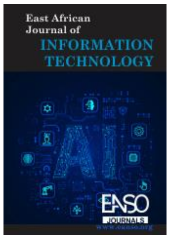

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Original Article

ICT for Sustainability or Sustainability in ICT? A Review of the Role of ICT in Enhancing Sustainability versus the Need to Enhance Sustainability in ICT

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ABSTRACT

Is ICT a solution to sustainability problems or is it just a greater environmental problem? Throughout their lifecycle, ICT products and services are associated with significant levels of energy consumption and carbon emissions. On the contrary, despite being one of the main contributors to global carbon emissions, the ICT sector has a crucial role to play in boosting productivity and sustainability in many sectors—education, transport, agriculture, business, buildings, health, power, and manufacturing. To improve their efficiency and mitigate carbon emissions from ICT products, producers and end-users of such ICT products should therefore, employ measures that enhance their sustainability. Such measures identified in this article include the use of sustainable manufacturing processes, sustainable procurement/purchasing of ICT products, proper ICT product use, reuse, recycle, and proper disposal of ICT devices that are out of use. In data centres, such measures include virtualisation, recovery and reuse of waste heat, designing data centres to allow free cooling, control of restricted air conditioning, replacement of old servers and processors with new energy-efficient ones, and locating data centres near renewable energy sources. This is because apart from enhancing sustainability in the ICT sector itself, ICT has the potential to enhance sustainability in other sectors through improvement in efficiency and reduction in carbon emissions. This article discusses how ICT can enhance sustainability in the transport, power, manufacturing, and building sectors, which are the major energy consumers and carbon-emitting sectors.

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INTRODUCTION

The demand for ICT products and services both at a personal and organisational level has been rising rapidly over the years due to increased reliance on ICT to offer solutions to individual and corporate challenges. As a result, the use of ICT products and services has been of great benefit to both the developed and developing nations, as it has led to improved productivity and an increase in economic output. Consequently, the manufacture and use of ICT products and services generate up to 2% of global carbon emissions, which is equivalent to emissions from the aviation industry (Environmental IT leadership team, 2009). However, with proper application, ICT has an enormous potential to significantly contribute to emissions reduction both within the ICT sector and other sectors.

Under business as usual scenario, it is predicted that global carbon emissions will rise from 47.3 $GtCO_2e$ in 2010 to 57.7 $GtCO_2e$ in 2030 (Boyd et al., 2015). However, apart from contributing to socio-economic benefits, the adoption of Green IT has the potential to provide immense environmental benefits against this prediction. For example, in 2008, World-Wide Fund (WWF) estimated that ICT-enabled emissions abatement potential would be 8.711 $GtCO_2e$ in 2030. However, with technological advancement, the recent SMARTer 2030 report states that although global carbon emissions from ICT are estimated at 1.25 $GtCO_2e$ in 2030, ICT's distinctive energy efficiency monitoring and maximisation ability both within the sector and in other sectors could save carbon emissions by ten times (12 $GtCO_2e$) its emissions by 2030 (GeSI, 2015). According to the report, with the application of information technology, global ICT CO_2 emissions are estimated to fall to 1.97% of total global emissions by 2030.

Therefore, considering the socio-economic and environmental benefits of ICT use, manufacturers, individuals, and organisations have the responsibility to work towards the sustainability of ICT in different sectors. As discussed in this article, some initiatives that could help to enhance the sustainability of ICT include sustainable manufacturing processes, sustainable ICT procurement, proper use of ICT products and services, and proper disposal of ICT products after use. Therefore, this article focuses on two main aspects as it relates to ICT and sustainability; (i) how ICT sustainability can be improved by making it go green or maintaining/enhancing its performance in an environmentally sustainable way, (ii) how ICT can be used to enhance sustainability in other sectors. Whereas ICT can be used to

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enhance sustainability in many sectors—education, transport, agriculture, business, buildings, health, power, and manufacturing—this article focuses on the role of ICT in enhancing sustainability in the transport, manufacturing, power, and buildings sectors, given that they are among the primary energy consumers and carbon-emitting sectors.

HOW TO IMPROVE ICT SUSTAINABILITY

As human dependence on technology increases, the relationship between ICT and the environment has continued to deteriorate. ICT's negative effects on the environment emanate during ICT equipment production and distribution, the consumption of energy during their operation, generation of electronic waste, and the potential for exploitative applications. Therefore, it is increasingly becoming essential for every computer user to contribute to the reduction of ICT's increasing carbon footprint. As such, the following measures have been identified as suitable measures that can be adopted to help to green the ICT sector:

Sustainable Manufacturing Process

According to the U.S. Department of Commerce (2007), sustainable manufacturing refers to the generation of manufactured products by using processes that have minimal adverse impacts on the environment, enhances the safety of employees, surrounding communities and consumers, and are economically sensible. In this definition, sustainable manufacturing processes is a process that puts into consideration the lifecycle of the product. This means that it takes care of a product's pre-manufacture, manufacturing, use, and after use.

