IT AND SUSTAINABILITY

CURRICULUM GUIDE

Integrating sustainability concepts into the computer science curriculum

Scotland eauc
The Alliance for Sustainability Leadership in Education

TABLE OF CONTENTS

INTRODUCTION

Employers are increasingly looking for new graduates to have both knowledge and skills in sustainability (Cade, 2008). Gordon, Kor and Pattinson (2014) found that IT companies are actively looking to hire computer science graduates who have skills and knowledge around green and ethical computing. This can be attributed to a widespread recognition that IT creates a huge volume of carbon emissions worldwide as well as contributes to and exacerbates social inequalities ranging from material sourcing to the workplaces themselves (Murugesan, 2008) (Alfrey and Twine, 2016).

However, computing also has the ability to alleviate some of these issues through the creation and generation of new technologies, apps and software that will be crucial for a transition to a low-carbon society.

By embedding notions of sustainability into the computer science curriculum, colleges and universities are not only meeting the employer's demands, but are also giving students the skills to become effective future citizens and critical thinkers. This will help to meet a wide range of graduate attributes that universities and colleges look to achieve, as well as meet wider institutional demands for teaching sustainability in accordance with the UN's Sustainable Development Goals.

LEARNING OUTCOMES

The concepts and curriculum ideas in this guide are aligned with and support the aims of computer science degree programmes as determined by the QAA Subject Benchmark Statement for Computing, particularly focusing on:

Aims

- Apply understanding, skills, knowledge and experience to create social and economic value by building secure, reliable and usable systems
- Equipping students to understand opportunities for the potential of automation, taking into account the balance between automation and human-computer interaction
- Generating the skills to analyse systems, system lifecycles and interactions within the context of socio-technical frameworks including dimensions of societal and environmental issues using case examples from a sustainability context

Skills Enhanced

- Analysis and design of computer-based models for improved comprehension and communication particularly around climate change
- Recognise factors in environmental and societal contexts relating to opportunities and challenges created by computing systems across a range of human activities on a global level
- Understand and meet the needs of individuals, business and the community, with an understanding and appreciation of how workplaces, organisations and people are governed
- Critical thinking and evaluation of complex concepts and problems in a real-world context
- Recognise the professional, economic, social, environmental, moral and ethical issues involved in the sustainable exploitation of computer technology

Attributes Fostered

- Increased awareness and appreciation of social and environmental implications associated with electronic manufacturing, sourcing and disposal
- Confidence to address and engage with real world problems particularly around climate change, equal access and privacy
- Critical and independent thinking taking into account alternative technological perspectives
- Adoption of appropriate professional, ethical and legal practices

WHAT IS SUSTAINABILITY?

Sustainability, in the simplest of terms, just means that something can *last*. This something could be anything ranging from a natural resource, to a business, to a society, to an ecosystem. However, merely lasting may not be enough, as society's wishes may change and that *thing* may need to be improving to meet new standards (Mearman and Plumridge, 2012).

The most common definition of sustainability exists from the 1987 Bruntland report:

> *'**Sustainable development** is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (1987, p.54).*

This definition has been important for recognising that sustainability is a multi-generational issue that has ethical repercussions about how we as individuals and a society choose to live today. Specifically within computing, sustainable IT can be seen as being a holistic approach that seeks to use physical resources and apply them in an environmentally and socially conscious manner for the improvement of society.

Sustainability in Computer Science

Integrating sustainability concepts into a course is a great way to bring in interdisciplinary ideas and connect learning to everyday life and the wider world. Students are likely to find learning about these connections engaging as it often relates an isolated topic to real-world events that are happening presently within the news around the globe. Climate change as well as social justice and equality issues are increasingly the focus of discussions and policy on a global level, and are critical issues today's students will have to address.

Sustainability thus provides an important platform and framework of understanding for students to recognise the impacts of their discipline and the influence they have once they become professionals in the sector. Cai (2010) contends that within computing specifically, teaching professionals have the *responsibility* to discuss sustainability as it plays such as critical role within society. This will improve students' critical thinking skills by giving them the opportunity to connect their learning with real-world problems, developing the skills needed to become part of the expected new wave of green jobs. Teaching sustainability within computing may also attract more students to the field, improve the retention rate of students and increase workplace diversity (Cai, 2010). Additionally, annual NUS surveys show that students are demanding more sustainability in the curriculum, across all disciplines including IT.

