ENERGY

GREEN DATA CENTERS FOR SUSTAINABILITY

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White Paper
Technology Innovation Program (TIP)
National Institute of Standards and Technology (NIST)
Gaithersburg, MD 20899

1. An Area of Critical National Need

Humankind is not living sustainably, and action must be taken, and taken soon, to reverse this negative trend and reconcile human use of the planet's resources with the ability of the Earth to supply them. A successful sustainability transition, moreover, will demand critical advances in basic knowledge, in humankind's social and technological capacity to utilize it, and in the political will to turn that knowledge and know how into action (NRC, 2002). The process goes beyond individual stakeholders and themes – populations, economy, water, food, energy, and climate – to identification of common threads and drivers of systemic change (NRC, 2002). Sustainability science seeks real world solutions to sustainability issues and aims to break down artificial and outdated disciplinary gaps between the natural and social sciences through the creation of new knowledge and its practical application to technology transfer and decision making (Clark & Dickson, 2003; Palmer et al. 2005; Weinstein et al. 2007).

The proposed research topic "Green Data Centers for Sustainability" resides in the NIST realm of "Energy", and is of critical importance to the global sustainability transition. It aims to create energy efficient data centers heading towards a greener and more sustainable environment. A corresponding research goal is the development of a Decision Support System (DSS) that will allow data center professionals to make better management decisions for server and other information technology (IT) systems while balancing energy efficiency with various functionality demands. While the focus is on data centers in academia, the outcomes of this research would also be useful in the corporate world where green energy is an important issue. Green energy was one if the topics mentioned in the State of the Union address of President Obama and is a national priority.

The U.S. data center industry is in the midst of a major growth period stimulated by increasing demand for data processing and storage at all levels (USEPA 2007). In 2006, the US Congress passed a law (P.L. 109-431) that required the USEPA to submit a report on data center energy consumption. Similarly, the European Union issued a voluntary "code of conduct" in 2007. During the past five years, increasing demands for computer resources has led to significant growth in the number of data center servers, along with an estimated doubling in the energy used by these servers and the power and cooling infrastructure that supports them. Pursuit of energy efficiency opportunities in data centers is important because of the potential for rapid growth in direct energy use, e.g., energy usage by the nation's servers and data centers is significant, estimated to be about 61 billion kilowatt-hours (kWh) in 2006 at a total electricity cost of about $4.5 billion. This estimated level of electricity consumption is more than the electricity consumed by the nation's color televisions and similar to the amount of electricity consumed by approximately 5.8 million average U.S. households.

The energy use of the nation's servers and data centers in 2006 was estimated to be more than double the electricity that was consumed for this purpose in 2000. Under current efficiency trends, national energy consumption by servers and data centers could nearly double again in another five years (i.e., by 2011) to more than 100 billion kWh, representing a $7.4 billion annual electricity cost. The peak load on the power grid from these servers and data centers is currently estimated to be approximately 7 Gigawatts (GW), equivalent to the output of about 15 baseload power plants. If current trends continue, this demand would rise to 12 GW by 2011 (USEPA 2007). Thus the development of green energy initiatives for sustainability in data centers is clearly of national significance.

2. Magnitude of the Problem

Institutions can achieve a step change in their data center efficiency by "pulling three interlocking levers" (USEPA 2007): 1) rationalizing demand for data center capacity; 2) optimizing supply for the data center capacity; and 3) putting in place underlying organizational enablers. To develop a better understanding of energy efficiency opportunities that would accelerate adoption of energy efficient technologies beyond current trends, three energy-efficiency scenarios were explored by the USEPA:

- The "improved operation" scenario includes energy-efficiency improvements beyond current trends that are essentially operational in nature and require little or no capital investment. This scenario represents the "low-hanging fruit" that can be harvested simply by operating the existing capital stock more efficiently.
- The "best practice" scenario represents the efficiency gains that can be obtained through the more widespread adoption of the practices and technologies used in the most energy-efficient facilities in operation today.
- The "state-of-the-art" scenario identifies the maximum energy-efficiency savings that could be achieved using available technologies. This scenario assumes that U.S. servers and data centers will be operated at maximum possible energy efficiency using only the most efficient technologies and best management practices available today.

