International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Green Data Center: Reviews and Challenges

Kaustav Dey[1], Suralina Roy Chowdhury[2], Puspita Bera[3], Dr. Chandi Pani[4]

[1,2,3]Department of Electronics and Communication Engineering, Sister Nivedita University
[4]Department of Electronics and Communication Engineering, Meghnad Saha Institute of Technology

Abstract

Data is undoubtedly the currency of the 21st century. The data that we are providing to or retrieving from the users has a very important role to play in the evolution of services in both the computing and non-computing spheres. Various internet services, such as web hosting, e-commerce, and Social Networking, find their roots in the Data centers. With the ever-increasing concerns about carbon emissions, reliance on non-renewable energy resources, and energy consumption by the cooling systems in conventional Data centers, it is imperative to shift our focus to newer, greener, and cleaner technologies that will aim to reduce the overall carbon footprint, technologies that will reduce energy consumption, and the integration of renewable energy resources into the existing setup. There are several studies that have highlighted challenges regarding the adoption of technologies in the hardware and software domains and the standardization of performance metrics, which are generally used to study trends in energy consumption and net emissions and, therefore, assess the sustainability and efficiency of Data center operations. This shift to Green Data centers will certainly involve both standardized performance metrics, effective strategies to reduce energy consumption, and the integration of renewable energy resources to reduce the carbon footprint. Furthermore, we are going to discuss data center network architecture that will make our future Green Data centers scalable, fault-tolerant, agile, and energy efficient. This paper reviews various strategies for designing an efficient data center, ways to incorporate renewable energy resources, standardization and benchmarking of performance metrics, and optimizing the cooling systems to improve energy efficiency. Finally, we are going to outline the future directions and opportunities for further research and innovation.

Index Terms: Data centers, performance metrics, challenges, cooling systems, architecture, energy resources.

I. INTRODUCTION

A. Background and significance of Green Data Centers

DATA centers are the backbone of our increasingly digital world, functioning as the nerve centers that power and enable the huge array of online services, applications, and communication networks on which we rely every day. The idea of data centers first emerged in the middle of the 20th century when early computers needed specialized settings to function properly. These surroundings had temperature, humidity, and power supply controls. Data centers expanded in complexity and sophistication as digital technology advanced and the need for processing power increased. The evolution of data centers from simple server rooms to massive, purpose-built buildings housing tens of thousands of servers and other hardware pieces that are all networked to provide high availability and efficient data processing. They make it possible for businesses to innovate, streamline their processes, and provide services to clients all over the world. Data centers serve as the backbone of cloud computing services, which let customers access processing power and data storage on-demand without having to buy and maintain their own gear.

B. Overview of problem statements with research objectives

With the ever-increasing dependency on data, it was important for us to work on sustainable methods and reducing the carbon footprint in every way possible. Green Data Centers are eco-friendly and aims to reduce the energy consumption and at the same time, efficiently handle large amounts of data and computing operations. The Information and Communication Technology (ICT) industry has prioritized Quality of Service (QoS), dependability, and performance over all other design considerations for a number of decades [1]. Data centers consumed around Data centers consumed around 1.5 % of the world's power in 2011, according to estimates [2]. As our reliance on fossil fuels is expected to increase significantly in the coming decades [3], factors such as (a) environmental concerns, (b) high energy costs, (c) increased demand, and (d) economic consequences are driving the need to prioritize energy efficiency as a primary data center design concern [4]. It is predicted that the energy consumption of network components within data centers would grow by up to 50 % [5]. In this paper, we examine the problem statements across various researches conducted on reducing the energy consumption in the Green Data Centres, while maintaining high levels of performance and availability. At the same time, we are also looking to incorporate renewable energy resources and the barriers to their adoption. All these objectives can only be achieved when we standardize the metrics, generally used to measure the energy efficiency of our data centres. We are also going to emphasise on the cooling systems, basically the non-computing parts in a data centre, which consume a significant amount of energy and how we can optimise them to reduce energy consumption and improve efficiency while ensuring that our equipment remains within safe operating temperatures.

II. REVIEW OF GREEN DATA CENTER EFFICIENCY AND CARBON FOOTPRINT

A. Importance of efficiency and carbon footprint reduction

Energy efficiency in the Data Centers in general and Green Data Centers in particular is very necessary from various aspects–

- Cost cutting.
- To minimize the impact on the environment.
- To fulfil the energy needs of a data center.

