http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (20): 5432-5439, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.5432.5439

Design of Resource and Power Management Framework and Strategies for Datacenters Powered by Intermittent Renewable Energy

Xiaoying Wang, Jianqiang Huang, Zhiqiang Liu and Xiaojing Liu
Department of Computer Technology and Applications,
Qinghai University, 810016, Xining, Qinghai, China

Abstract: As cloud computing attracts a lot of attention all over the world, the huge carbon footprints of its basic infrastructure cannot be ignored. Large-scale datacenters usually consumes significant amount of energy which leads to both economical wastes and social problems. Renewable energy has been explored in recent years as the power supply for large-scale datacenter. However, its intermittency and unpredictability brings more difficulty for efficiently utilizing the green energy instead of brown energy. In this study, we reviewed some related work which conducted study on how to utilize renewable energy. Then, the research framework for resource management and power management issues in such datacenters is proposed. A series of models and strategies are described in detail which might be suitable for different kinds of applications. Finally, on the basis of the review and analysis, some possible future research directions are discussed.

Key words: Renewable energy, datacenter, resource management, power management

INTRODUCTION

As the rapid development of cloud computing, its application area becomes more and more comprehensive pushed by the advancement of both academy and industry. As the key infrastructure of cloud computing environments, large-scale datacenters keeps growing which become high performance platforms integrating massive data computing and storage and provide online computing services for thousands of millions of customers simultaneously. These large-scale datacenters for cloud computing are usually comprised of hundreds of heterogeneous server nodes which could consume significant amount of energy. This leads to high carbon emissions since most of such energy is produced using fossil fuels. A study from (Mankoff *et al*., 2008) estimated world-wide datacenters will emit 116 million metric tons of carbon, even more than the entire country of Nigeria. The ratio of energy cost can reach to more than 50% compared with the total operational cost of the entire datacenter (Le *et al*., 2010). Each single year, more than 30 billion dollars are spent on dealing with the extra heat derived from massive enterprise services all over the world, even more than the money spent on buying new hardware and devices (Bianchini and Rajamony 2004).

Since, the basic function of large-scale datacenters is to provide services for high performance computing and massive data processing, it will limit the reduction amount of energy consumption by trying to reduce the total energy consumption of the entire datacenter via various approaches. Hence, considering the heavy emissions and increasing societal awareness of climate change, governments, non-profits and the public are trying to find cleaner products and services. Several large companies and enterprises have announced plans to build "green datacenters" which means that these datacenters might be partially or completely powered by renewable energy such as wind, solar and tidal energy. For example, Google has been pondering a "floating datacenter" that could be powered and cooled by the ocean (LaMonica, 2008); Apple planned to build a brand-new datacenter in Prineville, Oregon and vowed to use "100% renewable energy" (Rogoway, 2013); HP also attempted to create a "Net-Zero" datacenter that requires no net energy from utility power grids (Arlitt *et al*., 2012). There are also more examples which can be found in (EcobusinessLinks, 2012). However, since the generation of renewable energy is usually intermittent, it is difficult to reliably and efficiently exploit renewable energy due to its unpredictability and variability. For example, solar energy will be greatly impacted by the strength of the direct sunlight which is usually high in daytime and low in nighttime. Similarly, wind energy is greatly impacted by the wind force which is hard to predict beforehand. As the workloads of large-scale datacenters are also variable, we believe that coordinated resource management and power

Corresponding Author: Xiaoying Wang, Department of Computer Technology and Applications, Qinghai University, 810016, Xining, Qinghai, China

management could help datacenters to use renewable energy more effectively. For this purpose, we have to make efforts on how to manage uncontrollable and intermittent resources, by scheduling or migrating computing jobs or other kinds of workloads.

In this study, we attempt to outline a research framework of managing resources and power in such datacenters powered by intermittent renewable energy. First, we introduce some existing approaches for utilizing renewable energy in single green datacenters. Then, we also put insights into the load balancing and dispatching methods in multiple distributed datacenters. In the following sections, we outline our research framework and describe the relevant models and strategies in detail. Finally, conclusion remarks and some discussion of possible future work will be given in the last section. We hope that this study could pave the way for researchers to utilize the unique characteristics of datacenter workloads and reduce their dependence on traditional brown energy.

