Cloud Computing for Environment-Friendly Data Centers

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ABSTRACT
The purpose of this paper is to analyze the carbon footprint and utilization rates in a data center. The long-term goal of this work is to give data center administrators an enhanced perspective of data center operations to allow for more energy efficient operation and to lower the carbon footprint, promoting green data centers. Previous literature shows that low utilization rates in data centers are due to the forecasting of demand to meet spikes in data center use. This management policy has led to many servers running idle the majority of the time which is a waste of resources. We argue that a majority of the data centers should be down sized through decommissioning of phantom servers, virtualization, and shifting spikes in demand to a cloud provider. We use data from the operations of a mid-to-large scale data center in a university. We deploy data mining techniques of decision trees and case-based reasoning to conduct analysis for decision support in cloud computing at data centers. We provide recommendations based on a literature search and our own work. This paper describes our work in progress in the area of developing green data centers.

Categories and Subject Descriptors
H.2.8 [**Database Management**]: Database applications – *data mining;* J.2 [**Computer Applications**] Physical Sciences and Engineering – earth and atmospheric sciences.

General Terms
Management, Measurement, Documentation, Performance, Design, Economics, Experimentation.

Keywords
Cloud Computing, Data Centers, Decision Support, Green IT, Server Utilization, Sustainable Energy

1. INTRODUCTION
The Internet has clearly revolutionized communications, and has a profound impact on the majority of the world. The list of the many benefits that the Information Age has brought forth would be exhaustive; however, in the rush to build data centers, resource and energy efficiency have not traditionally been top priorities. We argue that the time is ripe for squeezing out greater efficiencies from the data centers around the world to better optimize resource use with a view to greening the environment.

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Traditionally data centers were built on forecasted expected future spikes in demand. Data center management would provision the data center's future capacity up to two years in advance and allow the demand to grow into the actual use [2, 3]. This strategy has the benefit of usually over allocating computing power at the expense of a high cost of ownership that includes such factors as power usage for servers and cooling, rent, management costs, and software licensing costs. These main operational costs cut into the profitability of companies running their own data centers, and needlessly raise expenses at organizations such as our university.

Two additional factors that raise costs in data centers are server sprawl and orphan servers. *Server sprawl* is the tendency of management professionals to simply add more servers when more applications are needed instead of optimizing existing servers by running more applications on fewer servers. A possible result of not managing servers efficiently is also *orphan servers* which are servers that are simply left on with no applications running on the servers due to changes in server use. Some researchers have estimated that orphan or also known as dead servers can represent up to 30% of energy cost in an average data center [13]. While it is challenging to obtain an accurate estimate of orphan servers, we recognize and encourage data center administrators to continually follow three main policies;

- retire servers that are not use
- seek out a virtualization strategy
- shift applications to a cloud provider

These three recommendations are simple to state, but challenging to follow due to what has been termed "legacy spaghetti" which represents all the previous wires and servers from former applications and management. Trying to understand the configuration of the existing data center will require time that should result in enhanced performance of a virtualization strategy. Virtualization allows more than one application to run on an individual server, and allows for management to shift loads in demand across many servers.

The next possible strategic step in consolidating a data center is to move applications to a cloud provider. The size and resources of an organization will determine whether the organization chooses to move to the cloud or continue to build out their respective data center. An interesting trend has developed over the past few years where electricity production has decentralized with more organizations producing part of their annual electrical production as opposed to centralization that is occurring in the data center industry primarily driven by the economies of scale of running large data centers. A switch to a cloud provider is controversial and we will address some of the main opportunities and challenges of moving applications to the cloud.

The rest of this paper is organized as follows. Section 2 explains the concept of environment-friendly data centers. Section 3 delves into utilization rates of servers. Section 4 gives a perspective on cloud computing use in data centers. Section 5 presents an analysis with decision trees and CBR to help support the management's decisions on the use of the cloud. Section 6 gives a general discussion based on the material presented in the paper while Section 7 states the conclusions and ongoing work.

2. ENVIRONMENT-FRIENDLY DATA CENTERS

An environment-friendly data center takes a life cycle management approach where resources are optimized such that the data center avoids polluting the atmosphere as much as possible and thus helps to green the surroundings. For example starting with the purchasing where servers are selected with an Energy Star rating, and have such features as sleep and idle mode to power down when the servers are not being used. During the usage period of the servers which is generally three to five years, the total design of the data center calls for running the servers at a high utilization rate. Finally when retiring servers, the data center management team needs to have worked out policy and procedures for the proper disposal of the servers and related equipment. *E-waste* is a growing concern for the world due to the relative short life of electronics, and while beyond the scope of this paper, the management team must work with local waste haulers on this pressing problem. Therefore, taking a life cycle management approach is required for integrating data center policies to make an organization more environmental friendly.