Data center efficiency and carbon footprint reduction efforts are crucial for both environmental sustainability and the long-term survival of digital infrastructure. Computing equipment consumes a lot of energy, and today's massive data centers may require tens or even hundreds of megawatts of electricity - nearly the power usage of 10,000 US households [6]. Carbon footprint reduction is critical for combating climate change, mitigating environmental damage, and ensuring a sustainable future.

B. Existing technologies and approaches for improving efficiency

We need to make our Green Data Centres, energy efficient and that can be partially achieved by optimizing the performance metrics used to measure the energy efficiency of our data centers. The Green Computing Performance Index (GCPI) [7] is a comprehensive statistic created by SiCortex [8] for assessing energy efficiency in the High-Productivity Computing segment. The GCPI assesses computing performance-per-kiloWatt across a range of industry-standard benchmarks, providing enterprises with critical direction in an era of out-of-control data center energy consumption. The GCPI is the first index to measure, evaluate, and rank computers based on a wide range of performance indicators relative to energy used [9]. Data Center Infrastructure Management (DCIM):DCIM software monitors and manages data center resources, providing information to optimize power consumption, cooling, and equipment layout. Green building design:Designing data centers with energy-efficient layouts, insulation, and reflective roofing can reduce cooling requirements and overall energy consumption. Monitor energy performance (PUE):Continuous PUE monitoring helps data center operators evaluate and improve overall efficiency by optimizing energy delivery and usage. Efficient cooling solution:Using advanced cooling techniques such as free cooling (using outside air when temperatures are low) and economizers can significantly reduce cooling energy consumption. Server group:Consolidating more servers into fewer through consolidation reduces hardware footprint, saves energy, and simplifies management.

C. Impact of efficiency improvement on performance and availability

A taxonomy for green data center performance indicators was addressed in this research. Basic performance indicators such as greenhouse gas emissions, humidity, power and thermal metrics, and extended metrics are included in the taxonomy. The following are the major motivators for developing the aforementioned metrics:- Economic aspects: For most industrial data centers, saving money is the most important reason for making their data centers ”green.”- Environmental concern: A green data center may conserve energy, therefore respecting the environment, for example, by lowering Carbon Dioxide emissions.A green data center must strike a compromise between attaining computational performance and green performance. The ”scale down”factor, which depicts how computing performance acts when green per se, is still necessary as a performance parameter [9].

III. INTEGRATION OF RENEWABLE ENERGY RESOURCES IN GREEN DATA CENTER OPERATIONS

A. Over-provisioning of resources and its implications

The most important problem and challenge for Data Center operators adopting Green Data Centers is to ensure infrastructure performance and reliability to meet customer Service Level Agreements (SLA). Most of the time, Data Center operators deploy redundant servers, networks, and storage equipment to ensure that the system will function properly at peak demand and be able to recover at any point of failure [10], [11]. It is evident that the Data Center’s over-provisioned system lowers energy efficiency. In order to increase their energy efficiency towards the Green Data Centers, Data Center operators must overcome difficulties to their system’s performance and reliability. Additionally, as network equipment’s bandwidth and workload grow, more energy from the Data Center is needed to handle the increased traffic [12], [13]. As a result, the old networking hardware needs to be more energy-efficient [17]. The current green networking techniques can be divided into three categories: consolidation, selective connectedness, and proportional computing [12]. According to Berge et al. [14], the heat produced by the IT system influences how much cooling is needed in a DC compared to non-IT systems. As a result, the cooling system needs more energy to cool the DC the more heat is produced by the IT equipment used to process the activities.