RENEWABLE ENERGY USE IN INDIVIDUAL GREEN DATACENTERS

The architecture of a typical large-scale datacenter with mixed energy supplies is shown as Fig. 1. The left half of the Fig. shows the supplying part of the whole system which integrates the traditional grid utility and renewable energy. The ATS (Automatic Transfer Switch) is in charge of combine different energy supplies together and provide the energy to the datacenter. The right half of the Fig. shows the consumption part of the whole system. The functional equipment inside the datacenter consumes energy for dealing with fluctuating incoming workloads.At the same time, some cooling units have to work in order to lower the temperature and guarantee the availability of the devices which will consume considerable amount of power too.

In such datacenters, new types of renewable energy such as solar, wind and tidal are employed to bring advantages by their features including: sufficiency, cleanness, sustainability, non-pollution and so on. Nevertheless, the generation of such energy is usually intermittent, greatly determined by weather, time and seasons. They cannot be obtained on demand like traditional utility grid. Thus, it's difficult to use green energy instead of traditional energy totally which involves solving a lot of challenging problems.

Some researchers have been studying on how to efficient utilize renewable energy inside a single datacenter. For example, Deng *et al*. proposed the concept of carbon-aware cloud applications (Deng *et al*., 2012) which treat carbon-heavy energy as a primary cost, provisioning a cloud instance only if its emission costs are justified by application-specific rules. A carbon-aware policy is proposed which can be expressed in formal models and can be applied to a wide range of practical scenarios. Preliminary results are presented for carbon-aware Web server running on a small renewable-energy cluster. Giori *et al*. designed a framework called GreenSlot (Goiri *et al*., 2011) which aims to schedule batch workloads and another framework called GreenHadoop (Goiri *et al*., 2012) which orients MapReduce-based tasks. Both frameworks are based on the prediction of the availability of renewable energy and try to maximize the utilization of available green energy by different scheduling strategies. Krioukov *et al*., presented an energy agile cluster that is power proportional and exposes slack (Krioukov *et al*., 2012). Then they invented a grid-aware scheduler using workload slack to reduce dependence on non-renewable energy sources to 40% of its original level. Li *et al*. (Li *et al*., 2012) proposed a light-weight server power management method called iSwitch which switches between wind power and utility grid following renewable power variation characteristics, leverages existing system

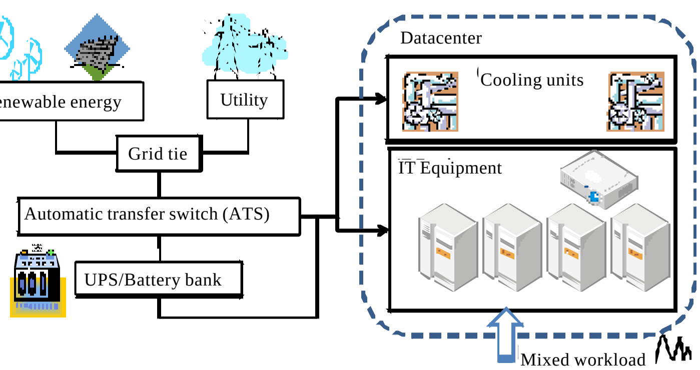

Fig 1: Architecture of the large-scale green datacenter

infrastructures and applies supply/load cooperative scheme to mitigate the performance verhead. Arlitt *et al.* (Arlitt *et al.*, 2012) from HP Labs introduced and designed a "Net-Zero energy" datacenter, managed in a manner that uses on-site renewables to entirely offset the use of any non-renewable energy from the grid.

Deng *et al.*, also conducted researches on Datacenter Power Supply System (DPSS) with multisources to mitigate power cost, carbon emission and power outage. Systematical online control policies that best utilize different characteristics of multisources are designed (Deng *et al.*, 2013a) in a complementary manner to deliver reliable energy to datacenters while minimizing DPSS operation cost. They proposed proposes an efficient, online control algorithm for DPSS, SmartDPSS (Deng *et al.*, 2013b), based on the two-timescale Lyapunov optimization techniques, helping to make online decisions in order to fully leverage the available renewable energy and time-varying prices from the grid markets, for minimum operational cost. Then, a control algorithm called MultiGreen (Deng *et al.*, 2013c) is designed which can make online decisions on purchasing grid power at two time scales (in the long-term market and in the real-time market), without requiring a priori knowledge of system statistics.

