing and Electronics Products - Paul Teehan and Milind Kandlikar, in Environmental Science and Technology 47, 2013.

# 3. Carbon Emissions – Use Phase

Carbon emissions in use are attributed to the electricity required to operate a computer from the moment it arrives at the end-user's premises to the moment it leaves for recycling and disposal. In most cases the physical carbon emissions occur remotely, at electricity generating stations, and are known as 'scope 2 emissions'. On the national electricity grid, one electron is indistinguishable from another, and its origin is not identifiable, so a national (UK-wide) average emission factor (units of $kgCO_2e$ /kWh) is used to attribute carbon emissions to each unit of electricity consumed.

At the University of Edinburgh the situation is different, as a significant proportion of the electricity consumed is self-generated from gas-fired Combined Heat and Power units. The emissions associated with such electricity occur on site and are 'scope 1 emissions'. The University does not currently define a universal emissions factor for electricity it uses, taking account of the mix of self-generated and imported electricity, so in this work we use the grid average figure: this has the benefit of making the results more generally relevant to other organisations. If the University did calculate its own emissions factor, taking account of the benefit of the co-generated heat, we would expect it to be somewhat (but not dramatically) lower than the current UK grid average.

Technically, the carbon emissions associated with the re-use process should be included in the analysis of emissions from the use phase. In this case, however, these emissions are taken to be negligible. The current reuse hub is a small room suitable for a single technician to work in: it has minimal energy demands for heating, lighting, and ventilation and these are not separately monitored. Similarly, the carbon emissions associated with the transport requirements for the reuse project will typically only be of the order of 100 grams per computer. Taken together, these emissions are a small percentage (certainly less than 5%) of the emissions associated with using a computer for one year.

## 3.1 Data on PC and Monitor Energy Use

Published data on actual – as opposed to theoretical – energy use by desktop computers in a variety of contexts (e.g. in University labs) is scarce. The key question is simple enough: how much electricity does a typical computer require in practice? But it is aimed at a moving target and even defining the boundaries of the question is not straightforward. Key complicating factors include:

- Wide variety of computer products and specifications available at any given time.
- Different usage patterns – including hours of operation, energy management features, peripherals, and software variables (computers running high-powered software might push the CPU harder than those equipped with regular business software, using more electricity in the process).
- Changes in the way we use computers, integrating our PC usage with various mobile devices and data storage on the cloud for instance.
- Temperature variables. Computers operate more efficiently at lower temperatures.[8]

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[8] Patterson [The Effect of Data Center Temperature on Energy Efficiency: Michael K Patterson (Intel Corp – 2009) – in Thermal and Thermomechanical Phenomena in Electronic Systems, (ITHERM), May 2008, pp. 1167 –1174] discusses the impact of CPU temperature on thermally induced leakage, an

- Possible drop in energy efficiency with age: heat sinks and fans will be less effective as dust accumulates, and the CPU use intensity might increase as software clutter accumulates (note that this might contribute an important element to a case for regular maintenance).
- The impact that computer usage has on building energy consumption (e.g. adding to cooling loads or reducing heating loads, depending on the climate, and adding to lighting electricity demand through use of blinds to eliminate glare). The energy demand for cooling is central to the design and management of dedicated server rooms and buildings, but can be a bit of an afterthought in connection with PC use.

Data relevant to desktop computer utilisation and energy consumption has been downloaded from the University's network management system. However there are some significant approximations in the methodology apparently used for calculating the energy consumption (which appears to be around 260 kWh p.a. per workstation = 185 kWh for the computer and 75 kWh for the monitor)[9], and it may well be that using the Energy Star 'Typical Energy Consumption' (TEC) algorithm and database would give just as accurate an answer.

Energy Star calculates the TEC by applying a percentage weighting to each of four operational modes for the computer[10] which are taken to be typical of general usage. Arguably, the University's usage might be more intense than average owing to weekend and late working, but the University data provided does show a sharp decrease in utilisation outside of normal office hours.

