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Sustainable IT

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50.1 Introduction

Sustainable IT is the design, production, operation, and disposal of IT and IT-enabled products and services in a manner that is not harmful and may be positively beneficial to the environment during the course of its whole-of-life [1]. Sustainable IT requires the responsible management of resources (both IT and non-IT) encompassing environmental, economic, and social dimensions. The first wave of sustainable IT, *Greening of IT,* aims to reduce the 2% of global greenhouse gas (GHG) emissions for which information technology (IT) is responsible [2], by reducing the footprint of IT thought actions such as improving the energy efficiency of hardware (processors and disk drives) and reducing waste from obsolete hardware. The second wave of sustainable IT, *Greening by IT,* also called Green IT 2.0 [3], is shifting the focus toward reducing the remaining 98%, as illustrated in Figure 50.1, by focusing on the innovative use of IT in business processes to deliver positive sustainability benefits beyond the direct footprint of IT, such as monitoring a firm's emissions and waste to manage them more efficiently. The potential of *Greening by IT* to reduce GHG emissions has been estimated at approximately 7.8 Gt CO_2 of savings in 2020, representing a 15% emission cut in 2020 and 600 billion ($946.5 billion) of cost savings [2]. It is estimated that the use of IT for greening will play a key role in the delivery of benefits that can alleviate at least five times the GHG footprint of IT itself [4].

This chapter provides an overview of sustainable IT best practices followed by discussion of the challenges faced by IT organizations in delivering sustainable IT. Green for IT practices covered include how software should be designed to minimize its resource usage, how the energy efficiency of data centers (DCs) can be improved through the use of virtualization, air management, and cooling, and the life cycle assessment (LCA) process that is used to determine the environmental impact of a

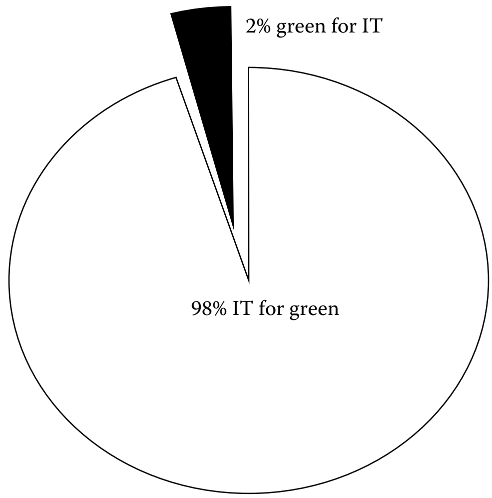


FIGURE 50.1 Target potential CO_2 reductions for sustainable IT.

product or service. Practices for IT for Green include how energy can be effectively managed with Green Information Systems (IS). Next, the chapter examines the challenges facing IT organizations as they put sustainable IT best practices into action, including how to benchmark the maturity of the sustainable IT. The chapter finishes with a brief look at future sustainable IT research directions and with a summary.

50.2 Two Faces of Sustainable IT

Sustainable IT is a broad topic that can have many motivations including:

- Self-interest (image, competitive advantage, innovation)
- Social, cultural, and political influence
- Regulatory and compliance requirements
- Environmental concerns
- Economic benefit

There are substantial inefficiencies in IT and its usage behavior that can be readily addressed. As illustrated in Figure 50.2, there are two faces to sustainable IT: Green for IT and IT for Green.

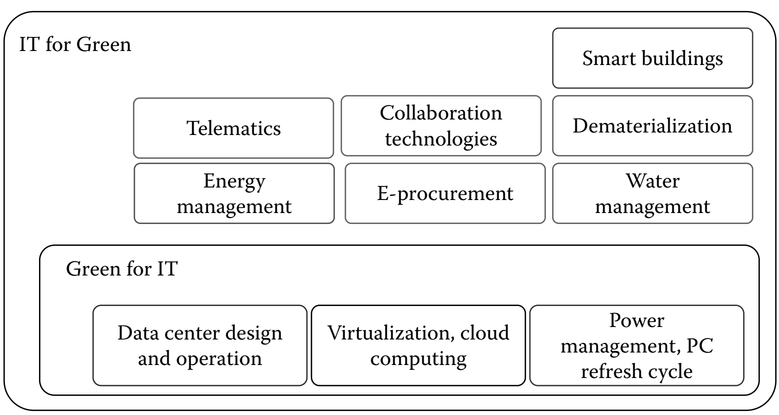


FIGURE 50.2 Two faces of sustainable IT.

50.2.1 Green for IT

Murugesan [5] details a holistic approach to *Green for IT* that comprehensively and effectively addresses the environmental impacts of IT using four key practices:

- *Green use of IT systems*: Reduce the energy consumption of computers and information systems and use them in an environmentally sound manner.
- *Green disposal of IT systems*: Refurbish and reuse old computers and properly recycle unwanted computers and other electronic equipment.
- *Green design of IT systems*: Design energy-efficient and environmentally sound components, computers, servers, and cooling equipment.
- *Green manufacturing of IT systems*: Manufacture electronic components, computers, and other associated subsystems with minimal or no impact on the environment.

By following these four practices, the environmental impacts of IT can be reduced to improve its sustainability throughout its entire life cycle. Examples of Green for IT include:

- Energy-efficient DC design and operation
- Virtualization and cloud computing
- Power management
- PC-refresh cycle
- Energy-efficient computing
- Responsible disposal and recycling of IT equipment
- Eco-labeling of IT products

50.2.2 IT for Green

There is substantial potential for sustainable IT to bring together business processes, resource planning, direct and indirect activities, and extended supply chains to effect positive changes across the entire activities of governments, organizations, and individuals. *IT for Green* is concerned with analyzing, designing, and implementing systems to deliver positive sustainability benefits beyond the direct footprint of IT, such as monitoring a firm's emissions and waste to manage them more efficiently. IT for Green provides an opportunity for the innovative use of IT in business processes to improve resource management. Examples of IT for Green are:

- Smart buildings
- Energy management
- E-procurement
- E-waste
- Telematics
- Water management
- Collaboration technologies
- Dematerialization

Understanding how to utilize sustainable IT requires understanding how IT can be used to improve the sustainability of an activity (both IT and non-IT). The following two sections discuss the application of IT to improve the sustainability of IT and then the application to a non-IT business activity.

50.3 Green for IT Practices

This section discusses Green for IT practices including Green Software, DC energy efficiency, and the LCA of products and services.

50.3.1 Green Software

Power-management features are becoming prevalent within hardware resulting in significantly improved hardware energy efficiency, with particularly high gains in mobile devices as a response to maximizing battery life. While hardware has been constantly improved to be energy efficient, software has not recorded a comparable track. The availability of increasingly efficient and cheaper hardware components has led designers up to now to neglect the energy efficiency of end-user software, which remains largely unexplored. While software does not consume power directly, software plays a critical role in the efficiency of the overall system as it interacts with power-consuming resources. Software causes the computations performed by the processor and is the root cause of all the consumption of the infrastructural layers within both a server and the DC (e.g., cooling, Uninterruptible Power Supply (UPS)).

