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Sustainable ICT: Mitigating the Carbon Footprint of the Digital Economy Through Standards

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ABSTRACT: The environmental impact of the information technology revolution over the last 50 years includes a variety of effects to the physical and energy domains, such as water and air pollution. Collateral damage to the environment due to mining, manufacturing, transportation, packaging, and solid waste disposal also contributes to this pollution in indirect ways. An acknowledgement of the impact on climate change from carbon pollution such as carbon dioxide and methane gases also occurred through this time. Meanwhile, society's evolution towards ICT (information communications technology) consumption and use contributed to an increasing use of electricity, much of it generated from burning fossil fuels, leaving a substantial "carbon footprint." Industries and governments have responded to these pollution issues with guidelines, standards, and resulting regulations in attempts to mitigate their effects. In this current time of the climate crisis, these standards are important tools for positive change, and the resulting applications have had and continue to have positive impacts on reducing carbon emissions. This paper explores some of the energy efficiency issues surrounding the ICT industry and some of the prominent standards intended to mitigate carbon emissions in several of the domains in this important initiative.

INTRODUCTION

Over the last 50 years, there has been a slow but steady increase in the amount of digital data created, stored, distributed, and consumed around the world. This era debuted personal computers and building-wide data networks and eventually led to the Internet. This universe of technologies is broadly referred to as ICT: information communications technology. The relative trickle of data in the 1980s is now a data explosion, with ubiquitous digital devices using ever-expanding data throughput as file sizes increase and networks are updated to accommodate them. Cellular phones, tablets, network appliances, and an ever-increasing array of Internet of things (IoT) devices such as smart watches and automobiles each add their share of data appetite, as illustrated in Fig. 1.[1] The shift toward "cloud-based" data further exacerbates data traffic, as people shift data storage and processing away from their devices to "hyperscale" data centers. In addition to building-based connectivity such as local area networks (LANs) and wireless (Wi-Fi) networks, the convenience of smartphones lets us create and consume data everywhere we go. It is understood that the purpose of these devices and networks is to support humanity's