In a study on the Product Sustainability Index, Shuaib et al. (2014) identified suitable metric clusters of the sustainability element of ICT manufactured products and services throughout their lifecycle. These clusters include raw material use and efficiency, energy use and efficiency, other resources (such as water) use and efficiency, wastes and emissions management, and product end of life management. To achieve these metric clusters, the following are initiatives that should be taken into consideration in the manufacturing industries (Tebbutt et al., 2009);

- Environmental certification of manufacturers
- Choice of cleaner manufacturing methods
- Designing of less energy and material consumptive products
- Taking products from users for recycling and reuse after use
- Provision of environmental information of manufactured products
- Clean sourcing of production materials.

These initiatives are emphasised in a recent U.S. Department of Energy report on sustainable manufacturing, where the critical role of the manufacturing industry in enhancing ICT sustainability is identified. The department stresses the need for development and use of alternative feedstock, minimisation of wastes in the manufacturing process, sustainability in design and decision-making, management of raw materials, energy and water resources, and end of life management of manufactured products (U.S. Department of energy, 2016). According to the report, accruing benefits from the sustainable manufacture of ICT products include (i) the reduction in GHGs emissions, water consumption, raw materials consumption, and wastes generation; (ii) integration of renewable energy use; (iii) enablement of the collection, disassembly, reuse, recycle and re-manufacturability of products.

For example, in the manufacture of its products, Microsoft has reported working to enhance products' recyclability, minimise packaging materials, shun toxic substance usage, and enhance efficiency in energy utilisation. Some of Microsoft's initiatives include the advancement to Surface Pro 2017, which, apart from having a faster CPU, the display is more energy-efficient than the earlier version, Surface Pro 4 (Microsoft, 2017). Additionally, the company now restricts the use of harmful substances in manufacturing. For instance, in compliance with the European Union's Restriction on the use of Hazardous Substances directives (RoHS), Microsoft reported phasing out lead, mercury, and cadmium in their products in 2017 (Microsoft, 2017). Further, the use of nickel, phthalates and halogenated flame retardants has been restricted as per the requirements of existing legal regulations.

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Sustainable ICT Procurement/Purchasing Strategies

ICT products are associated with significant levels of carbon emissions throughout their lifecycle. For example, a typical European P.C. and monitor were found to weigh almost 20 kg, contain more than 27 materials, produce 66 Kg of waste and 1096 Kg of CO_2 during its lifecycle (EAUC, 2011). Purchasing the right ICT products and services can, therefore, minimise ICT carbon footprint significantly. Sustainable ICT procurement refers to the consideration of sustainability aspects of ICT products which include energy efficiency, compatibility with existing software or hardware, recyclability, life expectancy, environmental certification of the product, and the manufacturer and need for a product before purchase (Gov. uk, 2014).

According to the EAUC (2011) ICT procurement guideline, there are three sustainability criteria applicable when purchasing ICT products;

- Green procurement criteria - an ICT product should be made from few natural resources, contain no hazardous and toxic materials, have a longer lifespan compared to other similar products, consume less water and energy during manufacture and use, use less packaging, generate minimal waste during production and be recyclable.

- Immeasurable procurement criteria - small ICT products (in terms of size) should be preferred as they are made using fewer materials and consume less energy. Further, end-users should always check for manufacturers guarantee for ICT product’s duration, what it covers, and the reparability of the product

- Measurable procurement criteria - end-users should always consider a product’s energy utilisation (EPEAT and energy star label), equipment consumables (such as toner and papers), equipment disposal (whether the product is recyclable or can be donated after use), and the sustainability cost of ICT equipment.

For example, according to EPEAT (2008), the sale of 44,047,352 EPEAT registered products in the USA in 2008 provided a range of environmental benefits, as shown in *Table 1*, which would not be realised with unregistered products.