The software development life cycle and related process management methodologies rarely consider energy efficiency as a design requirement. Software energy efficiency should be included in the initial design of software to optimize the efficiency of the software utilizing the hardware to satisfy a given set of functional requirements and workloads. Well-designed, efficient software should have good proportionality between the amount of useful work done and the amount of resources consumed [6]. In contrast, inefficient software demonstrates poor resource utilization to the amount of work done.

Effective resource management within software can contribute to the overall efficiency of the system. Where resources are over-allocated, or not efficiently used, the software can be responsible for lowering the efficiency of the entire system. The design of complex distributed software can affect the software energy efficiency. Well-known design issues that lower energy efficiency include sloppy programming techniques, excessive layering (deep inheritance trees leading to higher method invocation costs), code fragmentation (excessively small classes or small code objects inhibiting aggressive optimization), and overdesign (such as using databases to hold static configuration data) [7]. Software compilers cannot easily compensate for these design issues, resulting in lower energy efficiency [7]. An analysis [7] of the energy efficiency of software design has shown that:

- CPU is the component that absorbs most of the power (dependent on usage)
- Memory energy requirements are independent of use due to constant refreshing
- Hard disks consume most of the energy for their continuous spinning

The study concludes that an intelligent use of memory can shift the computational burden from the CPU to storage, possibly reducing the total energy consumption [7].

A concrete example of how software can be energy efficient is given by Steigerwald and Agrawal [8] for the efficiency of DVD playback software. When used on a notebook, is it better for the playback application to set up a large buffer and do less frequent optical drive reads or to keep the drive spinning? From an implementation perspective, there is not much difference between the two designs; however, the buffering strategy can add up to 20 min battery life. Within the analysis of the design of DVD applications, Steigerwald et al. [8] offer three key design considerations for energy-efficient software: (1) computational efficiency, (2) data efficiency, and (3) context awareness.

Computational efficiency: Reduce energy costs by improving application performance with respect to CPU utilization. The objective is to maximize the utilization of the CPU. The faster the workload can be completed, the sooner the CPU can return to idle and more energy can be saved. To achieve computational efficiency, use software techniques that achieve better performance such as efficient algorithms, multithreading, and vectorization.

Computational efficiency also extends to how the software interacts with the CPU. For example, a common design practice for threads waiting for a condition is to use a timer to periodically wake up to check if the condition has been satisfied. No useful work is being done as the thread waits, but each time it wakes up to check the condition, the CPU is forced to leave an idle power-managed state.

Ideally, applications should leverage an event-triggered mechanism to eliminate the need for time-based polling or, if possible, to move all periodic/polling activity to be batch processed.

Data efficiency: Reduce energy costs by minimizing data movement and using the memory hierarchy effectively. Data efficiency requires thinking about how an application reads and writes data (particularly I/O operations, such as read requests for a drive) and how it moves data around during execution. The DVD playback application is an example of data efficiency using I/O buffering to maximize I/O utilization by prefetching and caching. Other data efficiency techniques include:

- Software algorithms that minimize data movement
- Memory hierarchies that keep data close to processing elements
- Application software that efficiently uses cache memories

Data efficiency also covers the design of memory management. Data-efficient design will release memory that is no longer needed and watch for memory leaks. For example, a service that slowly leaks memory will over time allow its memory heap to grow to consume much of the system's physical memory. Even though the software does not actually need all this memory, it can restrict the opportunity to power manage memory since most of it has been allocated.

Context awareness: Reduce energy consumption by enabling applications to make intelligent decisions at runtime based on the current state of the system. Context-aware software knows the power state of the system and the current power policy, behaves appropriately, and responds to changes dynamically. These decisions are typically encapsulated in passive or active power policies. Passive power policies respond to a change in context by asking the user what action to take ("Switch to power-save mode?") or to acknowledge that the state change has occurred ("You have 10% battery left. OK?"). An active power policy would automatically take corrective actions, such as changing behavior to minimize energy consumption when a laptop is running on battery (i.e., dimming a screen when moving from AC to DC power sources).

Overall, the design of software can have a significant impact on its energy efficiency. If the software is less layered and more algorithmically efficient, it will consume less energy [7].

50.3.2 Data Center Energy Efficiency

With power densities of more than 100 times that of a typical office building, energy consumption is a central issue for DCs. Massive growth in the volumes of computing equipment, and the associated growth in areas such as cooling equipment, has led to increased energy usage and power densities within DCs. Trends toward cloud computing have the potential to further increase the demand for DC-based computing services [9].

The U.S. EPA estimates that servers and DCs are responsible for up to 1.5% of the total U.S. electricity consumption [10] or roughly 0.5% of U.S. GHG emissions for 2007. Power usage within a DC goes beyond the direct power needs of servers to include networking, cooling, lighting, and facilities management with power drawn for DCs ranging from a few kWs for a rack of servers to several tens of MWs for large facilities. While the exact breakdown of power usage will vary between individual DCs, Figure 50.3 illustrates an analysis of one DC where up to 88.8% of the power consumed was not used for computation; for every 100 W supplied to the DC, only 11.2 W was used for computation [10].

Air conditioners, power converters, and power transmission can use almost half of the electricity in the DC, and the IDC estimates that DC energy costs will be higher than equipment costs by 2015 [11]. The cost of operating a DC goes beyond just the economic bottom line; there is also an environmental cost. By 2020, the net footprint for DCs is predicted to be 259 $MtCO_2e$ [2]. There is significant potential to improve both the economic and environmental bottom line of DCs by improving their energy efficiency; however, a number of challenges exist.

