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The Role of Data Centers in Advancing Green IT: A Literature Review

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Abstract

The explosion in data consumption and data generation has led to expansion of data centers, which are significant stakeholders in obtaining sustainability. This paper investigates what role data centers can play in advancing sustainability and green IT by performing a literature review. The purpose of the review was to provide a holistic framework that can help to position current and new research on the factors influencing the implementation of green IT in the data center. The review was limited to peer-reviewed journal articles and conference papers. The reviewed papers were analyzed by inductive content analysis, which created the five categories of 1) power savings, 2) cost savings, 3) sustainability and green energy, 4) information technology for greening data centers, and 5) aligning business requirements with resource utilization. Based on these categories, a framework describing how data center can contribute to green IT was created. Power savings and cost savings were found to influence as well as contribute to choices and development of information technology for greening data centers. Also, the categories of sustainability and green energy and alignment of business requirements of business utilization have a bi-directional relationship with information technology used in data centers. The findings further indicate that there is a need to study the alignment of business requirements with resource utilization due to a lack of publications in this area.

Keywords: Data center, Green IT, Green IS, Sustainability, Literature review

1. Introduction

In 1987, the Brundtland Commission proposed sustainable development to comprise of three pillars; social, economic and environmental sustainability (Brundtland, 1987). According to Murugesan and Gangadharan (2012), green IT is an economic, technical as well as environmental imperative. The concept of green IT "denotes all activities and efforts incorporating ecologically friendly technologies and processes into the entire lifecycle of information and communication technology" (Hedwig et al., 2009, p. 2). There is sometimes an overlap between the concept of green IT and other concepts, such as green IS (information systems) and sustainability.

Green IT refers to "the direct impact of energy consumption and waste associated with the use of hardware and software" (Boudreau et al., 2008). Green IS, on the other hand, refer to "environmental systems that can be developed with or without green IT to support sustainability initiatives" (Boudreau et al., 2008; Jenkin et al., 2011). Other researchers attempt to separate Green IT from Green IS (Brooks et al., 2012; Erek et al., 2012) while some regard green IT as a part of Green IS (Brooks et al., 2012; Melville, 2010). Other authors use these terms synonymously (Huang, 2008; Mithas et al., 2010). Based on a structured literature review, Chasin (2014, p. 348) defines sustainability in information systems as a: "characteristic of a stakeholder activity (organizational process or individual behaviour), which impacts on natural and social environments and meets the (economic) needs of the present without compromising the ability of future stakeholders to meet their needs." According to Chasin (2014), the central implication of this definition is a need to analyze ecological, economic and social dimensions at the activity level of the stakeholder.

The Brundtland commission (1987) formulated the definition on sustainability which has become the most widely adopted definition on research in sustainability. The present scientific discourse on sustainability in information systems appears marginal in comparison to other disciplines such as engineering, mining etc. (Penzenstadler, 2013; Dovers, 1989; Brown et al., 1987; Owens, 2003; Kuhlman and Farrington, 2010; White, 2013; Glavic and Lukman, 2007).

Simmonds and Bhattacherjee (2012) state that environmental sustainability research in IS is sparse. Some IS researchers have developed frameworks in their research on environmental sustainability in IS. Some of the most notable are the energy informatics framework developed by Watson et al. (2010), a conceptual model on four key environmental issues and six stakeholder categories by Elliot (2011) and the Belief Action Framework (BAO) by Melville (2010).

Previous literature reviews on green IT and green IS has focused on:

i. Overlaps and differences between green IT practitioners and academic literature (Brooks et al., 2010);
ii. Investigating a taxonomy of corporate social responsibility, sustainability, stakeholders, environment, green IS and green IT (Marrone et al., 2011);
iii. Summarizing the existing research field and research gaps (Esfahani et al., 2014);
iv. A taxonomy of segments of green IT publications (Tushi et al., 2014);
v. Green IT/IS adoption (Lei and Ngai, 2013; Esfahani et al., 2015).
vi. Organizational research on green IT, focusing on research questions and gaps in current research (Asadi et al., 2017).

Information systems research has been responsible for increasing productivity in the later part of the last century. Much research has gone into design, development, adoption, usage, diffusion, maintenance and retirement of old systems. While organizations were busy with development and adoption of IS, they are also equally guilty of inefficiency and wastage. Therefore, it is the responsibility of the community to reduce wastage and increase initiatives that can support environmental sustainability (Watson et al., 2010). IS can shape the beliefs of individuals and organizations in improving environmental and economic performance (Melville, 2010). However, the current body of knowledge on Green IT does not provide enough information on how various actors and resources interrelate to create a successful Green IT practice (Ijab et al., 2012).

The explosion in data consumption and data generation has led to expansion of data centers. This has also started increasing the overhead on the existing data centers with the need to adapt to new technologies and new infrastructure. The facility management in charge of space, electricity usage and cooling are determined by the IT operations and business processes in the organization. Green IT as a concept needs to be implemented throughout the data center in a lifecycle starting from sourcing, building and use to disposal. Data centers are thus significant stakeholders in ecological sustainability as stated by Chasin (2014). To the best of our knowledge, no research article so far has focused on reviewing the role of data centers in advancing green IT. Thus, this study aims to fill a research gap.

