7 ICT and Sustainability

7.1 Introduction

Sustainability is the capacity to endure, and it is oft-quoted as a part of the concept of sustainable development. Sustainability embodies "stewardship" and "design with nature". The most popular definition can be traced to a 1987 UN conference. It defined sustainable developments as those that "meet present needs without compromising the ability of future generations to meet their needs". [1]

Over the years, this definition has evolved and many others have surfaced. However, it has been commonly accepted that the main components of sustainability consist of improving economic efficiency, protecting and restoring ecological systems, and enhancing the well-being of all people. The International Union for Conservation of Nature (IUCN) illustrated the relationships between these three components of sustainability using overlapping circles (Figure 1) to demonstrate that the three objectives are not mutually exclusive but can be mutually reinforcing[2].

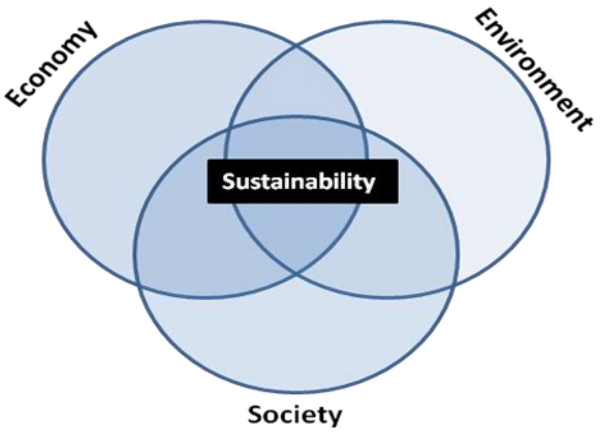

Figure 1: Relationships between the three components of sustainability[2]

Today, many nations have put in place policies to tackle the challenges brought about by practising sustainability. The challenges are often about balancing the need to grow economies while at the same time ensuring that resources are not depleted for future generations.

There are also numerous international protocols and conventions on sustainable development, such the Kyoto Protocol and the Copenhagen Accord, where nations come together to agree on meeting goals related to cutting carbon emissions and establish mechanisms to accelerate technology transfer to tackle climate change.

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[1] United Nations. Our Common Future, From One Earth to One World. [Online] Available from: http://www.un-documents.net/ocf-ov.htm#1.2 [Accessed 9th July 2012].

[2] IUCN. The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century. [Online] Available from: http://cmsdata.iucn.org/downloads/iucn_future_of_sustanability.pdf [Accessed 9th July 2012].

Singapore published its own Sustainable Development Blueprint[3] in April 2009. The blueprint outlined strategies and initiatives that will guide Singapore to achieve a higher level of environmental sustainability. The Blueprint also established clear goals to measure the performance from programmes, highlighting three key challenges that Singapore will face to ensure sustainable development:

- *Managing the Demands of a Growing City* - The growth of our city will put more pressure on our limited land, water and energy resources. Our city will also have to be more densely built as our economy grows and our population expands. It will be challenging to ensure that economic growth does not come at a high environmental price: depriving us of the clean air, water and land we have worked for over the years.

- *Adapting to Growing Resource Constraints* - As cities across the world grow, the global demand for, and cost of, energy, food, and construction materials will also rise. As a resource-scarce country, Singapore needs to use non-renewable resources like oil and gas more efficiently if we want to remain competitive and keep up economic growth. Even with renewable resources, such as water, we need to use them wisely and ensure that there will be sufficient supply for future generations. For Singapore, sustainable development means learning to achieve more with less.

- *Mitigating Climate Change* - Climate change and global warming have a significant impact on water, ecosystems, food, costal zones and human health. To secure our collective long-term future, we need decisive action from all countries, including Singapore, to reduce the emission of greenhouse gases and fight climate change.

For our society to be more sustainable, we have to transform the way we produce and consume, and the ways in which we define and measure value and progress. It is a huge challenge that calls for social, political, technological and behavioural transition to a more environmentally conscious national mentality so that we know how to:

- Reshape our cities for sustainable urban living and enhance our quality of life;
- Drive efficient use of energy and integration of renewable sources;
- Improve transportation systems that allow us to travel more seamlessly without causing too much congestion and pollution.

7.2 ICT For Sustainable Development

The use of ICT has profound effects on society and its production capacity. In Singapore, the use of ICT is pervasive in all sectors of the economy and the ICT sector alone is worth S$83 billion in 2011[4]. The government proactively promotes the use of ICT to improve efficiency and has invested heavily in building ICT infrastructure that. By 2015, Singapore will have an all-fibre network, the Next Gen Nationwide Broadband Network (NBN) that will deliver ultra-

[3] Ministry of the Environment and Water Resources, Government of Singapore. About the Sustainable Blueprint. [Online] Available from: http://app.mewr.gov.sg/web/Contents/ContentsSSS.aspx?ContId=1034 [Accessed 9th July 2012].

[4] Infocomm Development Authority of Singapore. Infocomm Statistics. [Online] Available from: http://www.ida.gov.sg/Annual%20Report/2010/subpages/infocomm_stats/infocomm_industry.html [Accessed 9th July 2012].

high broadband access speeds of 1 Gbps and more throughout the nation. The infrastructure and other ICT developments will place Singapore in a better position to tackle the challenges of sustainable developments.

According to a report from OECD[5], there are three main types of environment effects caused by ICT:

- First order impact – direct environment effects of the production and use of ICTs, such as resource usage, electricity consumptions and electronic (e-)waste disposal.

- Second order impact – the indirect environment impact related to the effects of ICTs on the structure of the economy, production processes, products and distribution systems. Examples are dematerialisation (substitution of tangible goods using digital goods) and 'demobilisation' (substitution of travel with "telecommuting").

- Third order impact – indirect effects on the environment through the stimulation of more consumption and higher economic growth by ICTs, and through impacts on life styles and value systems.

The following table (Table 1) elaborates on these effects:

	Positive Impacts	Negative Impacts
First order effects	environmental ICT applications e.g. *environmental monitoring, smart grid systems*	environmental impact on the production and use of ICTs e.g. *energy consumption by data centres hosting ICT applications*
Second order effects	Dematerialization *e.g. e-books and digital downloads to replace traditional physical goods*	Higher environmental burdens from new digital devices *e.g. e-book readers, mp3 players and the associated end-of-life cost of the devices (such as battery disposal)*
Third order effects	lifestyle changes e.g. green consumerism	"Rebound Effect", i.e. efficiency gained is outweighed by increases in consumption. e.g. using an energy-efficient mobile longer and charging it more frequently

Table 1: ICT impacts on the environment[5]

With regard to environmental impact, it is estimated that the global ICT sector currently produces around 2% of the world's greenhouse gas emissions[6], roughly equivalent to that of the aviation sector. According to the World Summit on the Information Society, the energy demand of the ICT sector is between 5 and 10% of the world's total energy demand. With the proliferation of ICT usage, electricity demand is expected to double to 10-20% by 2020[7]. Such demand comes from the extensive utilisation of ICT end-user devices, telecommunication networks, and the data centre facilities hosting servers and data storage devices (Figure 2).

[5] Frans Berkhout, Julia Hertin. Impacts of Information and Communication Technologies on Environmental Sustainability: Speculations and Evidence: Report to the OECD. [Online] Available from: http://www.ictliteracy.info/rf.pdf/OECD-ICT-EnvrnmtImpct.pdf [Accessed 9th July 2012].

[6] Gartner Press Release. Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO2 Emissions – 26 April 2007 [Online] Available from: http://www.gartner.com/it/page.jsp?id=503867 [Accessed 9th July 2012].

[7] United Nations. The 2005 World Summit. [Online] Available from: http://www.un.org/summit2005/ [Accessed 9th July 2012].

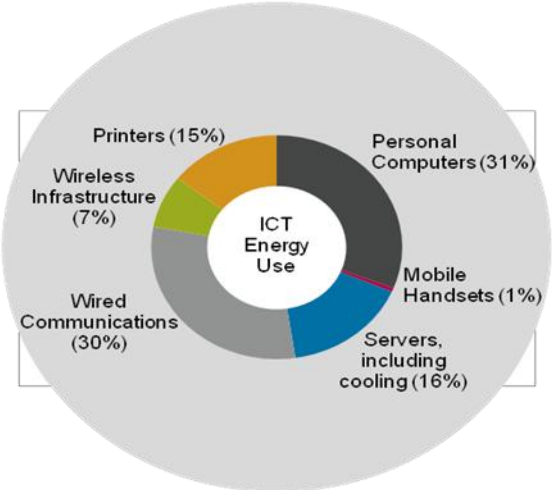

Figure 2: Energy Consumption by ICT Sector[8]

The frequent replacement of ICT devices, falling prices and rapid obsolescence have resulted in a fast-growing surplus of e-waste around the world. The global e-waste is estimated to be 53 million tonnes in 2012[9]; only 13% of this waste is reported to be recycled with adequate safety procedures[10].

There is a need for the ICT sector to drive energy and resource efficiency in its products and services to reduce the direct impact of ICT on the environment in areas such as material usage, manufacturing processes, supply chain transportation, product usage efficiency and end-of-life considerations.

E-stewardship, which is the responsible use and management of our e-resources and their disposal, is something the ICT industry should consider in the next wave of mass consumption of e-products and handheld devices. Some degree of urban mining, i.e. recycling of valuable metals and minerals from huge stockpiles of used electronics like cellphones and computers, could be practised more widely.

Despite the direct environmental impact from the usage of ICT, there exist larger opportunities for the ICT sector to help other industries to become even more efficient in resource/energy use and thus reduce operating costs. ICT plays three important roles that will contribute to overall sustainability.

7.2.1 Enabling Role of ICT

ICT enables new ways to deliver environmentally efficient business models, working practices and lifestyles. The shift towards electronic delivery of services holds out the prospect of both

[8] Gartner Says Data Centres Account for 23 Per Cent of Global ICT CO2 Emissions. [Online]. Available from: http://www.gartner.com/it/page.jsp?id=530912 [Accessed 9th July 2012]

[9] Satish Sinha. Sustainable E-Waste Management. [Online] Available from: http://www.toxicslink.org/art-view.php?id=134 [Accessed 9th July 2012].

[10] Electronics Takeback Coalition. Facts and Figures on E-Waste and Recycling. [Online] Available from: http://www.electronicstakeback.com/wp-content/uploads/Facts_and_Figures [Accessed 9th July 2012].

people and things moving less. Activities and transactions conducted by "moving bits rather than molecules" occupy less road space and consume fewer resources[11].

For example, Telehealth, the delivery of health-related services and information using ICT technologies, can enable society to better manage healthcare records and resources by allowing healthcare providers to remotely manage patients and to ensure that support can be provided as early as needed. At the same time, Telehealth can enable patients and healthcare providers to prioritise visits and manage their case loads more effectively. Telehealth also has the added benefits of educating and empowering patients. It puts the control of health and quality of life in the hands of the patients and their caregivers.

The Next Gen NBN, cloud computing and virtualisation technologies can provide a platform to catalyse development and deployment of innovative solutions that can fundamentally alter the way we live and encourage systemic shifts in the way society operates.