The efficiency of a DC can be improved by using new energy-efficient equipment, improving airflow management to reduce cooling requirements, investing in energy management software, charging back

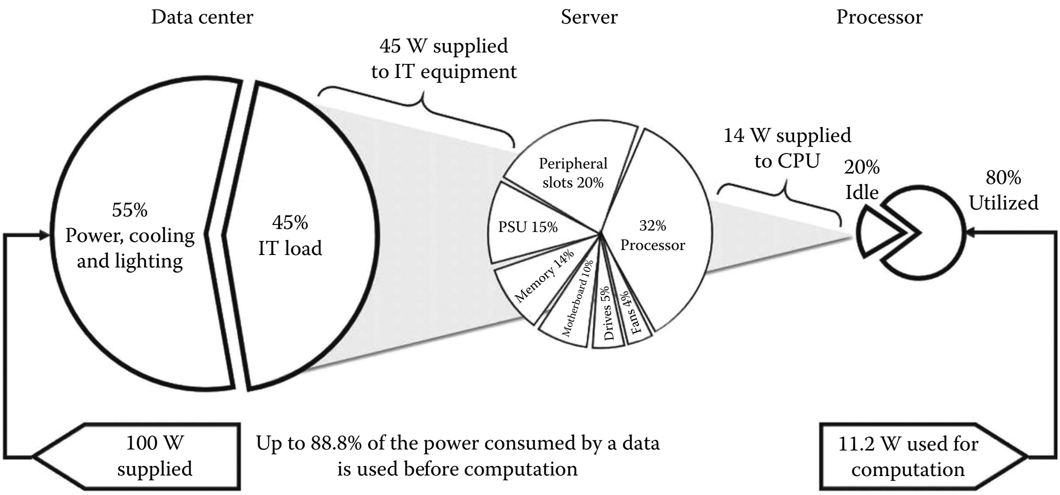


FIGURE 50.3 Example breakdown of power usage within a data center. (From Report to Congress on Server and Data Center Energy Efficiency Public Law 109–431, U.S. EPA, 2007.)

environmental impacts to consumers [12], and adopting environmentally friendly designs for DCs. In the remainder of this section, we will examine the most significant techniques for improving the energy efficiency within the DC, including virtualization, internal air management and cooling, and relevant metrics to understand the energy efficiency of a DC.

50.3.2.1 Virtualization

Virtualization is the creation of a virtual version (rather than actual physical version) of a computing resource such as a hardware platform, operating system, a storage device, or network resources. With virtualization, one physical server hosts multiple virtual servers as illustrated in Figure 50.4. Virtualization is a key strategy to reduce DC power consumption by consolidating physical server infrastructure to host multiple virtual servers on a smaller number of more powerful servers.

Virtualized DCs introduce additional degrees of freedom that are not available under traditional operating models where there is a hard binding between servers and the applications on which they run. Applications hosted in virtualized DCs run on virtualized operating systems. That is, the operating system does not run directly on the hardware, but it is mediated through a virtualization hypervisor. The hypervisor frees applications from a single physical host, allowing them to be moved around within a pool of servers to optimize the overall power and thermal performance of the pool. The loose binding between

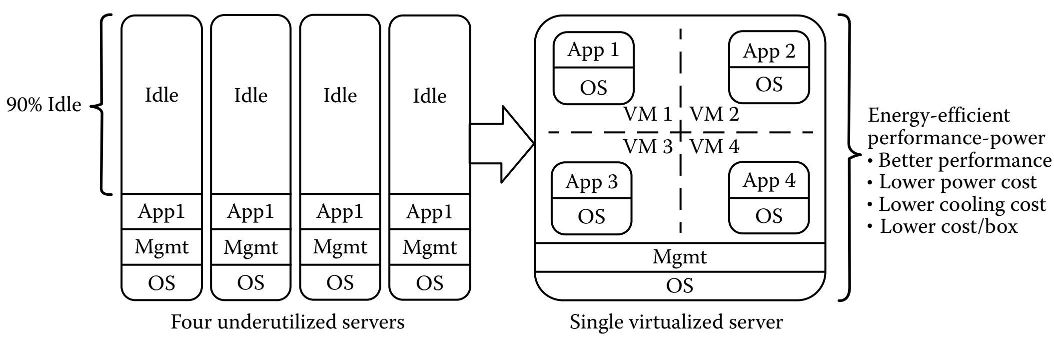


FIGURE 50.4 Saving achieved from virtualization of server resources.

applications and hosts allows treating a group of hosts as a pooled resources, allowing optimizations as a group that were not possible with individual machines, such as powering down servers during low demand.

50.3.2.2 Internal Air Management and Cooling

Air is the most common medium used to cool IT equipment. Moving air consumes energy; it is imperative that action is taken to ensure effective air management. How the air is supplied, how the exhaust heat is removed, what type of refrigeration cycle is utilized, and how the air circulates within the DC determine the energy efficiency of cooling [13,14].

Air segregation: Air mixing is an important issue with best practice to fully segregate hot and cold air. In the hot aisle, cold aisle configuration fans draw cool air from the front of the server, removing heat from the internal components and blowing the now heated air out through the back of the server chassis.

Air distribution strategies: Three common air cooling/distribution infrastructures are employed within the DC. (1) In *room-based (perimeter/peripheral) air-cooling*, cool air is delivered to the front of the server rack (cold aisle), typically through floor or overhead. The cool air is drawn through the servers and exhausted into the hot aisle. The hot air then propagates toward computer room air conditioners (CRACs) or computer room air handlers (CRAHs) at the peripheral of the room. (2) *Row-based* cooling is similar to perimeter cooling, but the individual CRACs/CRAHs are dedicated to a particular row of IT equipment as opposed to the room as a whole. (3) *Rack-based* cooling uses smaller CRAC/CRAH units associated with individual racks. In energy efficiency terms, row-based air distribution is typically an improvement on room-based cooling due to shortened air paths. However, rack-based cooling can be the most efficient given the reduced fan power required to move air within the confines of the rack itself.

Cooling: The main systems used to cool the DC include air-cooled direct expansion (DX) systems, glycol cooled systems, and water-cooled systems. Each utilizes a CRAC with an energy-hungry refrigeration cycle; a new practice is to use direct free cooling. Direct free cooling or airside economization is fast becoming an energy efficiency best practice. In climates that are suitable, air is supplied directly to the front of the IT equipment while the warmer exhaust air is ducted directly to the outside atmosphere. This essentially eliminates the refrigeration cycle providing what is typically called "free-cooling." In terms of redundancy and the percentage of the year when conditions are unfavorable, refrigeration-based backup is utilized.

50.3.2.3 Data Center Metrics

This section discusses a number of key metrics defined by the Green Grid* (a nonprofit group of IT enterprises formed in 2007) to understand the sustainability of a DC.