Data centers are energy intensive for both the cooling and powering of servers which results in a high carbon footprint. At the same time, the utilization rates have been documented to be rather low which represents from a broad level resources being wasted. The carbon footprint is the summation of energy usage multiplied by a national average. The greatest efficiency of resources and optimal performance of the data center is met when the utilization rate is high since at this period the data center is polluting the air less with carbon per computing operation.

2.1 Energy Usage and Carbon Footprint

From an environmental management perspective, the carbon footprint of an organization is increasingly becoming an important metric for pending national and international legislation. The carbon footprint of an organization is the estimated total of the output of carbon dioxide into the atmosphere from primarily burning fossil fuels to supply the power for in this case the data center. The formula to calculate the carbon footprint is:

$$\textit{Carbon footprint} = \textit{Electricity usage/year in kWh} \times \textit{U.S. } CO_2 \textit{ national emissions average in lbs/kWh} \times 1 \textit{ metric ton} \div 2{,}204.6 \textit{ lbs}$$

Table 1 gives a summary of energy usage for the servers by semester for 2010. Using the energy usage in Table 1 the carbon footprint was calculated using the prior equation. Note that the electrical usage/year could often be an estimate and hence the carbon footprint is often a forecasted value since it is based on estimated electricity usage. Currently the estimated amount of carbon dioxide released from data centers worldwide is 2% which is a growing concern [6].

Table 1: Total Server kWh and Carbon Footprint

	Total kWh	Carbon Footprint (in metric tons)
Winter & Spring Semester 2010	255,683	155
Summer Semester 2010	297,417	181
Fall Semester 2010	335,416	204
Total	**888,516**	**540**

In our evaluation, we have measured the energy usage of our servers at MSU and computed the carbon footprint using the formula listed below. Thus, for example, the total carbon footprint for data center servers at MSU in 2010 is calculated as:

*Carbon footprint = 888,516 kWh * 1.34 lbs/kWh * 1 metric ton/2,204.6lbs = 540 metric tons/year.*

The value 1.34 lbs/kWh is the national average of US CO_2 emissions [15]. A metric ton conversion ratio is used because CO_2 emissions are commonly expressed in the international community in metric tons.

Next we considered the carbon footprint for cooling or air conditioning. The estimated electrical usage is 58 kW per hour with three air conditioning units running 7 days a week, and 365 days per year. The electrical power usage for air conditioning is 1,524,240 kWh/year for 2010.

*Carbon footprint for cooling = 1,524,240 kWh/year * 1.34 lbs/kWh * 1 metric ton/2,204.6lbs = 926 metric tons/year.*

From Table 1 and the air conditioning power usage calculation above, we also obtain the combined power usage for 2010 including data center servers and air conditioning. This is calculated as 888,516 kWh/year (servers) + 1,524,240 kWh/ year (cooling) = 2,412,756 kWh/year. It is clear that the combined carbon footprint due to servers and cooling would thus be even greater. Therefore, based on our measurements and estimations our mid-sized data center is contributing around almost 1,500 metric tons per year into the atmosphere which is not a positive indicator. In addition, the data center has continued to grow with increasing emission levels, and there is a need to reduce the carbon footprint.

3. UTILIZATION RATES IN SERVERS

We consider an important issue in data center management, namely the utilization rates in data center servers. Utilization rate is defined as the extent to which servers are actually utilized, i.e., they are running applications as opposed to being on but idle.

We provide an equation for analysis here. The equation we formulate here serves as a performance metric for various aspects that are important for energy management and forecasting.

3.1 Equation for Utilization Rate

Equation 1 below determines the utilization rate based on its definition as:

$$Utilization\ Rate = \frac{\sum_{n=1}^{T}(\text{CPU Rate})}{\text{T}} \quad (1)$$

In this equation the CPU rate is the extent to which the CPU is busy at any given instance of time. The utilization rate is thus calculated in this formula as an efficiency ratio that sums up each instance of the CPU rate over a total time span T. The utilization rate gives management an idea of how much of the time the data center is being used. It is obviously desirable to maximize the server utilization rates to optimize data center performance.