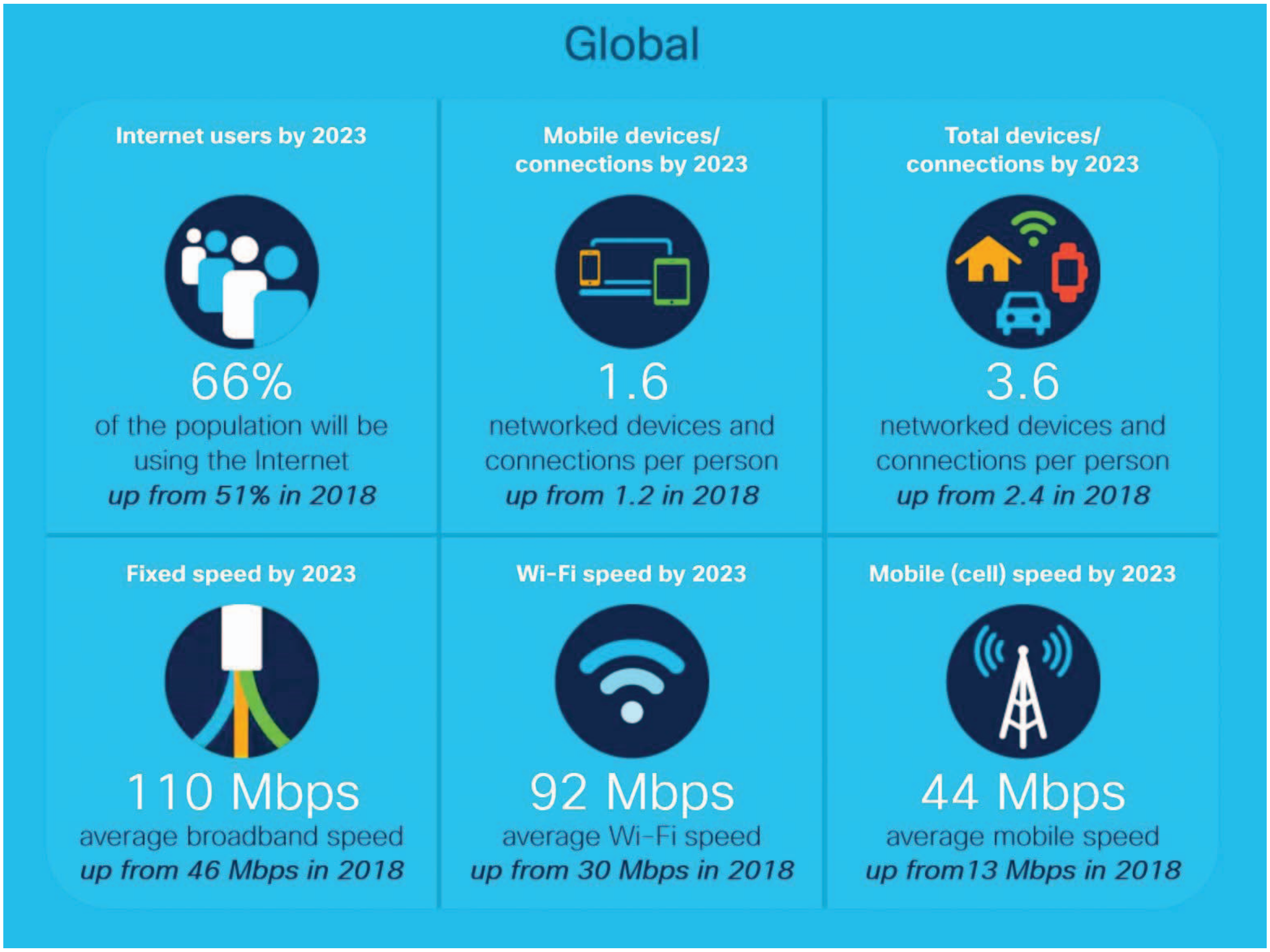

Figure 1. *Cisco Corporation Report: The Future of Digital Transformation.*

advancement: tools that are an extension of the human mind, a means to entertain and educate us, also increase our productivity, organize our complex world, and enhance our physical, social, and spiritual lives.

There have been countless benefits to humanity resulting from the innovation, productivity, and technological extension of society that is digital information, but as with any technology, this has not been without its consequences. These by-products of progress include drawbacks such as pollution and waste in the production of the equipment and enormous energy consumption by the equipment. These issues have become priorities, and industry trade associations and professional societies, comprising myriad volunteers, are addressing them. Association leadership is often composed of seasoned professionals who are "giving back" to their profession by volunteering to share their knowledge, often in the form of standards development. Over the last two decades, this leadership has also striven to contribute to the benefit of society by considering the impacts their profession has on pollution, sustainability, and social responsibility. Conscience and economics are powerful driving forces behind motivating people to transform their industries for the benefit of humanity and the environment and are needed to achieve sustainability goals. The recent corporate emphasis on ESG (environmental, social, and governance) criteria is also a motivator for businesses to contribute to sustainability-related standards development for their industries. This paper explores these issues and the standards behind them.

The Areas of Concern

There are countless factors, trends and technologies that contribute to the carbon footprint of the digital economy. Indeed, data technology is now so woven into nearly every aspect of global activity and society that it would be nearly impossible to account for all of it, (and, ironically, this would require a ridiculously massive database that would have to be updated continuously, supported by data networks). However, we can consider the major uses of these technologies and evaluate how we are doing in mitigating their impact on planet Earth. We are all aware of the big data consumers in our society; here are some of the origins:

- E-commerce
- Governance
- Healthcare
- Internet browsing
- Social media
- Streaming media
- Internet of Things (IoT)
- Cryptocurrency/Blockchain systems
- Mobile devices/Telecommunications
- Video surveillance
- Transportation

The digital economy has expanded and has fostered many benefits to society because of the information technology revolution. Here are some examples:

- Increased productivity and access to information
- Expansion of global commerce
- Social connectedness; experience archiving
- Quality of life: entertainment, personal knowledge expansion
- Reduction in the consumption of paper

Each of these beneficial and useful purposes of the digitalization of society requires hardware, software, connectivity/transport, and storage to operate. Each of these aspects also contributes to the sustainability conversation: What are the impacts on the environment through the life cycle of these products and their use—their "cradle-to-cradle®"[2] lifecycle? These ill side effects of the successes of the digital economy are well-known:

- Electronic waste (E-waste) from the rapid obsolescence of equipment
- Energy consumption, including consumption during idle equipment states
- Pollution from production and hazardous materials (e.g., lithium, arsenic, cobalt, and lead)

These pitfalls of ICT's benefits must be balanced with the side effects—and perhaps there is an argument that the benefits outweigh the harm—but this is impossible to determine. This relationship between benefits and harm is (or should be) a part of every type of technology implementation and, in hindsight, was also impossible to predict in the case of ICT proliferation. There is no clear answer to the question of which way the balance is tipped, and by no means is the story over, as we are certainly still in the infancy of the digital revolution. However, we do know that progress is being made, and the balance is being tipped by one of the fingers on the scale—the standards development community.