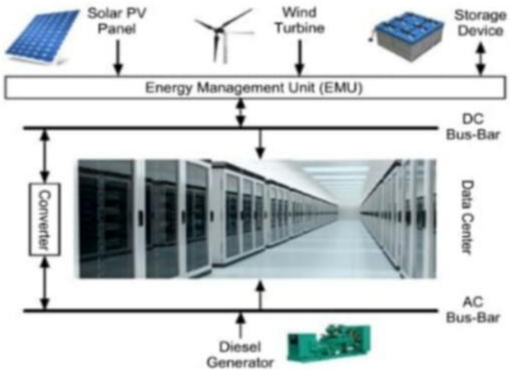

Fig. 1. Hybrid PV/WT/DG powered Green Data Center architecture

B. Potential renewable energy sources for data centers

Indian data center operators are entering into agreements for renewable energy power contracts and implementing sustain-ability initiatives to lower their carbon impact. The term ”Green Computing” refers to the study and practise of efficiently designing, producing, utilising, and disposing of computers, servers, and related subsystems like a monitor, servers, storage, and communication systems [15]–[16]. Other methods of implementation include [17]:-

- Virtualization.
- Scaling Unit-Based Architecture and Design Profiling the Energy Usage.
- Monitoring Systems—Wireless Sensor Networks.
- E-Waste Minimization.
- Developing thin client devices.

C. Barriers to the adoption of renewable energy in data centers

Studies that more closely match real systems have found that switching speeds involves considerable overhead since the CPU must pause while the voltage changes and that switching speeds frequently can reduce a processor’s lifetime reliability [18]. A distinct operating model is used in data centers, where servers can be activated and deactivated as needed [19] and where it is required to use the right amount of servers to handle the tasks that have been submitted. As a result, the attributes of data centres provide fresh difficulties and unsolved issues, with scalability, uncertainty, and efficiency serving as their fundamental requirements. The impact of turning servers or switches on and off and back on again cannot be disregarded due to the delay time and power consumption incurred during the rebooting process. Additionally, these impacts might result in the loss of communication data after a predetermined threshold delay time, which makes them more serious at the network level [20]. The main benefit of heterogeneous architectures is that they allow for the inclusion of specific processors that are tailored for specific job types, with the goal of allocating tasks to the processors that are most appropriate for them [21].

IV. STRATEGIES FOR DESIGNING AND OPERATING ENERGY EFFICIENT DATA CENTERS

A. Energy-efficient infrastructure design principles

We made the assumption in our suggested architecture that a Green Data Center (GDC) consists of various homogeneous servers. The hybrid power supply system for the planned GDC is only shown in Figure 1 :

B. Efficient cooling and airflow management techniques

A liquid cooling strategy or fresh air cooling was used to lower the cost of the cooling system in data centers because traditional air conditioning units couldn’t produce a better cooling result. It is suggested to use a heat pipe-based ice storage method [22] This type of cooling system is location-based; it is set up in a region with low temperatures to allow for the creation of cold water, which lowers temperature and lowers energy consumption by data centers. Other suggested plans might be built around water cooling systems, where water circulates around parts that have obviously warmer areas.[?].

C. Optimization of hardware and server utilization

To operate more effectively and efficiently, data centers need a lot of energy, which results in heat buildup on the servers. Utilising renewable energy sources to power data centers is one of the strategies. Another strategy is to reduce the amount of conversion between AC and DC. A single conversion is acceptable [23]. A promising technology like virtualization software, which uses software called virtual machines and gives the same inputs, outputs, and desired type of behaviour from hardware, can be utilised to manage excessive server power utilisation. Various measurement measures were proposed in [22]] and [25]. This might quantify and measure the efficiency of data centers’ air distribution.

V. MEASUREMENT AND REPORTING OF ENERGY EFFICIENCY AND SUSTAINABILITY

A. Best practices for measuring energy efficiency in data centers

The best practises for operating and developing green data centers should be adopted. These best practises were derived from field research and suggestions made by different vendors. By lowering Green House Gases emissions, they also aid in the creation of data centers that are environmentally friendly and green.[26]

TABLE I BEST PRACTICES FOR ENERGY EFFICIENT DATA CENTERS

Practice	Description			Effects		
Regular	1. The data center operations team			1. The data center		
utilisation audits	can automate the examination of			operations		team
	server, storage, network, and fa-			can automate the		
	cility utilisation rates and create			examination		of
	benchmarks for utilisation rates. 2.			server,		storage,
	Locate	optimisation	points where	network,		and
	low efficiency rates are present.			facility utilisation		
				rates and create		
				benchmarks		for
				utilisation		rates.
				2.	Audits	find
				optimisation		
				opportunities		to
				expand electricity		
				capacity		and

		establish efficiency benchmarks.
Bringing non-IT assets onto the Network	This method provides greater asset visibility onto IP-based network intelligence into supporting facilities, allowing for better decision-making and complementing or replacing outdated analogue networks.	1. This method provides greater asset visibility onto IP-based network intelligence into supporting facilities, allowing for better decision-making and complementing or replacing outdated analogue networks. 2. This procedure makes it possible to keep track of, measure, and regulate the biggest power-consuming components.
Governance	Create a Change Advisory Board (CAB) to oversee vendor management and efficiency benchmarking.	Governance directs resources towards boosting data center efficiency operation [28]