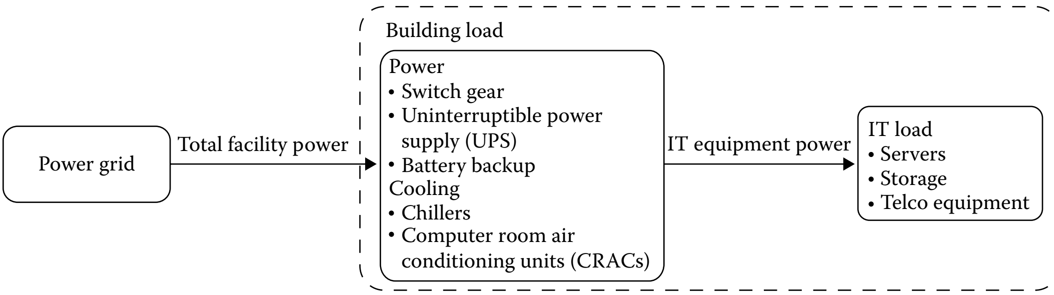
Power usage effectiveness/data center infrastructure efficiency: Power usage effectiveness (PUE) [15] is a measure of how efficiently a DC uses its power. PUE measures how much power the computing equipment consumes in contrast to cooling and other overhead uses. PUE is defined as follows:

$$\text{PUE} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}$$

The reciprocal of PUE is data center infrastructure efficiency (DCiE) and is defined as follows:

$$\text{DCiE} = \frac{1}{\text{PUE}} = \frac{\text{IT Equipment Power}}{\text{Total Facility Power}} \times 100\%$$

* http://www.thegreengrid.org



$$\text{Power usage effectiveness (PUE)} = \frac{\text{Total facility power}}{\text{IT equipment power}} \qquad \begin{array}{c}\text{Data center infrastructure}\\ \text{efficiency (DCiE)}\end{array} = \frac{\text{IT equipment power}}{\text{Total facility power}}$$

FIGURE 50.5 PUE/DCiE calculation overview.

IT equipment power includes the load associated with all of the IT equipment, such as computing, storage, and network equipment, along with supplemental equipment used to monitor or otherwise control the DC including KVM switches, monitors, workstations, and laptops. *Total facility power* includes everything that supports the IT equipment load such as power delivery (UPS, generators, batteries, etc.), cooling system (chillier, computer room air conditioning units [CRACs], direct expansion air handler [DX] units, pumps, and cooling towers), compute, network, storage nodes, and other loads such as DC lighting.

Both PUE and DCiE, illustrated in Figure 50.5, are metrics that give an indication as to the use of power by supporting infrastructure of the DC. An ideal PUE would be 1.0; this means that no additional energy is consumed by the infrastructure that is supporting the IT load. The lower the PUE value the better, and conversely, the higher the DCiE value the better. If total power was 150 kW and IT power was 100 kW, then PUE would be 150/100 = 1.5; for DCiE, it would be 100/150 × 100 = 66%. This means that for every watt supplied to the IT equipment, half a watt is required to support it. A 2011 study by Koomey [16] estimates typical PUE between 1.93 and 1.83, with large DC operators such as Google, Yahoo, Facebook, and Microsoft reporting industry-leading PUE ratings in the 1.07–1.2 range.

While PUE/DCiE have proven to be an effective industry tool for measuring infrastructure energy efficiency, there is a need to measure the operational effectiveness of the DC. To this end, the Green Grid has defined a number of metrics [17] to measure dimensions including resource utilization and environmental impact. Water usage effectiveness (WUE) measures water usage to provide an assessment of the water used on-site for operation of the DC, while carbon usage effectiveness (CUE) measures DC-specific carbon emissions.

The xUE (PUE, WUE, CUE, etc.) family of consumption metrics does not tell the full story of the impacts of DCs on the environment. In order to understand the full environmental burden of a DC, a full life cycle analysis of the DC facilities and IT equipment is needed. These additional costs should not be underestimated. Take, for example, Microsoft's DC in Quincy, Washington, that consumes 48 MW (enough power for 40,000 homes) of power. In addition to the concrete and steel used in the construction of the building, the DC uses 4.8 km of chillers piping, 965 km of electrical wire, 92,900 m^2 of drywall, and 1.5 metric tons of batteries for backup power. Each of these components has its own impact that must be analyzed in detail; the means by which this is done is called an life cycle analysis (LCA).

50.3.3 Life Cycle Assessment

Understanding the impacts of an IT product or IT service requires an analysis of all potential impacts during its entire life cycle. An LCA, also known as life cycle analysis, is a technique to systematically identify resource flows and environmental impacts associated with all the stages of product/service provision [18]. The LCA provides a quantitative cradle-to-grave analysis of the product/services global environmental costs (i.e., from raw materials through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). The demand for LCA data and tools has accelerated with the growing global demand to assess and reduce GHG emissions from different manufacturing and service sectors [18].

LCA can be used as a tool to study the impacts of a single product to determine the stages of its life cycle with most impact. LCA is often used as a decision support when determining the environmental impact of two comparable products or services.

50.3.3.1 Four Stages of LCA

The LCA standards, ISO 14040 and 14044 [19], follow a process with four distinct phases:

1. *Goal and scope definition*: It is important to ask the right question to ensure whether the LCA is successful. The first step in this process is the framing of the key questions for the assessment. Typical steps are to define the goal(s) of the project, determine what type of information is needed to inform decision makers, define functional units (environmental impact, energy efficiency, life span, cost per use, etc.), define the system boundaries, study perspective, allocation principles, environmental impact assessment categories, and level of detail.
2. *Inventory analysis*: The second phase involves data collection and modeling of the product/service system with process flow models and inventories of resource use and process emissions. The data must be related to the functional unit defined in the goal and scope definition and include all data related to environmental (e.g., CO_2) and technical (e.g., intermediate chemicals) quantities for all relevant unit processes within the study boundaries that compose the product system. Examples of inputs and outputs include materials, energy, chemicals, air emissions, water emissions, solid waste, radiation, or land use. This results in a life cycle inventory that provides verified information about all inputs and outputs in the form of elementary flows to and from the environment from all the unit processes involved in the study.
3. *Impact assessment*: The third phase evaluates the contribution to selected impact assessment categories, such as “Climate Change,” “Energy Usage,” and “Resource Depletion.” Impact potential of the inventory is calculated and characterized according to the categories. Results can then be normalized across categories (same unit) and weighted according to the relative importance of the category.
4. *Interpretation*: The final phase involves interpretation of the results to determine the level of confidence and to communicate them in a fair, complete, and accurate manner. This is accomplished by identifying the data elements that contribute significantly to each impact category, evaluating the sensitivity of these significant data elements, assessing the completeness and consistency of the study, and drawing conclusions and recommendations based on a clear understanding of how the LCA was conducted and how the results were developed.

50.3.3.2 CRT Monitor vs LCD Monitor: Life Cycle Assessment

The U.S. Environmental Protection Agency’s Design for the Environment program conducted a comprehensive environmental LCA of a traditional cathode ray tube (CRT) and a newer LCD monitor. The objective of the study [20] was to evaluate the environmental and human health life cycle impacts of functionally equivalent 17-in. CRT and 15-in. LCD monitors. The study assessed the energy consumption, resources input, and pollution produced over the lifetime of the equipment. The cradle-to-grave analysis was divided into three stages: (1) cradle-to-gate (manufacturing), (2) use, and (3) end-of-life (disposing or reusing). Each stage was assessed for the energy consumed, materials used in manufacturing along with associated waste. Components manufactured in different locations, where energy sources can differ due to the way local energy is produced, such as coal vs. nuclear, were taken into account. A sample of the results from a life cycle environmental assessment is presented in Table 50.1.