Consequently, the purpose of this paper is to provide a framework to position current research on the topic of how data centers can advance green IT. This is done to understand the position of the topic of data centers within the wider concept of Green IT.

The paper is structured as follows: First, the emergence of green IT within information systems research is presented and the concepts of green IT and data center are defined. Second, the methodology of the literature review is described. Third, the findings from the literature review are presented. Finally, the conclusions from the literature review are presented and discussed, as well as limitations of the present study and suggestions for further research.

2. Theoretical Background

2.1 Green IT

Green information technology is an important domain of green information systems as the use of environmentally sustainable information technologies facilitates informed decision making. Green IT is at the growth stage in developed countries and at the infancy stage in developing countries (Molla and Cooper, 2014). It is against this backdrop that the concept of green IT has been gathering importance. As per Murugesan and Gangadharan (2012, p. xxxii): "green IT refers to information technology, systems and applications that contains three complementary IT-enabled approaches which help to improve environmental sustainability. They (i) minimize the energy consumption and environmental impact of computing resources over their life cycle; (ii) harness the power of IT and information systems to empower – that is to support, assist and leverage - other environmental initiatives by businesses and (iii) leverage IT to help create awareness among stakeholders and promote green agenda and green initiatives". In addition, there exists an economic incentive in trying to adopt green IT processes as it can reduce operation costs and increase revenue from data center operations. Government mechanisms and taxes would increase demand for green IT services while forcing organizations to adhere to strict norms. Another definition of green IT could be a reference to environmentally friendly information systems, applications and practices (Murugesan, 2008).

The emergence of Green IT within IS research has been slow as the IS academic community took time to acknowledge the problem of environmental sustainability and act (Watson et al., 2010). The authors further suggest the need for a separate subfield of study called energy informatics that can investigate how IS can contribute in reducing energy consumption and carbon dioxide emissions.

The concepts of green IT and environmental sustainability are interlinked by the fact that green IT facilitates environmental sustainability. It consists of three IT enabled approaches that complement each other. These approaches help improve environmental sustainability (Murugesan, 2008). They are:

i. The entire cycle involving efficient and effective design, manufacture, use and disposal of computing hardware, software and communication systems in such a way that there is minimum impact on environment (Murugesan and Gangadharan, 2012).
ii. To use information technology and information systems to empower other enterprise wide environmental initiatives (Murugesan and Gangadharan, 2012).

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iii. Harnessing IT to create awareness among stakeholders and promote green agenda and initiatives.

The focus of this paper is on the impact of data centers on Green IT. A brief background on data centers would help to understand why data centers are important in the context of green IT.

2.2 Data Centres

A data center is "a department in an enterprise (organization), which houses and maintains back-end information technology (IT) systems and data stores—its mainframes, servers and databases." (Gartner, 2013). This is the physical (infrastructure) definition of a data center. From an operational perspective, a data center can be defined as a place that processes business transactions, host websites, process and stores intellectual property, maintains financial records and routes e-mails. In other words, a data center can be considered as the brain of the company (Khasawneh, 2015).

Market and industry trends are driving enterprises to look beyond traditional technology infrastructure silos and transform their business processes. Many enterprises are looking to virtualization, fabric-based infrastructure, modular designs and cloud computing to find the best strategy to optimize resources (Gartner, 2013).

Data centers have evolved since the days of their inception. In the current scenario with most operations moving online and into cloud services, most data centers of large corporations, such as Facebook and Twitter, that deals with large amounts of data fall into the category of enterprise data centers. Traditional organizations who own smaller data centers or smaller data rooms would like to either consolidate their data rooms or outsource their data centre operations to third party hosting service providers or improve the efficiency of their existing data rooms (Uptime Institute, 2016). The energy consumption of these data centers in the case of both electricity and cooling is equivalent to the energy needed to power a small city (Uddin and Rahman, 2012a). This has created a need for green data centers. The need for greening data centers or green data centers is defined as an ongoing process towards making data centers energy efficient, while ensuring that electricity and cooling are driven by sustainable resources. Data centers alone consume almost 1.5% of the total energy that is consumed worldwide. The impact of carbon dioxide emissions on climate change and the rapid concentration of IT services in data centers have raised questions about their energy sustainability (Koomey, 2011). Energy consumption is a significant share of data center costs. Thus, to save energy is a necessity for data centers to save costs. Regulations are also being established worldwide to limit corporate emissions, and to promote power generation and procurement from renewable energy sources.

The evolution of data centers can be better described through the categories of data centers also known as data center tier. This can be best illustrated by means of Fig. 1.