Embedding sustainability into the curriculum can be challenging, thus the aim of this resource is to help IT teaching professionals integrate sustainability concepts into the

curriculum. This guide is intended to be a first step to generating ideas of how sustainability relates to computer science, offering lecturers the opportunity to take ownership over other teaching topics and related sustainability concepts, connecting the dots between the wide range of ideas that relate computer science to pressing real-life issues. This motivation from teachers is necessary to make a successful integration of sustainability into computer science, and to ensure that students fully grasp why it is an important concept to learn within their subject area (Gordon, Kor and Pattinson, 2014).

This guide will give some examples of key concepts that integrate sustainability into computer science that can be used for teaching purposes, and provide some suggestions as to how you might embed them into your courses.

GREENING OF IT

The concept of **greening of IT** refers to the practice of making existing computer technology more sustainable. This is normally focused on lowering carbon emissions, but can also incorporate areas such as ethical material sourcing to minimise the environmental and unethical aspects of computer industries. This is an important area for computer science students to know about, as the IT industry is looking for a new generation of graduates who can help both new and existing companies become more sustainable.

Energy usage

The energy use from the IT industry is highly significant. It is estimated that with the rapid uptake of new technologies, up to one fifth of the world's electricity needs in 2025 could be utilised by the IT industry and internet connected devices (Guardian Environment Network, 2017). This means IT would surpass the global carbon emissions generated by both aviation and shipping. To try to combat this, many tech companies have vowed to reduce their carbon footprint.

CASE EXAMPLE: DATA CENTRES

On a large scale, in order to reduce their carbon footprint, some corporations have switched to renewable energy to power their data centres, partly due to pressure put on them from Greenpeace activists (Greenpeace, 2017). Data centres may also be placed in exceptionally cold climates so the cooling required to keep the machines functioning can be done naturally from the air outside rather than from an artificial air conditioning system, helping to reduce energy requirements and associated carbon emissions. Energy efficiency algorithms have also recently been tested that are able to re-route traffic from data centres that are experiencing especially warm weather, thus avoiding the need for additional air conditioning (Jones, 2018). On a smaller scale, individual IT companies can choose to host their data at external renewable energy powered data centres rather than on site, which will save immediate energy costs, recover floor space, and save on data centre management costs (Lamb, 2009). They can also very simply take steps such as ensuring sleep mode is switched on, saving on average 200kwh of energy per PC per year, or around $15 US dollars per computer of energy costs (Stedman, 2005).

While companies are able to make financial savings from implementing energy saving measures, they are also able to make non-financial gains too. This can range from enhancing relations between the workplace and the local communities who prefer to have a

sustainability focused business in their locality, and to improving employee satisfaction by being part of an environmentally and socially conscious workplace (Lamb, 2009).

Sourcing and manufacturing of materials

Energy use and carbon emissions are what people tend to immediately think of when considering the sustainability of a product or industry, and other aspects such as workers' conditions and the sourcing of raw materials are often neglected. The book '*Challenging the Chip'* is an exposé on the toxic chemical exposures faced by those working in the electronics industry (Smith, Sonnenfeld and Pellow, 2006). To keep products 'competitively priced', manufacturing is often outsourced to poorer countries in the Global South which allows these multinational companies to pay workers substantially lower wages, with less safety and environmental regulations than those that exist within most Western nations.

The manufacturing of tech items also exacerbates gender equality issues as the workers are usually women, who are viewed as being more subservient (and less likely to unionise) than male workers and more likely to put up with toxic conditions (Elson and Pearson, 1981). Women also tend to be usually more financially reliant on this sort of employment than men, who have the privilege of being able to be employed in a larger range of industries than women (Webster, 1996).