Industry Response through Standards Development

The ICT industry is intertwined with nearly every aspect of society and commerce. Along with the benefits and new capabilities ICT brings comes the need for sustainability to buffer its negative impacts. The myriad standards development organizations (SDOs; see Fig. 2) have responded by influencing their stakeholders with countless standards, best practices, guidelines, and other documents. Included with the positive parameters surrounding these industries has been a concern for the sustainability of this technology as a buffer to its widespread negative impacts.

Figure 2. *ICT Standards Development Organizations.*

Each SDO has focused on an aspect germane to its constituents, with a combined positive effect. Broadly, these focus areas center on materials, hardware, software, network infrastructure, facilities, and related industries. Some of the many success stories are reviewed here, with the open question, "Has the adoption of standards led to lower power consumption and pollution than predicted?" Next, we explore some of the main ICT domains and their corresponding carbon mitigation standards.

Figure 3. *ENERGY STAR Computer Certification Benefits.*

Computers

Globally, the number of computing devices has been continuously increasing, and there is no end in sight. Fortunately for the Earth, the power consumption of computers is being buffered by a trend toward smaller, nontraditional desktop systems. Meanwhile, the transition to laptops, tablets, smartphones and dedicated "network appliances" has contributed to a decrease in per-unit power consumption. The computer industry has also responded with market-driven features of greater speed, higher efficiency, and lower power consumption to remain competitive.

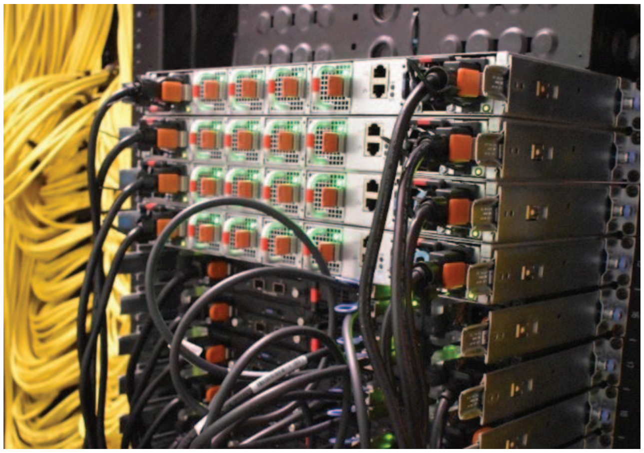

Figure 4. *University of Maryland Iribe Center: Network Electronics.*

This has had the effect of making computers more accessible to a wider population through lower costs, but has driven rapid device proliferation. The net result is an expanding use of power, with resulting carbon emissions.

In response to the ubiquitous use of computers, SDO efforts to control pollution and power consumption have become widespread, and the carbon mitigation potential is very significant (Figure 3).[3] For example, the ENERGY STAR® Specification states that "certified computer product criteria require that computers operate efficiently in multiple modes of operation (such as Off, Sleep, and Idle), utilize efficient power management features, and utilize energy efficient power supplies."[4] With this organization of the concepts around energy conservation through this type of standard, consumers are given a trustworthy understanding of their devices and the role they play.

The very nature of computers has also been rapidly changing. Microprocessors are built into so many different types of products now that the idea of what a computer is has blurred. Many of the most advanced processors are now essential to the operation of automobiles, for example, and as cars become more autonomous using artificial intelligence (AI), this trend will increase and expand to the transportation support infrastructure. This is one example of the Internet of Things, or IoT, whereby computers in devices are also connected to the Internet and rely on "cloud" services to operate. In effect, the energy expended at the device level is complemented by more energy consumption elsewhere: in data centers.