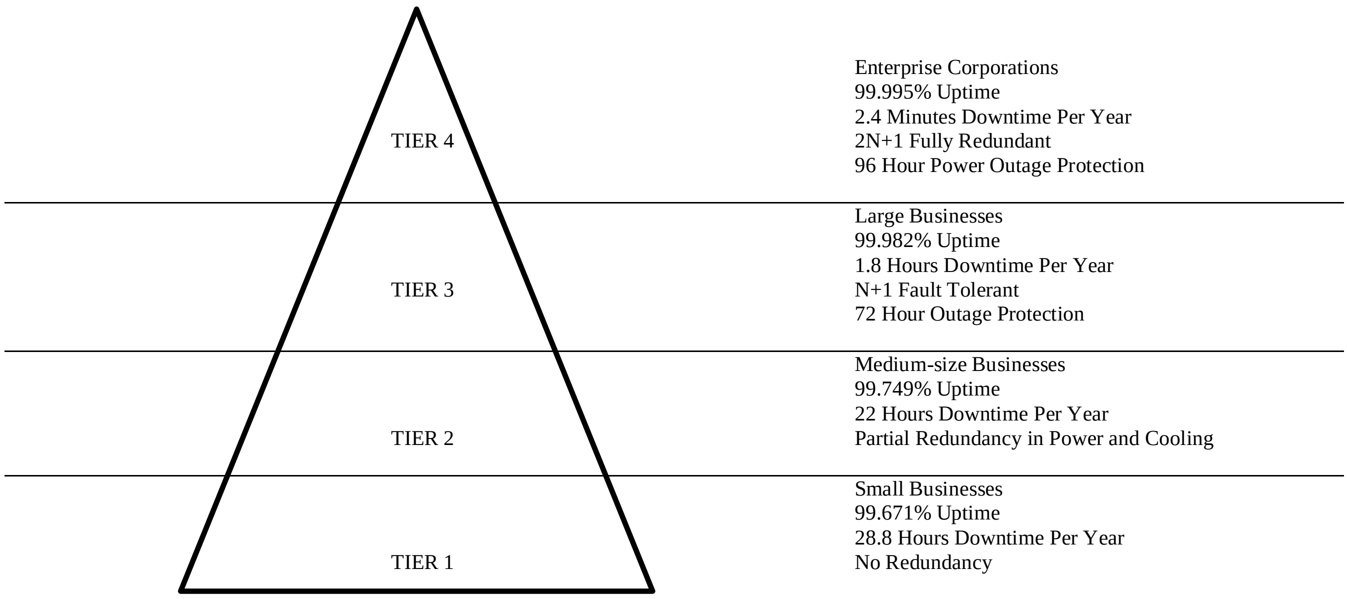

Fig. 1. Data Center Tiers (Uptime Institute, 2016).

This tier system can be explained as follows (Uptime Institute, 2016):

Tier I: Basic Capacity: Tier I data centers provide site infrastructure beyond a regular office setting. It includes a dedicated space for IT systems; an uninterrupted power supply (UPS) to filter power spikes, sags, and momentary disruptions as well as cooling equipment around-the-clock and an engine generator to protect from extended power outages.

Tier II: Redundant Capacity Components Tier II facilities include such as UPS modules, chillers or pumps, and engine generators to increase the margin of safety against IT process disruptions resulting from site infrastructure equipment failures.

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Tier III: Concurrently Maintainable Tier III data center requires no shutdowns for equipment replacement and maintenance. In addition to the functions of Tier II, there is redundant delivery path for power and cooling. This means that all s needed to support the IT processing environment can be shut down and maintained without interrupting IT operations.

Tier IV: Fault Tolerance Tier IV site infrastructure builds on Tier III, adding the concept of Fault Tolerance, which means that when equipment failures or distribution path interruptions occur, the impact of the events is stopped short of the IT operations.

Data center infrastructure costs and complexity increase with Tier Level, and the data center management must take a decision which Tier Level that fits their needs. There needs to be a match between the data center infrastructure and the business application, otherwise companies can overinvest or take risks regarding costs and environmental impact. In the present scenario with most operations moving online and into cloud services, most data centers of large corporations that deals with large amounts of data fall into Tier 4 category. The greening of data centers has been happening in the Tier 4 category as these data centers are capable of consuming energy needed to power a small city (Uddin and Rahman, 2012b).

This classification is based on the facility perspective of data centers. The facility management is responsible for the power distribution and management, Coolers, chillers and space management in the data centers. The reason for doing this was that data centers remained in the domain of facility management teams. Currently, after the massive explosion of data and development of new technologies data centers are changing into software defined data centers. An SDDC is a data center in which all the infrastructure is virtualized and delivered "as-a-service" (Gartner, 2013). This means that the focus of operations is changing from a hard ware perspective to a software perspective. The physical infrastructure of network, storage and servers is available as logical units.

3. Methodology

The purpose of the review is to provide a holistic framework that can help to position current and new research on the factors influencing the implementation of green IT in the data center. To categorize research articles, a concept-centric matrix based on Webster and Watson (2002) was used. The source of the literature review was Scopus database. The review was limited to peer-reviewed journal articles and conference papers. The search terms used were "green IT + data center", "green IS + data center", "Sustainability IT + data center", and "Sustainable IS + data center". The maximum search results were obtained by using "Green IT + data center". The other search criteria gave results that can be considered as a subset of the search results of "Green IT + data center". This reveals that the terms green IS, sustainable IT and sustainable IS are embedded within Green IT. The total number of peer reviewed journals and peer reviewed conference articles that could be obtained using the search term Green IT + data center was one hundred and eleven (111). The table below presents the search results based on different search criteria.

Table 1
Search terms used in the literature review.