CASE EXAMPLE: COLTAN AND THE DEMOCRATIC REPUBLIC OF CONGO

A powerful example of the importance of ethical sourcing lies with the mineral coltan, which is used in the manufacture of the miniature circuit boards found in mobile phones and laptops. Due to its importance within computing equipment it is priced very highly at up to $400 a kilogram (Delawala, n.d.). Because of this high price, and the fact that most of the coltan mining is done within the volatile and war-torn nation of the Democratic Republic of Congo (DRC), the sourcing of this precious metal has become intertwined with corruption, arms sales and the ongoing civil war within the DRC (Kay, 2018). The mining process itself is also very dangerous, with health concerns for the miners such as an increased rate of lung cancer, and also health concerns for the nearby populations such as an increased risk of birth defects and air pollution from the presence of toxic metals such as nickel and arsenic from the mines. The lucrativeness of coltan has further meant that the militias involved have cleared parts of the DRC's national parks, decimating communities who lived there sustainably as well as placing endangered species such as the mountain gorilla under greater threat.

Unfortunately, it is exceptionally difficult to fully trace the actual source of rare minerals such as coltan, due to its sourcing being obscured with long supply chain lines. At the consumer end, it is therefore very difficult to know how the raw materials used within IT equipment have been procured (Greenpeace, 2017). However, there are some organisations working to improve this:

- Electronics Watch, an independent monitoring organisation, is working to improve traceability, detect problems in electronics factories, and offers recommendations for ethical procurement and purchasing
- GoodElectronics Network connects and empowers individuals and organisations to improve human rights in the global supply chain

Lifespan of IT products from cradle to grave

The vast majority of computing equipment's environmental footprint is generated through its manufacturing and end of life disposal (Williams, 2004). Therefore, extending the equipment's lifespan, and preventing the need for additional equipment to be made and disposed of, is one of the biggest contributions that can be made within green computing. This could be as simple as upgrading the RAM on an older computer instead of purchasing a whole new machine, or could be more complex such as designing new devices specifically with modularity in mind.

New modular design could be focused on:

- **Modular hardware —** where computers and other devices such as mobile phones are built with easily replaceable parts and standardised components, allowing the users to upgrade the machine themselves with relative ease
- **Modular programming —** where a program is split up into independent and interchangeable modules so that each module contains everything that is necessary to only execute one aspect of the function of a program. Making code that is open-source and highly adaptable to be used within different programs can then become a way to extend the lifespan of IT equipment as new functions can be added without having to purchase a whole new machine.

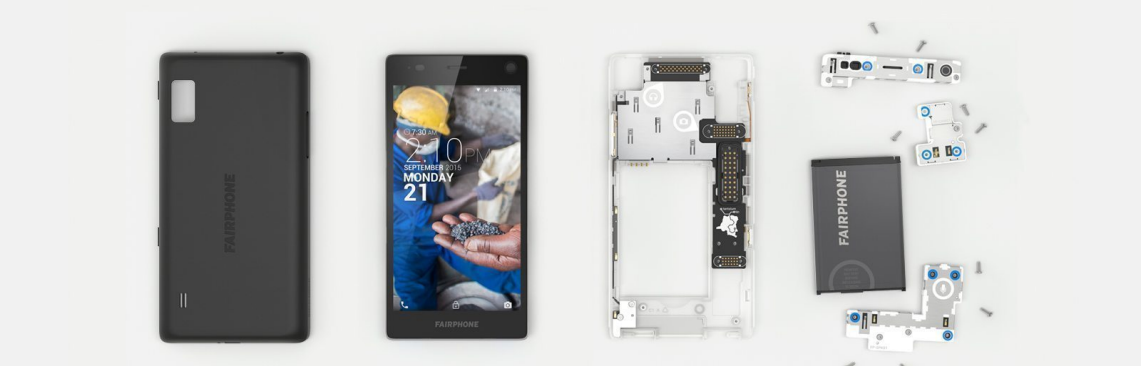

Image: The FairPhone modular components Source: www.fairphone.com

CASE EXAMPLE: FAIRPHONE MODULARITY

An example of a product that is built specifically with modularity in mind is the FairPhone. Unlike an Apple iPhone for instance, which locks its users out of upgrades and has been accused of deliberately slowing down its iPhones to encourage more sales, the FairPhone is made so that if one aspect, such as the camera, stops working, that individual part can be bought online to be replaced. They also provide instruction manuals and encourage users to replace these parts themselves, which is unlike other tech companies which have been known to punish users for repairing their own devices (for instance by removing warranties).