These scenarios, based on the assumptions outlined above, illustrate significant potential for efficient technologies and practices to improve the energy efficiency of servers and data centers by 2011:

- The state-of-the-art scenario could reduce electricity use by up to 55 percent compared to current efficiency trends, representing the maximum technical potential.
- The best practice scenario could reduce electricity use by up to 45 percent compared to current trends, with efficiency gains that could be realized using today's technologies.
- The improved operational management scenario offers potential electricity savings of more than 20 percent relative to current trends, representing low-cost energy efficiency opportunities.

Such estimates are however highly speculative. A recently published paper providing a description of the approach used to estimate power consumption in data centers is illustrative of the difficult task ahead. The study extracted vendor supplied data of systems manufactured and sold worldwide and then aggregated it with their power consumption characteristics. The study acknowledges the high variance in system count (due to under or over reporting) as well as the fact that no variation in power consumption (due to low processing load or powering down the systems) is being considered. Variation in power consumption for the same system can also play a significant role in achieving a reduction in electricity usage. In a study on a computer lab at Rochester Institute of Technology, careful power management of the computers was projected to yield 90% energy saving (Koomey 2008).

It is clear that current IT professionals charged with the massive task of improving energy efficiency in data centers face a confusing environment. While reports and publications provide estimates of power consumption, no clear strategy on how to individually assess this consumption for a single institution is provided. Modern IT facilities, especially those residing at academic institutions, utilize heterogeneous frameworks of servers and cooling solutions rendering vendor specific energy audits inefficient. Moreover, energy audits and energy monitoring applications are currently focused on simply power and cooling usage monitoring and do not provide any assistance to the IT professionals in deciding future actions such as system configurations, application scheduling, and new equipment installation. This is clearly a problem of substantial magnitude in data centers, and there is a real need for adequate decision-making in the area of energy conservation.

3. Transformational Results

In this green computing initiative, a decision support system (DSS) will be developed for the design and retrofitting of data centers. A DSS provides a mechanism to support or assist the users' decision-making, typically in a given domain, and is often based on a thorough analysis of existing data related to past experiences in addition to the incorporation of domain knowledge. In other words, a DSS is a computer based application assisting in providing solutions to multifaceted problems (Han and Kamber 2001). The role of a DSS can be considered analogous to the advisory role of human experts in decision-making. However, the volume of data handled by a DSS, the exhaustive nature of the analysis, the accuracy of the outcomes and the efficiency of processing is often beyond the capacity of a human expert. Moreover, the computational analysis performed by a DSS, is considered vital in many applications today to enable a more systematic understanding of the domain and to provide solutions.

Decision support systems are used throughout the world today in various fields such as medicine, farming, management, routing aircraft, mechanical engineering and others where complex organization is needed. An example of a DSS in materials science within the broader realm of mechanical engineering is found in (Varde et al. 2003) where an association rule based data mining approach (Han and Kamber 2001) is used for DSS design. Initially designing or retrofitting data centers is a complex problem with many decisions of what type of hardware, software and financial considerations to implement. Servers that make up a data center typically last for three to four years and must be backed up and swapped out while not creating any downtime for the data center. The cooling system on the other hand is designed to last at least fifteen to twenty years. With both the servers and cooling system running 24/7, and with the demand for continuous operation with no downtime, the use of an efficient DSS when designing or retro fitting a data center is imperative. A methodology for DSS development that would constitute an integrated framework **comprised of** decision trees and case based reasoning is described below.

Decision trees are ~~a~~ stem and leaf figures used to represent possible outcomes. At the core of the decision tree is the assignment of probabilities of possible outcomes to assist in complex decision-making (Han and Kamber 2001). The many decisions needed to build or update a data center can be overwhelming. By using decision tree analysis, a large number of different factors can be taken into account and thereby reduce uncertainty. For example, the net present value of energy savings can be calculated based on the energy savings when choosing between two or more servers. A decision tree could be developed by starting with two products and showing the initial cost of both, and then based on the net present value of energy cost over time, the decision tree would demonstrate the total operating cost over the product life-cycle as a whole. At the heart of the performance versus cost issue when purchasing new servers are the new tier of servers that will soon be on the market that are Energy Star rated by the U.S. Environmental Protection Agency (USEPA 2007). An Energy Star appliance, or in this case server, streamlines the decision process. However, since most data centers have a mix of hardware suppliers for their center, it will still be a major challenge to decide which vendor to select. Decision trees can be designed, for example, to compare the cost-benefits of purchasing an Energy Star server versus a common server. While it might be expected that an Energy Star server may cost more initially, the any net savings in electricity over time will be presented by the decision tree. Decision trees can also assist the data center management team in the area of virtualization. Currently it is estimated that most servers are running at about 25%-35% utilization rates and should be approaching a utilization rate of closer to 85% (Bean and Dunlop 2008; Sun Microsystems 2009). In addition, there are often servers that are "phantom" servers; i.e., are left on from previous applications that are not used any more. A decision tree can take stock of all the servers and racks and assist in the virtualization to better manage the data center. By eliminating phantom servers and consolidating other servers, there are numerous benefits such as reduced electric bills, reduction of CO_2 emissions, freeing up of valuable floor space, and lower administration costs (Schmidt et al. 2007).