Table 1: Estimated environmental benefits from U.S. 2008 EPEAT products purchases

	Reductions	**Equivalents**
Electricity	8.39 Billion kWh	Annual consumption of 701,329 US households
Primary Materials	14,8 million Metric Tons	Weight of 114,959,611 refrigerators
Greenhouse Gas Emissions	1.57 million Metric Tons Carbon Equivalent	Removing 1,059,363 US cars from the road for a year
Air Emissions	34,224,122 metric tons	-
Water Emissions	71,683 Metric Tons	-
Toxic Materials	1021 Metric Tons	The weight of 510,949 bricks and the amount of mercury in 149,685 household fever thermometers
Solid Waste	14353 Metric Tons	Equivalent to the waste generated annually by 7202 U.S. households.
Hazardous Waste	43,337 Metric Tons	Weight of 61,831,455 bricks
Cost Savings to manufacturers and end users		$793,826,980.52

Source: (EPEAT, 2008)

In a different case, (Carbon Trust, 2006) found that ENERGY STAR computer models use 70% less electricity than standard computers, ENERGY STAR monitors use 60% less electricity, printers use 60% less electricity while fax machines use 40% less electricity than standard machines and can scan double-sided pages, saving on paper and costs. According to Tebbutt et al. (2009), the following sustainable ICT procurement approaches should, therefore, be applied when purchasing ICT equipment:

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- Avoiding unnecessary purchases
- Requesting for environmental credentials of the product you are purchasing
- Requesting for environmental credentials of the company you are purchasing from
- Reading about IT products you want to purchase before purchase, for example, products energy efficiency, chemical composition, recyclability, and certification
- Choosing powerful devices, such as computers that can be used for long when disconnected from power
- Avoiding the use of non-recyclable devices, such as cathode ray tube monitor screens

Sustainable ICT Product Use and After-Use Management

Whilst the ICT industry is critical in offering innovative environmentally friendly solutions to minimise GHGs emissions in different sectors, individuals and organisations should take initiatives that enable green IT solutions. These seemingly less effective initiatives include switching off idle devices, environment-friendly printing, using few central printers, using low power devices, switching off screen savers and switching off chargers that are not in use (Tebbutt et al., 2009; O'Neill, 2010). For example, proper use of office IT products can provide a wide range of environmental and cost-saving benefits, as shown in *Table 2*.

Table 2: Office sustainable use of IT equipment and their benefits

Action	Savings
Switching off unnecessary equipment after work hours	Up to 60% of the costs of running office equipment
Enabling standby settings on all equipment	Approximately 30% of the costs of running office monitors and PCs
Turning off non-essential equipment during day time to minimise heat build-up	Improvement in comfort and reduced use of electricity to cool offices
Installing seven-day time controls on shared equipment such as printers	Approximately 50% of the costs of running photocopiers and printers
Setting default duplex printing and reducing print quality	Saving paper, toner, and energy
Using the right equipment for the right job	For example, inkjet printers use 50% less energy than laser printers when on sleep mode, and a 20-inch LCD monitor uses 60% less energy than a 20-inch CRT VGA monitor
Using low energy equipment that meets job requirements	Up to 10% of printing costs alone
Monitoring out-of-work hours energy utilisation	Up to 60% of the costs of running office equipment
Awareness creation among members of staff on the benefits of responsible use of office equipment	Maximum benefits can be achieved with responsible staff

Source: (Carbon Trust, 2006)

On the other hand, sustainable handling of ICT equipment once their need has been fully realised is critical in enhancing the sustainability of the ICT sector. Such measures include the return of old devices to manufacturers for refurbishing and recycling, giving out to charities for reuse instead of disposing or keeping, and always accompanying devices with their chargers whenever giving out for reuse or recycle (Tebbutt et al., 2009; O'Neill, 2010).

Further, instead of replacing old devices with new ones, old devices can now be reconditioned, and IT hardware parts replaced or software upgraded to obtain new services—this prolongs its utilisation and significantly minimise e-waste generation (Pazowski, 2015). Alternatively, IT devices can be

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donated to charities for reuse. For example, Computer Aid International, a UK-based charity organisation, helps in the professional refurbishment of computers which they donate for reuse in developing countries. By doing so, they offer sustainable disposal of IT devices to businesses while at the same time empowering communities in developing countries through technology.

Data Centres

ICT data centres are the main source of organisations' carbon emissions. Therefore, for organisations to cut down their carbon footprint and general environmental impact, data centres' efficiency must be enhanced. Globally, data centres are estimated to release up to 150 million tons of carbon annually, while poor cooling and poor energy utilisation in data centres cause over 60 million MWh of energy wasted (O'Neill, 2010). To address these environmental problems, measures such as virtualisation, recovery and reuse of waste heat, designing of data centres to allow free cooling, control of restricted air conditioning, replacement of old servers and processors with new energy-efficient ones, and locating data centres near renewable energy sources have been used (Tebbutt et al., 2009; Pazowski, 2015).