3.2 Observations from Data Center Host

Next we present one example of the calculation for the utilization rate, and in Table 2 and 3 we present the summary of utilization rates for the first four months of 2012. We obtained our data from our university's data center that is located approximately 14 miles west of New York City. Our university is a mid-to-large size university with a student population of approximately 18,000 plus staff and instructors. Our data center has two hosts that continually shift user demand for optimal performance.

As an example we will next present a utilization rate calculation for one host on a single day. The utilization rate is calculated accordingly and shown below.

Host 1

Monday 1/16/12

$\sum$ *CPU Rate = 41,433*

Utilization Rate = 41,433/ 1440 =28%

We calculated the average utilization rate on January 16th, 2012 for Host 1. Recall from our fundamental Equation 1, that the utilization rate is the summation of the CPU rate for each minute divided by the total number of minutes for the time span considered. We consider this over a time span of 1 day which is 1440 minutes. Also note that the CPU rate is recorded every minute which gives 1440 data points that need to be summed up. Thus, for example on our Host 1 on 1/16/12, the 1440 data points that give the CPU rate per minute are summed up to get 41,433 and this number is divided by 1440 to give a utilization rate of 28%. Tables 2 and 3 give a broad picture of utilization rates in hosts 1 and 2 for four months of 2012 based on this calculation.

Table 2: Utilization Rates for Host 1

2012	Host 1		
Month	*Average Utilization rate*	*Daily low for the month*	*Daily high for the month*
Jan.	38%	7%	86%
Feb.	34%	10%	85%
March	30%	7%	60%
April	35%	8%	68%

Table 3: Utilization Rates for Host 2

2012	Host 2		
Month	*Average Utilization rate*	*Daily low for the month*	*Daily high for the month*
Jan.	42%	20%	86%
Feb.	35%	25%	90%
March	38%	21%	87%
April	35%	9%	82%

We can see that table 2 and 3 provide a summary of utilization rates over a typical four month period. From examining the daily highs and lows for the month, there are busy days or spikes in activity in the data center of 80 to 90% utilization rates. While an argument could be made that the current data center is appropriately sized, we argue that from an environmental management perspective the monthly utilization rates are rather low at 30-42%. The discussion section will further address this low utilization rate problem that is typical for data centers in relationship to the carbon footprint. Shifting to a cloud provider, in addition to the benefits presented in the next section, will be more environmental friendly because cloud providers typically have average utilization rates of around 85%. With these high utilization rates, cloud providers are generating a lower carbon footprint in relative terms of data.

4. A CLOUD PRESPECTIVE ON DATA CENTERS

Data centers have been traditionally sized based on the highest expected demand during a year. For example, retail data centers have been built to meet the high demand during the peak holiday season and university data centers have been built to meet the demands of multiple users during the beginning and end of the semester during peak use. Therefore, the majority of the time data centers are being underutilized. In fact in a McKinsey study a large number of data centers have been operating at a utilization rate of below 15% [7]. These low utilization rates represent a problem to society since data centers consume a large percentage of energy use for cooling and powering servers, in addition to the continuous contribution of carbon emissions to the atmosphere. In addition, within only five years (from 2000 to 2005) the energy usage due to data centers has doubled constituting 1.5-2% of the world's energy consumption [10]. While many analysts and researchers were predicting another similar increase to follow this growth, due to the economic downturn as well as increase in energy efficiency of the computing systems, and increased use of virtualization and cloud computing this did not materialize [1, 8, 10, & 11].

Companies such as Intel have reduced their number of data centers in an effort to increase utilization rates [5], and also cloud computing offers significant opportunities to raise utilization rates while also experiencing economies of scale. Such features as easy access, no up-front investment, highly scalable, low operating costs and reducing business risk [15] provides many incentives to organizations to shift to the cloud; however, at the same time cloud computing brings many unique challenges primarily cost, security, privacy issues, regulation, reliability and compatibility [9, 12]. We will address the above opportunities and challenges in the forthcoming subsection.

4.1 Opportunities of the Cloud in Data Centers

A clear advantage of cloud computing is that often data center administrators and employees are usually stretched thin spending the majority of their time on maintenance with little time for innovating new ideas [9]. Innovation of a new idea involves provisioning for the future with the necessary task of forecasting demand for decision making of purchasing server hardware and software plus the required maintenance and installation of the system. These fixed capital costs and lag time must be weighed with the easy access, no up-front investment, highly scalable, and possibly lower operating costs of using a cloud provider.