Another technique that will be incorporated in DSS framework is Case Based Reasoning (CBR) which is the process of solving new problems based on solutions of similar past problems (Aamodt and Plaza 1994). CBR can be a powerful tool with the ability to retrieve similar cases for reuse and revision. Metrics to measure data center efficiency for use in conjunction with CBR are being developed that can be used for comparison against other data centers for benchmarking (Belday et al. 2008; Matthew et al. 2009). For data center management, the use of CBR can be supportive when updating hardware in the sense that previous cases can be obtained and the processes can become more automated. The full details of our DSS methodology are beyond the scope of this white paper.

Increasingly, managers are coming under pressure to reduce electrical usage at their facilities for cost savings and environmental considerations. The cost to operate a server or the electrical usage of a server throughout the lifecycle is increasingly more than the initial cost of the server's original purchase price. Due to this scenario, mega-datacenters such as Yahoo, Google and Microsoft have moved their data center operations closer to the Columbia River on the Oregon/Washington border to take advantage of relatively cheap hydro-electric power. This business decision may make sense from an economic perspective since hydro-electric power does not contribute carbon dioxide emissions into the atmosphere, but from an ecological perspective it is known to adversely impact fish migrations. Thus, balance is the key for making sustainable practice decisions as a business, citizen or manager. With government increasingly interested in reducing carbon emissions and organizations trying to be green, this decision by the mega-datacenter operators has the potential of being a win-win solution if potential negative externalities are addressed. However, a standard sized data center operator cannot easily move the data center across the country to take advantage of clean hydro-electric power. Yet there is increasing pressure to reduce electrical consumption and carbon dioxide emissions. A properly designed DSS can assist in the decision-making in such trade-offs on performance versus cost issues.

The DSS developed from the proposed effort would have the potential to support an institution not only to achieve cost savings in current energy usage for the data center, but also to predict how future decisions will result in savings. We also expect it to become a model for higher education institutions, with the potential of becoming a pioneering system for colleges and universities throughout the United States. The developed system would be such that it also can be potentially used in industrial decision-making scenarios to achieve energy efficiency for a greener environment. Likewise, there are several transformational results that we expect out of the proposed research activity.

4. Societal Challenges

While energy efficiency is viewed as a desirable outcome, there is a risk aversion by system administrators to any change that could possibly result in down time of data centers (USEPA 2007). There also exists a bureaucratic problem in logistically gathering data from various departments in universities such as IT, facilities and accounting. This is due to the fact that IT typically provides data center services, facilities provides the electricity to power the data center, and accounting pays for the services. Therefore, a disconnect exists or a split incentive occurs, according to the EPA, between these departments since there is no single entity responsible for lowering electrical usage and carbon footprint reduction (USEPA 2007). This presents a significant challenge.

Another challenge stems from the need for data collection, and the lack of equipment for this purpose. For example, often there are no sub-meters available for measurement, particularly within air-conditioning systems. There is a need to move from estimates of air-conditioning costs and carbon footprints, to more exact measurements. To overcome this challenge, it may be necessary to install such equipment in campuses, for instance, electric meters on the air-conditioning systems. There is obviously a need to justify this installation and procure the necessary funding.

An additional challenge to implementing green information technology initiatives in academia is the requirement of bringing different disciplines together. There is a need to draw together academic disciplines such as computer science, environmental management and related departments. It is important to work collectively with experts in their respective fields with various levels of knowledge on data center issues. Much of this can be achieved through various collaborative research projects heading towards transdisciplinary work, which can be viewed as interesting by various departments. Consequently, there is obviously the need to fund such trandisciplinary research initiatives.