VI. OPTIMIZING COOLING SYSTEMS FOR ENERGY EFFICIENCY AND EQUIPMENT SAFETY

A. Challenges and opportunities in cooling system optimization

Green data centers are advised to increase server intake temperature setpoints to reduce cooling energy use. However, it is still discovered that data center operators work at lower temperatures in tropical climes. Data centers are energy-intensive businesses that use 1% or less of the world's power [28]. In this analysis, a mid-tier data center with five levels and eight active data halls is taken into consideration.

The indoor environmental conditions must be maintained in each of the halls' individual zones in accordance with the suggested values established by [29]. The halls each share a chilled water supply through the use of individual air handling equipment. By modifying the Heating, Ventilation, and Air Conditioning system's setpoint and flow rate, the temperatures can be managed.

B. Energy-efficient cooling technologies and practices

In the past, chillers were employed in data centers to provide cooling. Chillers are a big factor in high Power Usage Effectiveness since they utilise a lot of energy. In order to reduce their Power Usage Effectiveness, green data centers are therefore using alternative technologies and continuing to research cutting-edge possibilities.[30].These are the operational temperatures and the cooling process :

- Two main water cooling loops: cooling tower loop (evaporative cooling) and chilled water loop (In-row coolers).
- Hot aisle containment prevents mixing of hot and cold air for efficiency.
- In-row coolers (IRCs) placed near racks to cool extracted hot air.
- In-row coolers actively adjust fan speeds and chilled water flow to match computing heat load, enhancing efficiency.
- Environmentally friendly and cost-effective cooling solution for the data center.

C. Balancing energy consumption, efficiency, and equipment operating temperatures

A PUE of 1.29 on average is much lower than a PUE of 1.7 on average. The PUEs near 16.1 claimed by the newest and most efficient data centres established by major Internet corporations like Facebook and Google, on the other hand, are not as low as the value of energy usage.[31] [32].In the summer, the cooling devices—the chillers, pumps, and in-row coolers—all use close to 60% of the non-IT electricity. For instance, from October through March, the use of chillers is almost entirely absent, leading in decreased non-IT power utilisation and low Power Usage Effectiveness values (close to 1.21).

VII. CHALLENGES AND FUTURE DIRECTIONS

1. Data Center operators encounter a variety of problems and difficulties when implementing energy management, including the potential for a decrease in maximum throughput [33], performance degradation [34], and equipment damage [35] that lowers the degree of Data Center reliability and performance. Energy management lowers energy use by monitoring equipment status and anticipating behavior.
2. Deterioration in performance and an increase in latency could lead to significant revenue loss. Due to the additional 100ms of delay, Amazon saw a 1% drop in sales [36]. Initiatives for green networking must therefore be trustworthy and guarantee the required performance and Quality of Service limitations.
3. The majority of current research on multiple processors (servers) focuses on situations with homogeneous groups of identical processors (servers). However, according to many computer architects, heterogeneous processor-based systems will predominate in future architectural design [37], [38].
4. Data centers run on a distinct paradigm where servers can be added and deactivated as needed [19], and where it's required to utilize the right amount of servers to handle the tasks that have been submitted. As a result, the characteristics of data centers present novel difficulties and unsolved issues, with the main prerequisites of scalability, uncertainty, and efficiency.