ENERGY-AWARE LOAD DISPATCHING IN DISTRIBUTED DATACENTERS

Some big companies and enterprises usually establish multiple datacenters around different areas all over the world, powered by mixed green energy and utility grid. Since the locations of these datacenters are different, the variation of load intensity, renewable energy generation amount and grid market prices will be distinguished among different locations. Such heterogeneous features will bring new opportunities for synthetic energy utilization. There are also some works discussing the possibility of exploring the heterogeneousness of the distributed datacenters and co-scheduling the workload among multiple datacenters, in order to further improve the energy utilization. For example, Stewart et. al. outlined a research agenda for managing renewable in the datacenter (Stewart and Shen 2009) which compliments ongoing efforts to integrate renewables into the grid. They have conducted request-level energy profiling which could potentially guide fine-grained request routing and pointed out that datacenters with excessive renewables could process a greater share of user requests.

Akoush *et al.*, introduced a design called "Free Lunch" (Akoush *et al.*, 2011), a computation architecture that exploits otherwise wasted renewable energy by co-locating datacenters with these remote energy sources and connecting them over a dedicated network. A software framework is provided that supports the seamless execution and migration of virtual machines in the platform according to power availability.

Later, some researches focused on the specific implementation problems In such architectures. Chen *et al.*, proposed a holistic workload scheduling algorithm (Chen *et al.*, 2012), called Min Brown, to minimize the brown energy consumption across multiple geographically distributed datacenters with renewable energy sources. The designed workload scheduling algorithm is aware of different amounts of green energy supply and dynamically schedules the workload across datacenter.

Le *et al.*, sought to exploit datacenters geographically distributed that pay different and perhaps variable electricity prices (Le *et al.*, 2009), the benefit of different time zones and near sites that produce renewable electricity to reduce brown energy consumption that is mostly produced by carbon-intensive means. Experimental results showed that the proposed green policy could reduce up to 35% brown energy consumption with only 3% more cost.

Heddeghem *et al.*, looked at the feasibility of t globally distributing a number of these renewable sources for powering already distributed datacenters in order to operate at a reduced total carbon footprint (Van Heddeghem *et al.*, 2012) and provided a mathematical model for calculating the carbon footprint and savings of such a distributed datacenter infrastructure. Furthermore, potential footprint savings are evaluated and the notion of renewable energy is generalized.

Li *et al.*, proposed a collaborative cost optimization framework by coupling utilities with datacenters via dynamic pricing (Li *et al.*, 2013). Models were developed to describe the information exchange framework for utilities and datacenters and a distributed constraint optimization solver called Cologne is employed to negotiate a mutually optimal price.

To sum up, the above works considered to utilize the benefit of geographically distributed locations, different time zones and prices to schedule and dispatch loads onto multiple datacenters.

RESEARCH FRAMEWORK

From the introduction of prior work in previous two sections, we can see that there is still a wide space for us to explore the possibility and address the challenges of how to efficiently utilize renewable energy supplies. Here, we propose a research framework to guide our following research in this area, as shown in Fig. 2.

Figure 2 illustrates the overall framework and also the relationship between the main components and important stages. The basic concept is to adopt the "autonomic computing" loop : first, data such as load intensity, energy generation amount and resource usage situation will be obtained by the monitoring component and then be sent to the analyzing component; according to these collected data, detail analysis will be conducted on the basis of historical matching results among energy generation amount and consumption amount during a period of time; the analysis results will be used for instructing the model modification and the strategy determination.

As shown in Fig. 2, the key factors and components are all lined with each other and thus impact on others a lot. For instance, the strategy of load scheduling will directly impact the resource usage situation; the resource usage amount will further impact the energy consumption and the temperature of IT devices; the temperature variation will lead to different choices of cooling strategies and cooling energy consumption. Furthermore, the weather and climate change will also impact the generation of renewable energy and the environment temperature which might then trigger other cooling strategies of the datacenter. Consequently, to start research in this area, enough survey and estimation is necessary to learn the restrictions between multiple key steps in the entire system. Models for characterizing the relationships between different pairs of key components should be preliminarily established, in order to instruct later stages including determining the corresponding strategies and designing efficient scheduling algorithms.