In summary, the LCA concluded that LCD monitors are about 10 times better for resource usage and energy use and 5 times better for landfill use. However, LCDs are only 15% better for global warming due to the fact that the LCD manufacturing process uses sulfur hexafluoride, a significant GHG.

TABLE 50.1 Life Cycle Analyses of CRT and LCD Monitors

	17″ CRT	15″ LCD
Total input material	21.6 kg	5.73 kg
Steel	5.16 kg	2.53 kg
Plastics	3 lb	1.78 kg
Glass	0.0 kg	0.59 kg
Lead-oxide glass	9.76 kg (0.45 lb of lead)	0.0 kg
Printed circuit boards (PCBs)	0.85 kg	0.37 kg
Wires	0.45 kg	0.23 kg
Aluminum	0.27 kg	0.13 kg
Energy (in manufacturing)	20.8 GJ	2.84 GJ
Power drawn	126 W	17 W
Energy (use—5 years' full power)	2.2 GJ	850 MJ

50.4 IT for Green Practices

50.4.1 Green Information Systems

As sustainable information is needed at both the macro and micro levels, it will require a multilevel approach that provides information and metrics that can drive high-level strategic corporate/regional sustainability plans, as well as low-level actions like improving the energy efficiency of an office worker. Relevant and accurate data, information, metrics, and Green Performance Indicators (GPIs) are important key to support sustainable practices, and the development of information systems that support this information need has led to the emergence of Green IS as a field in itself. There is substantial potential for Green IS to bring together business processes, resource planning, direct and indirect activities, and extended supply chains to effect positive changes across the entire activities of governments, organizations, and individuals. Green IS has been applied to a number of problems, from optimization of logistical networks [21], to buildings, DCs [12], and even cities. Within organizations, Green IS is the engine driving both the strategic and operational management of sustainability issues. Organizations pursuing a sustainability agenda will need to consider their Green IS to be a critical part of their operations [22]. This presents many challenges for Green IS research, and Melville [23] has outlined these under six themes:

1. *Context*: How do the distinctive characteristics of the environmental sustainability context, such as values and altruism, affect intention to use and usage of information systems for environmental sustainability?
2. *Design*: What design approaches are effective for developing information systems that influence human actions about the natural environment?
3. *Causality*: What is the association between information systems and organizational sustainability performance?
4. *New business models*: What is the association between IS and business models from an efficiency and environmental perspective?
5. *Systems approaches*: How can system approaches shed light on organizational and environmental outcomes that result from the use of IS for environmental sustainability?
6. *Models/metrics*: What are the multilevel models and metrics that encompass enterprise-wide sustainability initiatives?

50.4.1.1 Energy Informatics

The research field of energy informatics [22], a subfield of Green IS, recognizes the role that information systems can play in reducing energy consumption and thus CO_2 emissions. Energy informatics is concerned with analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems. The core idea requires the collection and analysis of energy data to support optimization of energy. Watson [22] expresses this as:

$$\text{Energy} + \text{Information} < \text{Energy}$$

The Energy Informatics Framework [22], as illustrated in Figure 50.6, addresses the role of the information systems in the management and optimization of energy. The key components of the framework are as follows:

Supply and demand: There are two parties to any energy consumption transaction: a supplier and a consumer. Both sides have a common need for information to manage the flow of the resources they deliver and consume.

Energy system technologies: Three types of technology are present in an intelligent energy system:

1. *Flow network*: a set of connected transport components that supports the movement of continuous matter (e.g., electricity, oil, air, and water) or discrete objects (e.g., cars, packages, containers, and people).
2. *Sensor network*: a set of spatially distributed devices that reports the status of a physical item or environmental condition (e.g., air temperature, location of a mobile object) providing data that can be analyzed to determine the optimum use of a flow network.
3. *Sensitized object*: a physical good that a consumer owns or manages and has the capability to sense and report data about its use (i.e., GPS in a car). They provide information about the use of an object so that a consumer is better informed about the impact of the object on their finances and the environment. In addition, there needs to be remote control of the state of some sensitized objects so that suppliers and consumers can manage demand (i.e., smart appliances).

Information system: An information system ties together the various elements to provide a complete solution. It has several important functions from collecting data from the sensor network and feeding them into flow optimization algorithms, to transmitting data to automated controllers in the flow network to dynamically change a network based on the output of the optimization algorithms. The information system is also responsible for information provision to flow network managers, consumers, and governments about the consumption of resources. They can also enable consumers to automate or control object usage to reduce energy consumption.

Key stakeholders: The three most critical stakeholders in typical energy supply/demand systems are *suppliers* (provide energy/services, manage flow networks), *governments* (regulation), and *consumers* (user of the resource).

Eco-goals: The sustainability literature has identified three broad sustainability goals: *eco-efficiency* (ecological friendly competitively priced goods and services), *eco-equity* (social responsibility), and *eco-effectiveness* (working on the right products and services and systems).

The energy informatics framework provides a solid basis for managing different resource types with a Green IS (i.e., logistics [21]). Having discussed a number of sustainable IT practice, attention will now be turned to the challenges faced by IT organizations as they put sustainable IT best practice into action.

50.4.2 Sustainable IT in the Enterprise

To deliver on the promise of sustainable IT, IT organizations need to develop a sustainable IT capability to deliver benefits both internally and across the enterprise. However, due to the new and evolving nature of the field, few guidelines and guidance on best practices are available. Organizations face many challenges in developing and driving their overall sustainable IT strategies and programs as follows:

- The complexity of the subject and its rapid evolution
- The lack of agreed-upon and consistent standards

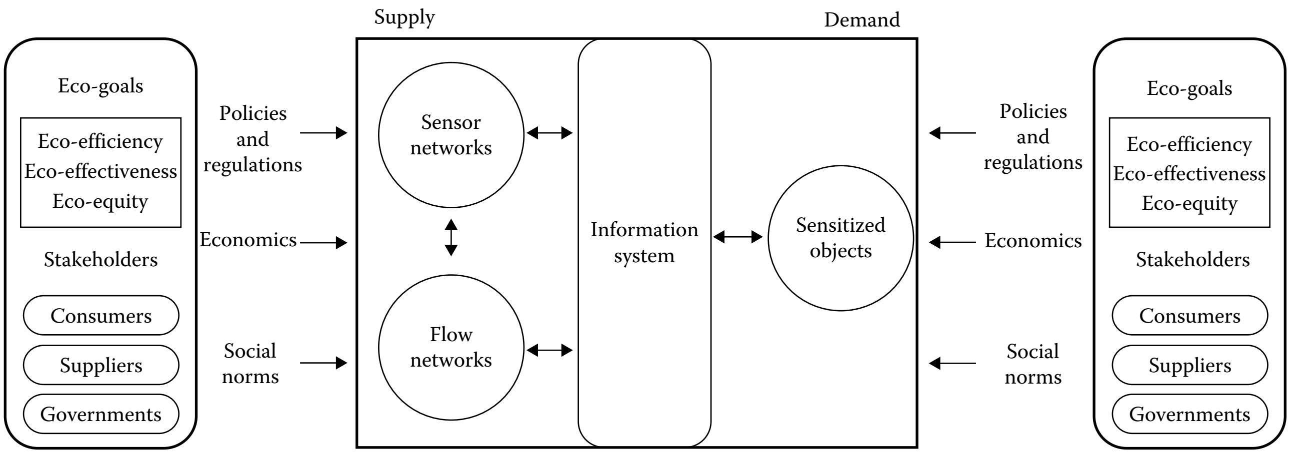


FIGURE 50.6 Energy informatics framework. (From Watson, R.T. et al., *MIS Quart.*, 34(1), 23, 2010.)