Cloud computing mainly due to the economies of scale of the providers is gradually developing into a potentially revolution in the data center community. Productivity gains by such cloud providers as Box and Dropbox that allow file sharing have revolutionized the workplace by allowing groups working on projects to simultaneously view documents, photos, spreadsheets, blueprints and other files. Traditionally users would have to go through the IT department to request different accounts to be allocated user rights which was a time delay plus it required more space on the data center. Now all these files are hosted on the cloud that eliminates the sizing requirements for an organization's data center plus the file sharing speeds up the workflow. These productivity gains while tough to measure quantitatively represent an evolution on the way team project management is presently being developed.

4.2 Challenges of Cloud Computing

The main challenges of cloud computing that have been stated earlier are cost, security, privacy issues, regulation, reliability and compatibility. All these concerns will now be addressed individually. There is a current debate as to the cost of an in house data center versus a pure cloud computing scenario. While the decision making process can be boiled down to a simple lease or buy scenario, the decision can become convoluted and complex due to the numerous variables in determining the choice. Many advocates of cloud computing point out that having a data center with legacy gear that requires continue maintenance may be a crutch in operations compared with the lean provisioning of operating in the cloud. And while studies by different agencies have determined different outcomes of what may be more cost effective with different outcomes due to the many variables; flexibility to market conditions is an important variable that is also hard to quantify.

Security is often cited as a reason to avoid moving applications to the cloud. This is clearly an important concern that should be further examined to shed light on from perhaps a cloud perspective. Considering that many data centers have security problems each year due to viruses or hackers one must question whether local data center operators are best equipped to deal with such threats. Large cloud providers are probably better equipped with the ability to hire experts to deal with such threats in a better manner than the typical data center administrator that maybe already overwhelmed with maintenance issues.

Privacy issues are an area that has repercussions throughout the industry. Some instances such as legal records may perhaps be better left on a local data center as opposed to a cloud provider. Clearly in this regard legal counsel needs to be involved in the decision making process, and case law will continue to evolve with the situations that arise with cloud computing. This also brings forth another disadvantage of regulation which typically lags behind innovation. For example, many countries are requiring that data be required to be hosted in the country of origin. Cloud providers are struggling with this issue since at a fundamental level it is challenging to determine exactly where the data is being hosted in a cloud environment.

Regulation of the cloud will prove challenging since case law for the cloud is still evolving, and traditionally cloud technology does not respect any international boundaries. Increasingly legislation is being passed requiring cloud providers to know specifically where data is being stored. For example the U.S. Health Insurance Portability and Accountability Act places strict requirements for organizations that handle personal health related data [9]. In addition, the European Union (EU) is setting the stage for the storage of consumer data by requiring consent and approval before transferring data outside a country or EU region.

Another common argument is that the cloud is not as reliable as an in house data center. An often cited case is when Amazon's Web Services was down for almost three days in April 2011 [9]. While the problem was eventually traced to just one of Amazon's data centers, the reputation for cloud computing undoubtedly suffered a setback. Outages of cloud providers are relatively rare, and organizations will need to build redundancy into their systems for mission critical data. When compared to in house data centers though the outage rate of cloud providers still is an improvement over traditional data centers [8].

A final concern often voiced by some is compatibility of data or data lock-in to a specific cloud provider. Research in this area is still in the initial stages, and in the information industry and business community there seems to be an open call for standard formatting. Switching from one cloud provider to another may incur costs in time and data processing.

5. ANALYSIS FOR DECISION SUPPORT

5.1 Decision Trees and Case Based Reasoning

We have conducted analysis with the data mining techniques of decision trees and case-based reasoning to provide decision support in the operations of the management with respect to cloud computing in data centers. We present a few examples of our analysis below.