Computer Networks and Data Centers

Early computer systems were based on large, centralized "mainframe" computers accessed by "dumb" terminals with no computing power of their own. There are still examples of this model, but through the years, data became more de-centralized as computing power became affordable and data could be stored and processed locally. Ironically, now we are seeing this trend change again: large "data centers" consisting of "server" computers, arrays of storage devices, and corresponding network equipment are accessed through the Internet by a variety of user devices and machine interfaces. As the landscape outside metro areas became populated with large, windowless data center buildings, attention was drawn to this new phenomenon and the extensive power required to operate them. "US data centers consumed about 70 billion kilowatt-hours of electricity in 2014, the most recent year examined, representing 2 percent of the country's total energy consumption. That's equivalent to the amount consumed by about 6.4 million average American homes that year. Data center electricity consumption is projected to increase to roughly 140 billion kilowatt-hours annually by 2020, the equivalent annual output of 50 power plants (500 megawatt), costing American businesses $13 billion annually in electricity bills and emitting nearly 100 million metric tons of carbon pollution per year."[5] The real power consumption and corresponding use of fossil-fuel based electricity have shifted to these data "farms." Indeed, a special name has been coined for the largest of them: "Hyperscale Data Centers."

Figure 5. *U.S. Library of Congress National Audio Visual Conservation Center: Data Center.*

When we refer to "the cloud," we are referring to these relatively new modern marvels. "'Hyperscale data centres emerged about a decade ago when companies such as Amazon and Google began to need fleets of a quarter of a million servers or more,' says Bill Carter, chief technical officer at the Open Compute Project. 'It was started by Facebook in 2011 to share hardware and software solutions to make computing more energy efficient. At that point, it made no sense to use off-the-shelf hardware from a computing firm, as companies had typically done.'"[6] In many ways, this new paradigm has the potential to be more efficient than "on-premises" data centers in schools and corporations, for a variety of market-driven technical innovation reasons. Interestingly, just as this hyper model was maturing and becoming available from a range of large service providers, it became essential during the pandemic, as business transportation decreased, replaced by higher ICT utilization for functions like web conferencing.

Hyperscale data centers take advantage of specialized components and distribution techniques, and there are now standards advising many of the energy consumption/carbon emissions aspects of their operations:

- Optimized data transport[7]
- Minimum data center energy efficiency[8]
- Network switches: high port densities
- Data center infrastructure, lighting, architecture[9]
- Liquid cooling
- Efficient data center operating systems software
- Low voltage power distribution
- Air-side cooling opportunities in appropriate data center Locales
- Low power idle (lpi) requests
- Cable length detection and power adjustment
- Cable routing/airflow design
- Full-mesh networks
- Subsystem management and interaction
- Low consumption standby power network interface cards (NICs)

As data centers have become such large consumers of energy, mainly from fossil-fuel-based electricity, there has been a widespread industry initiative to migrate toward renewable energy. This trend holds the potential for some of the greatest mitigating factors for the digital economy's carbon emissions, and a standard is available to advise on how to allocate these clean resources. "The Open Standard for Data Center Availability (OSDA) promises to modernize data center availability classification and rating, similar to how PUE (Power Usage Effectiveness)[10] modernized data center power usage. This new approach, which will be applicable to new designs and retrofits, will allow for data center designers and operators to increase resource efficiency and sustainability by integrating renewable energy sources into the overall availability considerations. Data centers will be enabled to access innovations and dynamically changing designs and power sources in the area of renewables. OSDA promises to be more inclusive, non-proprietary, flexible, and a means of fostering industry collaboration and innovation. The development of a companion tool will enable owners/operators to put the OSDA recommendations into practice and provide the ability to assess availability and reliability of their data centers."[11]

After some criticism of their extensive energy use, some data center operators have committed to 100% renewable energy, and these guidelines are proving to be effective in driving down digital economy carbon emissions. One prominent company is showing leadership in this area: "Amazon Web Services (AWS) is focused on efficiency and continuous innovation across our global infrastructure, as we continue on our path to powering our operations with 100% renewable energy by 2025."[12] The journal *Mission Critical* summarizes these trends, referring to some of the technical metrics in this arena: "Data center power and cooling efficiencies have improved significantly and made substantial progress since TGG (The Green Grid) first introduced PUE (Power Usage Effectiveness). PUEs have dropped down to 1.1 for some hyperscalers and range from 1.3 to 1.5 for many new colocation facilities. However, IT power demands have increased massively since 2007."[13] This is another good/bad news scenario for the global warming mitigation journey, but the standardization efforts to contain this enormous aspect of the economy are commendable, making this mitigation effort more important than ever.