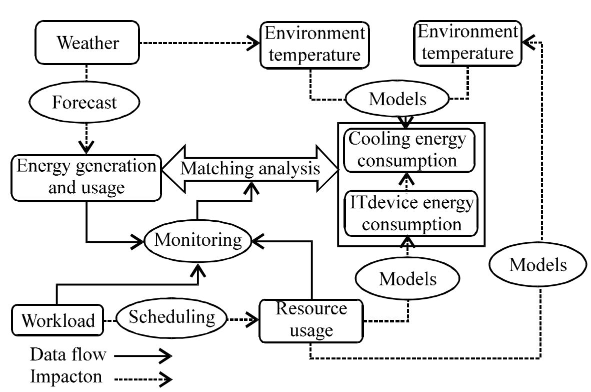

Fig 2: Research framework and relationship between models

MODELS AND STRATEGIES

In this section, we try to establish some preliminary models and introduce some strategies in the forecast and scheduling stages.

Forecasting framework: Now, let's take the solar energy as an example. A simple solar energy computing model can be described as Eq. 1:

$$P = N \cdot A_p \cdot \phi \cdot \eta_p \cdot \eta_{DC} \quad (1)$$

where, N is the number of solar photovoltaic panels, A_p is the superficial area of each PV panel, φ is the solar radiant quantity, $ç_p$ denotes the efficiency of the PV panel, .and $ç_{DC}$ denotes the efficiency of the maximum power tracker of the solar PV panel array. In these factors, φ is essentially random which will be impacted by seasons, sun radiation, temperature and pressure and so on. Hence, to guide the following research, first we have to establish a forecasting framework to standardize and unify the prediction procedures.

The holistic forecasting framework is shown in Fig. 3. The input of the system includes: A. Sample data and B. Necessary data for prediction and the output of the system is C. prediction results. The execution of the system contains following steps:

- **Step 1:** Explanation variable filtering. Sample data are used in this step and (i) Optimal explanation variable set is generated then
- **Step 2:** Modeling the prediction algorithm. The raw data come from B. necessary data for prediction. The prediction model will be calculated filtering the explanation variables

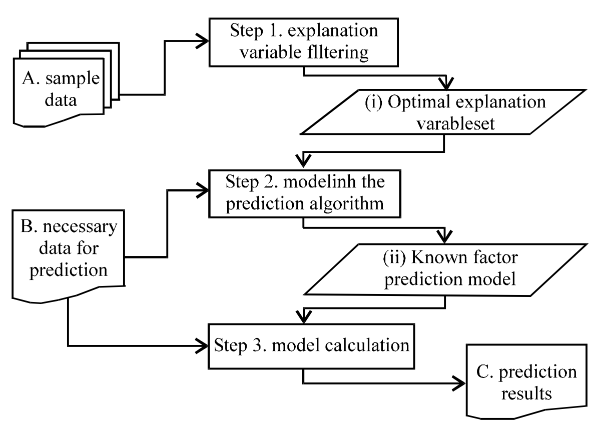

Fig 3: Holistic framework for renewable energy forecasting

- **Step 3:** Model calculation. Using "B" as input, the prediction results could be obtained by calculating according to the prediction model

The advantage of the above described framework is that different kinds of algorithms could be incorporated, including the algorithm for filtering the explanation variables and also algorithms for prediction. Thus, this framework could be expressed as a tuple of two algorithms and a data set. Under this framework, a series of different prediction model could be obtained by changing the three key elements in the tuple.

In the scope of the above framework, we should also consider the impact of different weather types when forecasting solar energy amount. By mining the useful information from the weather forecast, e.g. cloud intensity, wind speed, wind direction, temperature, pressure and so on, explanation variables could be filtered out. Stochastic searching algorithms such as Genetic Algorithm could be employed in the filtering process. Then, corresponding neutral network could be established for inputting basic data. The coefficient inside it could be adjusted from time to time based on the measured values which helps improving the accuracy of prediction.

Energy profiling models: The overall energy consumption of the datacenter mainly includes two parts: functional device energy consumption and non-functional device energy consumption, here denoted as E_f and E_n, respectively. Functional devices include server nodes, network devices and security devices which guarantee the service availability of the entire datacenter. Hence, we can get an equation as follows:

$$E_f = E_{sv} + E_{nw} + E_{sc} \qquad (2)$$

where, E_{sv} denotes the energy consumption of server nodes, E_{nw} denotes the energy consumption of network devices and E_{sc} is the energy consumption amount of security devices.