- Changing stakeholder expectations
- The lack of subject-matter expertise
- The need for new metrics and measures
- Evolving and increasing regulations and legislation around the world

Unfortunately, organizations often do not exploit IT's full potential in their efforts to achieve sustainability. Business and IT leaders frequently cannot find satisfactory answers to questions such as the following:

- Does the organization recognize IT as a significant contributor to its overall sustainability strategy?
- How is IT contributing to the organization's sustainability goals?
- What more could IT do to contribute to those goals?
- Are there clear measurable goals and objectives for sustainable IT?

IT departments face additional challenges specific to new IT methods and tools, industry metrics, and standards bodies as well as a general lack of relevant information such as power consumption quantifications. The challenge for IT departments is further complicated by the fact that sustainability is an enterprise-wide issue that spans the full value chain. The business is facing its own challenges in developing clear strategies and priorities to address a burning problem in such a dynamic and uncertain environment. It might lack the maturity to fully include sustainable IT in its efforts. This puts the onus on the IT organization to deliver sustainable IT benefits across the organization. In the remainder of this section, we examine two tools that can help an IT organization to develop a sustainable IT program: (1) a set of principles for Sustainable Enterprise IT and (2) the Sustainable Information Communication Technology-Capability Maturity Framework (SICT-CMF) from the Innovation Value Institute (IVI).

50.4.3 Sustainable IT Principles

In order to drive the adoption of sustainable IT, it is important for an IT organization to develop a clear set of IT sustainability principles for their activities. Sustainable IT principles are a set of aspirational statements to provide guidance on sustainable IT practices. An example of principles from the IT organization of Intel is described in Table 50.2 [24]. Within Intel IT, the principles play an important role in decision-making and are included in measurement models, standards, and processes. The criteria set out by the principles may also influence programs toward suppliers with sustainable business practices.

TABLE 50.2 Examples of Sustainable IT Principles from Intel IT

Principle	Example Actions
Consciously manage our capabilities	Include sustainability value and impacts in our proposals, measurements, and decision-making
Select sustainable suppliers	Work with our supplier managers to ensure our purchases represent and support sustainable business practices
Enable the organization to meet global sustainability compliance	Proactively monitor global regulations and requirements to ensure IT's and the organization's compliance
Measure, monitor, and optimize consumption	Reduce consumption and actively manage resources using sustainability metrics
Enable sustainable facilities	Work with Technology and Manufacturing Group (TMG) and Corporate Services (CS) to use IT capability to reduce resource consumption within TMG and CS IT capabilities to reduce resource consumption
Enable IT sustainability behavior	Create global awareness of IT sustainability that encourages IT employees to be corporate role models
Enable travel avoidance	Showcase all IT collaboration technologies across Intel
Promote IT's sustainability innovations across Intel and externally	Support sustainability innovations in our IT solutions and share those successes across Intel and externally

50.4.4 Capability Maturity Framework for Sustainable Information Communication Technology

The SICT-CMF gives organizations a vital tool to manage their sustainability capability [25,26]. The framework provides a comprehensive value-based model for organizing, evaluating, planning, and managing sustainable information communication technology (ICT) capabilities. The framework targets the broader scope of ICT to include communication technologies such as online collaboration tools, video conferencing, and telepresence, which can have positive impacts on sustainability (i.e., reduce business travel). Using the framework, organizations can assess the maturity of their SICT capability and systematically improve capabilities in a measurable way to meet the sustainability objectives. The SICT-CMF offers a comprehensive value-based model for organizing, evaluating, planning, and managing SICT capabilities, and it fits within the IVI's IT-CMF [27]. The SICT-CMF complements existing approaches for measuring SICT maturity, such as the G-readiness framework (which provides a benchmark score against SICT best practices [28,29]) or the Gartner Green IT Score Card (which measures corporate social responsibility compliance).

The SICT-CMF assessment methodology determines how SICT capabilities are contributing to the business organization's overall sustainability goals and objectives. This gap analysis between what the business wants and what SICT is actually achieving positions the SICT-CMF as a management tool for aligning SICT capabilities with business sustainability objectives.

The framework focuses on the execution of four key actions for increasing SICT's business value:

- Define the scope and goal of SICT
- Understand the current SICT capability maturity level
- Systematically develop and manage the SICT capability building blocks
- Assess and manage SICT progress over time

50.4.4.1 Defining the Scope and Goal

First, the organization must define the scope of its SICT effort. As a prerequisite, the organization should identify how it views sustainability and its own aspirations. Typically, organizational goals involve one or more of the following:

- Develop significant capabilities and a reputation for environmental leadership.
- Keep pace with industry or stakeholder expectations.
- Meet minimum compliance requirements and reap readily available benefits.

Second, the organization must define the goals of its SICT effort. It is important to be clear on the organization's business objectives and the role of SICT in enabling those objectives. Having a transparent agreement between business and IT stakeholders can tangibly help achieve those objectives. Significant benefits can be gained even by simply understanding the relationship between business and SICT goals.

50.4.4.2 Capability Maturity Levels

The framework defines a five-level maturity curve [26] for identifying and developing SICT capabilities (Figure 50.7):

1. *Initial*: SICT is ad hoc; there is little understanding of the subject and few or no related policies. Accountabilities for SICT are not defined, and SICT is not considered in the systems life cycle.
2. *Basic*: There is a limited SICT strategy with associated execution plans. It is largely reactive and lacks consistency. There is an increasing awareness of the subject, but accountability is not clearly established. Some policies might exist but are adopted inconsistently.