7.2.2 Quantifying Role of ICT

The old management adage, *"You can't manage what you can't measure",* is equally applicable when tackling sustainability challenges. ICT can provide the quantitative basis on which environmentally efficient strategies can be devised, implemented and evaluated.

For example, smart metering uses ICT to quantify utility consumption and provide relevant information to both the utility providers and consumers. The information collected enables consumers to make informed decisions on how they can optimise their consumption and reduce their bills. Providers can eliminate manual meter reading and the real-time data can provide insightful information for load balancing and outage prevention.

7.2.3 Integrating Role of ICT

Our cities are fast transforming into artificial ecosystems of interconnected, interdependent and intelligent digital organisms[12]. ICT can provide new functionalities by integrating these independent, heterogeneous and multi-disciplinary systems to provide a "System of Systems" intelligence where the overall properties will be greater than the sum of its parts. The resulting combined system will be able to address problems which the constituent systems alone would not be able to do and can result in the creation of new "emergent" information sources. Consequently, such information and data will help to better configure the various elements of a system so as to optimise its overall energy performance in a cost-effective manner.

The idea of the "System of Systems" intelligence can be illustrated using the climate control system in a building. The cooling, lighting and electrical systems and their sensors, access control and management systems could be combined to control the climate within a building

[11] Flexibility ICT & Sustainability. [Online] Available from http://www.flexibility.co.uk/issues/sustainability/sustainability.htm [Accessed 9th July 2012]

[12] William J. Mitchell. Smart City 2020. [Online] Available from: http://www.metropolismag.com/story/20060320/smart-city-2020 [Accessed 9th July 2012].

and thereby control its power requirements. This would lead to an overall efficient use of existing systems in a way that would not be possible without the components being combined.

Intelligent applications for transport can enhance capacity utilisation and enable integrated logistics. Warehousing, inventories and transport loads can be minimised/optimised to cut costs, improve efficiencies and reduce environmental impact and congestion.

7.3 OPPORTUNITIES AND RISKS

7.3.1 Opportunities

While there are many challenges posed by the need for sustainable development, there are a multitude of opportunities that can be reaped. The most significant of these opportunities is the advent of the "Green Economy", a new engine of growth for economies around the world.

The Green Economy Report[13] published by United Nations Environment Programme (UNEP) in November 2011, suggested that by investing just **2%** of a nation's GDP into key sectors of the economy (such as transportation, manufacturing, water and waste management), higher growth in GDP compared to a business-as-usual scenario can be produced within five to 10 years. In addition, such an investment can help reduce energy-related CO2 emissions by about one-third of current levels by 2050.

According to the Smart 2020 Report[14] published by The Climate Group and Global E-Sustainability Initiative (GeSI), ICT-enabled energy-efficient solutions represent a massive €600 billion savings opportunity globally. While the increased use of ICT may grow the carbon footprint of the ICT sector from 0.5 $GtCO_2e$ to 1.4 $GtCO_2e$ by 2020, these smart ICT solutions can help to reduce up to 15% of total global emissions – 7.8$GtCO_2e$ or up to 5 times ICT's own footprint (Figure 3).

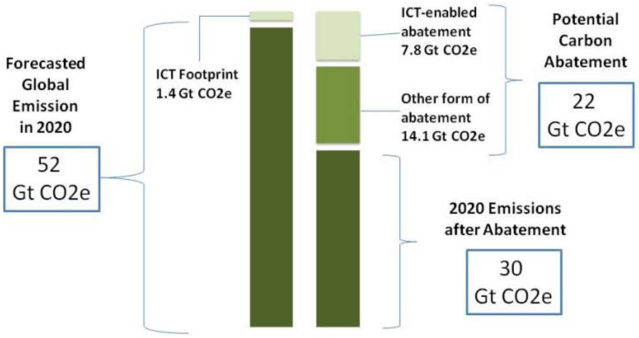

Figure 3: ICT-enabled Energy Efficiency and Carbon Abatement Opportunities

The report highlighted four areas that will have the most accessible opportunities for ICT:

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13 United Nations Environment Programme. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. [Online] Available from: http://www.unep.org/greeneconomy/Portals/88/documents/ger/ger_final_dec_2011/Green%20EconomyReport_Final_Dec2011.pdf [Accessed 9th July 2012].

14 The Climate Group and Global e-Sustainability Initiative. The Smart2020 Report. [Online] Available from: http://www.smart2020.org/ [Accessed 9th July 2012].

- **Smart logistics**: Through a host of efficiencies in transport and storage, the global emissions savings from smart logistics in 2020 would reach 1.52 $GtCO_2e$, with energy savings worth €280 billion.

- **Smart buildings**: In most countries, buildings are the largest driver for both energy use and CO_2 emissions. Globally, smart buildings technologies would enable 1.68 $GtCO_2e$ of emissions savings, worth €216 billion.

- **Smart grids**: Reducing Transmission and Distribution (T&D) losses by 30% is possible through better monitoring and management of electricity grids, first with smart meters and then by integrating more advanced ICTs into the so-called energy Internet. Smart grid technologies could globally reduce 2.03 $GtCO_2e$, worth €79 billion.

- **Dematerialisation:** Dematerialising the way we live and work by replacing physical objects and activities with electronic or 'virtual' alternatives could save 500 Mt CO_2e in 2020 – the equivalent of the total global footprint of the ICT industry in 2002.

7.3.2 Risks

Most technologies are not inherently sustainable and ICT is no exception. Some of the risks associated with the pervasive use of ICT include e-waste, privacy, security, and health-related issues. In the past few decades, ICT products have followed the growth rate predicted in Moore's Law, where performance of the computing power doubled every two years while the price has fallen by half during the same period. Such advancements have resulted in rapid reduction of prices in ICT hardware, making it easily affordable for consumers.

The unintended consequence of such rapid innovation is faster obsolescence of consumer electronics and ICT systems. These could indirectly contribute to an increasing demand for raw materials and an increasing amount of waste.

ICT has helped connect people and businesses. The side effect is that privacy and security may be compromised as large amounts of personal data are collected by ICT applications such as smart grids and telehealth. With the various systems in our society interconnected, new form of ICT crime may emerge. Many countries now see cyber threat as one of the most serious economic and national security threats.

While the net impact of increased efficiency should lead to less resource/energy use and lower levels of emissions, there are concerns that these gains will be negated by increases in overall consumption. These "rebound effects" have been highlighted in the Smart2020 Report

The challenge moving forward is to balance the short-term gains of ICT and usage of ICT with long-term goals of sustainable development. This is a problem facing every industry and nation.

7.4 TECHNOLOGY OUTLOOK

Overview

This section on technology outlook is structured into two segments. The first will look at ICT-enabling sustainability where we will examine the technologies that have and will continue to help achieve sustainable development. These technologies have transformed the way some industries operate and the lifestyle of consumers to make resource consumption more efficient.

The next segment will examine how the ICT sector has and can become even more efficient in the consumption of natural resources and energy. It will examine the progress made in the development and manufacturing of products so as to reduce carbon emissions.

7.4.1 Sustainability through the use of ICT

The ICT sector plays a significant role in creating a low carbon society and enabling sustainability. It has delivered innovative products and services that are integral to everyday life and increased productivity and supported economic growth. According to the SMART 2020 Report, ICT can reduce about 15% of emissions in 2020 based on a Business As Usual (BAU) estimation. In economic terms, ICT-enabled energy efficiency translates into cost savings of approximately €600 billion.

This section will outline the areas (smart grid, smart transport, smart buildings and dematerialisation) where ICT plays an integral part in helping other sectors of the economy achieve significant reductions of carbon emissions and ensuring cost savings.

7.4.1.1 Smart Grids

The world recognises that the current state of energy supply and consumption is unsustainable, from the standpoint of economics and the environment. As such, many nations are turning to smart grids to enable the use of a range of low carbon technologies (renewable resources and electric vehicles), to address growing energy consumption and the stress put on ageing infrastructures.

A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the delivery of electricity from the source of generation to meet the varying needs of the users. Smart grids are used to respond to increased demand and promote energy efficiency, integrate variable energy resources and provide electric vehicle re-charging services. At the same time, smart grids stabilise the electricity system by moderating peak demand.

The International Energy Agency (IEA) projected that peak demand will continue to increase and the deployment of smart grids could reduce projected peak demand between 13% and 24%. Smart grids will provide significant benefits, especially to developing nations where the demand for energy continues to increase.

How ICT can help

At the heart of the smart grid is the integration of advanced ICT solutions into the traditional power distribution infrastructure. This encompasses communication systems to enable real-time, two-way data transfer throughout the network and ICT systems that will enable intelligent routing, power storage, usage, billing and management of security.

Smart grids will enable utilities providers to see how much and where energy is being consumed, and if there are problems in the network. System disturbances that may result in uncontrolled disruption (such as blackouts) can be better contained with real-time data providing insights into electrical demand. Consumers will be able to see how much energy they have consumed and adjust their consumption habits accordingly. Smart meters can also enable new business models, such as real-time pricing where energy can be priced at different rates, depending on the time of day and how much demand there is for the electricity at that point of time. Utilities can use real-time pricing to better manage the loads on the grid while consumers can use the information reduce their monthly energy bills.

Smart Grid Technologies

The technologies for smart grids are wide-ranging and span across the entire grid – from generation, transmission through to distribution. They are also at varying stages of maturity and application. The figure below from an IEA report[15] provides a good overview of the technology areas across the grid.

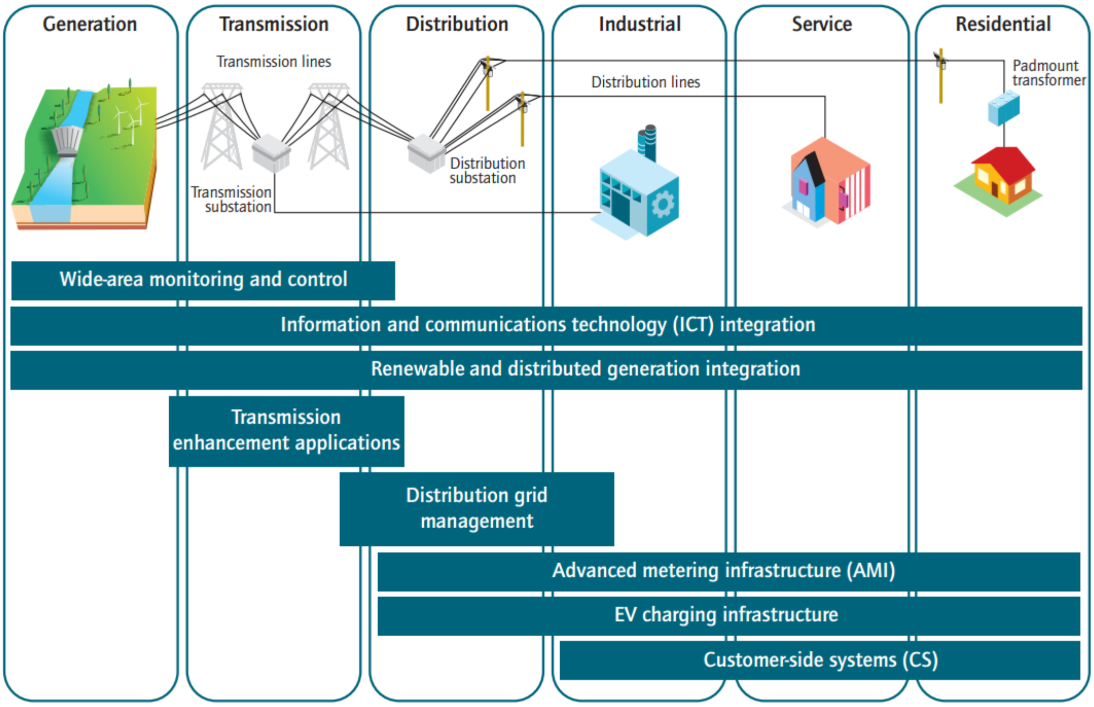

Figure 4: Smart Grid Technology Areas[15]

Wide-area Monitoring and Control

The automation of power systems enables rapid diagnosis of problems and the application of precise solutions to specific grid disruptions or outages. Some of the technologies include distributed intelligent control systems, analytical tools such as software algorithms, and operational applications such as substation automation.