Since there are usually a large number of server nodes inside the datacenter, E_{sv} devotes most to the total energy consumption. Moreover, a server contains multiple kinds of hardware devices, among which the CPU is the central working unit and has been discussed a lot. The power consumption of CPUs is usually directly relevant with the supplying voltage and its running frequency and is often impacted heavily by the workload intensity. Generally, if we consider only the CPU power consumption, the overall power consumption of server nodes could be calculated as:

$$E_{SV}(t) = \sum_{s \in S^A} \int^t \left(p_s^i + \left(p_s^f - p_s^j\right) \cdot u_s(t)\right) dt + \sum_{s \in S^S} P^S \cdot t + \sum_{s \in S^H} P^H \cdot t \qquad (3)$$

where, S^A, S^S, S^H are the sets of server nodes, sleeping nodes and hibernating nodes, respectively; t is the target time period; p_s^i (p_s^f) denote the energy consumption value of a server which is idle (100% utilized); $u_s(t)$ denotes the measured utilization value of server node s in time slot t; P^S and P^H denotes the power of sleeping nodes and hibernating nodes, respectively.

Besides, since plenty of applications deployed in the datacenter involve frequent storage access operations, the energy consumption of hard disks should also be considered in the energy profiling model. Generally, most mainstream disks could switch between high-speed mode and low-speed mode at least and we denote the corresponding power under there two modes as P_h and P_l. Assume a disk will consume E_u energy amount switching from low-speed mode to high-speed mode and E_d energy by switching reversely. Then, during a time period Δt, the total energy consumption of storage devices could be calculated as:

$$E_{disk}(\Delta t) = P_h \cdot t_h + P_l \cdot t_l + E_u \cdot n_u + E_d \cdot n_d \qquad (4)$$

where, n_u (n_d) is the number of times that the disk switches from low-speed mode to high-speed mode (vice versa), t_h (t_l) denotes the time length when the disk is working in high-speed mode (low-speed mode). Here, these four factors will all be impacted by workload access situations. Since there are a great number of disks inside the datacenter, if appropriate scheduling algorithms are designed and employed, t_h can be controlled as short as possible and the switching times could be reduced.

Non-functional devices mainly include cooling equipment, monitoring devices and management devices which constitute the peripheral environmental infrastructure. Here, cooling equipment has remarkable variability and controllability and usually consumes a dominant ratio of the total energy, hereafter denoted as E_{CRAC}. To characterize the energy consumption of cooling devices, factors such as space and temperature should be considered together, in order to draw the spatial distribution map of the temperature inside the whole datacenter which can be denoted as:

$$Tmap_t = T(\langle x, y, z \rangle, t) \qquad (5)$$

where, <x, y, z> is the 3-dimensional coordinate of a certain point in the machine room and t denotes the current time. This means that the map is constructed of the temperature values of all points in the space at time t.

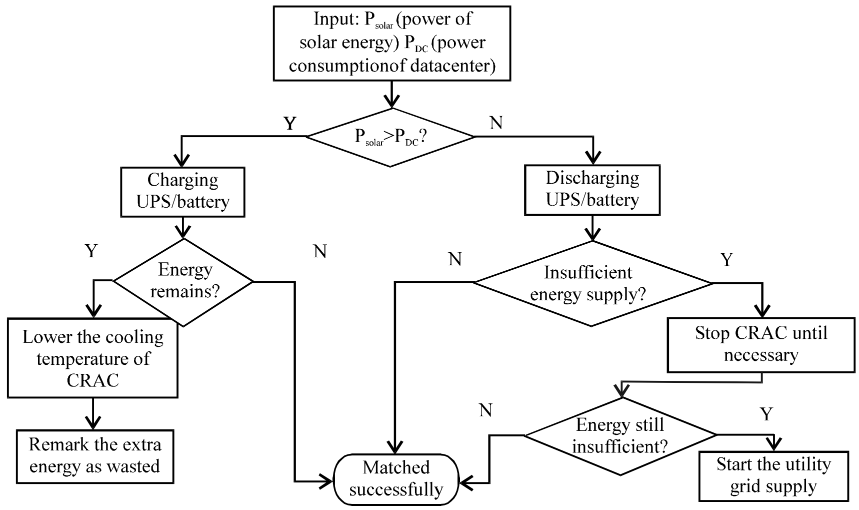

Fig 4: Working diagram of the power management strategy

Resource management strategies: Under the circumstance that the amount of available resources and workload intensity both varies a lot from time to time, resource and power management strategies have to be elaborately designed. Here, we have to co-schedule the workload with the aim of sufficiently utilizing renewable energy, while eliminating the usage of traditional brown energy. Hence, we can define the optimization goal as to maximize the ratio of green energy consumption, i.e:

$$\text{Maximize}: \frac{E_{green}}{E_{green} + E_{brown}} \quad (6)$$

where, E_{green} and E_{brown} stand for the consumption amount of green energy and brown energy, respectively.