Search terms	Number of peer-reviewed journal articles	Number of peer-reviewed conference articles
Green IT + data center	45	65
Green IS + data center	3	6
Sustainable IT + data center	2	9
Sustainable IS + data center	0	0
Sustainable IT	163	106
Sustainable IS	155	77

There are two important aspects regarding writing a literature review per Webster and Watson (2002). In the case of a mature topic in which extensive research has been done an extensive body of knowledge has been created that needs analysis and synthesis. A thorough literature review would help to produce a conceptual model that can extend existing research. The other aspect would be to tackle an emerging issue whose theoretical foundations can help create a conceptual model. As the search term of green information technology and data center yielded maximum results, the authors decided to continue with these terms. Further, it can be said that the result of the other terms such as green IS, sustainable IS and sustainable IT lie within the scope of Green IT and data centers. The search within Scopus data base automatically extends to others such as ABI/INFORM, Springer and the search results were similar. This could be attribute to the fact that most authors used the two concepts of Green IT and Green IS interchangeably. The data base was generated for the period between 2008 and 2015. 45 peer-reviewed journal articles (see Table 1 in Appendix A) and 65 peer-reviewed conferences articles (see Table 2 in Appendix A) were included in the literature review.

Based on the research question "How can data centers advance green IT?" an inductive content analysis (Elo and Kyngäs, 2008; Graneheim and Lundman, 2004) was performed. Meaning units and codes were identified from the articles to create categories corresponding to the concepts in the matrix as per Webster and Watson (2002). In Table 2, examples of meaning units, codes and categories from the content analysis are presented.

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4. Findings

The inductive content analysis of the article resulted in five main categories; 1) power savings, 2) cost savings, 3) sustainability and green energy, 4) information technology for greening data centers, and 5) aligning business requirements with resource utilization. The full concept-centric matrices describing what articles belong to what categories and subcategories is presented in Tables 1 and 2 in Appendix A. Table 3 summarizes the findings from the literature review. The categories and subcategories will be described in detail in the following sections, with examples of articles within each category.

4.1 Power savings

One of the objectives of any data center is to use power efficiently, which would result in power savings. The articles within this category fall into the three subcategories of Renewable energy and waste heat usage (3 articles), Power management/energy efficiency/cooling (68 articles), and Performance metrics (14 articles). Most articles fall into the subcategory of Power management/energy efficiency/ cooling (68 out of 86). Aslekar and Damle (2015) investigate the need for new types of data center design that can help to optimize energy consumption and bring in operation excellence. Cameron (2014) identify the challenges faced by data centers in power management while Carter and Rajamani (2010) describe the conflicts involved in hardware and software designs at different levels that need to be overcome by co-design to improve efficient usage of power in the data center. Drenkelfort et al. (2015) present an alternative cooling option for data centers that can reduce energy consumption. Similarly, the paper by Tae et al. (2014) discusses how data center cooling efficiency can be increased by managing the air circulation in an effective manner. Sarood et al. (2012) discusses about cooling energy consumption and reducing hot spot formation. Bagci (2014) investigate power management in cloud servers while Beloglazov and Buyya (2012) discuss the need for designing algorithms that will help in power management. Berral et al. (2010) propose a machine learning algorithm for energy aware scheduling in data centers.

Performance metrics is another important aspect of power savings as most data center operators as well as government bodies use metrics to monitor data center energy consumption. Performance metrics are indicators of the health and efficiency of a data center. Pawlish et al. (2014) discuss metrics such as server energy usage, power usage effectiveness and utilization rate, i.e., the extent to which the servers are used in the data centers. Schott and Emmen (2011) study metrics such as carbon footprint and power usage effectiveness. The metric carbon footprint is related to power consumed and energy dissipated by the data center. Hence it is directly related to power savings. Seegolam and Usmani (2014) present the EU code of conduct for data centers. They describe a set of metrics which could be used in the early stage of the greening process. Finally, Uddin et al. (2014a) describe power usage efficiency as a metric to measure the performance of a data center.

The issue of renewable energy (electricity from renewable sources of energy and waste heat usage) is the smallest subcategory. Goth (2010) is the only journal article that discusses the challenges of renewable energy generation for data centers. Janacek et al. (2014) explore renewable energies and waste heat usage while Klingert et al. (2012) describe smart grids for energy generation.

4.2 Cost savings

The category of cost savings is divided into the subcategories of Energy pricing (29 articles) and Financial implications (32 articles). Energy prices depend on the source of energy and other economic parameters, while financial implications are the impact of actions taken to improve data center efficiency. Another aspect of financial implications is the increase in profit through adoption of new technologies and strategies in the data center.

Garg et al. (2011) describe how energy cost, workload, carbon emission rate and central processing unit power efficiency can change across different data centers depending on their location, architectural design, and management system. Liu et al. (2012) explain the use of sensors to monitor performance and reduce operation cost in the data center. Amokrane et al. (2015) describe how operation cost can be reduced, and cloud service provider's profit be increased. Sabbir Hasan and Huh (2013) suggest reduction in operation cost through consolidation of virtual machines in cloud data centers. Uddin et al. (2012b) explain the need for maximizing energy utilization to reduce the total cost of ownership in the data center. Berral et al. (2010) proposes a framework for optimizing profit and reducing power consumption cost. Bodenstein et al. (2011) presents mathematical models to work on the energy consumption cost of data centers. Gu et al. (2012) provide a model to link green strategies with economic impact to reduce costs, while Hertel and Wiesent (2014) propose a business case on cost and energy saving for investment in green data centers. Moghaddam et al. (2012) propose an algorithm for operation cost reduction in the data center. Vodel et al. (2015) explain that the respective trade-off between power consumption and cooling capacity results in significant cost savings.