VIII. OPPORTUNITIES FOR FURTHER RESEARCH AND INNOVATION

1. To tackle the rising Green House Gas emissions produced by the Information and Communication Technology sector, new Data Center Network architectures are needed. Data Center Networks typically have average loads that are no higher than 25% of peak loads. Additionally, a sizable portion of the links inside data centers are idle for roughly 70% of the time [39]. Additionally, it was noted that 80% of the connections were only inactive for 0.002% of the time [39]. As a result, before using ALR, it's crucial to take into account the data center's traffic characteristics. Data Center Networks have exciting prospects thanks to hybrid Data Center Networks.
2. Around 80% to 90% of the energy consumed at peak load is consumed by network devices when they are idle [40]. It is necessary to build energy-proportional network equipment, which can save a significant amount of money.
3. For improved performance and energy economy, network protocols may be modified or optimized. Such services may be transparently put to sleep without disrupting network operations using ”interface proxying” techniques [14].
4. Very few comparison studies have been done on Data Center Networks [41], and it is likely that none have been done on various Data Center Network architectures under real-world traffic scenarios. To highlight the Data Center Networks shortcomings and future research for improvement, various Data Center Network comparative studies with realistic workloads are necessary.
5. Furthermore, tracking green metrics in data centers helps identify energy inefficiencies and put preventative measures in place to boost efficiency. However, there hasn't been much focus on this issue up to this point, and many monitors have been suggested for either specific architectures or unique applications [42].
6. Lastly, while systems like GreenCloud [43] and GDCSim [44] have offered data center energy-aware simulation en-vironments, their main drawback is that the majority of them are coarse-grained and concentrated solely on specific components or functions. Therefore, more research is needed to determine how to develop a system-wide experimental and simulation platform that incorporates all data center components, including the CPU, memory, cache, I/O, disc, and communication network.

IX. CONCLUSION

In the 21st century, apart from food, shelter and sunlight, data has become an integral part to be utilized in the best possible ways by the humankind. As the humankind embarks on an entirely new, yet exciting journey, data is going to be one of the most important companions of the humankind. That implies greater our hold on data, greater are our chances of winning on any field and front. In fact, Data is the 'currency' of 21st Century. Unfortunately, the current architecture of the Data Centers has significant drawbacks. Though the Energy demand across various traditional data centres has decreased, time has now come that we bring stricter legislations and rules so that the environment is not harmed any further. We have to shift the focus on renewable energy resources, which are over-provisioned and need to find suitable ways for efficient utilization. This revolution and paradigm shift, will surely require lots and lots of data as well. Therefore, we need to find a way that solves our purpose of efficiently utilizing the renewable energy resources while maintaining the same levels of efficiency and performance. Here, we would like to discuss about three performance metrics, namely, Power Usage Effectiveness, Data Center Energy Productivity and Carbon Usage Effectiveness. According to estimates, the world's data centers currently use up to 3% of all the electricity produced. Such a significant amount of energy. User behaviour and a growing reliance on technologies and services that require data center power are major contributors to this energy consumption. Cooling systems are one of the main causes of this consumption. The surge in Green Data Centers will also require the Semiconductor industry, especially the branch of Material Science, to come up with exciting and innovative solutions to already existing, complex problems. Semiconductor technologies, such as silicon and wide-bandgap semiconductors like silicon carbide and gallium nitride (GaN), are essential for enabling this efficiency. This can result in greater power efficiency, smaller, lighter, and more affordable solutions for green data centers. It also increases the switching frequency to improve system architecture and thus, makes the power supply more efficient with lower cooling requirements. To summarize, the above statements also support our work on Green Data Centers, which extensively focuses on ideas like power consumption, efficiency, utilization of renewable energy resources and building an indigenous Green Data Center simulator with built-in Computational Fluid Dynamics system that will support our purpose. Green Data Centers are the future of Data storage and computation; time has now come that we incorporate various parts of each and every technology to achieve our desired purpose.