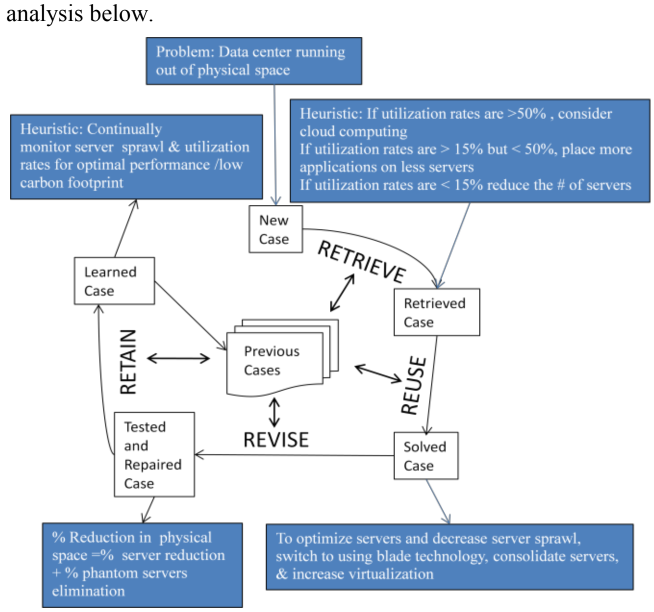

Figure 1: CBR for Cloud Usage in a University Data Center

The conceptual Case Based Reasoning Model presented in Figure 1 represents a problem for when a data center is running out of physical space to place more servers. The first step is to retrieve information on a heuristic of standard operating procedures for a data center. Drawing from other cases provides examples on methods to achieve the overall goal of pruning the data center for optimal performance. The heuristic from the retrieved case examines utilization rates, and states the suggested course of action in the CBR model. The second step is to reuse the information from solved cases that are pertinent to the new case. In this specific instance ways to reduce server sprawl are using blade technology, consolidating servers, and increasing virtualization. With this information, the third step is to revise the previous cases, and in this specific instance examine how decreasing server sprawl can cut the carbon footprint of the organization. The final step in the CBR Model is to retain the solved case for future research. The overall objective is to manage the data center for optimal performance in an environmental friendly manner. The CBR model therefore seeks to balance physical space with utilization rates, and because a majority of data centers operate with low utilization rates, excess spikes in demand over 50% suggest moving capacity to a cloud provider.

A decision tree is presented in Figure 2 to examine cloud computing with the objective of examining growth in the data center and utilization rates. The decision tree in Figure 2 has been developed to assist management in the decision-making process for shifting to the cloud by examining some of the most important aspects. Our preliminary hypothesis is that utilization rates are rather low which from the decision tree would indicate a consolidation of servers. In cases where the utilization rate is above 50%, the recommendation would be to consider shifting to the cloud depending on the objectives of the individual organization. Considering the opportunities and challenges from section four of this paper and the data center management objectives of the organization; a shift to a cloud provider is a fundamental change in operations. Therefore, if the organization decides to shift some of the capacity to a cloud provider, higher level management and legal counsel should be consulted.