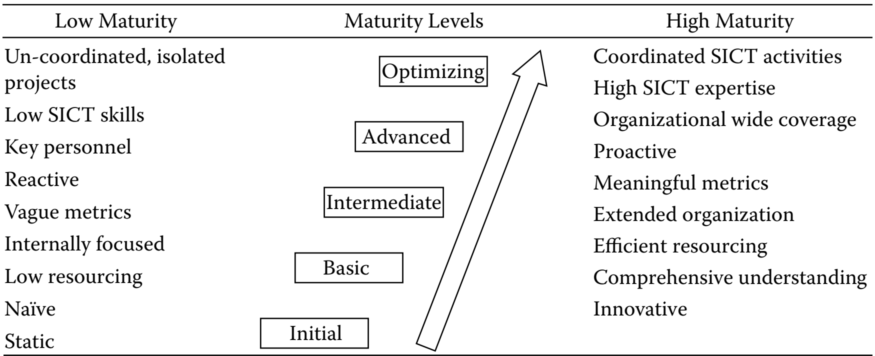


FIGURE 50.7 Comparison of low and high maturity of SICT.

3. *Intermediate*: An SICT strategy exists with associated plans and priorities. The organization has developed capabilities and skills and encourages individuals to contribute to sustainability programs. The organization includes SICT across the full systems life cycle, and it tracks targets and metrics on an individual project basis.
4. *Advanced*: Sustainability is a core component of the IT and business planning life cycles. IT and business jointly drive programs and progress. The organization recognizes SICT as a significant contributor to its sustainability strategy. It aligns business and SICT metrics to achieve success across the enterprise. It also designs policies to enable the achievement of best practices.
5. *Optimizing*: The organization employs SICT practices across the extended enterprise to include customers, suppliers, and partners. The industry recognizes the organization as a sustainability leader and uses its SICT practices to drive industry standards. The organization recognizes SICT as a key factor in driving sustainability as a competitive differentiator.

This maturity curve serves two important purposes. First, it is the basis of an assessment process that helps to determine the current maturity level. Second, it provides a view of the growth path by identifying the next set of capabilities an organization should develop to drive greater business value from SICT. A contrast of low and high levels of sustainable ICT is offered in Figure 50.1.

50.4.4.3 SICT Capability Building Blocks

While it is useful to understand the broad path to increasing maturity, it is more important to assess an organization's specific capabilities related to SICT. The SICT framework consists of nine capability building blocks (see Table 50.3) across the following four categories:

1. *Strategy and planning,* which includes the specific objectives of SICT and its alignment with the organization's overall sustainability strategy, objectives, and goals
2. *Process management,* which includes the sourcing, operation, and disposal of ICT systems, as well as the provision of systems based on sustainability objectives and the reporting of performance
3. *People and culture,* which defines a common language to improve communication throughout the enterprise and establishes activities to help embed sustainability principles across IT and the wider enterprise
4. *Governance,* which develops common and consistent policies and requires accountability and compliance with relevant regulation and legislation

The first step to systematically develop and manage the nine capabilities within this framework is to assess the organization's status in relation to each one.

The assessment begins with the survey of IT and business leaders to understand their individual assessments of the maturity and importance of these capabilities. A series of interviews with key stakeholders augments the survey to understand key business priorities and SICT drivers, successes

TABLE 50.3 Capability Building Blocks of SICT

Category	Capability Building Block	Description
Strategy and planning	Alignment	Define and execute the ICT sustainability strategy to influence and align to business sustainability objectives
	Objectives	Define and agree on sustainability objectives for ICT
Process management	Operations and life cycle	Source (purchase), operate, and dispose of ICT systems to deliver sustainability objectives
	ICT-enabled business processes	Create provisions for ICT systems that enable improved sustainability outcomes across the extended enterprise
	Performance and reporting	Report and demonstrate progress against ICT-specific and ICT-enabled sustainability objectives, within the ICT business and across the extended enterprise
People and culture	Adoption	Embed sustainability principles across ICT and the extended enterprise
	Language	Define, communicate, and use common sustainability language and vocabulary across ICT and other business units, including the extended enterprise, to leverage a common understanding
Governance	External compliance	Evangelize sustainability successes and contribute to industry best practices
	Corporate policies	Enable and demonstrate compliance with ICT and business sustainability legislation and regulation. Require accountability for sustainability roles and decision-making across ICT and the enterprise

achieved, and initiatives taken or planned. In addition to helping organizations understand their current maturity level, the initial assessment provides insight into the value placed on each capability, which will undoubtedly vary according to each organization's strategy and objectives. The assessment also provides valuable insight into the similarities and differences in how key stakeholders view both the importance and maturity of individual capabilities and the overall vision for success.

Figure 50.8 shows an example of consolidated survey results, resulting in an overall maturity level for each capability building block. This organization is close to level-three maturity overall but is less mature in some individual capabilities. It views alignment and objectives under the strategy and planning category as the most important capability building blocks, but it has not achieved level-three maturity in these areas. It also views operations and life cycle as important capabilities, but its maturity level for that building block is even lower (level 2.4).

50.4.4.4 Assessing and Managing SICT Progress

With the initial assessment complete, organizations will have a clear view of current capability and key areas for action and improvement. However, to further develop SICT capability, the organization should assess and manage SICT progress over time by using the assessment results to:

- Develop a roadmap and action plan
- Add a yearly follow-up assessment to the overall IT management process to measure over time both progress and the value delivered from adopting SICT

Agreeing on stakeholder ownership for each priority area is critical to developing both short-term and long-term action plans for improvement. The assessment results can be used to prioritize the opportunities for quick wins—that is, those capabilities that have smaller gaps between current and desired maturity and those that are recognized as more important but might have a bigger gap to bridge.

The assessment of sustainable IT was carried out in a number of global firms over the last 2 years. The assessment methodology included interviews with stakeholder from both the IT organizations and the business organization, including individuals involved with IT and corporate sustainability programs. The average results for the SICT maturity of the examined organizations are presented in Table 50.4.