REFERENCES

1. S. Murugesan, "Harnessing Green IT: Principles and Practices," IEEE IT Professional, Vol. 48, No. 1, 2008, pp. 24–33.
2. Adam Wierman, Zhenhua Liu, Iris Liu, Hamed Mohsenian-Rad, Opportunities and challenges for datacenter demand response, in: Proceedings of IEEE IGCC, 2014.
3. Energy efficiency in the data center, Hewlett-Packard, Sep. 2008.
4. K. Bilal, S.U. Khan, J. Kolodziej, L. Zhang, K. Hayat, S.A. Madani, N. Min-Allah, L. Wang, and D. Chen, "A Survey on Green Communications using Adaptive Link Rate," Cluster Computing, (DOI 10.1007/s10586-012-0225-8).
5. D. Abts, M. Marty, P. Wells, P. Klausler, and H. Liu, "Energy Proportional Datacenter Networks," In Proceedings of the 37th International Symposium on Computer Architecture, Saint Malo, France, June 2010, pp. 338–347.
6. P. Sharma, P. Pegus II, D. Irwin, P. Shenoy, J. Goodhue and J. Culbert, "Design and Operational Analysis of a Green Data Center," in IEEE Internet Computing, vol. 21, no. 4, pp. 16-24, 2017, doi: 10.1109/MIC.2017.2911421.
7. Green Computing Performance Index (2011) Web Page http://www.sicortex.com/green indexSiCortex (2011) Web Page http://www.sicortex.com/
8. Wang, Lizhe Khan, Samee. (2011). Review of performance metrics for green data centers: A taxonomy study. The Journal of Supercomputing. 63. 1-18. 10.1007/s11227-011-0704-3.
9. A. Hammadi and L. Mhamdi, "A survey on architectures and energy efficiency in Data Center Networks," Comput. Commun., vol. 40, pp. 1–21, 2014.
10. K. Bilal, S. U. Khan, and A. Y. Zomaya, "Green Data Center Networks: Challenges and Opportunities," 2013 11th Int. Conf. Front. Inf. Technol., pp. 229–234, 2013.
11. T. Wang, Y. Xia, J. Muppala, M. Hamdi, and S. Foufou, "A general framework for performance guaranteed green data center networking," Glob. Commun. Conf. (GLOBECOM), 2014 IEEE, no. 2, pp. 2510–2515, 2014.
12. Y. Mei, L. Liu, X. Pu, S. Sivathanu, and X. Dong, "Performance analysis of network I/O workloads in virtualized data centers," IEEE Trans. Serv. Comput., vol. 6, no. 1, pp. 48–63, 2013.

13. L. Ma, Y. Chen, Y. Sun, and Q. Wu, "Virtualization maturity reference model for green software," Proc. - 2012 Int. Conf. Control Eng. Commun. Technol. ICCECT 2012, pp. 573–576, 2012.
14. S. Murugesan, "Harnessing Green IT: Principles and Practices," IT Prof., vol. 10, no. 1, pp. 24–33, 2008.
15. D. Niyato, S. Chaisiri, and L. B. Sung, "Optimal power management for server farm to support green computing," 2009 9th IEEE/ACM Int. Symp. Clust. Comput. Grid, CCGRID 2009, pp. 84–91, 2009.
16. Cabusao, G., Mochizuki, M., Mashiko, K., Kobayashi, T., Singh, R., Thang, N. and Xiao, W. (2010) Data Center Energy Conservation Utilizing a Heat Pipe Based Ice Storage System. Proceedings of the IEEE Symposium Components, Packaging and Manufacturing Technology, Tokyo, 24-26 August 2010, 1-4. http://dx.doi.org/10.1109/cpmtsympj.2010.5680287.
17. A.K. Coskun, R. Strong, D.M. Tullsen and T. S. Rosing. Evaluating the impact of job scheduling and power management on processor lifetime for chip multiprocessors. In Proceedings of SIGMETRICS'09, pages 169-180, 2009.
18. R. Buyya, C.S. Yeo and S. Venugopal. Market-oriented cloud computing: vision, hype, and reality for delivering IT services as computing utilities. In Proceedings of HPCC'08, pages 5-13, 2008.
19. J. F. Kurose and K. W. Ross. Computer networking: a top-down approach. Addison-Wesley publish, 2013.
20. A. Gupta, S. Im, R. Krishnaswamy, B. Moseley and K. Pruhs. Scheduling heterogeneous processors isn't as easy as you think. In Proceedings of SODA'12, pages 1242-1253, 2012.
21. Obasuyi, G. and Sari, A. (2015) Security Challenges of Virtualization Hypervisors in Virtualized Hardware Environment. International Journal of Communications, Network and System Sciences, 8, 260-273. http://dx.doi.org/10.4236/ijcns.2015.87026.
22. Arif Sari, Murat Akkaya" Security and Optimization Challenges of Green Data Centers" Int. J. Communications, Network and System Sciences, 2015, 8, 492-500.
23. A Heat Pipe Based Ice Storage System. Proceedings of the IEEE Symposium Components, Packaging and Manufacturing Technology, Tokyo, 24-26 August 2010, 1- 4.
24. Sari, A. and Rahnama, B. (2013) Addressing Security Challenges in WiMAX Environment. In: Proceedings of the 6th International Conference on Security of Information and Networks (SIN'13), ACM Press, New York, 454-456. http://dx.doi.org/10.1145/2523514.2523586.
25. Molla, A., Cooper, V.A. and Pittayachawan, S. (2009) 'IT eco-sustainability: developing and validating a green IT readiness model', Proceedings of International Conference of Information Systems, December, Phoenix, AZ,
26. Newcombe, L. (2009) Data Center Energy Efficiency Metrics, http://www.bcs.org/upload/pdf/data-center-energy.pdf
27. J. Morley et al. Digitalisation, energy and data demand: the impact of Internet traffic on overall and peak electricity consumption Energy Res Soc Sci(2018)
28. K. Dong et al. Research on free cooling of data centers by using indirect cooling of open cooling tower Proc Eng. (2017)
29. J. Hamilton, "Data Center Cooling Done Differently," Perspectives, Oct. 2014; http://perspectives.mvdirona.com/2014/08/data-center-cooling-done-differently.
30. Google, Efficiency: How We Do It, tech. report, Aug. 2016; www.google.com/about/datacenters/efficiency/internal.