Under this goal, there are many restraints of the deployed applications which have to be satisfied. For example, response time is a key metric for transactional interactive applications. In the scenario with multiple server nodes providing services, the performance model of the application could usually be established based on queuing theory, as follows:

$$R_i = \frac{1}{\mu_i} + \frac{1}{n\mu_i - \lambda_i} \quad (7)$$

where, R_i denotes the average response time of the *i*th class application, λ_i denotes the mean arrival rate of the application requests, μ_i denotes the service rate for dealing with the requests which is determined by the resource amount allocated for the application. Since the workloads of different applications vary a lot as time elapses, virtual machines holding these applications could be consolidated to reduce the overall energy consumption.

For batch applications, the throughput is one of the main metrics and each job might have a deadline constraint. The execution time of the jobs will be determined by the computing resources allocated to the application from the datacenter. For such applications, the looseness of these jobs could be mined. Through suspending and resuming some non-urgent jobs under the constraint of their deadline, the resource demand might be matched better with the variation of supplying energy.

Besides, for applications with frequent data access operations, the placement strategy for data replica will also impact the resource usage and corresponding energy consumption. Thus, the migration and gathering strategy could be employed on demand to consolidate the data resources, leading to space locality of the data accesses which would be useful for controlling the temperature and energy consumption.

Figure 4 shows the working diagram of a general power management strategy for utilizing renewable energy such as solar energy. First, the relationship of the amount of solar energy and power consumption are judged. If the solar energy is sufficient, the extra energy will be used to charge the UPS battery. If there is still extra energy, it can be used to lower the cooling temperature of CRAC for later use. On the other hand, if the solar energy is not enough, the UPS battery will be discharged to release some energy for use. If the energy is still insufficient, the CRAC could be stopped for a while until the temperature exceeds the predefined threshold. At the worst case when more energy is needed, the utility grid supply has to be started to cover the energy shortage.

CONCLUSION AND FUTURE WORK

In this study, we have reviewed the research progress of the resource and power management issues inside large-scale datacenters. We listed some relevant work on scenarios in both single datacenter and multiple distributed datacenters. Then, we presented the research framework from our point of view, explaining the inter-operative relationship of several key components in it. Then, a general forecasting framework is introduced and then some energy profiling models are described, including several parts of the energy consumption for different hardware devices. At last, resource management strategies are proposed for some common applications in the datacenter and the power management strategy of hybrid power supply is explained in detail.

Considering that the generation process of renewable energy is usually intermittent and random, some possible future research directions could be explored: (1) The slackness of the workload inside the datacenter should be further exploited which could facilitate the adjustment of resource allocation towards the requirements of varying power supply amount., (2) Since the utilization of all nodes in the datacenter is usually unbalanced, hotspots will exist at some high-loaded servers, leading to instability of devices. Hence, how to design location-aware and thermal-aware strategies is still an important open issue.

ACKNOWLEDGEMENTS

This research is funded in part by National Natural Science Foundation of China (No. 61363019) and Tsinghua-Tencent Joint Laboratory for Internet Innovation Technology (No. 2011-1).

REFERENCES

Akoush, S., R. Sohan, A. Rice, A.W. Moore and A. Hopper, 2011. Free lunch: Exploiting renewable energy for computing. Proceedings of the 13th USENIX Workshop on Hot Topics in Operating Systems, (HOS'11), Berkeley, CA., USA., pp: 17.

Arlitt, M., C. Bash, S. Blagodurov, Y. Chen and T. Christian *et al*., 2012. Towards the design and operation of net-zero energy data centers. Proceedings of the 13th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, May 30-June 1, 2012, California, USA., pp: 552-561.

Bianchini, R. and R. Rajamony, 2004. Power and energy management for server systems. Computer, 37: 68-76.

Chen, C.B., B.S. He and X.Y. Tang, 2012. Green-aware workload scheduling in geographically distributed data centers. Proceedings of the IEEE 4th International Conference on Cloud Computing Technology and Science, December 03-06, 2012, Taipei, Taiwan, pp: 82-89.