The disposal and recycling of old computer equipment must also be done with care and consideration. If this electronic waste (e-waste) disposal is not managed properly, it can harm the workers who deal with the waste, who are more likely to be located in the Global South (Ifixit.org, n.d.). This can cause additional harm to nearby communities and the local environment through direct contact with the minerals as well as through exposure to the pollution created in the disposal processes, such as from the burning of plastic which creates highly toxic air pollution (Brigden et al., 2005). This further exacerbates the divide between the Global North and the Global South, with the North doing the majority of the consuming and using of the electronic devices, while those in the South having to live with the consequences of Western technological consumption (mining, manufacturing and disposal).

Software and application efficiency

Increasing the efficiency of software and applications not only speeds up an application's processes but saves energy too. Improved efficiency is important for mobile computing, where battery drainage is a real concern and considerably affects the mobile user's review and experience (Pinto and Castor, 2017).

Increasing efficiency can be as simple as making sure that a procedure for creating a data report is not searching the entire database each time but is only searching within the smaller section that is required (Lamb, 2009). Another aspect of this can include data deduplication, which not only saves storage space but also reduces the volume of data that needs to be sent across for company backups and recovery, saving the resources involved in database storage and searching as outlined above. This can also be extended to the optimisation of code libraries to decrease load times of website therefore reducing energy requirements.

The incorporation of software and application efficiency and its impacts on energy use into computer science education is an interesting way to also integrate sustainability, as these concepts can be practically applied to the design and development of technology.

FURTHER READING

The Greenpeace 2017 report on Greener Electronics goes into a lot of depth about the environmental and social impacts of major IT companies:

- *Greenpeace (2017). Guide to Greener Electronics 2017. [online] Greenpeace USA. Available at: https://www.greenpeace.org/usa/reports/greener-electronics-2017/ [Accessed 6 Mar. 2019].*

Fairphone, which was mentioned above as a device that has been specifically designed with repairability in mind, also focuses on the ethical sourcing of its materials. It provides an interesting alternative to other major mobile phone manufacturers and actively positions itself as being an ethical substitute for the Apple iPhone.

- *Fairphone. (2019). Fairphone. [online] Available at: https://www.fairphone.com/en/ [Accessed 7 Mar. 2019]*

EMBED THESE CONCEPTS INTO TEACHING

- This section could be slotted into a lecture (or on its own) about how technology connects to the environment and society
- Mining of rare minerals, particularly of coltan in the DRC, is an interesting case study as there is a lot of evidence for students to review, including some incredible videos and interesting news and academic articles highlighting the extent of the violence, political issues and human rights impacts associated with sourcing materials for electronics manufacturing
- Set a challenge: Have students redesign a piece of electronic or computational equipment so that it can be easily fixed, repaired or updated by the everyday user
- For a tutorial or seminar, students could be asked to trace the life cycle stages of a piece of electronic hardware, identifying where it is manufactured, how far it travels, its use and longevity, and then what happens to it once it is disposed of.
    - We have a video resource on our Sustainability Exchange with Electronics Watch discussing recurring issues in the supply change and ethical procurement: (https://www.sustainabilityexchange.ac.uk/sustainable_procurement_and_the_sdgs)

GREENING BY IT

While IT can be the source of many environmental and social problems as detailed in the last section, it can also become a part of the solution. IT is now seen as being a crucial component to transitioning to a lower carbon society through its ability to track data and energy usage, maximise efficiency in a whole manner of areas, and to create brand new technologies that replace old carbon-intensive ways of doing things.