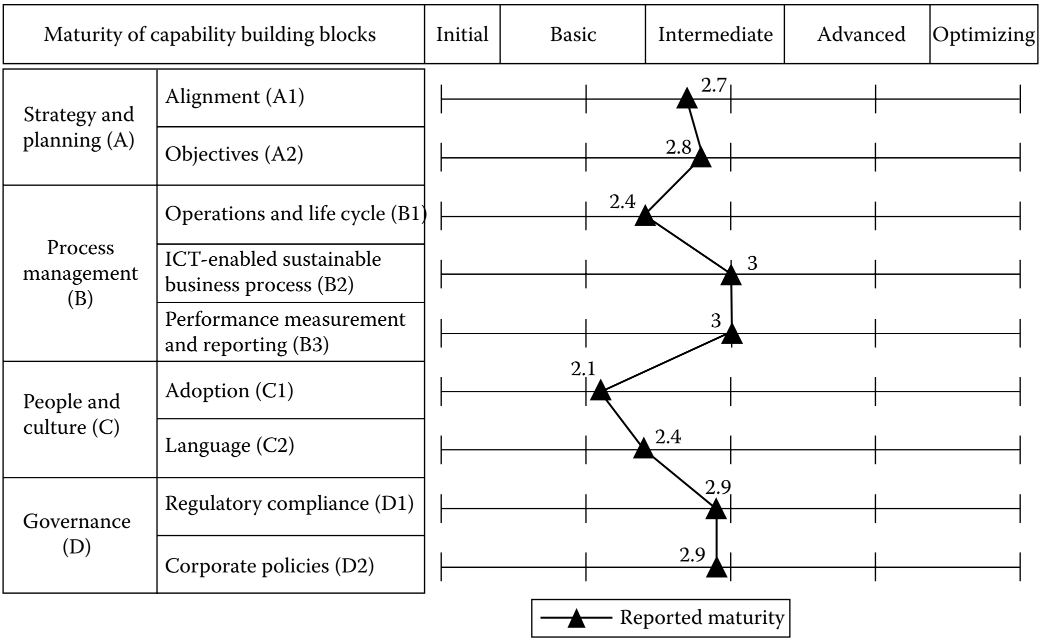


FIGURE 50.8 Aggregated result for the current maturity level from the assessment.

TABLE 50.4 Average SICT Maturity

Category	Capability	AVR CBB	Low	High	Diff	AVR Cat
Strategy and planning	Alignment	2.61	2.38	3.2	0.82	2.51
	Objectives	2.41	2.08	2.8	0.72	
Process management	Operations and life cycle	2.46	2.32	2.8	0.48	2.52
	ICT-enabled business processes	2.70	2.5	3	0.5	
	Performance and reporting	2.40	1.2	3	1.8	
People and culture	Adoption	2.03	1.89	2.3	0.41	2.18
	Language	2.33	2	2.9	0.9	
Governance	External compliance	2.19	1.8	2.9	1.1	2.24
	Corporate policies	2.28	1.4	2.9	1.5	

50.5 Research Directions

Many organizations think that sustainability requires a significant transformational change, yet the ultimate goal is to embed sustainability into business-as-usual activities. Improving sustainability performance [26], especially through changing the way an organization operates, requires a number of practical steps that will include the need for a systematic approach for information-gathering and analysis [30].

While organizations are fighting a data deluge within their information systems [31], there is a significant lack of data on sustainability concerns. A 2010 survey of more than 600 chief information officers and senior IT managers highlighted that few organizations are performing well at measuring the effectiveness of their sustainability efforts [29]. The paucity of sustainable information within organizations is a significant challenge and one that needs to be addressed if sustainable IT efforts are to deliver on their potential. Determining the granularity for effective sustainable data is not well understood, and research is needed to define the appropriate level of usefulness [22]. The appropriateness of information will also be highly dependent on the stakeholders and the task or decision at hand. Sustainable IT will need to be flexible to provide the appropriate level of information for the given situation.

Emerging next-generation smart environments such as Smart Grids, Smart Cities, and Smart Enterprises are complex systems that require a complete and holistic knowledge of their operations for effective decision-making. Multiple information systems currently operate within these environments and real-time decision support will require a system of systems (SoS) approach to provide a functional view of the entire environment to understand, optimize, and reinvent processes. The required SoS will need to connect systems that cross organizational boundaries, come from multiple domains (i.e., finance, manufacturing, facilities, IT, water, traffic, waste, etc.), and operate at different levels (i.e., region, district, neighborhood, building, business function, individual). These SoS pose many significant challenges, including the need for flexible mechanisms for information interoperability that require overcoming conceptual barriers (both syntax and semantic) and technological barriers. Overcoming these challenges will require rethinking the design and approach to interoperability of green information systems using decentralized information management approaches such as Semantic Web and Linked Data [32].

50.6 Summary

The first wave of sustainable IT focused on the Greening of IT (i.e., software, DCs, etc.), and the next wave of sustainable IT will tackle the broad sustainability issues outside of IT (i.e., energy management, logistics, etc.). Sustainability requires information on the use, flows, and destinies of energy, water, and materials including waste, along with monetary information on environment-related costs, earnings, and savings. There is substantial potential for sustainable IT to bring together business processes, resource planning, direct and indirect activities, and extended supply chains to effect positive changes across the entire activities of governments, organizations, and individuals.

Glossary

Energy: A physical quantity that describes the amount of work that can be performed by a force. A device that is energy efficient requires less energy for its "work" or task than its energy-inefficient counterpart. Energy can be expressed in units such as Joules.

Heat: Resistive heat is a natural by-product of running current through a conductor. Heat is a form of energy, and engineers strive to minimize heat release in computer design to minimize the need for cooling (typically by a fan).

Joule: Standard unit of energy measurement or work in the International System of Units.

Power: The rate at which energy is transferred, used, or transformed per unit of time. Within IT, power is typically measured in Watts, where a Watt equals 1 J/s. For example, a light bulb rated at 60 W consumes 60 J in 1 s.

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Further Readings

- *IEEE IT Professional*, Special issue on Green IT 13(1): The January/February 2011 issue of IT Professional focused on Green IT and its transition toward sustainable IT. Articles focus on topics including sustainable IT, assessment of Green IT practices, power consumption of end-user PCs browsing the web, and corporate strategies for Green IT.

- *Harnessing Green IT: Principles and Practices,* (2012) S. Murugesan and G. R. Gangadharan (eds.), Wiley—IEEE, ISBN-10: 1119970059: This book presents and discusses the principles and practices of making computing and information systems greener—environmentally sustainable—as well as various ways of using information technology (IT) as a tool and an enabler to improve the environmental sustainability. The book comprehensively covers several key aspects of Green IT—green technologies, design, standards, maturity models, strategies, and adoption—and presents holistic approaches to greening IT encompassing green use, green disposal, green design, and green manufacturing.
- *Green Business Process Management–Towards the Sustainable Enterprise*, (2012), J. vom Brocke, S. Seidel, and J. Recker (eds.), Springer, ISBN-10: 3642274870. This volume consolidates the state-of-the-art knowledge about how business processes can be managed and improved in light of sustainability objectives. This book presents tools and methods that organizations can use in order to design and implement environmentally sustainable processes and provide insights from cases where organizations successfully engaged in more sustainable business practices.
- IT@Intel: IT Best Practices: (http://www.intel.com/content/www/us/en/it-management/intel-it/intel-it-best-practices.html) The IT @ Intel best practices portal gives insights into how an IT department can be run like a business, enabling the organization to take advantage of new technologies. In addition to general IT topics, white paper covers topics on data center energy efficiency, sustainable IT roadmaps, smart buildings, and Green Software.
- *Green IT/Sustainable IT columns in IEEE Computer and IEEE Intelligent Systems*: At the time of writing, both IEEE Computer and IEEE Intelligent Systems had regular columns dedicated to Green IT and sustainable IT. These columns covered many topics including, energy management, server power management, energy awareness, Green Software, and consumption-based metrics.

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