Software and Applications

Unseen and underappreciated, software/code plays an enormous role in the energy usage of the digital economy. Every line of code that is executed uses a miniscule amount of processing power, which in turn uses energy. The energy efficiency of ICT is usually defined as the number of bits that can be sent over a unit of power consumption, which is usually quantified by "bits per Joule." This adds up to a significant amount of energy and corresponding carbon emissions in total, leading to the importance of the efficiency of code. In the earliest days of computer code, resources such as RAM (random access memory) and floating point operations per second (FLOPS) were limited, and software developers were pressed to be creative in minimizing code instructions. As technology advanced and software features and capabilities expanded, it was not as critical to be as efficient in code writing, although this has always been a personal challenge for code writers. Standards developers have addressed this aspect of energy efficiency in computer operations. One such example is from ISO/IEC: Systems and software Quality Requirements and Evaluation (SQuaRE): "The characteristics … are relevant to all software products and computer systems. The characteristics and sub characteristics provide consistent terminology for specifying, measuring and evaluating system and software product quality. They also provide a set of quality characteristics against which stated quality requirements can be compared for completeness." [14] This includes guidelines for efficient code: "A set of attributes that bear on the relationship between the level of performance of the software and the amount of resources used, under stated conditions." Software programmers have standardized guidance for time behavior, resource utilization, and efficiency compliance.

There has been recent media attention to one of the newest types of code and its power carbon footprint: blockchain. In particular, the use of blockchain technology for cryptocurrency (crypto) and non-fungible tokens (NFTs) has expanded tremendously, as has the resulting power consumption. Blockchain uses a multitude of distributed computer systems throughout the world to authenticate data in its ledgers, but the biggest headlines have been about Bitcoin. Bitcoin relies on additional computing power to "mine" coins and uses a computation-intensive schema known as Proof of Work (PoW). There is now a trend toward reducing crypto energy use, for example with the major competing crypto Ethereum, which is migrating toward the Proof-of-Stake (PoS) schema. The power consumption of Bitcoin must be balanced with its promising alternative currency advantages, acknowledging that Bitcoin miners have been locating data centers in colder climes, using renewable energy such as hydropower and solar.

Regardless of its benefits, crypto's power consumption is extensive: "The process of creating Bitcoin to spend or trade consumes around 91 terawatt-hours of electricity annually, more than is used by Finland, a nation of about 5.5 million … Could the way Bitcoin works be rewritten to use less energy? Some other minor cryptocurrencies have promoted an alternate bookkeeping system, where processing transactions is won [sic] not through computational labor but by proving ownership of enough coins. This would be more efficient. But it hasn't been proven at scale, and isn't likely to take hold with Bitcoin because, among other reasons, Bitcoin stakeholders have a powerful financial incentive not to change, since they've already invested so much in mining."[15] Not surprisingly, SDOs are taking action in mitigating crypto's negative effects, with standardization initiatives such as the IEEE's "General Requirements for Cryptocurrency Exchanges."[16] Interestingly, this standard includes a rare subjective advisement for its users: "Self-discipline and professional ethics of cryptocurrency exchange platforms, as well as relevance between them and to cryptocurrency wallets, are covered in this standard."

Product Design, Packaging, and Transportation

In every industry, efficiently designed products that are upgradeable, recyclable, shipped without paper documentation in the smallest recyclable packages, and transported in direct and efficient paths are having an effect on mitigating their carbon footprints. The ICT industry has a particular responsibility in this arena, due to the rapid obsolescence, high content of rare and toxic materials, and high density of metals and petroleum-based plastics. SDOs are having a positive impact in these areas:

- Recyclable, compactable, returnable/reusable products[17]
- Recyclable packaging materials[18]
- Transportation

Transportation is particularly timely as the global supply chain has been in disruption as of this writing, and much of the world's ICT equipment components originate in Asia. According to the EPA,[19] "Freight Matters to Supply Chain Sustainability. Global trade has a net positive effect on the world economy. However, associated freight transportation produces adverse impacts on the environment and public health. U.S. trends point to rapid growth in freight activity:

- Between 1990 and 2013, freight activity grew by over 50 percent and is projected to nearly double again by 2040
- Experts project that by 2050, global freight transport emissions will surpass those from passenger vehicles

These trends compel many corporations to seek opportunities to assess and streamline shipping operations so they can use less fuel and generate less pollution."

The EPA has responded with the "SmartWay Transport Partnership (which) seeks to improve the environmental performance of the company's shipping operations. The SmartWay Transport Partnership works with freight carriers, shippers, and other stakeholders in the goods movement industry to reduce fuel consumption, greenhouse gases, and air pollution." There are so many hidden carbon footprints in the silicon sand of the ICT industry, and every one of them threatens ICT sustainability.