Real-time monitoring and display of power system components and performance across geographical regions help system operators by giving them an overview of the operations of the grids. With an understanding of system performance, operators can optimise the power system components and behaviour. Monitoring and control tools, coupled with advanced system analytics, will bring about better decision making, mitigate large-scale disturbances and improve the transmission capacity and reliability.

Integrated Communications

There are a number of communication options that can be used in smart grid deployment to enhance real-time control, information and data exchanges in the grid. These include:

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15 Technology Roadmap: Smart Grids © OECD/International Energy Agency 2011, Figure 8, Page 17 [Online] Available from www.iea.org/papers/2011/smartgrids_roadmap.pdf [Accessed 9th July 2012].

- Power Line Communication (PLC) – PLC is an attractive option for the grid operators because it makes use of the same infrastructure as their distribution system. Hence, there is no need to run additional wires to connect the different devices in the grid. PLC can also work in environments, e.g. building basements, where radio frequency (RF) cannot reach,. However, PLC has its limitation because the distribution system is consistently affected by voltage transients and harmonics that are hard to predict. This results in higher error rates in the data transmission.
- Fibre Optical Network – Although the bandwidth requirement for smart grid communication is not very high, fiber optics cable has the advantage of being immune to electromagnetic and radio frequency interference. This makes it an ideal communication medium for high voltage power lines. EPB, a publicly owned utility company in Chattanooga, Tennessee, USA, has one of the largest smart grid deployments using fibre optical networks, with over 110,000 smart meters connected via fibre.
- Wireless Network – Wireless connection provides a feasible communication medium without the need for physical connection. Solutions range from licensed band technology, such as cellular networks (2G, 3G, LTE and WiMax) to unlicensed band technology, such as WiFi and Zigbee. The Institute of Electrical and Electronics Engineers (IEEE) recently ratified a new international standard known as Wireless Smart Utility Network (802.15.4G) to address the unique needs of low-cost, low-power wireless sensors and control networks for the large-scale process control market, with a particular focus on the Smart Utility Network. The IEEE community is also looking at a new standard, 802.15.4m, for the use of TV white space spectrum for communication.

Integration of Renewable and Distributed Generation

Today, energy comes from multiple sources and they may be in a wide range of geographical locations. The challenge is how to dispatch and control these distributed sources. Energy storage systems can help with the integration of renewable and distributed energy resources by decoupling the production and delivery of energy. Smart grids can help control the generation and demand to ensure the balancing of supply and demand.

The Virtual Power Plant (VPP) is one of the main functions in smart grids to solve these challenges. VPPs facilitate the aggregation of several hundreds or even thousands of electricity generating units into a single technical unit. Any type of generation and storage sources (e.g. wind, solar, hydro, electric vehicles) can be bundled to form a VPP. Fluctuations of individual components can be balanced out at the system level, thereby providing greater predictability of overall power supply from the VPP.

The main ICT components of a VPP are interconnected control and management devices, as well as an integrated software management system to control the power supply of individual units to the grid in real time.

In a European Commission-funded pilot project, FENIX, a VPP was developed around the city of Alava, Spain, by Iberdrola and the Spanish grid operator Red Eléctrica de España.

Transmission Enhancement Applications

Numerous applications in the transmission system are used to enhance the controllability of transmission networks, improve efficiency and reduce further investments.

For example, High Voltage DC (HVDC) technologies are used to connect distant energy sources such offshore wind and solar farms to densely populated areas, and contol system losses for the more efficient use of energy. Dynamic line rating (DLR) which uses sensors to identify the current-carrying capacity of networks can optimise the utilisation rate of transmission assets. High speed sensors, called Phasor Measurement Units (PMUs), are often distributed throughout the electrical grid to monitor power quality and respond to them automatically.

Distributed Grid Management

Advanced distribution automation can greatly reduce outage, improve repair time and maintain voltage level. Real-time information from sensors and meters can help spot fault location and allow operators to react by reconfiguring the systems to optimise the grids. The most basic Distributed Grid Management consists of the supervisory control and data acquisition (SCADA) functionality and distribution operations management.

Advanced Metering Infrastructure

Smart meters are being deployed to record usage in real time and provide a communication path extending from the generation plants to the electrical outlets of customers. The advanced metering infrastructure has a wide range of functionalities including remote price signalling for consumers, the ability to collect, store and report on energy consumption patterns, and the management of cash and debt collection. The use of meter data management systems is fairly prevalent today.

Electric Vehicle Charging Infrastructure

The use of electric vehicles is on the rise and many cities are building charging infrastructures to handle the scheduling, charging and billing of grid-to-vehicle charging (G2V) and vehicle-to-grid (V2G) discharging during periods of low energy demand.

The role of ICT in this area focuses on managing the flow of information between the grid operators and electric vehicles. During periods of high electricity demand, ICT systems can communicate with vehicles to search for vehicles that are willing to “sell” excess electricity from their batteries back to the grid (V2G). During periods of high electricity supply (e.g. when solar energy is available), ICT systems can communicate with vehicles to let them charge their batteries at a lower cost. Such communication needs to be secured so that the integrity of the information can be guaranteed.

Customer-side Systems

Customer-side systems are used to help manage the consumption of electricity at all levels. These systems typically include energy management systems, storage devices and smart appliances. Customers can be encouraged, through rate programs and incentives, to moderate their consumption of energy (and demand). Using these systems can accelerate peak demand reduction and gains from energy efficiency. These systems also empower the users by providing them the appliances/thermostats to control usage.

Trends

Smart grids are continually evolving and some trends[16] to watch include the following:

Smart meters are shifting from deployment to applications
Pike Research estimates show that some 200 million smart meters have been deployed across the globe. Smart meters have reached critical mass and it is time for new meters to start delivering on the promise of helping consumers reduce consumption and spending on energy. However, the expectation is that this shift from deployment to applications will take longer as utilities have yet to learn to manage and mine the data provided by smart meters..

"Architecture" will be the new buzzword
Major smart meter makers have launched more open and flexible metering platforms and solutions designed to meet IP-based advanced metering infrastructure standards. Increasingly, we will see enterprise architecture process and techniques enhanced with some measure of externally managed services such as cloud computing.

Cyber security failure risks will be inevitable
This calls for new cyber security products and services targeted at smart grids. However the lack of standards may slow down the pace of development in this area and put smart grids at the risk of cyber attacks.

Cyber security will continue to be an important focus
Security is a priority and Pike Research estimates that utilities will invest US$14 billion between 2011 and 2018 in cyber security solutions to secure their infrastructure. Security vendors will shift their focus from IT security functions to industrial control systems security to better secure transmission systems, substation automation and distribution automation.

End-to-end smart grids will become a reality
The industry will be transformed by smart grid technologies and in the not too distant future, end-to-end smart grids will become a reality.

Distributed diversity
Every part of the value chain from generation, delivery to end use will be more diverse and distributed. Instead of generation from centralised plants, we will see co-generation, distributed generation and distributed renewables. The delivery infrastructure will also be

[16] Navigant Consulting, Inc. Smart Grid: Ten 10 Trends to Watch in 2012 and beyond. [Online] Available from: http://www.pikeresearch.com/research/smart-grid-ten-trends-to-watch-in-2012-and-beyond [Accessed 9th July 2012].

transformed as distribution must be upgraded to handle challenging uses such as server farms and electric vehicles.

Challenges and Opportunities

Smart grid technologies must be deployed in both existing systems and within new systems. The existing systems are typically legacy systems that may have been around in the past four decades. The deployment of smart grid technologies must be done in a non-intrusive manner so as not to disrupt the daily operations of the electricity systems.

In certain parts of the world, there are significant impediments to the adoption of smart grid technologies. These include regulatory environments, concerns over consumer privacy, social concerns over "fair" availability of electricity, and the limited ability of utilities to rapidly transform their business and operations environments to take advantage of smart grid technologies.

These challenges, however, do not detract from the opportunities and significant benefits gained from developing and deploying smart grids.

In 2009, the US smart grid industry was valued at about US$21 billion. By 2014, this figure will exceed US$42.8 billion. At the same time, the global market is expected to grow from US$69.3 billion in 2009 to over US$170 billion in 2014. Makers of smart metering hardware and of software used to transmit and organise data collected from meters are expected to profit the most from this growth.

Developing countries and emerging economies will benefit from the growth of smart grids. With rapid economic growth, increasingly dense urban populations and dispersed rural populations will need smart grid technologies to meet the challenges of development. In the more developed parts of the world, smart grid technologies will be in greater demand as nations place emphasis on ensuring sustainability in the use of resources.

In Singapore, the Energy Market Authority (EMA) launched a pilot project, the "Intelligent Energy System" (IES) in November 2009 with the aim of testing a range of smart grid technologies to enhance the capabilities of Singapore's power grid infrastructure. Specifically, the IES pilot project seeks to develop and test the following components of a smart grid:

- Advanced Metering and Communications Infrastructure
- Demand Response Management Systems
- Management Systems for Distributed Energy Sources

Other test-beds in Singapore include the Experimental Power Grid Centre (EPGC) on Jurong Island and the intelligent micro-grid on Pulau Ubin.

7.4.1.2 Intelligent Transport Systems (ITS)

The transport sector accounts for nearly 25% of global energy-related carbon emissions[17]. This figure is set to grow as the world sees rapid economic and population growth in robust economies such as China and India, fuelling the increase in vehicle ownership.

While the global motor industry tackles the problems of global warming and air pollution by designing resource-efficient, environmentally friendly vehicles, many economies are still struggling with the challenge of congestion which has exacerbated the carbon emission problem.

How ICT can help

While a country can improve its transport infrastructure by building new and better roads, highways and bridges, resources such as land, concrete and steel are finite. The use of ICT in transport management can maximise the capacity of the infrastructure.

Intelligent Transport Systems (ITS), also known as Smart Transport, is a concept that encompasses a range of systems and applications to tackle transportation challenges. ITS can include different modes of transport and traffic management, real-time traveller information, centralised fleet management, road usage charging, smart charging for electric vehicles, and vehicle-to-vehicle systems. According to Pike Research, the global investment in smart transport systems will total US$13.1 billion between 2011 and 2017[18]. Most of this investment will be in intelligent traffic management systems.