31. J. Parr, Designing a Very Efficient Data Center, tech. report, Facebook, 14 Apr. 2011; www.facebook.com/notes/facebook-engineering/designing-a-very-efficient-data-center/10150148003778920
32. Y. Jin, Y. Wen, and Q. Chen, “Energy efficiency and server virtualization in data centers: An empirical investigation,” Proc. - IEEE INFOCOM, pp. 133–138, 2012
33. K. Chait and C. Juiz, “Research Line on Improving Energy Efficiency in Web Servers,” 2013.´
34. A. Fernandez´-Montes, D. Fernandez´-Cerero, L. Gonzalez´-Abril, J. A. Alvarez-Garc´ıa, and J. A. Ortega, “Energy wasting at internet data centers due to fear,” Pattern Recognit. Lett., vol. 67, pp. 59–65, 2015
35. A. Greenberg, J. Hamilton, D. Maltz, and P. Patel, “The Cost of a Cloud: Research Problems in Data Center Networks,” ACM SIGCOMM Computer Communication Review, Vol. 39, No. 1, Jan. 2009, pp. 68–79.
36. R. Kumar, D. M. Tullsen and N. P. Jouppi. Core architecture optimization for heterogeneous chip multiprocessors. In Proceedings of PACT’06, pages 23-32, 2006.
37. F. A. Bower, D. J. Sorin and L. P. Cox. The impact of dynamically heterogeneous multicore processors on thread scheduling. In IEEE Micro, 28(3), pages 17-25, 2008.
38. T. Benson, A. Anand, A. Akella, and M. Zhang, “Understanding Data Center Traffic Characteristics,” SIGCOMM Computer Communication Review, Vol. 40, No. 1, 2010, pp. 92–99.
39. L. Niccolini, G. Iannaccone, S. Ratnasamy, J. Chandrashekar, and L. Rizzo, “Building a Power Proportional Router,” Usenix ATC ’12, Boston, June2012.
40. K. Bilal, S.U. Khan, L. Zhang, H. Li, K. Hayat, S.A. Madani, N. Min-Allah, L. Wang, and D. Chen, “Quantitative Comparisons of the State of the Art Data Center Architectures,” Concurrency and Computation: Practice and Experience, (DOI: 10.1002/cpe.2963).
41. G. Lu, J. Zhang, H. Wang, L. Yuan and C. Weng. PowerTracer: tracing requests in multi-tier services to diagnose energy inefficiency. In Proceedings of ICAC’12, pages 97-102, 2012.
42. D. Kliazovich, P. Bouvry, Y. Audzevich and S.U. Khan. GreenCloud: a packet-level simulator of energy-aware cloud computing data centers. In Proceedings of Globecom’10, pages 1-5, 2010.
43. S.K.S. Gupta, R.R. Gilbert, A. Banerjee, Z. Abbasi, T. Mukherjee and G. Varsamopoulos. GDCSim: a tool for analyzing green data center design and resource management techniques. In Proceedings of IGCC’11, pages 1-8, 2011.