Cellular and Wi-Fi Communications

Global cellular telecommunications is an enormous part of the ICT industry and is expanding to meet the needs of a data-hungry world, with a massive expansion of global infrastructure This sector's power consumption affects individual users on a personal level through the battery life of their devices and on a network level through the efficiency of the cellular infrastructure. The global cellular networks are of particular concern, and there is a call for more standardization in their energy efficiency. According to the GSMA (Groupe Speciale Mobile Association): "The current reality is that overall energy usage by the telecoms industry needs to come down as the industry consumes between 2–3% of global energy currently. Many national governments are mandating businesses to adhere to energy reforms (e.g., the EU's 2030 climate and energy framework), with the global goal to reduce greenhouse gas (GHG) emissions since 2014 by 30% in absolute terms by 2020 and 50% by 2030. The telecoms industry is not exempt from these pressures, and the evolution to 5G is an opportunity to deliver a cleaner, greener telecoms footprint—indeed, 3GPP's 5G specification calls for a 90% reduction in energy use."[20] The world has the opportunity to create standards for a more sustainable cellular telecommunications infrastructure as it rolls out 5G and as we approach 11 billion cellular endpoints.

With the expansion of Wi-Fi in buildings and residences, similar energy efficiency efforts are necessary. According to ATIS (the Alliance for Telecommunications Industries Solutions), in reference to one of its efficiency initiatives: "This standard provides guidelines on calculating the Telecommunication Energy Efficiency Ratio (TEER) of a Wi-Fi Access Point. By comparing the TEER reports of multiple products that have the same functional capabilities and meet a common set of requirements, a communications network operator, reseller, or end user can select the equipment that best meets their energy efficiency targets."[21] This attention to another invisible technology that we take for granted is a welcome step in mitigating the carbon footprint of ICT.

ICT Peripherals and Systems

The carbon footprint of the ICT industry reaches far beyond computers and their networks. There are countless peripheral devices that also have an enormous environmental impact, such as audiovisual equipment, printers, and the emerging devices that make up the Internet of things. These "appliances" are the "endpoints" of ICT and its data: sensing, entering, viewing, printing, collaborating, and automating. Nearly every day there are product introductions of networked equipment, in building automation, lighting, security, entertainment, and industry-specific areas such as healthcare, automotive, and others. These devices fall under the broad categories of wireless sensor networks (WSN), the Internet of things (IoT) and cyberphysical systems (CPS) applications. SDOs are actively addressing the carbon footprints of their industries through product and system standards, with these examples from the ICT electronics industries:

- A/V product energy efficiency[22]
- Audiovisual systems energy management[23]
- Operational efficiency of information technology servers[24]

ICT Issues in Buildings

Every building today includes ICT in many forms to serve the occupants' activities, and to run the building itself. One timely ICT application is building automation, which relies on networked devices to operate many systems in buildings. In addition, networks are a part of buildings, and buildings are a leading contributor to carbon emissions. According to the non-profit organization Architecture 2030, "Buildings generate nearly 40% of annual global CO2 emissions. Of those total emissions, building operations are responsible for 28% annually, while building materials and construction (typically referred to as embodied carbon) are responsible for an additional 11% annually."[25] Architecture 2030 issued the "2030 Challenge," which was adopted by the American Institute of Architects in 2006 and forms the basis of the AIA's 2030 Commitment."[26] The "right-sizing" of

ICT infrastructure of components, and the contributions of ICT to sustainable buildings, contribute to the sustainability of the world's building stock. [SH39][JB40]ICT Carbon mitigation falls into two broad categories in buildings: building systems and network infrastructure. These aspects are being advised by a variety of important standards, such as the following:

- Intelligent buildings ICT design and implementation[27]
- Sustainable information communications technology[28]
- Smart building systems[29]
- Building automation: unified automation for buildings[30]
- Power over ethernet (PoE) lighting systems[31]

Conclusions

The world has been transformed by ICT, and the future holds an ever-increasing expansion of this technology into every aspect of our lives. Every email and text we send, movie we watch, status we check, call we make, document we produce, and photo we post on social media is a type of data that is created, transported, stored, and distributed by myriad devices that use electricity. Until the world has shifted to renewable energy generation, all these activities contribute to humanity's collective carbon footprint. The global relationships between relevant issues, their industries, and their societal goals—and the standards developed to organize and provide guidance through these issues—are at work in this arena. There are positive impacts of ICT standardization toward sustainable goals, but there is much more work to be done. The standards development community understands this responsibility and is working to meet this existential challenge.

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