ICT enables the elements within the transport system – vehicles, road, traffic controlling equipment (signs and traffic lights) – to become intelligent by embedding sensors and micro-chips in these elements. Using wireless technologies to enable communication between these elements, the performance of the system can be greatly enhanced, reducing congestion and increasing road safety. Better traffic management to ease congestion means that vehicles do not sit in roads and highways, emitting harmful carbon gases.

ICT also enables better management of the public transportation system, making it more reliable as an alternative to vehicle ownership. As people drive less, the consumption of fuel will be reduced which, in turn, will reduce carbon emission.

ITS Technologies

To derive the benefits of ITS, the integration of systems, information and services is essential. The combination of these factors will optimise the flow of transport and reduce wastage of time and energy.

ITS vary in application, from basic management systems such as car navigation and traffic signal control systems to more advanced applications that integrate live data and feedback

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[17] International Energy Agency. Transport, Energy and CO2: Moving toward Sustainability – How the World can achieve deep CO2 reductions in transport by 2050. [Online] Available from: http://www.iea.org/press/pressdetail.asp?PRESS_REL_ID=293 [Accessed 9th July 2012].

[18] Navigant Consulting, Inc. Smart Transportation. [Online] Available from: http://www.pikeresearch.com/research/smart-transportation [Accessed 9th July 2012].

from a number of other sources such as parking guidance and information systems and weather information. Additionally, predictive techniques are being developed to allow advanced modelling and comparison with historical baseline data.

Traffic Message Channel

Traffic Message Channel (TMC) is a technology for delivering real-time traffic and travel information to drivers. It is typically digitally coded, using the Frequency Modulation Radio Data System (FM-RDS) on conventional FM radio broadcasts. It can also be transmitted on Digital Audio Broadcasting (DAB) or satellite radio. It allows silent delivery of dynamic information suitable for reproduction or display in the language chosen by the user and without interrupting normal audio broadcast services. When data is integrated directly into a navigation system, traffic information can be used in the system's route calculation and the driver can have the option to take alternative routes to avoid traffic incidents.

In Singapore, Quantum Inventions offers a traffic data service-based TMC which includes dynamic navigation, routing and traffic information services based on real-time information such as traffic speeds, parking availability, weather conditions and road closures.

Floating Car Data

Floating car data (FCD) refers to the concept of collecting information from vehicles as they go about their normal business through the road network. Localised data such as speed, direction of travel and time information can be collected. This means that every vehicle with an active mobile phone acts as a sensor for the road network. Based on the data, traffic congestion can be identified, travel times can be calculated, and traffic reports can be rapidly generated. In contrast to traffic cameras, number plate recognition systems, and sensor loops embedded in the roadway, no additional hardware on the road network is necessary.

FCD techniques can be very useful in providing an overview of traffic, weather, and road conditions for the entire road network. In addition, given the need for digital maps to be as accurate and up-to-date as possible, vehicles reporting exceptions to their map database can serve an important role in contributing data that supports the creation of real-time map updates.

Data privacy can be a concern with FCD deployment as the data could be used for surveillance purpose. There will be a need to ensure that data is anonymised in such systems, or kept sufficiently secure to prevent abuse.

Sensing Technologies

The combination of advances in telecommunications, improvement in design of microchips, Radio Frequency Identification (RFID) and the relatively inexpensive intelligent beacon technologies have encouraged the adoption of sensing systems in ITS globally.

Many of these systems are either vehicle or infrastructure-based networked systems. Vehicle-sensing systems include the deployment of infrastructure-to-vehicle and vehicle-to-infrastructure electronic beacons for identification communications. In some cases, video automatic number plate recognition or vehicle magnetic signature detection technologies could be used to increase sustained monitoring of vehicles operating in critical zones.

The infrastructure-based networked systems include the use of sensors such as in-road reflectors devices that are installed or embedded in or surrounding the road (on buildings, posts, and signs) and may be manually disseminated during preventive road construction maintenance or by sensor injection machinery for rapid deployment.

Wireless Transmission

Wireless communications technologies are extensively used in intelligent systems. For longer-range communications, infrastructure networks such as WiMAX and GSM (3G and LTE) are often used.

For shorter range communication needs, Dedicated Short Range Communications (DSRC) provides two-way wireless communications between the vehicle and the roadside equipment up to a range of 1,000 meters. Many ITS such as vehicle-to-vehicle communication, electronic toll collection and electronic road pricing are enabled by DSRC.

IEEE 802.11p is an approved amendment to the IEEE 802.11 standard to add wireless access in vehicular environments (WAVE). It defines enhancements to 802.11 required to support ITS applications. This include data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz). IEEE 1609 is a higher layer standard on which IEEE 802.11p is based.

Another emerging area of technology known as Visible Light Communications (VLC, IEEE 802.15.7), which uses the rapid flickering of advanced light-emitting diodes (LEDs) to encode data, could open up new and exciting possibilities in the way we send and receive information in ITS applications. One promising application is in car-to-car communication. If the headlights on a car could communicate with the tail lights of the car ahead, VLC collision-avoidance technology would be hugely significant in the automotive industry. In the same way, traffic lights could send detailed information of congestion up ahead directly to a vehicle.

One of the standards promoted by the International Organisation for Standardization (ISO) is CALM (ISO 24102:2010). It stands for stands for “continuous air interface for long and medium-range communications”. This family of standards specifies a common architecture, protocols and interfaces for wired and wireless vehicle infrastructure communications. It was designed for robustness and reliable performance in the extremely dynamic traffic management environment, an environment where many actors are all moving simultaneously, and where even the traffic light timing is constantly and unpredictably changing as it adapts to the current vehicle flows. CALM’s job is to maintain a continuous connection to a vehicle by managing access to a wide range of standard technologies like GSM, UMTS, satellite, infra-red, 5Ghz micro-wave and mobile wireless broadband like Wi-Fi and WiMAX.

Geographic Information Systems (GIS)

GIS specialises in the input, management, analysis and reporting of geographical or spatially related information. The use of GIS is fairly wide-ranging in the area of transportation –

infrastructure planning and management, travel demand analysis, routing and scheduling, vehicle tracking and dispatching, etc.

With the pervasiveness of Internet and wireless communications, there has been a growing number of Internet-based and wireless GIS applications. Mobile versions of maps such as those of Google and MapQuest are frequently used to get driving directions. Global positioning systems (GPS) are also commonly available as portable or built-in devices in vehicles. These devices, when used with wireless communications, can offer real-time traffic information and provide location-based services.

Autonomous Car

An autonomous car, also known as the driverless or self-driving car, is a vehicle that uses artificial intelligence, sensors and GPS coordinates to drive itself without the active intervention of a human operator. Advanced control systems interpret the information to identify appropriate navigation paths, as well as obstacles and relevant signage. For example, for managing lane changes, the algorithm will determine the smoothest route through the surrounding roads by combining information on trajectory, speed and the safest distance from obstacles.

Nevada, USA, is the first in the world with a jurisdiction where autonomous vehicles can be legally operated on public roads. The bill was signed into law by Nevada's Governor on 16 June 2011. Nevada awarded the first license for a self-driven car to a Toyota Prius modified with Google's experimental driver-less technology. As of May 2012, the Google driver-less car has driven 175,000 miles (282,000 km).

Trends

Some of the key trends in the development of ITS are briefly outlined in this section:

a. Growing interest in Connected Vehicles
According to ABI Research[19], the installed base of embedded and hybrid connected car systems is expected to grow from 45 million at the end of 2011 to 210 million by 2016. Many different fkinds of connected car implementations contribute to this trend, e.g. fully embedded OEM systems (such as GM's Onstar and BMW's Connected Drive); embedded aftermarket solutions for vehicle tracking, road user charging and insurance; factory-installed hybrid systems such as Ford SYNC Hybrid aftermarket solutions from Pioneer and Kenwood, offering Pandora Internet radio via smartphone integration We can expect to see more car companies partnering with Internet software companies to provide innovative technical advances at the touch of a button on a steering wheel.

b. Role of Social Networking
Mobile devices like smartphones are becoming more pervasive. The wide ranges of new online services for smartphones utilising both cellular phones and GPS data will not only revolutionise the way people communicate and interact, but also how

[19] Allied Business Intelligence, Inc. 210 Million Connected Cars by 2016. [Online] Available from: http://www.abiresearch.com/press/3655-210+Million+Connected+Cars+by+2016 [Accessed 9th July 2012].

individuals receive and disseminate temporal and spatial information. Social networks will transform the traveller information landscape with P2P resource sharing models. The networks are good sources to conduct crowdsourcing; agencies can tap on the wisdom of the crowd for some of their decision making.

c. Big and Open Data
Internet businesses have developed new tools to mine big, structured/unstructured data often in tera and peta-bytes. Mashups are complementing Extract-Transform-Load for business intelligence. Open data will allow agencies to build on the application layer and develop more applications for ITS.

Challenges and Opportunities

ITS implementation faces a range of challenges that may be technical, political or economic in nature, e.g. system integration, system interdependency, network effect, scale and funding .

Many ITS implementations operate at the national level and to be successful, involves adoption by the overall transportation system . Associated challenges include system coordination as there is a set of system interdependencies dealing with legacy systems that have to be managed. The challenge for ICT is to integrate these disparate systems while keeping pace with technology innovation and progress.

Singapore is recognised as one of the few global leaders in ITS deployment. The Land Transport Authority (LTA) has successfully deployed ITS within the transportation network. Some of the components include traffic monitoring and alerts to provide current information on road conditions, using taxis as probes to gather data for traffic management, and operating electronic road pricing (ERP) to influence road usage patterns.

As migration continues into urban areas and citizens become increasingly affluent, more cars will go on the roads, putting more pressure on public transportation systems. ICT solutions can be used to manage demand and help cities achieve sustainability in the development of the transport sector.

7.4.1.3 Smart Buildings

Rapid urbanisation has led to an exponential growth in the number of cities globally. With the emergence of these cities come buildings and mega-skyscrapers. This has in turn led to an increase in energy consumption. Buildings account for over 40% of the world's energy consumption and 20% of total CO2 emissions[20].

To sustain the growth of cities and economies in the face of limited resources (including energy), there is an urgent need to look for ways to reduce energy consumption and carbon emissions.

How ICT can help

We have witnessed the advent of "smart buildings" in the past decade or so. This document will adopt the definition of "smart buildings" used in the SMART 2020 Report. The term "smart buildings" describes a suite of technologies used to make the design, construction and operation of buildings more efficient, and is applicable to both existing and new-build properties.

The vision is to have the multiplicity of sub-systems within a building work in tandem, seamlessly, collectively minimising energy cost and mitigating environmental impact. The challenge is in bringing these technologies together in order to optimise the use of energy so as to achieve sustainability.

The role of ICT in smart buildings is manifold. At the basic level, it enables the monitoring, controlling and automation of systems. Higher order functions allow users to create simulation or modelling, implement interconnectivity and use data/information collected for diagnostics and analytics.

ICT has also transformed the way we work. Collaboration tools and connectivity have enabled telecommuting which, in turn, reduces the need for office space, contributing to energy conservation and environmental preservation.