Relying on the Energy Star database as a single resource for judging energy consumption by computers would also lead to other approximations. For instance, the full specification of every computer would need to be known and looked up on the database: a typical new PC at the University – the **HP EliteDesk 800 G2 SFF Business PC** – has five variants[11] listed on the database, with TECs ranging from **92 to 132 kWh p.a.** TEC data from older machines is at best difficult to find or, more likely, absent altogether, but it is notable that the TEC figures for the PCs covered in the carbon studies (all now at least a few years old) are in this range.

With regard to monitors, those in the size (around 23 inches) and specification range most widely used have power demands of around 15 to 20 Watts in use / idle mode, and less than one Watt when in sleep mode or off. Assuming 40% utilisation, this would amount to **52 to 70 kWh p.a.**

## 3.2 Accounting for Energy Efficiency Improvements

As mentioned earlier, there is an argument that continuous or incremental improvements in the energy efficiency of new products might encourage users to retire equipment and replace

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increasing challenge owing to the 'shrinking geometries' in the silicon which shorten leakage pathways. The paper cites studies reporting 1 to 2% increases in leakage per °C temperature increase.

[9] For instance, the model appears to apply a simple (and quite high) conversion factor to the number of hours that PCs and monitors operate for. Also, computers left in their boxes don't report their zero energy demand.

[10] The TEC operational modes are: off, sleep, long idle, and short idle, with the computer taken to be in the more energy intensive long/short idle modes for 35-45% of the time, depending on the network set-up.

[11] Different CPUs, and potentially other differences too, such as discrete GPUs.

it with more efficient stock. This has been looked at in detail in a German study[12], which has concluded that:

> *…the environmental impacts of the production phase of a notebook are so high, that they cannot be compensated in realistic time-periods by energy efficiency gains in the use phase. In case of a 10% increase in the energy efficiency of a new notebook as compared to the older one, replacement of the older notebook can only be justified after 33 to 89 years, if environmental concerns are considered. The study concludes that the share of the production phase in the total greenhouse gas emissions of a notebook can be significantly reduced by taking measures to extend the useful life-time of a notebook.*

These conclusions would apply equally to the equipment (PCs and monitors) discussed in this report, as the ratio of embodied emissions to operational emissions in the Dell Optiplex 9010 (for instance) is comfortably within the range covered by the notebooks used in the German study.

Furthermore, the report considers the impact of a doubling of energy efficiency (i.e. a 50% reduction in operational carbon emissions). In such an improbably optimistic scenario (with regard to energy efficiency) the replacement cannot be justified on environmental grounds until the computer is 7 to 16 years old. Some observations on this:

- It is clear that with any realistic assumptions about energy efficiency improvement, there will very rarely be a case for replacing a computer on environmental grounds.
- As the emission factor of electricity used in the UK decreases, the proportion of lifecycle carbon emissions linked to the 4-year use phase decreases, and the proportion of emissions associated with manufacture and distribution increases, making any case for early replacement even poorer.
- Dramatic decreases in TEC (of the order of 50%) during a typical product lifecycle are less likely now, following years of focus on the challenge.

### *Trends in energy consumption by computers*

Moore's law suggests that computing speeds double every year and a half or so, depending on which loose definition you subscribe to. A similar 'law' applies to energy efficiency of computer processing. The net effect of this is that the electrical power needed to operate a desktop computer remains fairly steady from one computer generation to the next. In earlier years, specific efforts to manage energy use in computers were limited, but the adoption of Energy Star standards has changed that, leading to improved energy management systems and very low levels of power demand in sleep modes. Also, the switch from cathode ray tube monitors to flat panels resulted in a steep drop in display energy use. Arguably, such improvements are unrepeatable in future generations, so it is likely that we will not continue to see significant declines in power demand by PCs.