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Table 2
Examples of meaning units, codes and categories.

Meaning unit	Code	Category
We have designed an initial set of indicators for energy-efficiency of e-services	Energy efficiency.	Power savings.
The scheduler can decrease energy costs by up to 39%.	Decrease energy costs.	Cost savings.
Green IT framework for promoting green energy efficient data centers.	Green energy efficient data centers.	Sustainability and green energy.
Server consolidation algorithm for live migration of virtual machines.	Algorithm.	Information technology for greening data centers.

Table 3
Summary of literature review per category and subcategory.

Category	Subcategories	Journal articles	Conference articles	Total subcategory	Total category
	Renewable energy and waste heat usage	1	2	3	
Power savings	Power management/ energy efficiency/cooling	21	47	68	85
	Performance metrics	10	3	14	
Cost savings	Energy pricing	11	18	29	
	Financial implications	12	20	32	61
	Frameworks and models	10	21	31	
Sustainability and green energy	Bodies and organizations	8	10	18	
	Institutional motivations	7	15	22	126
	Carbon footprint reduction	18	37	55	
	Cloud computing	9	18	27	
	Network/storage/ infrastructure	5	2	7	
Information technology for greening data centers	Virtual machines/ virtualization	12	18	30	
	Algorithms, information systems, software	17	27	44	131
	IT infrastructure manufacturing and resource allocation	6	17	23	
Aligning business requirements with resource utilization	Improving service level efficiency	2	7	9	
	Business utilization	3	5	8	17

4.3 Sustainability and green energy

The category of Sustainability and green energy consist of four subcategories; Framework and models (31 articles), Bodies and organizations (18 articles), Institutional motivation (22 articles), and Carbon footprint reduction (55 articles). This category addresses the organizational strategy to accomplishing green IT. It can be hypothesized that the other categories or subcategories are implemented through this category. These subcategories need to be implemented at the organizational, managerial level rather than at the individual department level.

Being an emerging topic, there were few articles taking a comprehensive view or developing theories or frameworks. Two exceptions from this were the articles by Alaraifi et al. (2011), and Molla and Cooper (2014). Alaraifi et al. (2011) investigated nineteen information systems used to automate data centers. The information systems were identified from five case studies and a review of existing practitioner literature, resulting in a characteristics-based framework for information systems in data centers. Molla and Cooper (2014) tested seven hypotheses about what drives the greening of data centers. Their findings showed that institutional forces created managerial expectations and thus influenced the development of organizational ability and actions leading to green IT in data centers, for example virtualization and cloud computing.

The article by Cigaric (2015) on big cloud infrastructures mentions all the four subcategories as well as the significance of stakeholders, such as governments, to implement green IT strategy in data centers. Gabriel (2008) focuses on the organizational processes and best practice framework that will standardize IT operations and facilitate Green IT. Gorge (2008) states that it is necessary to understand green IT to realize its full benefits in data centers. Kern et al. (2011) argue for the need for institutional and organizational motivations to implement green IT. Murugesan (2008) specifies a framework and structure for implementing green IT. The subcategory pertaining to bodies and organization has the least number of articles. This suggest that this could be an area for more research.

4.4 Information technology for greening data centres

This category, which is the largest including 131 articles, consists of five subcategories; Cloud computing (27 articles), Network and storage infrastructure (7 articles), Virtual machines and virtualization (30 articles), Algorithms, information system and software (44 articles), and IT infrastructure manufacturers and resource allocation (23 articles). The subcategories were created based on the

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main concepts in information technology that influence data center operations. All energy consumption (power and cooling) costs occur due to IT operations in the data center as the electricity and cooling infrastructure exist for cooling the servers, storage and networking equipment. However, the number of articles and conference papers about network and storage infrastructure is limited which indicates an area for further research. Goiri et al. (2015) and Garg et al. (2010) describes how schedulers can contribute to distribution of data loads and thus lower power consumption. Sabharwal et al. (2013) and Alarifi et al. (2012) focus on information systems solutions which can advance green IT. Liu et al. (2012) studies the use of sensors and infrastructure equipment to monitor data centers. Kachris and Tomkos (2013) focus on green network infrastructure. Uddin et al. (2014b) focus on using virtualization technology to implement green IT in data centers. Patel et al. (2015) discuss the impact of green cloud computing as well as Pawlish et al. (2012). Piazolla et al. (2015) explains the impact of virtualization on power consumption which influences green IT.

4.5 Aligning business requirements with resource utilization

This classification is based the aspect of improving efficiency of operations in data centers. Initially most information technology operations were organized along technical/engineering specialty. However, with the increase in business most IT operations are organized along business lines. The consumption of IT resources is directly proportional to business decisions or business impact. From the table, it is seen here that articles and conference papers pertaining to this aspect are negligible as most of them tend to focus on the engineering/technical aspects of data center. Arnoldus et al. (2013), and Berral et al. (2010) are some of the articles that deal with the business aspects of managing data centres.

The subcategories of improving service level efficiency and business utilization were created based on the content of the articles and conference papers that fit into these sub categories. Subburaj et al. (2014), explains how the goal of Green IT can be achieved by aligning business requirements with IT resource utilization.