Smart Building Technologies

New buildings can be designed to be energy-efficient prior to construction but these opportunities are often limited. Hence, the biggest challenge is in converting existing infrastructure to achieve sustainability goals. Besides the option to retrofit existing buildings, which can be disruptive and capital-intensive, ICT solutions can be deployed to better manage energy consumption. The latter option is also more cost-efficient and less disruptive.

Smart building technologies enable the connection of independent sub-systems to facilitate information sharing, thereby optimising the performance of the buildings. Today, some of these technologies such as energy-efficient heating, ventilation and air conditioning (HVAC)

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[20] Siemens Building Technologies, USA. Smart Energy Consumption and the Smart Grid. [Online] Available from: http://www.industry.usa.siemens.com/topics/us/en/cse/engineeringadvantage/Documents/smart-energy-consumption.pdf [Accessed 9th July 2012].

systems and submeters are in the mature state. There are other rapidly developing technologies that will likely offer impactful innovations for the building industry.

Facility Energy Management

Facility energy management involves the use of advanced ICT systems and metering to provide building management with granular and real-time insights into the performance of the facility. With these integrated systems, users can track, report and get alerts in real time. The dashboard views of these systems reveal energy consumption levels, provide data feeds from a wide range of building equipment such as HVAC, lighting and access control. The benefits are wide-ranging. On a basic level, simply providing a window into energy use paints a picture of how the building is operating and using energy. In addition, this will add significant value in corporate decision making even before energy is used.

While the primary focus is on energy management, more vendors are incorporating other building-related data such as water usage into their applications. The trend is heading towards dynamic intervention and automated optimisation.

Intelligent Lighting

Intelligent lighting solutions combine the intelligence of ICT with the application of highly efficient lighting technologies such as LEDs and sensors (time, motion). This combination of applications can help deliver lower running costs and efficient lighting solutions to buildings.

These solutions typically integrate mature technologies (e.g. movement and heat sensors, and daylight compensation) with the latest in disruptive technologies (e.g, high-efficiency white LEDs and advanced software) to adjust the intensity, location and direction of lighting. Many of these solutions provide users with usage data time series for reporting and analysis.

Integrated and Open Building Automation and Control Systems

These are systems that use IP and other open standards to integrate and optimise the management of the wide range of building infrastructure equipment such as power supply, HVAC, lighting, surveillance and access control. Many of these systems allow remote access and distributed control over secure IP networks. Some systems are equipped to handle pre-defined rules and policies set by users and external data feeds.

The data collected from these systems is often based on open and industry standards, and provide visibility and insights into building and building subsystem performance.

Due to the disparate nature of the building infrastructure equipment, the challenge is to integrate through open standards, across multiple vendors, and to ensure the security of systems and data. However, with the ubiquity in the deployment of sensors and network, adoption of this technology is likely to accelerate.

Building Information Modelling (BIM)

BIM is a digital representation of physical and functional characteristics of a facility. It is a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle, defined as existing from earliest conception to demolition[21].

BIM tools and software enable the creation of a virtual information model of a building. This model can then be shared and be used to guide decisions that impact energy efficiency, such as the integration of lighting, access control and HVAC. The model can also help determine building materials and orientation, which may also have an impact on energy consumption.

Today, the integration of the design and construction process of a building is not well developed and different groups (architects, engineers and contractors) operate fairly independently. This does not bode well for the development of smart buildings.

Energy Harvesting Technology

A trend we are seeing in smart buildings today is energy harvesting. The idea behind energy harvesting is that devices such as sensors and light switches within the building are self-powered and do not require batteries. These energy-harvesting devices convert ambient energy into electrical energy to remain self-powered.

When used in building automation systems, these energy-harvesting devices can significantly reduce energy consumption.

Trends

Some key trends are transforming the smart building industry today:

a. Facility Energy Management turns to the cloud
As the volume of data and information from facility energy management systems grows, the industry is turning to the cloud for storage and to tap on the rich offerings of Software as a Service (SaaS). Many are also adopting open platforms so as to allow data from disparate systems to come together for monitoring and analysis. Independent software developers can participate in the building of solutions and the industry can use crowdsourcing for best practices and innovation solutions.

b. Convergence of Building Communication Protocols
ICT is increasingly converging with the facility management systems. The use of ICT-enabled building devices such as sensors and thermostats is becoming pervasive and players in the market offer software suites aimed at interfacing systems based on other protocols with the automation systems on IP networks.

c. Demand Response is Shifting into Automatic
Automatic demand response is starting to emerge to replace the manual process of demand response. This cuts out the middleman and guarantees faster response time.

d. The Line between Smart Buildings and Smart Grids is Blurring

21 National Institute of Building Sciences. National BIM Standard - United States. [Online] Available from: http://www.buildingsmartalliance.org/index.php/nbims/ [Accessed 9th July 2012].

Around the world, grid operators are changing rules and providing market mechanisms that allow and incentivise demand response. To take advantage of these types of programmes, building owners would need sophisticated control systems that allow them to aggregate the demand and adjust usage accordingly. The likelihood is that in future, smart buildings and smart grids will reinforce each other and improve energy efficiency.

Challenges and Opportunities

As cities continue to grow in size and number, there will be greater demand for smart buildings and related technologies. In the Asia Pacific region, particularly in China, the growth figures of the building industry are staggering. According to McKinsey & Company, China is expected to build 200 cities by 2025.

As improving sustainability becomes top priority in businesses, there will be opportunities for innovation and new business models and technologies in building management , as well as the creation of economies of scale which will lead to cost savings.

As the technologies evolve and mature, they provide a host of opportunities. A case in point in Singapore is the wiring up of buildings as part of the Next Gen NBN rollout. Buildings are being equipped with improved infrastructure which will enhance connectivity and integration. This will enable smart building technologies to be deployed.

7.4.1.4 Dematerialisation

In the book, *Being Digital,* published in 1995, Nicholas Negroponte presented an argument that humanity will inevitably head toward a future where everything, be it newspapers or entertainment, can be digitalised. His ideas may seem rather prophetic as today the ubiquity of ICT has brought about a host of "digital goods".

Digital technologies make it possible for dematerialisation to take place. The dematerialisation of products means that less or no material is used to deliver the same level of functionality to users. Dematerialisation will bring about lower material/resource intensity in the economy, leading to greater environmental sustainability which will reduce waste, limit human exposure to hazardous materials and conserve landscapes.

Dematerialisation has occurred in all types of products and services. Banking has transformed to a handful of electrons moving on computers or ICT devices. Encyclopaedias, maps, games, camera and books no longer need to occupy physical space.

For the purpose of this document, we will define dematerialisation as replacing physical objects and activities with electronic or virtual alternatives such as digital music, movies, e-books and e-money.

How ICT can help

The use of ICT can accelerate the pace of dematerialisation and slow down resource/energy consumption. Since Negroponte's writing of *Being Digital*, we have witnessed many digital products and services replacing their analogue predecessors. Today, a wider audience can reap the benefits of dematerialisation because of the widespread use of the Internet.

a. ICT as a Conduit for Dematerialisation

The Internet is key to dematerialisation as it acts as the distribution channel for digital content and services. ICT technologies and devices enable the creation of digital goods and services and can help other sectors become more efficient in achieving dematerialisation.

Digital music/movie downloads are replacing the physical production, shipping and storing of CDs and DVDs while e-readers provide a disruptive technology in the publishing industry. These are but a few examples of how ICT has helped traditional businesses reduce carbon emissions.

Digital content such as e-books can cut down on paper printing as a single copy can be used or borrowed an unlimited number of times. Digital movies will help reduce our carbon footprint as the resources needed to run movie theatres can be minimised.

For consumers, the benefits are improved quality, potential for personalisation and the possibility of reducing physical goods that will require storage space (which in turn is resource-intensive).

b. Creating New Business Models

The use of ICT technologies to deliver goods and services has also created new business models and brought new types of players into the industry. ICT can enable new models of sharing, borrowing and the organisation of group services that will meet the needs of communities and alleviate the need to physically own products. This is a process of dematerialisation as the new models have shifted the reliance on products to services.

Here are some examples to illustrate these new business models that only took off in the very recent past:

i) E-books – the digitisation of books took off when Amazon, one of the world's largest online retailers moved into offering e-books after introducing the Kindle e-book readers. Today there are numerous players in this space – Sony, Barnes & Noble (a traditional bookstore that introduced the Nook e-reader), and Apple (which offers e-books on their iTunes app store).

ii) On-demand digital media entertainment – The advancements made in digitising and compression technologies have enabled music and movies to be converted into digital goods that are available for download or on-demand streaming over the Internet. Today, players such as Apple, Amazon, Netflix and Hulu compete on equal footing with traditional music stores and cable/satelite TV providers such as ComCast and DirecTV to sell or rent digital music/movies on a pay-per-use model.

c. Other Transformations

ICT has also catalysed dematerialisation in other ways:

i) *Electronic Medical Records* – Hospitals and dental offices no longer use physical copies of film for X-rays as they are often stored in digital formats that will make transmission, retrieval and review easy. We are beginning to see medical records in the process of dematerialising as paper records are being slowly phased out.

ii) *Education* – The education sector has been a forerunner in the use of ICT technologies. Besides the increasing pervasiveness of e-books, the process of dematerialising is also taking place in the form of online learning and assessment. With ICT technologies, individuals can learn anywhere and do not have to always travel to a physical location, thus reducing their carbon footprint). Assessments and tests can be conducted and graded online, doing away with paperwork.

iii) *Online Shopping/E-commerce* – In 2009, GigaOM[22] commissioned a study to understand the greenhouses gas emissions of online holiday shopping versus in-store holiday shopping. The study found that in-store purchases represented an increase of more than 15 times the greenhouse gas emission

22 Katie Fehrenbacher. Why Cyber Monday is greener than Black Friday. [Online] Available from: http://gigaom.com/cleantech/why-cyber-monday-is-greener-than-black-friday/ [Accessed 9th July 2012].

of online purchases. Using data from the sale that took place after Thanksgiving in the USA in 2009, the impact of Black Friday in 2009 was about 50 times that of Cyber Monday in 2009. In-store shopping meant that shoppers had to drive to the store (using fuel and emitting CO2). In addition, the retail outlets used considerable energy resources to keep the stores running for the sale, and retailers had to ship their inventory to the stores.

Trends and Opportunities

The development of ICT technologies such as virtualisation and the shrinking of ICT devices has helped contribute to dematerialisation. It is estimated that digital alternatives could help save 500 Mt CO_2e by 2020 [SMART 2020].

Here are some trends that we can expect to see in the years ahead:

a. The ICT sector will dematerialise. ICT gadgets and devices will have multiple functions - a smartphone now has the added functionalities of an alarm clock, a radio, music player, camera and GPS/navigational tool. Instead of manufacturing different devices, developers may phase out certain gadgets by embedding them in other devices.

b. Apps are becoming the new wallet[23]. The rise of digital goods and experiences has brought about a new payment paradigm. As payments go mobile, apps will become the new wallet. Dematerialisation will offer opportunities in the development of virtual currencies and mobile payments.

c. ICT will continue to effect change in other sectors through dematerialisation. With digitisation, for example, the office of today is no longer filled with stacks of paper. This has spillover effects on the consumption of energy in offices (e.g. a smaller space is required) and even furniture design. The dematerialisation process can contribute to the use of fewer materials in furniture manufacturing[24].

d. A new set of metrics will emerge for digital goods. There is a need to redefine the ways the sales of goods/services are tracked as they become digital. For example, instead of measuring by looking at box office collections and the number of albums or copies of books sold, the new metrics will consider the number of downloads and online rentals. The ease of access to ICT technologies will facilitate data capturing, tracking and measurement.