CASE EXAMPLE: CLIMATE CHANGE AND IT

For instance, it has only been through developments in IT that we have been able to model climate change data, leading to confirmation that we are causing climate change through human activities, and how the warming process could progress over time. IT has also enabled the widespread dissemination of this evidence, and helped humans and organisations across the world to share their knowledge, practices, and methods for attempting to tackle the environmental crisis. As Tomlinson (2012) contends, IT has made a beneficial contribution to environmental problems from allowing individuals, groups and institutions to broaden the space and time horizons of their own views, which allow for more people to understand the systematic and interdependent nature of climate change causes and effects,enabling a more effective response to various environmental concerns.

Smart Cities

Smart cities are urban zones that use new technology to improve their services, become more efficient, and minimise energy usage. While originally the first attempts at creating these cities were concentrated in Western Europe, they have since proliferated around the world. The concept is gaining popularity as city planners are becoming more aware that technology can help with the streamlining and tailoring of services required due to the very rapid urbanisation of populations from all over the world. Currently, over 50% of the world's population live within cities, and this is predicted to increase to over two-thirds of the population residing in urban areas by 2050 (UN Department of Economic and Social Affairs, 2018).

Smart cities often add intelligent 'Internet of Things' features to currently 'dumb' and common city objects such as streetlamps, traffic lights, car parks and more. A useful example has been to integrate smart meters to communal recycling bins to create alerts to the recycling departments when the bins are almost full (Zanella et al., 2014). This creates a more responsive and satisfactory recycling service as the bins being full creates a huge barrier towards recycling and people tend to dump their recycling instead in the waste bins which can be personally disheartening as well as wasteful. Another commonly installed

feature is to attach air pollution monitors to streetlights so data can be gathered about what areas are most affected by poor air quality, as well as to check that clean air legislation is not being breached, particularly around primary schools which is becoming an increasing concern.

> **CASE EXAMPLE: TRIKALA, GREEN**
>
> Within the city of Trikala, Greece, their e-complaints system has made a great impact on resident's lives. The citizens' requests and comments (on issues such as reporting potholes) are submitted via an app which has resulted in issues being solved more quickly as the locality can see common and prominent issues, as well as more transparently as users get updates with what problems are currently being worked on (Rainey, 2018). They also supplied Raspberry Pi kits to all of their schools giving children the opportunity to learn basic programming skills. This is expected to open up the field of computer science as a potential career option to a wider range of people who otherwise may not have considered themselves to have the skills or interest in coding or technology.

However, not all places have been keen to embrace the smart city trend, as some have viewed it as an attempt to Westernise and assimilate a city for marketing potential which could weaken the unique character of their locality (Wattenbarger, 2018). There are also concerns that smart cities may exacerbate existing disparities between the wealthy central zones of cities and the poorer outskirts, creating enclaves where high technology only benefits the few (Silver, 2014). Lastly, there is the potential for smart city technology to be harnessed to decrease citizens' freedoms. Authoritarian governments may use the data collected from the users of smart city technology to monitor and track those who are critical of the government for instance, or to stop social uprisings and public protests.

Remote working

Remote working, also referred to as telecommuting, is a work arrangement where employees do not need to travel to a central place for work, and may involve working from home or a shared hub. Telecommuting has made a significant contribution towards cutting carbon emissions related to commuting. This has especially been the case when business meetings or conferences (particularly international ones) have either been fully hosted online or offer the option for attendees to attend remotely using video calling software, saving on carbon emissions from transportation, such as flying. Tomlinson (2012) argues that while attending international conferences may add an element of excitement and a

chance to network in person for workers or academics, it has now gotten to the stage where environmental concerns should weigh heavily in the choices we make.

Giving employees the option and flexibility to work from home has been of great benefit to both the workers, through increased freedom to work when and where they like, ability to manage family obligations, and to skip out commuting, and to the employers who benefit through having happier employees and heightened productivity (Goudreau, 2011). Working from home is commonly done within IT industries and often brings benefits to the company, however it can also cause problems if safeguarding measures aren't in place to make sure remote workers receive the same kinds of perks that in-office workers have. Remote employees can find working from home to be isolating if there are not enough chances for the social interaction that would commonly take place within an office environment. It also can hinder teamwork as collaboration has been found to be easier in person rather than online (Collins, 2018).