5. Conclusion

The purpose of this article was to answer the question of how data centers can contribute in advancing green IT. To fulfil this purpose, a framework describing how data centers can contribute to this was created based on the findings of the literature review. The framework is presented in Fig 2.

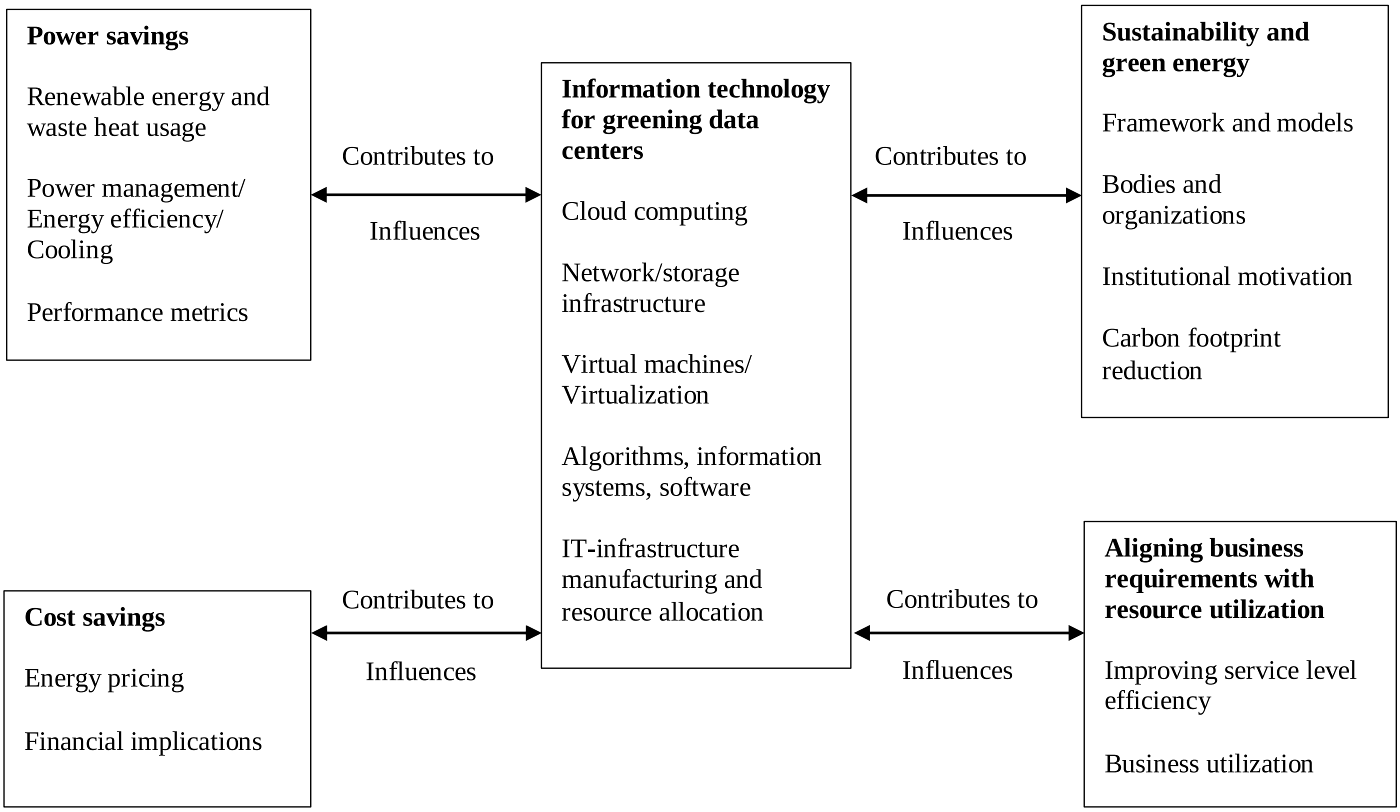

Fig. 2. Framework on how data centers advance green IT.

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The framework includes all the categories and subcategories derived from the articles and conference papers. The framework aims to contribute to the understanding of the relative connections between different categories and the different methods by which green IT can be implemented. The information technology for data centers is seen to be at the heart of data center operations, with other infrastructure such as power and cooling management to support it. The reason for having bidirectional arrow marks between the categories is that while one contributes towards the performance of other category, the latter influences the former. The categories of power savings, cost savings, business alignment and green energy and sustainability are connected through information technology in the data center as they exist to support the applications and data that are executed in the IT infrastructure.

The terms “contributes” means that information technology contributes to power saving with efficient operation while the need to save power influences the need for efficient technologies. Similarly, information technology can contribute to cost saving while the need to save cost influences cost effective technologies. Information technology contributes to sustainability and green energy. The different subcategories listed under sustainability and green energy influences information technology in data centers. Information technology contributes to better resource utilization and business alignment while the need for aligning business with Information technology influences technology in the data center. The relationship between business alignment with resource utilization and information technology can be considered as having higher precedence over other relationships as this the challenge that companies are confronted with owing to the dynamic business environment.

Conclusively, green IT starts from the design of software, applications and architecture based on business requirements. This is an area that is yet to be explored in detail as the technology exists to serve business requirements. This is related to the concept of sustainable software engineering. Both green IT and ICT support each other mutually (Murugesan and Gangadharan, 2012). Decisions related strategic information technology (IT) evaluation and management are necessarily complex because they incorporate multiple strategic decision-making dimensions. Complexities increase in these IT decisions because multiple decision makers, functions, and sometimes organizations are also involved (Sarkis and Sundarraj, 2003; Sarkis and Talluri, 2004; Sarkis and Sundarraj, 2006).