Dematerialisation is the future of an ecologically and economically balanced world, and ICT will play a significant role in helping to achieve that future.

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[23] Stacey Higginbotham. Will Apps Become the New Wallet. [Online] Available from: http://gigaom.com/2011/03/28/will-apps-become-the-new-wallet/ [Accessed 9th July 2012].

[24] Steven Kurutz. Furniture Meets the Digital Age. [Online] Available from: http://www.nytimes.com/2012/03/29/garden/furniture-design-adapts-to-technology.html?_r=2&pagewanted=all [Accessed 9th July 2012].

7.4.2 Sustainability in the use of ICT

Beyond facilitating the "greening" of other industries, the ICT sector needs also to be sustainable. Gartner estimates that at present, ICTs account for about 2% of global carbon emissions[25].

The main contributors include personal computers (PCs) and monitors, data centres, and fixed and mobile telecommunications. To mitigate the environmental impact of all this energy consumption and in order not to negate the benefits of using ICT to enable sustainability, the ICT sector has been working on ways to be even more efficient in the consumption of natural resources and energy.

This segment will outline the areas where developments and innovations have prevailed in helping to reduce the carbon footprint of ICT.

7.4.2.1 Energy-Efficient Data Centres

Data centres play a critical role in supporting the operations of all sectors in an economy. The ubiquity of ICT and the recent "Big Data" trend have contributed to the exponential growth in data centre facilities.

These facilities can consume up to 100 to 200 times as much electricity as standard office spaces. According to OECD[26], data centres and network equipment account for almost 32% of the ICT sector's carbon footprint. To put this in perspective, let us look at the 10 largest data centres in Singapore which consumed energy equivalent to the consumption of 130,000 households[27], more than 10% of households in Singapore.

As a voracious consumer of energy, data centres are prime targets for energy-efficient designs that can save money and reduce electricity use. Coupled with rising costs of energy, the energy bill makes up a significant portion of the operating budget of data centre operators. Gartner has put energy-related costs, a cost item that is seeing the fastest increase, at approximately 12% of the overall data centre expenditure[28]. Figure 5 presents the energy use of a typical data centre.

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[25] Gartner Press Release. Gartner Estimates ICT Industry Accounts for 2 Percent of Global CO2 Emissions – 26 April 2007. [Online] Available from: www.gartner.com/it/page.jsp?id=503867 [Accessed 9th July 2012].

[26] Organisation for Economic Co-operation and Development. Greener and Smarter: ICTs, the Environment and Climate Change. [Online] Available from: http://www.oecd.org/site/stitff/45983022.pdf [Accessed 9th July 2012].

[27] Information Technology Standards Committee. Saving Data Centres' Costs with the Green Revolution.Source. [Online] Available from: http://www.itsc.org.sg/newsletter/april2012/data-centres.html [Accessed 9th July 2012].

[28] Gartner. Gartner Says Energy-Related Costs Account for Approximately 12 Percent of Overall Data Centre Expenditures. [Online] Available from: http://www.gartner.com/it/page.jsp?id=1442113 [Accessed 9th July 2012].

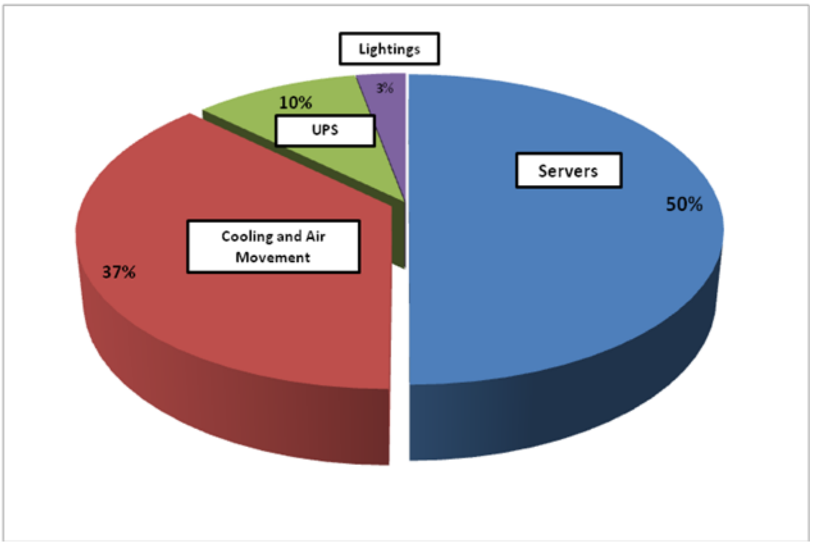

Figure 5: Typical Data Centre Energy Use[29]

However, the critical nature of data centre loads places other considerations, such as reliability and high power density capacity, above energy efficiency. Often the design cycle for data centre facilities is short and leaves little time to fully assess the opportunities for efficient design. This leads to designs that are simply scaled-up versions of standard office space or the re-use of specifications of existing facilities that are deemed "good enough", with little or no regard for energy performance.

This document will look at the various opportunities for energy efficiency in data centres and the top trends in data centre energy management.

Opportunities for Energy Efficiency

To design or operate an energy-efficient data centre, operators should look at the various categories of ICT systems, environmental conditions, air management, cooling and electrical systems, and other factors such as on-site generation and heat recovery.

We will first look at energy efficiency as the measures taken in this area will have a cascading effect on secondary measures for the mechanical and electrical systems.

a. ICT Systems

In a typical data centre, IT equipment can account for over half of the energy use within the facility. This means that with the use of efficient IT equipment, the loads within the data centre will be significantly reduced and the demand on the cooling systems reduced. The purchase of servers equipped with energy-efficient processors, fans and power supplies will bring down energy consumption.

[29] Getting to know your Power Usage Effectiveness (PUE), Raritan. [Online] Available from: http://www.raritan.com/resources/the-basics/power-management/power-usage-effectiveness/ [Accessed on 9th July 2012].

In addition to operating more energy-efficient equipment, consolidating storage devices, power supplies and implementing virtualisation are added measures to reduce loads within a data centre.

Server consolidation involves reducing the total number of servers or server locations by combining workloads from separate servers or applications into a smaller number of systems. There are several ways to consolidate: bringing together heterogeneous workloads from multiple servers into a single server, combining multiple workloads into a single operating system, and converging multiple applications such as e-mail and database into a single system.

The savings will be from reduced costs of energy and rental/floor space.

In the last few years, many data centres have been turning to server virtualisation technologies to enhance server utilisation and consolidate physical servers. With virtualisation, physical servers provide pools of logical computing capacity. Servers are divided into multiple "virtual machines" that run multiple operating systems and applications. The technologies have matured and we are looking at consolidation ratios in the 10:1 to 15:1 range, without any considerable stress on server resources.

Other forms of virtualisation have also come onto the market:
- *Platform virtualisation* – separation of the operating system from underlying platform resources;
- *Resource virtualisation* – virtualisation of specific system resources such as storage, name spaces and network resources;
- *Application virtualisation* – hosting of individual applications on foreign hardware/software;
- *Desktop virtualisation* – remote manipulation of computer desktops.

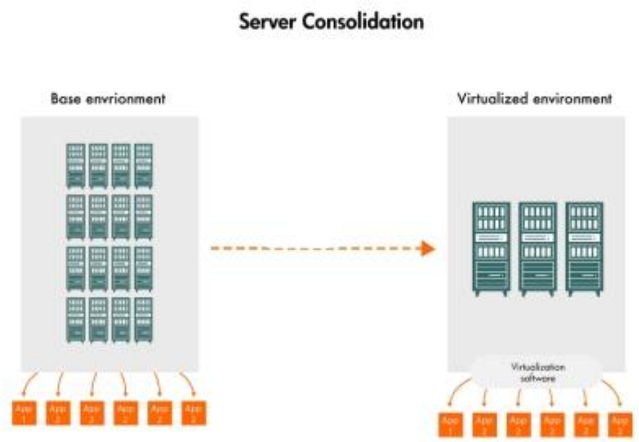

Figure 6: Server Consolidation at a Glance

b. Environmental Conditions

Many data centres are kept at a lower temperature than necessary. The consideration should instead be to optimise airflow distribution. Experts are also beginning to question the conventional wisdom of keeping data centres as cool as they have been in the past. The first step in designing the cooling and air management systems is to look at the standardised operation environments for equipment set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). In collaboration with ICT equipment manufacturers, ASHRAE has expanded the recommended environmental envelope for inlet air entering the equipment.

c. Air Management

Air management in data centres involves the elimination of the mixing of cool air supplied to the equipment and the hot air emitted from the equipment. When designed correctly, it will minimise the recirculation of hot air back into the racks and equipment, causing heat-related interruptions or failures. It will also reduce operating costs and equipment investment while increasing the data centre's power density.

d. Cooling Systems

The challenge in installing a cooling system for data centres is to ensure it is flexible, scalable and has built-in redundancy cooling features to guarantee consistency in performance. Today, there are many cooling technologies in the marketplace and with more emphasis placed on being green and sustainable solutions we are seeing a growing number of eco-friendly solutions. Some of these technologies are in row cooling, liquid cooling racks, outside air-economiser, rotary heat exchanger (Kyoto Wheel) and dielectric fluid submersion cooling.

Free cooling is an emerging technology that uses the natural outdoor environment to reduce the amount of energy required for mechanical cooling. Free air cooling eliminates the need for cooling via compressors. By reducing the number of hours that power-hungry chillers are run, data centres can save significant amounts of energy and cost. Since free cooling takes advantage of the ambient temperature outside, it remains an area of research to understand how this method can work in tropical countries like Singapore

e. Electrical Systems

Similar to planning cooling systems for data centres, the design of the electrical systems should take into consideration initial loads and plans for the capacity to be scalable to handle future loads.

To reduce energy consumption, three areas should be considered:

- *Power Distribution* – Data centres typically have an electrical power distribution path that consists of the utility service, switchboard, switchgear, alternate power sources (backup generator), parallel equipment for redundancy (UPS and PDU), and auxiliary conditioning equipment (line filters and capacitor bank). These components have heat output that is tied to the load in the data centre. Through careful selection of these components, operating efficiencies can be controlled and optimised.

- *Demand Response* - This refers to the process by which facility operators voluntarily curb energy use during periods of peak demand. Demand response programmes can be implemented to reduce loads through a building management system or switching to backup power generation. This will lead to cost savings as operators take up the incentives offered by utility programmes to alter usage patterns.

- *Direct Current (DC) Power* – Most electrical components within the data centre require DC power even though the grids supply AC power. This has resulted in multiple conversions, power loss and wasted energy. One way to reduce the number of times power gets converted is to utilise DC power distribution.

- *Lighting* – Not all the spaces within the data centre will be occupied; hence full illumination during all hours results in wasted energy. Using efficient lighting layout and equipment coupled with sensors can lead to energy savings.

f. Other Opportunities
In addition to some of the ways to reduce energy costs outlined above, there are other secondary opportunities for facility operators to consider.