5. Mapping to Administration Guidance

We consider the policy document available from NIST TIP sources, in the Office of Science and Technology Policy (OSTP 2010). It states that, “Scientific discovery and technological innovation are major engines of increasing productivity and are indispensible for promoting economic growth, safeguarding the environment, improving the health of the population and safeguarding our national security in the technology driven 21^{st} century.” Furthermore, here is a quote from President Obama available from the same site (OSTP 2010) “Whether it is improving our health or harnessing clean energy, protecting our security or succeeding in the global economy, our future depends on reaffirming America’s role as the world’s engine of scientific discovery and technological innovation”. Our initiative addresses the issue of energy usage and heads towards innovative research and development, thereby conforming to administration guidance. We elaborate on this further.

Around the world today, data centers have become a critical component of the infrastructure in corporations, universities, government agencies and other organizations. The electrical power that fuels the data center has doubled from 2000 to 2005 for both the United States and the world, and is expected to double again by 2010 (Koomey 2008; Tschudi et al. 2006). From 2007 estimates, the U.S. currently uses approximately 1.2 percent of total electrical consumption for data centers, which is comparable to all the televisions that are used in the U.S**.** (Koomey 2008). The amount of power used by servers is equivalent to five 1000 MW power plants in the U.S., and 14 similar power plants for the world (USEPA 2007). Data centers also contribute up to 2 percent of the world’s CO_2 emissions (Daim et al. 2009). Due to these strong growth trends, organizations are becoming more focused on ways to reduce electrical consumption and the carbon footprint at data centers.

In addition, Kant (2009) argues that the future of data centers will be outsourced and virtualized. Outsourced data centers fall within the realm of cloud computing. Cloud computing represents a paradigm shift of how data centers operate (Armbrust et al. 2009). Cloud computing can turn a capital expense into an operating expense which will lower the initial costs of starting a business or expanding a data center. Virtualization offers IT administrators the ability to consolidate and optimize servers to reduce power and cooling costs. Three of the main advantages to virtualization are underutilized servers, data centers running out of space, and mounting system administration costs (Schmidt et al. 2007). The proposed project will identify the opportunities and challenges of shifting resources towards a data center that is operated in the cloud and virtualized. This aspect of our work will benefit similar organizations that are exploring the costs and benefits of moving towards cloud computing and continuing virtualization consolidation.

This research focuses “globally” on energy conservation, and “locally” on one of the most intensive energy users in society, i.e., the worldwide network of complex data centers. Power consumption and dissipation of heat from microprocessors, and the concomitant need to cool the system are extraordinary. In 2009 alone, approximately 330 tera-hours of energy (about 2 % of global electricity) was consumed to operate data centers worldwide (Meijer 2010). In addition to the economic impact, of around $30 billion, the ecological consequences also are substantial in the form of greenhouse gas emissions. Although some progress has been made, the prospects for restraining the power dissipation at peak performance with the newest generation of microprocessors looks “grim” (Meijer 2010).

We envisage that this study would build one of the first DSS systems for supporting green data centers, thereby representing innovative work in the area. The study would investigate whether state-of-the-art developments such as cloud computing would be a better alternative to building in house data centers. The benefits of the proposed study will have positive implications for data center system administrators by providing a case study of reductions in electrical and carbon emissions. In addition, the majority of case studies conducted have been through vendor companies which are not peer reviewed. By providing a third party audit of a data center will increase the knowledge in energy efficiency of data centers. The outcomes of the proposed research would thus lead to technological advances in terms of energy efficiency with decision support. Hence, the proposed research plan maps to administration guidance.

6. Justification for Government Attention

In order to justify the need for government attention for the proposed research, we present an insight into the literature survey of related work. Other areas of development in the field of data center operations are the improvement of data center metrics. Experts in the field have been trying to develop and improve metrics similar to the Corporate Average Fuel Economy (CAFE) standards in the automotive sector for similar efficiency standards for data centers. The purpose of introducing data center metrics, such as Power Usage Effectiveness (PUE) and Data Center Productivity (DCP) is to have comparable metrics across data centers (Daim et al. 2009; Marwah 2009). Some of the organizations that are working to develop the metrics include such groups as the Uptime Institute, Green Grid, U.S. EPA Energy Star, and Climate Savers (Stanley et al. 2007). These groups are seeking to implement the metrics across sectors to have a few equivalent standards so that there are common comparisons.