For example, in a rationalisation project, the closure of an old, less efficient data centre by Capgemini, a global ICT consultancy company, in 2016, led to a reduction in emissions by 2,077 tCO_2e (Capgemini U.K., 2017). In a different case, the Merlin data centre project was constructed on brownfield site to minimise the need for construction, 95% of construction materials used were recyclable, it is operated using cleaner flywheel energy technology instead of batteries, powered by renewable energy, and cooled by free air. Environmental benefits from this centre include power saving by 91% compared to regular data centres, power usage effectiveness of 1.10, while free air cooling saves running costs by 80% and carbon emissions by 50% (Capgemini U.K., 2017).

Additionally, in a bid to enhance the energy efficiency, most data centres are now using virtualisation, in which case several servers are made to run several virtual machines on one piece of hardware. Virtualisation contributes to green technology by reducing the number of servers, reducing the need for hardware disposals, reducing staff and customer travels, and reducing paper use (Pazowski, 2015). For example, according to Green data house (2016), whereas a typical data centre will have more than 100 servers, virtualisation enhances server efficiency by 40-60%, and therefore, the virtualisation of 100 servers is comparable to planting 1,569 trees or removing 89 cars from the roads.

Virtualisation forms the basis for cloud computing. According to the carbon disclosure project by a non-profit organisation in 2011, cloud computing is referred to as the IT solution for the 21st Century. This is because apart from contributing to economy-wide financial benefits, cloud computing has the potential to cut down carbon emissions significantly. For example, if an organisation with 60,000 employees worldwide moves its H.R. application to a public cloud, carbon emissions would be reduced by 30,000 metric tons over five years, while moving the same H.R. application to a private cloud would cut carbon emissions by 25,000 metric tons over the same period (Verdantix, 2011). This implies that the use of public cloud is more environmentally friendly and preferable to private cloud in greening the IT sector.

THE ROLE OF ICT IN ENHANCING SUSTAINABILITY IN OTHER SECTORS

On the one hand, ICT is one of the main contributors to global carbon emissions and energy utilisation. On the other, ICT plays a key role in forming a low carbon society and energy efficient economies. While under business as usual scenario global ICT emissions are expected to rise from 0.53 $GtCO_2e$ in 2002 to 1.25 $GtCO_2e$ in 2030, ICT has the potential to reduce these emissions by up to ten times its footprint, which translates to 12 $GtCO_2e$, and which is ten times more than ICTs estimated emissions by 2030 (GeSI, 2015). This can be achieved through the use of ICT to enable other sectors—transport, power, building, agriculture, business, and manufacturing—to become more efficient, as described in the following sections of this report. In general, the application of ICT in different sectors is projected to enable global carbon emissions reduction by 2030, *Table 3*.

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Table 3: Estimated ICT-enabled CO_2 abatement potential by 2030

Sector	ICT-enabled CO_2 abatement potential ($GtCO_2e$)
Transport	3.6
Manufacturing	2.7
Agriculture	2.0
Buildings	2.0
Energy	1.8
Total	**12.1**

Source: (GeSI, 2015)

Transport Sector

Application of ICT in Transport Infrastructure and Vehicles

The management and organisation of the transport sector is an increasing area of concern, especially in urban areas. For example, in the U.S urban areas, fuel wastage due to traffic congestion increased from 500 million gallons to 2.9 billion gallons between 1982 and 2005 (International chamber of commerce, 2010). However, according to the International chamber of commerce (2010), ICT-enabled transport sector management has the potential to significantly contribute to emissions reduction and fuel consumption efficiency through:

- Intelligent traffic monitoring
- Fleet management telematics to track vehicles movement and idleness
- Eco-driving, for example, the use of a GPS in selecting routes allows for route optimisation
- Optimisation of supply chain logistics to reduce travels between distribution systems
- Optimisation of routes management, for example, by use of smart maps which can help minimise time spent by drivers in traffic jams

The application of ICT in vehicles provides benefits such as enhancing the engine efficiency, provision of real-time information on fuel utilisation, monitoring vehicles' air conditioning systems, mechanical conditions, and facilitating new innovative transport solutions (WWF, 2008). Consequently, according to SMARTer 2020 report, the application of ICT in transport infrastructure had an emissions abatement potential of 1.46 $GtCO_2e$ by 2020 as shown in *Table 4*. However, with the expansion of the ICT-enabled transport industry, ICT-enabled transport emissions abatement potential is expected to rise to 3.5 $GtCO_2e$ by 2030 (GeSI, 2015).