- *On-Site Generation* – A near constant electrical load coupled with the need for a high degree of reliability make large-sized data centres well-suited for onsite electric generation. This provides an alternative to grid power - waste heat can be used to meet nearby heating needs or harvested to cool the data centre through absorption or absorption chiller technologies. In some cases, the surplus capacity from the onsite generation plant can be operated to sell power back to the grid, thus offsetting capital costs.

- Use of Waste Heat – The waste heat from data centres can be used to reduce energy costs. Using the absorption or adsorption chillers, waste heat can be used to supply cooling required by the data centres.

Trends in Data Centre Energy Management

In the face of rising energy costs, the days of taking power for granted in the data centre are coming to an end. Costly operating model where assets such as servers, cooling and lighting are powered at full capacity 24x7 will be outdated. The new operating model will match server capacity with demand in real time and energy efficiency will be a key consideration.

Here are some key trends that we can expect to see in the years ahead:

a. Organisations will accelerate the consolidation of data centres to improve overall efficiency through greater economies of scale.

b. More data centre operators will move towards a virtualised and load-balanced infrastructure. These vresources will be split between at least two facilities to satisfy the need for disaster recovery.

c. We will see consistency in the monitoring and management of data centres. Within organisations, we will see ongoing efforts to integrate monitoring and automation capabilities across the various functions.

d. Vendors will further reduce the idle power IT equipment consumes, thus making the spread between idle and loaded power consumption much wider. This will cause more power spikes in data centres during periods of high application demand.

e. Big organisations have begun to deploy multiple data centres around the world to meet the need for growth in server capacity and to improve disaster recovery preparedness. This move also gives organisations the power to shift the loads to locations where costs are lower and energy stability is greater.

f. With the increased emphasis placed on becoming more "green", organisations may start to appoint a "chief sustainability officer" to look into ways to reduce carbon footprint and energy costs.

7.4.2.2 Energy-Efficient Telecommunication Networks

The ubiquity of computing devices has brought about a global dependence on communication networks. These networks are made up of devices and systems that need to be kept constantly running to meet the on-demand nature of modern-day computing. As these networks proliferate at an amazing pace, the devices/systems will have a voracious appetite for power and the consequence is increased emission of harmful greenhouse gases.

Today's networks are optimised for capacity, not energy. As networks become even more pervasive, there is a need for new network architecture as it plays a significant role in reducing energy consumption. One of the challenges is that most organisations need to deal with legacy systems/equipment and may not always have a chance to start on a clean slate. Increasingly, too their network platforms must be capable of supporting networked sustainability and green IT services, mobility and network virtualisation.

Various ongoing collaborative groupings are looking into energy-efficient networking. Green Touch Consortium, **T**owards **R**eal **E**nergy-efficient **N**etwork **D**esign (TREND) and Climate Savers Computing are just a few. They all are working toward a common goal of reducing the carbon footprint of the ICT sector. However, each grouping takes a different approach or is tackling the problem differently. As the idiom goes, there is more than one way to skin a cat.

Green Touch is a consortium and has a goal to deliver the architecture, specifications and roadmap that will increase the network energy efficiency by a factor of 1,000 by 2015 from current levels.

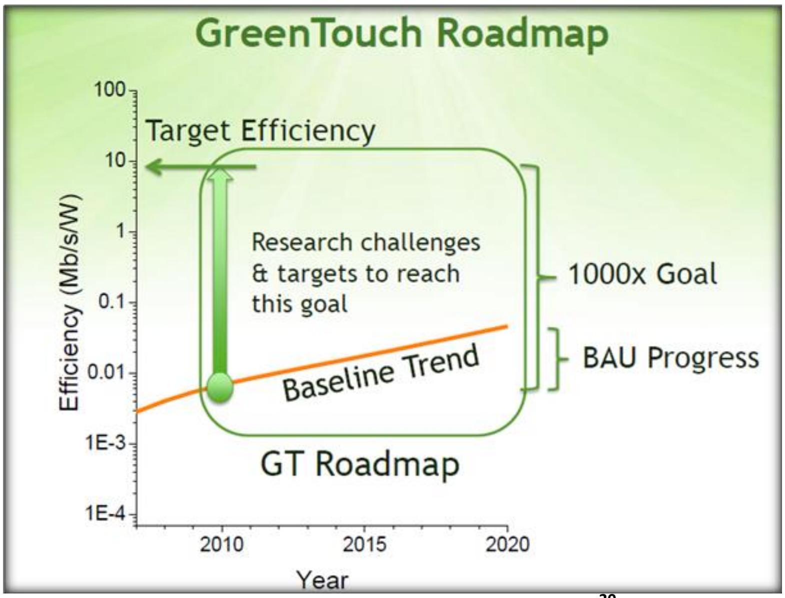

Figure 7: Greenwich Initiative Roadmap[30]

TREND is a Network of Excellence (NoE)[31] and aims at integrating the networking activities of major European players including manufacturers, operators, research centres, so as to

[30] Dan Kilper. GreenTouch Consortium: Roadmap Review. [Online] Available from: http://www.greentouch.org/uploads/documents/GT_Seattle_Tech_Comm_Roadmap_2011.pdf [Accessed 9th July 2012].

[31] TREND. About TREND. [Online] Available from: http://www.fp7-trend.eu/content/about-trend [Accessed 9th July 2012].

quantitatively assess the energy demand of current and future telecom infrastructures, and to design energy-efficient, scalable and sustainable future networks.

The NoE integrates and drives members toward commonly agreed technical goals highlighted by the many recent research efforts in energy-efficient networking, thus laying down the basis for a new holistic approach to energy-efficient networking, investigating effective strategies and mechanisms to reduce energy consumption in current and future networks in general, and the future Internet in particular.

Technology Areas

To look at energy efficiency in networks, we examine the parts where the biggest improvements can take place. Networks can be segmented into a core network and several types of access networks. In these different segments there will be equipment/devices involved. Some of the researchers investigate how to make these equipment/devices more energy-efficient while others focus on the transmission and switching technologies.

Networking systems are designed to over-provide and have built-in redundancy. Networks are dimensioned to sustain peak-hour traffic with extra capacity to allow for unexpected events. Devices are added to the network infrastructure with the purpose of taking over when another device fails. All these add to the overall energy consumption and these objectives (of resiliency and fault tolerance) are radically opposed to environmental considerations. A radical shift is needed in networking R&D to introduce energy awareness in the network design without compromising network reliability and quality of service.

As understanding energy use in networks is a complex exercise, this document can only briefly touch on a handful of the ongoing research and technologies. We look at the four areas where the network infrastructure can be exploited to meet energy efficiency objectives:

a. Resource Consolidation
   This area looks at how to reduce energy consumption by under-utilising devices at any given time. Network traffic can be tracked and information on usage patterns made easily available, which means there are opportunities to “spot” the level of over-provisioning to the current network, allowing the tweaking of resource allocation This can be achieved by shutting down some lightly loaded routers and re-routing traffic onto a smaller number of active network equipment.

   Resource consolidation is already a popular approach in the management of data centres and improving the performance of CPUs.

b. Virtualisation
   Virtualisation allows more than one service to operate on the same piece of hardware, thus improving hardware utilisation and resulting in lower energy consumption. It can be applied to multiple types of resources including network links, storage devices and software resources.

   Virtualisation is today widely applied in data centres where we see the sharing of servers. However today, the solutions available for virtualisation are not specific to reducing network energy consumption.

c. Selective Connectedness
   Similar to resource consolidation, the selective connectedness of devices comprises distributed mechanisms which allow single pieces of equipment to go idle for a period of time. The difference between resource consolidation and selective connectedness is that consolidation applies to resources that are shared within the network infrastructure while selective connectedness allows the turning off of unused resources at the edge of the network.

d. Proportional Computing
   Proportional computing may be applied to a system as a whole, to network protocols and to individual devices and components. Dynamic Voltage Scaling and Adaptive Link Rate are common examples of proportional computing.

   Dynamic Voltage Scaling reduces the energy state of the CPU as a function of a system load. Adaptive Link Rate applies a similar concept to network interfaces to reduce their capacity and hence energy consumption, as a function of the link load.

Outlook and Trends

Given the complexity of networks, trying to propose solutions or innovations to achieve energy efficiencies will lead to trade-offs that have to be carefully considered. We see that increasingly the ICT and research communities are coming together, organising to address the challenges. It will be a long-term evolution before we see any dramatic and holistic change.

Here are some key trends that we can expect to see in the years ahead:

a. Standardising benchmarks
   The concern about the energy consumption of IT equipment has captured the attention of the research community, resulting in a variety of methodologies, devices and network scopes. Consequently, there is a notable heterogeneity of power consumption models and performance evaluation figures.

   One key challenge is the lack of a common vision with respect to two variables – the power consumption of equipment and the improvements introduced by the proposed mechanisms.

   The research community will work toward standardising benchmarks for the energy consumption of network devices and propose frameworks for analysis of energy efficiency in communication networks. We envisage more efforts in this area.

b. Solutions based on renewable sources
   Power efficiency is appealing because it allows the saving of energy and money. But more importantly, it enables the development of green devices, generating a sustainable carbon footprint. In turn, the installation of power-efficient devices makes it possible to operate systems by means of renewable energy generators which are not reliable in terms of guaranteed power generation and may necessitate massive deployments for the generation of large amounts of power.

c. Network operators are likely to employ virtualisation and selected connectedness to make their networks more energy-efficient.

d. Vendors will continue to invest in the development of low-power IT equipment/devices such as routers and switchers. They anticipate a strong demand in these products as they help networks to be energy efficient. Green products will become a key asset and differentiator. Products and services will be advertised, using eco-labels.

7.4.2.3 Energy-Efficient ICT Devices

Pervasive computing is having a substantial impact on energy use. Computing devices are getting smaller, having faster computing power, getting cheaper to produce and becoming less power-intensive. Consumer electronics companies and equipment manufacturers can design products that are more energy-efficient or which offer the possibility of tapping into renewable sources of energy.

The components that make up these devices - such as the power supply units, processors, storage and display - are more energy-efficient compared to the previous generations of these devices.

The processing power of these devices has shown tremendous growth. According to a study conducted by Jonathan Koomey[32], the electrical efficiency of computing has doubled every 18 months since the 1970s. The graph below illustrates the number of computations computers can carry out, using the same amount of energy.