Improving the use of technological communication methods such as video calling or online collaboration tools is an important area of development within computer science. Aiming to make the technology advanced enough to replicate face-to-face interactions is a challenge that is likely to become more necessary as remote working continues to grow. Remote working can make it harder to decipher subtle meanings or emotions that are easier to garner in person (Workman, Kahnweiler and Bommer, 2003), but new technologies may be developed that make online communication more socially satisfying, allowing for better interaction and observation of communication cues.

Privacy on the Internet

With the rapid uptake of internet use throughout the world and the rapid increase in everyday items connected to the internet such as through the Internet of Things (IoT), there are major concerns about privacy and data misuse. Everyday objects such as toasters, dog collars and lighting are now being fitted with IoT devices which allow the user, but also the manufacturer and systems designer, to track and record data from an individual's home, which has previously been a space where individuals have expected to be free from intrusion (Kang, 1998). This has led to concerns about privacy as organisations, companies and even governments are now being granted access to even more personalised data from individuals, with many now claiming that 'data is the new oil' (The Economist, 2017).

A major part of the challenge in regards to data privacy is that it is exceptionally difficult for people to completely opt-out of data tracking technology, as choosing not to engage with it can place individuals at a disadvantage in terms of social life, work life and everyday ease of access to information. Due to the difficulty of avoiding data-tracking technologies, it is now being expected that people are instead self-regulating their own behaviour, leading to a 'chilling effect' where people are deterred from exercising their freedoms fully or engaging

in legal activities online (such as being part of activist or religious groups) due to fear about them being watched and surveilled (Penney, 2017). This leads to fears that the widespread implementation of online devices could be used to discipline and control populations by authoritarian governments or even by businesses.

Alternatively, the internet has also given many the privacy and means to overcome repressive governmental laws and controls through creating new encrypted channels to communicate through. Examples include:

- Wikileaks has enabled whistleblowing about widespread and systematic corruption, illegal campaigning activities, misuse of military power etc. They also have been at the forefront of leaking information about the potential security dangers of IoT devices, such as showing evidence that the CIA is able to hack into Smart TVs and record private conversations (WikiLeaks, 2017).
- The Arab Spring beginning in 2010 was also facilitated through encrypted software tools such as Tor as well as public social media platforms such as Twitter and Facebook (often through 'fake profiles') to organise mass protests (Eltantawy & Wiest, 2011).
- Apps such as Grindr, whether accessed directly or through a VPN, are also a means of overcoming repressive anti-homosexuality laws, giving freedom of sexual expression to many more around the world, one case example being in Iran where same sex relationships are punishable by death (Yadegarfard, 2019).

Technological Fixes

Despite the role that technologies play in enabling progress on sustainability, it is important to emphasise that issues such as climate change are unlikely to be solved by technological innovation alone. Framing it as purely a problem that requires technological advancement recasts this deeply complex social, economic, political and environmental problem as one with a neat and definable solution (Morozov, 2014). Climate change is a problem of such massive proportions that it cannot be solved by simply tweaking existing technology to make it more efficient. Tackling it requires global cooperation and a fast move away from the burning of fossil fuels that create the majority of the world's carbon emissions.

While technological improvements are welcome and necessary, they need to coincide with widespread political and policy reform and perhaps ought to be seen as being complementary to existing activist struggles.

EMBED THESE CONCEPTS INTO TEACHING

- Another interesting case study is examining the role of technology in the Hong Kong Protests of 2019 from both the government and activists point of views
- Governments are also working toward more sustainable IT – the UK Government is no exception. Students can review the UK Greening Government policy paper (December 2018) and identify the key objectives and actions the Government aim to take for more sustainable technology (See the policy paper at: https://www.gov.uk/government/publications/greening-government-sustainable-technology-strategy-2020/the-greening-government-sustainable-technology-strategy-2020-sustainable-technology-for-sustainable-government)
- For a tutorial, students could be asked to design a digital service for a 'smart' city – taking a common unconnected, or 'dumb', object or service and coming up with a creative and innovative solution for citizens and/or local government

REFERENCES

INTRODUCTION

Alfrey, L. and Twine, F. (2016). Gender-Fluid Geek Girls. *Gender & Society*, 31(1), pp.28-50.