Deng, N., C. Stewart, D. Gmach and M. Arlitt, 2012. Policy and mechanism for carbon-aware cloud applications. Proceedings of the IEEE Network Operations and Management Symposium, April 16-20, 2012, Maui, HI., USA., pp: 590-594.

Deng, W., F. Liu, H. Jin and C. Wu, 2013. SmartDPSS: Cost-Minimizing multi-source power supply for datacenters with arbitrary demand. Proceedings of the IEEE 33rd International Conference on Distributed Computing Systems, July 8-11, 2013, Philadelphia, USA.

Deng, W., F. Liu, H. Jin and X.F. Liao, 2013. Online control of datacenter power supply under uncertain demand and renewable energy. Proceedings of the IEEE International Conference on Communications, June 9-13, 2013, Budapest, Hungary, pp: 4228-4232.

Deng, W., F. Liu, H. Jin, C. Wu and X. Liu, 2013. MultiGreen: Cost-Minimizing multi-source datacenter power supply with online control. Proceedings of the 4th International Conference on Future Energy Systems, May 25, 2013, Berkeley, CA., USA., pp: 149-160.

EcobusinessLinks, 2012. Green webhosts. Sustainable Solar and Wind Energy Web Hosting. http://www.ecobusinesslinks.com/green_webhosts/.

Goiri, I., K. Le, M.E. Haque, R. Beauchea and T.D. Nguyen *et al*., 2011. GreenSlot: Scheduling energy consumption in green datacenters. Proceedings of the International Conference for High Performance Computing, Networking, Storage and Analysis, November 12-18, 2011, Seatle, WA., USA., pp: 1-11.

Goiri, I., K. Le, T.D. Nguyen, J. Guitart, J. Torres and R. Bianchini, 2012. GreenHadoop: Leveraging green energy in data-processing frameworks. Proceedings of the 7th ACM European Conference on Computer Systems, April 10-13, 2012, Bern, Switzerland, pp: 57-70.

Krioukov, A., S. Alspaugh, P. Mohan, S. Dawson-Haggerty, D.E. Culler and R.H. Katz, 2012. Design and evaluation of an energy agile computing cluster. Technical Report No. UCB/EECS-2012-13, University of California, Berkeley, January 17, 2012.

LaMonica, M., 2008. Google files patent for wave-powered floating data center. September 8, 2008, http://news.cnet.com/8301-11128_3-10034753-54.html.

Le, K., O. Bilgir, R. Bianchini, M. Martonosi and T.D. Nguyen, 2010. Managing the cost, energy consumption and carbon footprint of internet services. Proceedings of the ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems, June 14-18, 2010, New York, USA., pp: 357-358.

Le, K., R. Bianchini, M. Martonosi and T. Nguyen, 2009. Cost-and energy-aware load distribution across data centers. Proceedings of Workshop on Power Aware Computing and System, October 10, 2009, Big Sky, MT., USA.

Li, C., A. Qouneh and T. Li, 2012. iSwitch: Coordinating and optimizing renewable energy powered server clusters. Proceedings of the 39th Annual International Symposium on Computer Architecture, June 9-13, 2012, Portland, OR., USA., pp: 512-523.

Li, Y., D. Chiu, C.B. Liu, L.T.X. Phan and T. Gill *et al*., 2013. Towards dynamic pricing-based collaborative optimizations for green data centers. Proceedings of the IEEE 29th International Conference on Data Engineering Workshops, April 8-12, 2013, Brisbane, Australia, pp: 272-278.

Mankoff, J., R. Kravets and E. Blevis, 2008. Some computer science issues in creating a sustainable world. Computer, 41: 102-105.

Rogoway, M., 2013. Apple outlines green energy plans for Prineville data center. March 21, 2013, http://www.oregonlive.com/silicon-forest/index.ssf/2013/03/apple_outlines_green_energy_pl.html.

Stewart, C. and K. Shen, 2009. Some joules are more precious than others: Managing renewable energy in the datacenter. Proceedings of Workshop on Power Aware Computing and System, October 10, 2009, Big Sky, MT., USA.

Van Heddeghem, W., W. Vereecken, D. Colle, M. Pickavet and P. Demeester, 2012. Distributed computing for carbon footprint reduction by exploiting low-footprint energy availability. Future Gener. Comput. Syst., 28: 405-414.