Table 4: ICT-enabled emission abatement potential within transport sector by 2020

Transport end-use	Abatement potential ($GtCO_2e$)
Eco-driving	0.25
Real-time driving alerts	0.07
Intermodal travel applications/public transportation	0.07
Optimisation of routes management and planning	0.19
Optimisation of supply chain logistics	0.57
Incorporation of electric vehicles	0.20
Intelligent traffic monitoring	0.03
Fleet management and telematics	0.08
Total	**1.46**

Source: (GeSI, 2012)

Telecommuting and Teleworking

Telecommuting, also referred to as e-commuting or home working, is a mode of work whereby employees work from outside their offices. Often, they work from their homes or places near their homes, such as libraries and coffee shops. Since its discovery in the 1970s, practitioners and scholars

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have increasingly developed a significant interest in telecommuting work mode (Allen et al., 2015). According to Pflueger et al. (2016), telecommuting positively contributes to environmental sustainability through:

- Reduction in GHGs emissions from the use of vehicles by employees
- Reduction in facility emissions footprint through minimisation of the need for new infrastructure
- Reduced lifecycle emissions because of the reduced employee vehicle wear
- Reduction in congestion on roads and need for roads construction and repairs
- Reduction in office energy use because of reduced employee presence

Additionally, according to the Global e-Sustainability Initiative (2012), telecommuting reduces commuting car mileage by 48-77%, and if a substantial number of people work from home for at least 3days a week, 20-50% of energy would be saved even with increased energy used at home. In Australia, 75% of employees drove to work in 2010, which contributed to 8% of the country's emissions (Kidney, 2010). However, teleworking had the potential to cut down the country's emissions by 3.1 $MtCO_2e$ per year worth $1.2 billion of energy and $30-150 of carbon (Kidney, 2010). A different study conducted in the U.K. came up with near similar results. In this case, the potential for telecommuting-enabled emissions reduction by 2020 was 0.26 $GtCO_2e$ given a net enabling effect of 14.27 $KtCO_2e$ per year as shown in *Table 5*. This translates to 1.4 tCO_2e emissions reduction per employee per year (Global e-Sustainability Initiative, 2010).

Table 5: U.K. telecommuting-enabled emissions abatement potential per year

Effect	The effect per year ($Kt\ CO_2e$)
Mitigated emissions from reduced vehicle use	9.97
Reduced building use	15.6
ICT/rebound emissions	11.3
Net mitigated emissions	14.27

Source: (Global e-Sustainability Initiative, 2010)

Elsewhere in the USA, if 30 million people worked through telecommuting, $75 - 100\ MtCO_2e$ emissions would be saved by 2030 (Global e-Sustainability Initiative, 2012). For example, according to a recent report from a study conducted in the country by Pflueger et al. (2016), the use of telecommuting reduces emissions by 1.15 $MtCO_2e$ per Dell U.S. employee per year as shown in *Table 6*.

Table 6: Emissions reduction through telecommuting among Dell US employees

Effect	Per employee effect per year ($MtCO_2e$)
Mitigated emissions	1.80
Increased emissions due to rebound effects	-0.645
Increased emissions due to ICT footprint	-0.0057
Net mitigated emissions	1.15

Source: (Pflueger et al., 2016)

Such cases indicate that telecommuting has a vast potential to transform the global economy from a high carbon emission to a low carbon emission with increased productivity.

Virtual Meetings

Virtual meetings refer to the conduct of meetings online through teleconferencing or video-conferencing, replacing the need for face-to-face meetings. The replacement of face-to-face meetings that would require air or road travels with virtual meetings is one of the most suitable ways of

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reducing GHGs emissions and minimises economic expenditure. For example, according to Global e-Sustainability Initiative 2012, teleconferencing can reduce 5-20% of global business travels which could save up to $260\ MtCO_2e$ emissions per year.

Assuming a 5%, 10% and 15% baseline travel avoidance due to virtual meetings, the estimated reductions in carbon emissions through the replacement of air travel with virtual meetings are as shown in *Table 7*. This table depicts that a 5%, 15%, and 30% substitution of air travels with virtual meetings would bring about a global reduction in GHGs emissions by 24.7, 74 and 148 $MtCO_2e$ respectively. Apart from being applied to remote employees, video-conferencing could also be applied to enhance the flexibility of local employees and the conduct of meetings with clients. In effect, this would significantly reduce carbon emissions from driving to work. For example, in Coleg Meirion-Dwyfor, 200 internal virtual meetings were conducted in 2010, replacing the need to travel between the college's three campuses (Bristow et al., 2015). Assuming that 50% of these meetings replaced the need for road travel, the institution was in a position to save 8,000 miles and two tons of carbon dioxide. Also, the replacement of face-to-face meetings with virtual meetings saved on paper and food waste. This is because in-person meetings often require printing reports, agendas, and other materials for every attendee; while most of the food provided for the attendees ends up not being eaten and is thrown away.