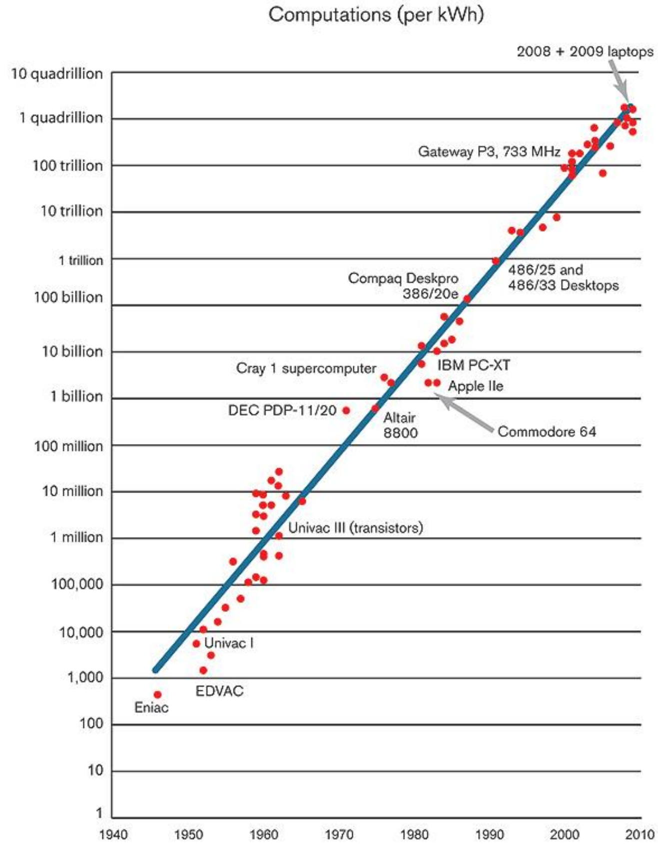

Figure 8: Improvements in Computer Energy Efficiency: Computations per Kilowatt Hour (kWh)[32]

To put things into context, Koomey mentioned that a modern-day MacBook Air operating at the energy efficiency of computers from 1991, with its battery fully charged, will only last 2.5 seconds. That is how much progress has been made in computing power.

[32] Koomey, Jonathan G., Stephen Berard, Marla Sanchez, and Henry Wong. Implications of Historical Trends in The Electrical Efficiency of Computing. [Online] Available from: http://doi.ieeecomputersociety.org/10.1109/MAHC.2010.28 [Accessed 9th July 2012].

We can expect to see a proliferation of even smaller and less power-intensive computing devices, making new mobile computing and communications applications possible. As devices shrink in size, energy consumption can be made more efficient. Today, watching a movie on a tablet device uses 33 times less energy than watching it on a television set, 10 times less energy than watching it on a desktop PC, and 3 to 6 times less energy than on a laptop computer.

Improvements in the energy efficiency of computing (and associated technologies) will revolutionise the way we collect, process and analyse data to help us make better decisions. It will help propel the "Internet of things", enable us to control industrial processes with more precision, empower businesses to reinvent and reflect new realities in a timely manner.

In the next section, we will look at the technology components that make up these devices, helping them achieve energy efficiency. Specifically, we will look at microprocessor, memory, and storage and display technologies.

Microprocessors/Central Processing Unit (CPU)

The central processing unit or CPU, housed in a single chip known as the microprocessor, is the brains of the computing device. Chip makers such as Intel, AMD and ARM are always racing to produce a faster and smaller microprocessor. While the focus has been primarily on performance, in recent years these chipmakers are also putting more attention in developing low-power processors. Newer CPUs also have graphic processors integrated onto the same chip. By doing so, a system can become even more efficient.

Besides designing the chips to achieve power efficiency, accompanying technologies built into some of the microprocessors can allow the computing device to run more efficiently. Most devices may be operating at high clock speeds but doing partial processing, often generating more heat and consuming more power. There are technologies that allow the core voltage to be reduced when the computing device is under low load or is idle. The benefits are reducing power consumption and heat generation. Intel's SpeedStep and AMD's PowerNow! are examples of such technologies.

Outlook and Trends

Chip makers will continue to break new ground in advancing processing technology, coupled with increasing power density, to bring better performance per unit of power. Aggressive power management and system-wide power optimisation have become prerequisites as technology has enabled the increasing trend of system integration onto the processor die. The consequence of lower-power design requirements will likely spur innovation in this area.

The increased focus on power is helping rein in the immense demands which computing devices and data centres have put on power grids. The result will be lower cost, less cooling demands and a greener product.

The trends in integration, power consumption and parallel computation will bring new challenges to processor development. The chip making industry will continue to innovate and look for new techniques to ensure robustness to power supply fluctuations and improve power/clock delivery networks that are required as multiple voltage domains become *de facto* on these microprocessors.

Memory / Storage

As the memory capacity of computing devices continues to increase rapidly to bridge the widening gap between disk and processor speeds, memory energy efficiency becomes an increasingly important consideration.

The figure below outlines the memory taxonomy. Volatile memory requires power to maintain the stored information while non-volatile memory can retain the stored information, even when not powered.

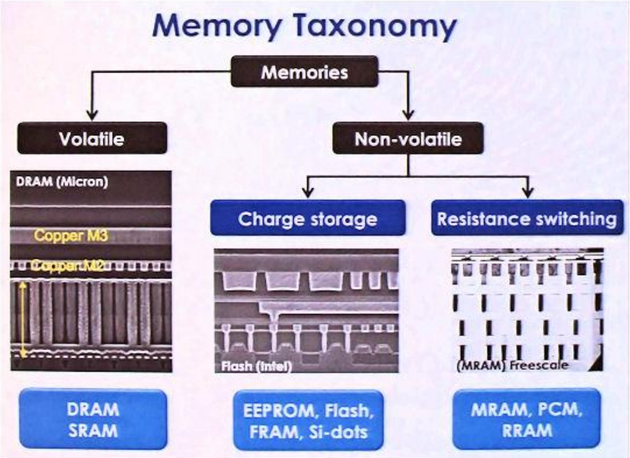

Figure 9: Taxonomy[33]

As with the case of microprocessors, many of the energy-efficient improvements for memory occur at the design and manufacturing stage. Emerging memory technologies allow memory devices to dynamically adjust their power states. Samsung was the world's first DRAM maker to ship a 30-nm-class DRAM in 2011. The DRAM uses two-thirds less energy than those manufactured with industry standard 50nm class technology (Figure 10).

[33] Christophe Muller. Resistive Switching Concepts: towards a paradigm change in using non-volatile memories. [Online] Available from: http://www.isqed.org/English/Archives/2012/Keynote_Speeches.html [Accessed 9th July 2012]

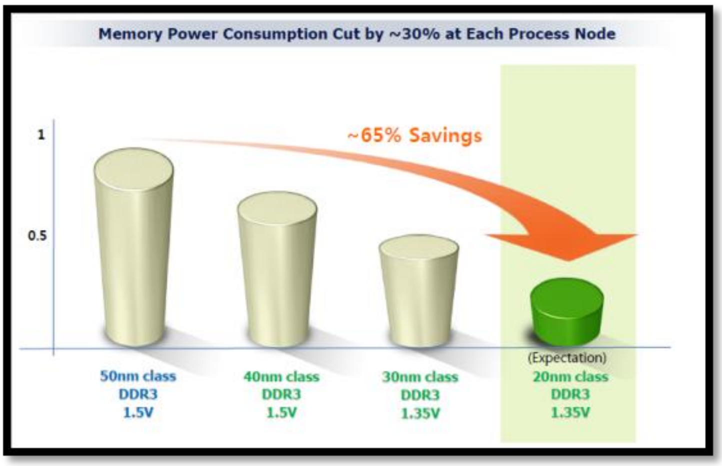

Figure 10: Advanced Process Technology is driving significant power reduction[34]

Outlook and Trends

A recent innovation in DRAM memory architecture is the Hybrid Memory Cube (HMC)[35] which sets a new standard for memory performance, power consumption and cost. HMC combines high-speed logic process technology with a stack of through-silicon-via (TSV) bonded memory die. HMC promises to deliver dramatic improvements in performance and is exponentially more efficient than current memory.

While technologies in volatile memory have led to improvements in energy efficiency in recent years, they still require a power source to retain the information. Leading semiconductor companies such as Intel, Samsung and Texas Instruments are looking at ways to replace volatile memory with more efficient and power-friendly, non-volatile memory. The industry is looking at ways to combine the cost benefits of DRAM, the speed of SRAM and the non-volatility of flash memory to come up with what is termed “universal memory”. However, industry watchers expect this effort will take a while before bearing fruit.

There are currently a few candidate technologies that are closest to a “universal memory” solution. Magnetoresistive RAM or MRAM seems to be closest as it replaces the capacitor of a DRAM cell with a pair of magnets. MRAM has lower power consumption than DRAM, is able to retain data longer (twice as long as flash) but is only as fast as a low-end SRAM and has less than a tenth of cell density of flash memory. Other candidates are Resistive RAM (RRAM), and Phase-change RAM (PCRAM), but all have their own shortcomings.

The research and investments in this area will continue even if the industry is struggling to keep pace with demand for chips that are faster, more reliable, more energy-efficient and cheaper.

Display Technology

34 Samsung Lab. Current and Future Memory Technologies for your Intel Architecture Based Platforms. [Online] Available from: http://www.samsung.com/us/business/oem-solutions/pdfs/Current-and-Future-Memory-Tech%20IDF2011.pdf [Accessed 9th July 2012].

35 Hybrid Memory Cube Consortium. About the Technology. [Online] Available from: http://hybridmemorycube.org/ [Accessed 9th July 2012].

The advancement in display technologies has enabled the creation of many new products and computing devices. Display technologies such as OLEDs or organic light-emitting diodes has been around for more than a decade but has only taken off in the past few years and for very small screens. The use of OLEDs has transformed the consumer electronics industry as a proliferation of consumer ICT devices such as smartphones, tablets and smart TVs come on the market.

As an OLED generates its own light, it consumes less power. The cost of production for OLEDs is also lower as the manufacturing process involves a simple continuous method at a low temperature. OLEDs do not contain mercury so it is environmentally friendly compared to other display technologies such as liquid crystal displays (LCDs).

Another display technology is electronic or e-paper, enabled by E-Ink technology, which today has found its main application in e-book readers, such as Kindle by Amazon and Nook by Barnes & Noble. The market for e-paper displays is expected to reach US$8.5 billion by 2022, according to a forecast by IDTechEx[36].

E–paper is a portable and reusable storage and display medium which is thin and flexible. The manufacturing of e-paper is not limited to one technology, which means there is potential for cost reduction as different technologies mature. It also has many other applications such as wristwatches, smartphones and e-labels on shelves. Whether e-paper is more eco-friendly is still very much in question today.

Outlook and Trends

The future of display technologies continues to look bright as researchers work to overcome key challenges and limitations of current technologies. Some of the trends in this area are as follows:

- *Flexible Display* – Researchers and manufacturers are working on bendable OLED displays that will allow for foldable devices.

- *Better colour displays* – Colour e-readers are available in the consumer market but researchers will continue to work toward the next generation of colour displays in e-readers.

- *Low-power digital display* – LEDs that consume high levels of electricity and are not visible under direct sunlight may be replaced by displays that are low-power and clearly visible in the day.

7.5 CONCLUSION

The application of ICT in all aspects of society has a tremendous impact on sustainable development. ICT has helped revolutionalise business models and consumer behaviour – enabling new ways of working, learning and provision of private and public services. The ICT

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36 IDTechEx. E-Paper Displays: Markets, Forecasts, Technologies 2012-2022. [Online] Available from: http://www.idtechex.com/research/reports/e-paper-displays-markets-forecasts-technologies-2012-2022-000289.asp [Accessed 9th July 2012].

sector is also continually transforming itself and its outputs, encouraging innovation and responsible global citizenship in the use of the world’s resources.