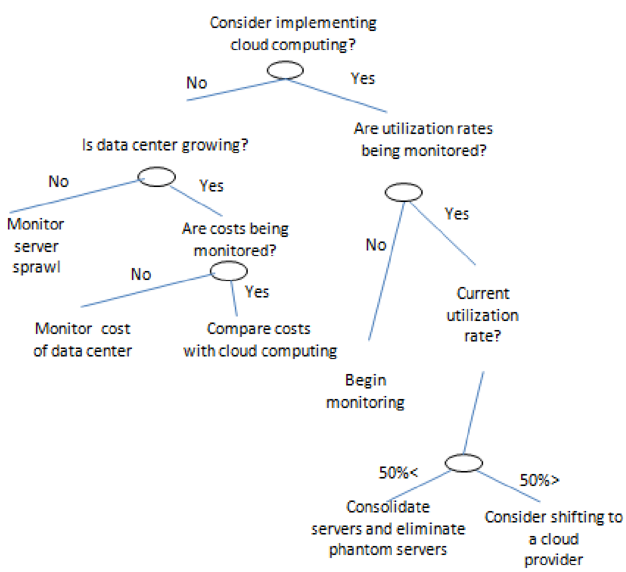

Figure 2: A Basic Decision Tree for Cloud Computing

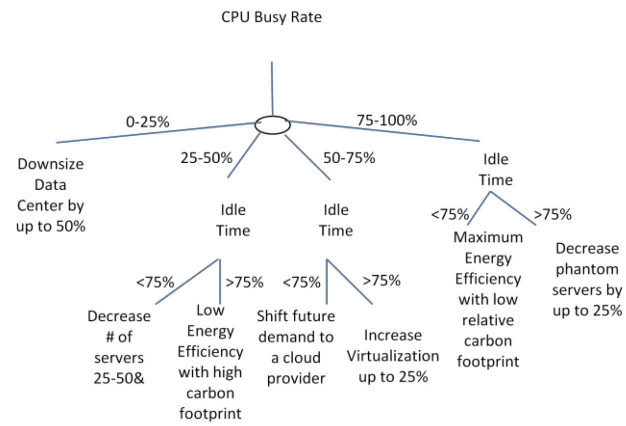

Figure 3: A Decision Tree based on the CPU Busy Rate

The decision tree in Figure 3 represents an examination of the relationship between CPU busy rate and idle time. The CPU busy rate is divided into four groups of 25%. Following each branch of the tree gives a leaf with a recommended action or statement. From our research, we found that our data center falls between the 25-50% range, and therefore depending on idle time the data center is too large. The recommendation is to decrease the number of servers with extra demand being shifted to a cloud provider. In the next section this paper will discuss this policy shift.

6. DISCUSSION

Reviewing Table 2 and 3 an initial observation is that average monthly utilization rates are around 30% to 42% range which tends to be on the low side. At the same time the carbon footprint of the data center is almost 1500 metric tons per year when cooling and server usage are combined. Therefore with a utilization rate of 40%, the carbon footprint for the year would be 600 metric tons. Shifting excess capacity to a cloud provider would provide the benefits outlined previously in the paper plus a reduction in the carbon footprint because cloud providers operate at much higher utilization rates. From an environmental management perspective in order to enhance energy efficiency and lower the carbon footprint, our argument is that the given data center is too large. Switching to a cloud provider to handle the spikes in demand would reduce the carbon footprint by consolidating servers.

While we did observe points that reached 100% utilization rate during daily workloads, the majority of the time these high rates occurred in the midnight hours when batch processing job where being run. These high utilization rates in the midnight hours may suggest opportunities to move certain applications to a cloud provider in order to consolidate servers. This suggestion would depend on a number of factors such as the current contract with the software license company, legal issues of information on a cloud provider, and of course a cost-benefit analysis of switching to a cloud provider.

The suggested course of action of downsizing data centers is controversial since the standard data center management procedure has been to continually grow the data center, but faced with physical space limitations and the technological developments of cloud computing; this change is the future direction in data centers. Listed below are a few suggestions to consider before shifting to a cloud provider;

- Build support throughout the organization prior to moving to a cloud provider
- Gain upper management and legal consul perspectives for pending shift in data center operations
- Conduct a analysis of the data center examining such factors as utilization rate, CPU busy rate, and other factors prior to shifting to a cloud provider

Following the above management suggestions should ease the transition to the new direction in data center operations, and at the same time will reduce the carbon footprint by not having servers operating in idle mode with emissions to the atmosphere.

7. CONCLUSIONS AND ONGOING WORK

In this paper we investigated data center management taking into account utilization rates and related factors with the goal of providing energy efficiency for enhancing performance. We provided a background on cloud computing and an overview on utilization rates supported with data from a mid-to-large size data center in a university setting.

Our initial hypothesis that servers were being underutilized has been confirmed both through a literature review and examples. Ongoing work includes continuing to monitor the servers on our campus and also trying to get external data from other data centers while seeking ways to optimize utilization rates. In summary, a few ways in which organizations can seek higher utilization rates or shift to a cloud provider are the following:

- Data center managers are usually overwhelmed with maintenance issues and by providing current information on utilization rates will assist in demand forecasting
- Continually move towards eliminating phantom servers and implement virtualization
- Provide a cost-benefit analysis of shifting applications to a cloud provider
- More effectively schedule batch processing jobs to better utilize the data center's resources

Taking the above listed incremental steps that promote higher utilization rates will encourage energy efficiency in an organization and also may possibly reduce the carbon footprint of the organization. And while we find it interesting that the electricity industry is moving towards a decentralized model, in the data center industry, the opposite seems to be occurring with a move towards centralization of data centers in the form of cloud providers. Existing organizations may be at a competitive disadvantage with their legacy data centers in comparison to newer organizations that maybe more flexible to market conditions using a cloud provider. In the future, cloud computing will undoubtedly play an important role in data center operations. Currently, we are at a period when management is becoming more comfortable with the new technology, and as the information technology industry works towards solving and proving cloud technology, management will be more comfortable to shift to the cloud. The current cost structure with the strong economies of scale for cloud computing favor a shift to the cloud, but more case studies and papers will be needed to document savings and features. Finally, we believe that this paper documents the need for greater efficiency in natural resource use in data centers to promote a more sustainable world.

8. ACKNOWLEDGMENTS

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