Table 7: Estimated Virtual meetings emissions reductions (only aircraft direct emissions considered)

	Percentage baseline travel avoided due to virtual meetings			**Emission reductions from virtual meetings ($MtC0_2e$)**		
	Low	**Medium**	**High**	**Low**	**Medium**	**High**
OECD North America	5%	15%	30%	6.9	20.6	41.2
OECD Europe	5%	15%	30%	5.0	15.1	30.1
OECD Pacific	5%	15%	30%	1.6	4.8	9.7
FSU	5%	15%	30%	0.6	1.9	3.9
Eastern Europe	5%	15%	30%	0.6	1.8	3.6
China	5%	15%	30%	2.2	6.5	12.9
Other Asia	5%	15%	30%	2.3	6.8	13.5
India	5%	15%	30%	0.8	2.3	4.5
Middle East	5%	15%	30%	0.9	2.7	5.4
Latin America	5%	15%	30%	2.9	8.6	17.3
Africa	5%	15%	30%	1.0	2.9	5.9
Total				**24.7**	**74.0**	**148.0**

Source: (WWF, 2008)

In an evaluation of potential alternatives to face-to-face scientific society meetings, Ponette-González & Byrnes (2011) identified virtual and video-conferencing as the most effective initiatives towards carbon emission reduction by about 52%. Other alternatives identified include reducing meeting frequency, carbon offsetting, reducing international participation, geographical selection, and alternating schedule. For example, Cisco is one of the companies worldwide that have been working to harmonise business growth and profitability with environmental sustainability. Among the company's many GHGs emissions reduction initiatives, Cisco committed itself to reduce air travel carbon emissions by at least 10% (Cisco, 2008). In this regard, the company requires all its employees to consider available virtual meeting options before organising for travels.

Among the environmental benefits that Cisco is able to get from its connected workplace in the San Jose campus are increased energy efficiency, saving on space, and reduction in GHGs emissions. In comparison to a traditional business building, the company's redesigned building to a connected workplace was found to be 44% more energy-efficient, cut employee space requirement by 40%, and reduced per-capita materials and equipment consumption by 22% (Cisco, 2008). Therefore, such companies are a perfect demonstration of virtual meetings potential to contribute to environmental sustainability, not forgetting other benefits such as costs and time saving, which are not discussed in this article. However, as Guerin (2017) notes, adoption of technology is often met with resistance due to factors such as lack of experience, high installation costs, lack of funds, unawareness of benefits, and people's perception that it is unnatural, hard to use and unreliable.

Power Sector

Energy generation leads to direct GHGs emissions, while energy losses during transportation and distribution increase GHG emissions. The power sector is responsible for 21% of global GHG emissions (GeSI, 2012). However, an improvement in power generation, transmission, and distribution can enhance sustainability through a reduction in GHGs emissions. This can be achieved through the use of ICT in demand management, power load balancing, grid optimisation, energy pricing depending on the time of day, virtual power plants, incorporation of renewables in power production, and incorporation of off-grid applications storage (Tebbutt et al., 2009).

Smart grids use advanced technologies to link several energy suppliers with end-users, while high-tech monitoring and sensor technologies monitor energy demand, supply, and transmission, thereby saving energy and reducing carbon emissions. Another advantage of a smart grid is its ability to incorporate energy supply from varied sources, including low-carbon sources such as CHP systems, solar P.V., and wind turbines (Laitner & Ehrhardt-Martinez, 2007). According to the European Commission, the application of ICT in the development of transmission and distribution grids coupled with renewables integration in power generation could prevent power loss during transmission and distribution by 1% in 2020 in Europe (European Commission, 2007). If the full grid potential is utilised, 30 $MtCO_2e$ would be saved per year.

Unlike traditional grid systems, smart grids allow the flow of energy and information both to the supplier and the consumer; the data obtained on production, consumption, sources, and costs can then be used in automated decision-making processes (Laitner & Ehrhardt-Martinez, 2007). Apart from that, smart grids also increase consumer energy choices and allow demand-side energy consumption management (Laitner & Ehrhardt-Martinez, 2007). Therefore, if used together with smart meters and smart building systems, smart grids enable the consumers to go for smart decisions using instantaneous information.

As estimated by GeSI (2012), ICT-enabled GHGs emissions abatement potential in the power sector by 2020 was 2.02 $GtCO_2e$ as shown in *Table 8*. However, by 2030, this potential is estimated to rise to 3.4 $GtCO_2e$ (GeSI, 2015); and will include energy savings by 6.3billion MWh, and 700,000km saved grid.