5.1 Limitations and Suggestions for Further Research

From the articles analyzed, it is seen that certain areas such as sustainable software engineering and space management in data centers need more attention in research. The framework proposed is based on the literature review. It is missing out on the vital component of space utilization in the data center. This is because the literature review has not covered this subcategory. Space is an important subcategory that can be categorized within the main category of cost savings. Similarly, the influence of business alignment with information technology needs to be explored further. One suggestion for future research would be to study the relationships between various categories and subcategories quantitively to determine priorities and dependencies when it comes to implementing green IT in a data center of any given industry.

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Appendix A

Table 1
Concept matrix for journal articles.

Main categories	Power savings			Cost savings		Sustainability and green energy				Information technology for greening data centers					Aligning business requirements with resource utilization	
Subcategories/ Authors	**RE & WHU**	**PM/EE/C**	**PM**	**EP**	**FI**	**F & M**	**B & O**	**IM**	**CFR**	**CC**	**N/SI**	**VM/V**	**AISS**	**ITIM & RA**	**ISLE**	**BU**
Alaraifi et al. (2012)													X			
Amokrane et al. (2013)						X			X	X		X	X			
Amokrane et al. (2015)					X	X	X		X	X		X				
Arnfield (2009)									X	X		X				
Aslekar & Damle (2015)		X			X											
Beloglazov et al. (2012)										X			X	X		
Cameron (2014)		X							X			X				
Carter and Rajamani. (2010)		X				X			X							
Ciglaric (2015)		X				X	X	X	X							
Drenkelfort et al. (2015)		X														
Fukaya et al. (2010)											X		X			
Gabriel (2008)						X	X	X								X
Garg et al. (2010)				X						X			X			
Gorge (2008)						X	X	X	X							
Goth (2010)	X								X							
Kachris & Tomkos (2013)											X					
Kern et al. (2011)							X	X	X				X			
Knobloch (2013)		X											X			
Liu et al. (2012)		X		X										X		
Llopis et al. (2013)		X		X							X					
Moghaddam et al. (2014)									X				X			
Murtuazev & Oh (2011)												X	X			
Murugesan (2008)		X				X			X	X	X	X	X	X		
Onda et al. (2014)														X		
Park et al. (2012)						X										
Pawlish et al. (2014)		X	X									X				
Rao & Rao (2015)												X	X			
Ruth (2009)			X				X	X	X	X						
Ruth (2011)		X	X				X	X	X			X	X			

Main categories		**Power savings**		**Cost savings**			**Sustainability and green energy**					**Information technology for greening data centers**			**Aligning business requirements with resource utilization**	
Subcategories/ Authors	**RE & WHU**	**PM/EE/C**	**PM**	**EP**	**FI**	**F & M**	**B & O**	**IM**	**CFR**	**CC**	**N/SI**	**VM/V**	**AISS**	**ITIM & RA**	**ISLE**	**BU**
Sabbir Hasan & Huh (2013)		X		X	X							X	X			
Sabharwal et al. (2013)		X											X			
Sarood et al. (2012)		X	X	X	X								X			
Schott & Emmen (2011)		X	X													
Smith (2011)				X	X	X	X	X	X							
Stansberry (2013)				X	X									X		
Subburaj et al. (2014)									X						X	X
Taj & Basu (2015)		X		X	X											
Tae et al. (2014)		X		X	X								X			
Tian et al. (2013)			X										X			
Uddin et al. (2011)		X	X							X	X			X	X	X
Uddin et al. (2012a)		X	X			X			X	X		X				
Uddin et al. (2012b)		X		X	X				X							
Uddin et al. (2013)			X	X	X											
Uddin et al. (2014a)			X	X	X											
Uddin et al. (2014b)		X							X			X				
Total per subcategory	**1**	**21**	**10**	**11**	**12**	**10**	**8**	**7**	**18**	**9**	**5**	**12**	**17**	**6**	**2**	**3**
Total per category		**32**		**23**			**43**					**49**			**5**	

Abbreviations of subcategories:
RE & WHU: Renewable energy and waste heat usage, PM/EE/C: Power management/energy efficiency/cooling, PM: Performance metrics, EP: Energy pricing, FI: Financial implications, F & M: Frameworks and models, B & O: Bodies and organizations, IM: Institutional motivations, CFR: Carbon footprint reduction, CC: Cloud computing, N/SI: Network/storage/infrastructure, VM/V: Virtual machines/virtualization AISS: Algorithms, information systems, software, ITIM & RA: IT infrastructure manufacturing and resource allocation, ISLE: Improving service level efficiency, BU: Business utilization.