Brundtland, G. (1987) Our common future: Report of the 1987 World Commission on Environment and Development.

Cade, A. (2008). Employable graduates for responsible employers. StudentForce for Sustainability/HE Academy. Available at: https://www.heacademy.ac.uk/system/files/esd-employable-graduates-responsible-employers.pdf (accessed 11 Jan 2019)

Cai, Y. (2010). *Integrating sustainability into undergraduate computing education*. SIGCSE '10 Proceedings of the 41st ACM technical symposium on Computer science education. [online] Milwaukee: SIGCSE Technical Symposia. Available at: https://dl.acm.org/citation.cfm?id=1734439 [Accessed 17 Feb. 2019].

Gordon, N., Kor, A. and Pattinson, C. (2014). *Enhancing employability through sustainable computing*. [online] STEM Annual Conference. Available at: https://www.heacademy.ac.uk/knowledge-hub/enhancing-employability-through-sustainable-computing [Accessed 17 Feb. 2019].

Tilbury, D. and Wortman, D. (2004). *Engaging People in Sustainability*. Commission on Education and Communication. Cambridge, UK: ICUN.

GREENING OF IT

Brigden, K., Labunska, I., Santillo, D. and Allsopp, M. (2005). *Recycling of Electronic Waste in China and India*. [online] Exeter: University of Exeter. Available at: https://www.greenpeace.org/austria/Global/austria/marktcheck/uploads/media/report_recycling_electronic_waste_2005.pdf [Accessed 7 Mar. 2019].

Delawala, I. (n.d.). What Is Coltan?. *ABC News*. [online] Available at: https://abcnews.go.com/Nightline/story?id=128631&page=1 [Accessed 6 Mar. 2019].

Elson, D. and Pearson, R. (1981). 'Nimble Fingers Make Cheap Workers': An Analysis of Women's Employment in Third World Export Manufacturing. *Feminist Review*, (7), p.87-107.

Greenpeace (2017). *Guide to Greener Electronics 2017*. [online] Greenpeace USA. Available at: https://www.greenpeace.org/usa/reports/greener-electronics-2017/ [Accessed 6 Mar. 2019].

Guardian Environment Network (2017). 'Tsunami of data' could consume one fifth of global electricity by 2025. *The Guardian*. [online] Available at: https://www.theguardian.com/environment/2017/dec/11/tsunami-of-data-could-consume-fifth-global-electricity-by-2025 [Accessed 6 Mar. 2019].

Ifixit.org. (n.d.). *The Problem with E-Waste - iFixit*. [online] Available at: https://ifixit.org/ewaste [Accessed 7 Mar. 2019].

Jones, N. (2018). How to stop data centres from gobbling up the world's electricity. *Nature*. [online] Available at: https://www.nature.com/articles/d41586-018-06610-y [Accessed 6 Mar. 2019].

Kay, A. (2018). 5 Top Tantalum-mining Countries. *Investing News Network*. [online] Available at: https://investingnews.com/daily/resource-investing/critical-metals-investing/tantalum-investing/2013-top-tantalum-producers-rwanda-brazil-drc-canada/ . [Accessed 6 Mar. 2019].

Lamb, J. (2009). *The greening of IT*. Upper Saddle River, NJ: IBM Press/Pearson.

Pinto, G. and Castor, F. (2017). Energy Efficiency: A New Concern for Application Software Developers. *Communications of the ACM*, 60(12), pp.68-75.

Smith, T., Sonnenfeld, D. and Pellow, D. (2006). *Challenging the chip*. Philadelphia: Temple University Press.

Stedman, R. (2005). *Reducing Desktop PC Power Consumption Idle and Sleep modes*. [online] Dell. Available at: https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/ReducingPCPowerConsumption.pdf [Accessed 6 Mar. 2019].

Webster, J. (1996). *Shaping Women's Work: Gender, Employment and Information Technology*. London: Routledge.