Table 8: ICT driven power sector GHGs emissions abatement potential, 2020

ICT-enabled activity	Abatement potential ($GtCO_2e$)
Demand management	0.01
Time of day pricing	0.21
Power load balancing	0.38
Optimisation of grid power	0.33
Incorporation of renewables in electricity generation	0.85
Virtual power plants	0.04
Incorporation of off-grid renewables and storage	0.20
Total	2.02

Source: (GeSI, 2012)

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Buildings Sector

ICT can help to enhance energy efficiency and reduce GHGs emissions in buildings through better design, buildings management and automation, voltage optimisation, and the incorporation of renewable technologies both in residential and commercial buildings. This can be achieved both in existing and in new buildings. SMART 2020 report states that global buildings emissions were estimated at 11.7 $GtCO_2e$ in 2020. However, with ICT-enabled buildings management, these emissions can be minimised by up to 18% (2.0 $GtCO_2e$) by 2030 (GeSI, 2015).

Building management system (BMS) refers to a computerised system designed to manage and operate different types of equipment within a building. These equipment include heaters, lighting equipment, ventilation devices, security devices, coolers, access equipment, fire equipment, air conditioners, and energy production and storage devices. The system is designed to connect to the various subsystems, components, and different sensors available. Data obtained from BMS can then be used to determine the opportunity to improve efficiency (Rawte, 2017).

An example of BMS managed building is the Solaire building in New York, the first green residential home in the USA. The building's energy efficiency is 35% more than the building code requirements, and energy consumption in the building during peak hours is 67% less than other similar-sized buildings. Because of its green qualifications, the building has won several awards, and its operators charge a 10% rental premium (Global e-Sustainability Initiative, 2008).

Other ICT applications to enhance sustainability in buildings include facilitation for booking and tracking shared durable and semi-durable household products. For example, instead of every household owning such products as laundry machines, trailers, and vacuum cleaners, Kramers et al. (2014) recommends that households can pool together to share or subscribe to the services of an operator of such products. Besides, instead of relying on grid electricity for the intelligent operation of buildings, smart grid technology could also be adapted to operate a district heating network which would help to minimise power usage and cut peaks. For example, although district heating heats only about 2% of the U.K., building projects such as the Owen Square community energy project in Bristol utilises intelligent energy storage control and are a perfect demonstration of heating decarbonisation (ICAX, 2018). The project employs an innovative solar district heating network that uses borehole thermal energy storage—it stores heat from summer for use during cold winter months.

Assuming that ICT adoption will hit 30% in developed countries and 20% in developing countries by 2030, it is predicted that smart buildings technology would account for $121 - 969\ MtCO_2e$ emissions reduction in existing buildings by 2030 as shown in *Table 9*; and $46 - 832\ MtCO_2e$ emissions reduction by 2030 in new buildings as shown in *Table 10* (WWF, 2008).

Table 9: GHGs emissions reduction in existing buildings due to ICT-enabled energy efficiency improvement

	2010-2030 ($MtCO_2e$) GHG emissions from legacy buildings	**% ICT-enabled Energy Efficiency gains**	**Potential ICT-enabled GHG emission reductions ($MtCO_2e$)**	**ICT adoption to achieve energy efficiency**	**GHG emission reductions ($MtCO_2e$)**
Pacific OECD	872	5 – 40%	44 – 349	30%	13 – 105
Canada/US	2,880	5 – 40%	144 – 1,152	30%	43 – 346
Europe	1,768	5 – 40%	88 – 707	30%	27 – 212
Transition Economies	1,139	5 – 40%	57 – 456	20%	9 – 68
Latin America	404	5 – 40%	20 – 162	20%	3 – 24

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	2010-2030 ($MtCO_2e$) GHG emissions from legacy buildings	**% ICT-enabled Energy Efficiency gains**	**Potential ICT-enabled GHG emission reductions ($MtCO_2e$)**	**ICT adoption to achieve energy efficiency**	**GHG emission reductions ($MtCO_2e$)**
Africa/Middle East	1,120	5 – 40%	56 – 448	20%	8 – 67
Asia	2,451	5 – 40%	123 – 981	20%	18 - 147
World	10,634		532 – 4,254		121 – 969

Source: (WWF, 2008)

Table 10: GHGs emissions reduction in new buildings due to ICT-enabled energy efficiency improvement

	2010- 2030 ($MtCO_2e$) GHGs emissions	**% ICT-enabled Energy Efficiency gains**	**Potential ICT-enabled GHG emission reductions ($MtCO_2e$)**	**ICT adoption to achieve energy efficiency**	**GHG emission reductions ($MtCO_2e$)**
Pacific OECD	81	5 – 90%	4 – 73	30%	1 – 22
Canada/US	282	5 – 90%	14 – 254	30%	4 – 76
Europe	159	5 – 90%	8 – 143	30%	2 – 43
Transition Economies	232	5 – 90%	12 – 209	20%	2 – 42
Latin America	307	5 – 90%	15 – 276	20%	3 – 55
Africa/Middle East	855	5 – 90%	43 – 769	20%	9 – 154
Asia	2,445	5 – 90%	122 – 2,201	20%	24 – 440
World	4,360		218 – 3,924		46 – 832