Table 2
Concept matrix for conference articles

Main categories	Power savings			Cost savings		Sustainability and green energy				Information technology for greening data centers					Aligning business requirements with resource utilization	
Subcategories/ Authors	**RE & WHU**	**PM/EE/ C**	**PM**	**EP**	**FI**	**F & M**	**B & O**	**IM**	**CFR**	**CC**	**N/SI**	**VM/V**	**AISS**	**ITIM & RA**	**ISLE**	**BU**
Abe et al. (2011)		X														
Alaraifi et al. (2011)													X			
Alaraifi et al. (2012)									X				X	X		
Amokrane et al. (2015)		X		X	X	X			X	X		X		X		
Anandharajan & Bhagyaveni (2014)		X				X				X		X	X		X	X
Arnoldus et al. (2013)		X											X		X	X
Bagci (2014)		X								X		X	X	X		
Beloglazov & Buyya (2010)		X		X	X				X			X		X		
Beloglazov and Buyya (2012)		X								X		X	X			
Berral et al. (2011)		X				X				X		X	X		X	
Berral et al.(2010)		X	X			X							X		X	X
Bodenstein et al.(2011)		X		X	X	X							X			
Brandt et al. (2012)		X		X	X	X							X			
Capra & Merlo (2009)		X							X				X			
Chait & Juiz (2013)		X										X	X			
Dick et al. (2010)		X				X			X							
Farahnakian et al. (2013a)		X								X		X			X	X
Farahnakian et al. (2013b)				X	X								X			
Farahnakian et al. (2014)		X											X	X	X	
Garcia et al. (2011)		X		X	X		X	X					X			
Garg et al. (2011)		X							X	X		X		X		
Germain-Renaud et al. (2011)		X				X							X			

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Main categories		**Power savings**		**Cost savings**		**Sustainability and green energy**				**Information technology for greening data centers**					**Aligning business requirements with resource utilization**	
Subcategories/ Authors	**RE & WHU**	**PM/EE/ C**	**PM**	**EP**	**FI**	**F & M**	**B & O**	**IM**	**CFR**	**CC**	**N/SI**	**VM/V**	**AISS**	**ITIM & RA**	**ISLE**	**BU**
Godbole & Lamb (2014)		X		X	X			X	X	X		X	X	X		
Godbole & Lamb (2015)				X	X		X		X	X		X	X			
Gu et al. (2012)				X	X	X			X							
Harmon & Demirkan (2011)							X	X	X							
Harmon et al. (2010)		X				X	X	X	X							
Hertel & Wiesent (2014)		X	X	X	X			X	X							
Herzog (2013)						X	X	X	X							
Hintemann & Fichter (2012)		X												X		
Janacek et al. (2014)	X	X				X								X		
Karanasios et al. (2010)				X	X	X	X	X	X							
Klingert et al. (2012)	X					X	X	X	X							
Lamb & Marimekala (2013)		X							X				X			
Lamb and Marimekala (2015)		X					X	X	X	X						
Lamb (2011)		X		X	X			X	X	X		X				
Lee et al. (2015)						X					X			X		
Lincke (2012)		X		X	X	X	X	X	X							
Liu et al. (2011)		X		X	X				X					X		
Malik & Barthel (2008)		X							X							
Merlo (2009)		X							X				X		X	
Moghaddam et al. (2012)		X		X	X				X							
Molla & Cooper (2014)					X	X	X	X	X							
Ouchi et al. (2011)		X							X							
Patel et al.(2013)		X						X	X							
Patel et al. (2015)		X		X	X				X	X	X	X				

Main categories	Power savings			Cost savings		Sustainability and green energy				Information technology for greening data centers					Aligning business requirements with resource utilization	
Subcategories/ Authors	**RE & WHU**	**PM/EE/C**	**PM**	**EP**	**FI**	**F & M**	**B & O**	**IM**	**CFR**	**CC**	**N/SI**	**VM/V**	**AISS**	**ITIM & RA**	**ISLE**	**BU**
Pawlish et al. (2012a)									X	X		X	X			
Pawlish et al. (2012b)		X			X				X			X				
Peoples et al.(2011)		X				X			X				X			
Petrovic et al. (2011)		X							X	X				X		X
Piazzolla et al. (2015)		X										X	X	X		
Rao et al. (2011)								X	X				X			
Rawas et al. (2015)		X							X	X						
Schödwell et al. (2013)		X				X			X				X			
Schott & Emmen (2010)		X												X		
Seegolam & Usmani (2014)		X	X						X							
Shaw & Singh (2014)				X	X					X						
Siddavatam et al. (2011)													X	X		
Singh et al. (2013)										X			X			
Skejic et al. (2010)		X										X		X		
Vereecken et al. (2012)		X				X			X	X		X				
Vodel et al. (2015)		X		X	X			X	X					X		
Yoshino et al. (2010)		X				X										
Total per subcategory	**2**	**47**	**3**	**18**	**20**	**21**	**10**	**15**	**37**	**18**	**2**	**18**	**27**	**17**	**7**	**5**
Total per category		**52**		**38**			**83**					**82**			**12**	

Abbreviations of subcategories:
RE & WHU: Renewable energy and waste heat usage, PM/EE/C: Power management/energy efficiency/cooling, PM: Performance metrics, EP: Energy pricing, FI: Financial implications, F & M: Frameworks and models, B & O: Bodies and organizations, IM: Institutional motivations, CFR: Carbon footprint reduction, CC: Cloud computing, N/SI: Network/storage/infrastructure, VM/V: Virtual machines/virtualization AISS: Algorithms, information systems, software, ITIM & RA: IT infrastructure manufacturing and resource allocation, ISLE: Improving service level efficiency, BU: Business utilization.

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