Taking this all into consideration, it is safe to say that in almost every circumstance, from a carbon emissions and environmental perspective, it is better to keep using a functional computer rather than replace it with a new one.

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[12] Timely replacement of a notebook under consideration of environmental aspects. Prakash, Liu, Schischke and Sto, on behalf of the Federal Environment Agency (Germany). 2012

# 4. Conclusions and Recommendations

For reasons that should already be clear, the summary carbon emissions associated with purchase, use and reuse of computers and monitors are approximations and even the degree of uncertainty is not quantifiable when using secondary data sources. That said, the results are sufficiently conclusive to give a strong steer.

| | Typical annual energy use - kWh | Typical Emissions – $kgCO_2e$ 4-year lifecycle | Typical Emissions – $kgCO_2e$ 6-year lifecycle |
|---|---|---|---|
| PC – product build, transport and EOL | - | 260 | 260 |
| Monitor – product build, transport & EOL | - | 120 | 120 |
| PC – Use | 90 - 180 | 222 | 333 |
| Monitor – Use | 50 - 75 | 104 | 156 |
| **Total Life Cycle Average annual emissions – PC and monitor** | **-** | **177** | **145** |

Table 1 Summary energy consumption figures and carbon footprints for a PC and monitor. Carbon footprints are calculated from the mid-points of the ranges given. Of the three data columns, the central column represents the base case (4-year life time for a single computer and monitor) and the right hand column represents the case where the life time of computer and monitor are both extended to 6 years.

The implications of the information in table 1 are as follows:

(1) The one-off benefit of meeting the target to reuse 100 computers for the pilot is 19,000 $kgCO_2e$, assuming that each computer is reused for two years following a 4-year first life. With the project achieving an actual total of 174 computers reused, the benefit is consequently more, at 33,000 $kgCO_2e$.

(2) That by extending the life of a computer and monitor from 4 to 6 years, the average emissions associated with equipping that deskspace will be reduced by 32 $kgCO_2e$ per annum on an ongoing basis.

(3) And therefore if rolled out over an estate of 12,000 workstations, using the scenario described in Section 1, the benefit would be a very striking **reduction in carbon emissions of 380,000 $kgCO_2e$ per annum**, with the potential to increase this further if efforts are successfully made to reuse more than half of the computers available at the end of their first four-year cycle. This is equivalent to keeping more than 150 cars off the road (assuming an average of 16,000 km driven p.a. and $CO_2$ emissions of 150g/km)

## 4.1 Recommendations

On the topic of reuse.

- The key recommendation is to scale up the pilot to a sustainable operational mode, as the carbon footprint benefits clearly justify it. The basic objective should be to take this as far as possible internally – setting an initial reuse target in line with the scenario presented in this document.
- In terms of resourcing this project, explore the opportunity to work with other organisations with similar drivers and challenges and potentially achieve a useful economy of scale. For instance, other Universities and colleges in Edinburgh. Also consider possibility of selling excess stock externally.
- Include goods other than Windows PCs and monitors where the quantities available and cost and carbon benefits suggest that the effort would be worthwhile.

  Develop information sheets (and similar) to sell the initiative and also to detail the minimum specification of each category of reused computer and the purposes to which it might reasonably be dedicated.
- Explore possibility of cascading less efficient (if any) older computers to less intensive usages

Although this is not necessary to deliver the benefits outlined in this report, further steps forward in sustainable ICT might be achieved by also considering the approach to purchase and management of computers in order to minimise energy consumption in use.

- Further investigations into energy efficiency of (a) existing stock and (b) new computer specifications
- Consider cost-benefit associated with specifying the most energy efficient equipment and incorporating into purchasing strategy
- Explore the practicalities, costs and benefits of a more assertive approach to energy management, e.g. enforcing the sleep mode for computers that are inactive between certain hours.
- Explore the potential benefits of a planned maintenance strategy (computer cleaning) kicking in earlier than 4 years.