Williams, E. (2004). Energy Intensity of Computer Manufacturing: Hybrid Assessment Combining Process and Economic Input–Output Methods. *Environmental Science & Technology*, 38(22), pp.6166-6174.

GREENING BY IT

Collins, A. (2018). *The Ultimate Guide to Telecommuting*. [online] Blog.hubspot.com. Available at: https://blog.hubspot.com/marketing/telecommuting [Accessed 16 Mar. 2019].

Goudreau, J. (2011). The Best-Paying Work-At-Home Jobs. *Forbes*. [online] Available at: https://www.forbes.com/sites/jennagoudreau/2011/09/27/the-best-paying-work-at-home-jobs/#5c07ff6f4ed2 [Accessed 16 Mar. 2019].

Eltantawy, N. and J. Wiest. (2011). Social Media in the Egyptian Revolution: Reconsidering Resource Mobilisation Theory. *International Journal of Communication,* 5, pp.1207–1224. Available at: https://ijoc.org/index.php/ijoc/article/viewFile/1242/597 [Accessed 19 October 2019].

Kang, J. (1998). Information Privacy in Cyberspace Transactions. *Stanford Law Review*, 50(4), p.1193.

Mearman, A. and Plumridge, A. (2012). *Embedding Sustainability in the Economics Curriculum*. Bristol: University of the West of England.

Morozov, E. (2014). *To Save Everything, Click Here: Technology, Solutionism, and the Urge to Fix Problems that Don't Exist*. London: Penguin Books.

Penney, J. (2017). Internet surveillance, regulation, and chilling effects online: a comparative case study. *Internet Policy Review*, 6(2).

Rainey, V. (2018). Inside Greece's first smart city: 'Now you don't need to know a politician to get something done'. *The Guardian*. [online] Available at: https://www.theguardian.com/cities/2018/sep/04/trikala-greece-first-smart-city-dont-need-to-know-a-politician-to-get-something-done [Accessed 16 Mar. 2019].

Silver, J. (2014). The rise of Afro-Smart cities should be viewed with caution. [Blog] *Africa at LSE*. Available at: https://blogs.lse.ac.uk/africaatlse/2014/07/16/the-rise-of-afro-smart-cities-should-be-viewed-with-caution/ [Accessed 16 Mar. 2019].

The Economist (2017). The world's most valuable resource is no longer oil, but data. *The Economist*. [online] Available at: https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data [Accessed 16 Mar. 2019].

Tomlinson, B. (2012). *Greening through IT*. Cambridge, Mass.: MIT Press.

UN Department of Economic and Social Affairs (2018). *2018 Revision of World Urbanization Prospects*. [online] United Nations. Available at: https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html [Accessed 16 Mar. 2019].

Wattenbarger, M. (2018). The Mexican town that refused to become a smart city. *The Guardian*. [online] Available at: https://www.theguardian.com/cities/2018/oct/16/the-mexican-town-that-refused-to-become-a-smart-city [Accessed 16 Mar. 2019].

WikiLeaks (2017). *Vault 7: CIA Hacking Tools Revealed*. [online] Wikileaks.org. Available at: https://wikileaks.org/ciav7p1/ [Accessed 16 Mar. 2019].

Workman, M., Kahnweiler, W. and Bommer, W. (2003). The effects of cognitive style and media richness on commitment to telework and virtual teams. *Journal of Vocational Behavior*, 63(2), pp.199-219.

Yadegarfard, M. (2019). How are Iranian Gay Men Coping with Systematic Suppression Under Islamic Law? A Qualitative Study. *Sexuality & Culture*, 23(4) pp.1250-1273. Available at: https://link.springer.com/article/10.1007/s12119-019-09613-7 [Accessed 20 October 2019].

Zanella, A., Bui, N., Castellani, A., Vangelista, L. and Zorzi, M. (2014). Internet of Things for Smart Cities. *IEEE Internet of Things Journal*, 1(1), pp.22-32.

A special thanks to all the teaching staff from universities and colleges around the UK who engaged with us on this project

These case studies were collated by the
EAUC-Scotland Winter 2018-19 Intern, Daisy Jamieson

Scotland eauc
The Alliance for Sustainability Leadership in Education