Source: (WWF, 2008)

However, ICT-enabled energy efficiency and GHGs emissions reduction are increasing over the years as smart building technology becomes more embraced. For instance, in 2010, global smart buildings technology potential to reduce emissions was estimated to be significantly higher than 2008 WWF estimation, at 1.68 $GtCO_2e$ worth $295 billion of energy and $45.7 billion of carbon costs (Global e-Sustainability Initiative, 2008); this estimate increased to 2.0 $GtCO_2e$ in 2015 (GeSI, 2015).

Manufacturing Sector

Industrial activities contributed up to 23% of global emissions in 2002 and used half of the energy generated globally (Global e-Sustainability Initiative, 2008). As the demand for manufactured products rises, GeSI (2012) predicted that the manufacturing sector emissions would increase to 17.4 $GtCO_2e$ by 2020. Industrial motor systems alone use 65% of total industrial energy, and it was projected that the motor systems were responsible for 7% of global carbon emissions by 2020. However, the use of ICT had the potential to reduce these emissions by 1.3 $GtCO_2e$ by 2020 (GeSI, 2012) and 2.7 $GtCO_2e$ by 2030 (GeSI, 2015) through industrial motor systems automation and optimisation of industrial processes.

The use of ICT to improve data availability, utilisation of resources and energy, and improved manufacturing processes can significantly help the manufacturing industry increase efficiency and reduce GHGs emissions. This is achievable by minimising waste generation, increasing production, reducing the use of toxic chemicals, enabling the use of renewable energy, and improving product quality (WWF, 2008; GeSI, 2012). The application of IT technologies in designing industrial processes and facilities can also help reduce energy utilisation and GHGs emissions. For example, regardless of the load, traditional motor systems are designed to operate at a constant potential, therefore, utilises the most significant share of industrial energy. By operating at a constant speed at varying load capacities, a lot of energy is wasted, and the motors do not perform efficiently. However, ICT can be used to monitor energy utilisation and provide data to business owners; this would enable change of manufacturing systems hence saving on energy utilisation and the associated costs (Global e-Sustainability Initiative, 2008; GeSI, 2012).

For example, in China, where the main economic activity is manufacturing, industrial motor systems are 20% less efficient than systems used in western countries. It was estimated that the industrial motor systems would be responsible for 34% energy utilisation in the country and 1-2% increase in global carbon emissions by 2020 (Global e-Sustainability Initiative, 2008). To prevent this occurrence, the use of ICT for motor optimisation was aimed to cut China's emissions by $200\ MtCO_2e$ by 2020. This is achievable because variable speed drives are used to manage the incidence of electrical power supply to the motor, which helps to adjust the rotation speed to the desired amount and can cut on energy use by 20-30% (Global e-Sustainability Initiative, 2008).

Additionally, intelligent motor controllers are used to monitor the load state of the motors and regulate the power supply appropriately. This has the potential of improving motor efficiency by 3-5% and prolonging the motor lifespan, hence a reduction in the need for new motors and the associated manufacturing emissions. According to GeSI (2008), ICT can, therefore, enable the manufacturing sector in China to save up to $6.3 billion per year in carbon costs and $12.6 billion per year in electricity costs.

CONCLUSION

In summary, the ICT sector utilises a high amount of global energy and produces a significant amount of e-waste per year. Consequently, the sector is associated with significantly high levels of global carbon emissions and environmental pollution, which is a leading cause of global warming and climate change. However, owing to its distinctive energy efficiency monitoring and maximisation ability, both within the sector and in other sectors, ICT has the potential to save carbon emissions by up to ten times its emissions ($12\ GtCO_2e$) by 2030. Therefore, it plays a vital role in enhancing sustainability both in the ICT sector and other sectors, including transport, power, manufacturing, and buildings.

Apart from contributing to environmental sustainability, the adoption of ICT in other sectors has also proven to provide other socio-economic benefits such as cost-saving, time-saving, and saving on the workspace. Therefore, despite being associated with carbon emissions and energy utilisation which accelerate environmental pollution, it can be concluded that investing in ICT is essential because its benefits far outweigh the negative impacts. On the other hand, given the wide range of socio-economic and environmental services provided by the use of ICT, individuals, businesses, and organisations have a responsibility to adopt strategies to enhance the sustainability of ICT in different sectors. Such strategies identified in this article include sustainable manufacturing, sustainable procurement, proper use and disposal of ICT products after use, and energy efficiency enhancement in data centres.

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