To the best of our knowledge our work constitutes a pioneering direction in the field. The strength of our project is that it constitutes work on managing a data center from a sustainability perspective, with the focus being on consumption measurement. In the market place companies such as Google, IBM and Sun have performed studies to reduce cost and green operations, but have been limited to commercially produced white papers. Related research groups could also be other universities that are implementing sustainability IT projects. At this time it is hard to gauge the extent of detail of various universities in their efforts on green IT. For example, Tufts University has been experimenting with different cooling options for their data center, but has not released an official report. At Villanova University, Talebi and Way (2009) examined green computing, however their focus was on energy savings of individual computers, and their study did not focus on the data center. The superiority of our project is that the study is conducted in house and from a cross disciplinary research team. The results will be applicable to educational facilities as well as small to medium size business units.

Server rooms are notorious for needing to be kept cool. With cooling costs of data centers representing up to 50% of the operational costs, administrators are increasingly looking for ways to reduce costs (Tschudi et al. 2006). While computers still need to be kept cool, server designers are building newer product lines to have the capacity to operate effectively at higher temperatures (ASHRAE 2008). Recently, in 2008, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) widened the range of recommended temperature of data centers from 68 to 77 degrees F. in 2004, to the current 64.4 to 80.6 degrees F. (ASHRAE 2008). Raising the temperature of the air-conditioners can lower operating costs; however, data center managers must check the warranty of their server contracts. Server manufacturers only warranty their products on the condition that the server rooms do not rise above a certain temperature for a specific period of time.

While the above researchers and agencies are focused on such topics metrics, cloud computing, virtualization, and cooling of data centers, our project is technologically superior in that we will consider all of these topics for a university setting and from a cross-disciplinary approach. The repercussions of our work will impact data center management resulting in a novel software development toolkit that can be deployed in similar organizations. We therefore justify the need for government attention in supporting this novel research activity.

7. Essentials for TIP Funding

The Technology Innovation Program (TIP) at the National Institute of Standards and Technology (NIST) was established for the purpose of assisting domestic businesses and institutions of higher education or other organizations, such as national laboratories and nonprofit research institutions, to support, promote, and accelerate innovation in the United States through high-risk, high-reward research in areas of critical national need.

TIP seeks to support accelerating high-risk, transformative research targeted to address key societal challenges. Funding selections will be merit-based and may be provided to industry (small and medium-sized businesses), universities, and consortia. The primary mechanism for this support is cost-shared cooperative agreements awarded on the basis of merit competitions.

Hence this Technology Innovation Program in the National Institute of Standards and Technology can play a vital role in enabling the development of Green Data Centers for Sustainability. This initiative fits into the areas of interest that are seen on the NIST TIP website. Energy is one of the items of focus and it can be seen that NIST has already started work in the area by working on some projects such as the Smart Grid and the establishment of Domain Expert Working Groups (DEWGs) as cited in relevant proposals on their website (NIST TIP 2010). The DEWGs comprise industry experts from electric utilities, manufacturers, industry organizations and users groups, consultants, standards development organizations (SDOs), and academia. They are working in several Smart Grid domain areas (commercial buildings, industrial plants and centralized generation, residences, transmission and distribution grid) to identify the key interfaces, interoperability barriers and standards necessary to overcome them, and to enable the rapid development of energy efficient technologies such as the Smart Grid.

Our initiative of “Green Data Centers for Sustainability” is likewise an important step towards achieving energy-efficiency for a greener planet. While the details of funding sought are beyond the scope of this white paper, we wish to indicate that this work provides the potential for a Ph.D. dissertation with contributions towards multiple disciplines such as Computer Science and Environmental Studies. Thus, the nature of the funding provided by TIP could ideally be such that it encompasses the tuition for a doctoral student along with one or two more students at the graduate / undergraduate level who can assist in this project playing suitable team-work roles. It should also take into account the related support needed for faculty involvement in terms of summer salaries and / or release time from courses to work on the project. Other venues for funding would be travel support for presenting and publishing the outcomes of this work as transformational results in various reputed conferences and seminars. This is essential in order to disseminate the findings of this study to the public. No specific cost estimates are provided at this point but can be made available upon request.

This research on “Green Data Centers for Sustainability” is an area of critical national need and is a problem of large magnitude leading towards potentially transformational results and involving significant societal challenges. The technical contributions of this work mainly include the development of a decision support system in green computing along with related research contributions in Computer Science and Environmental Studies at finer levels of granularity. This work has considerable intellectual merit in terms of the challenging research involved proposing appropriate techniques for the development of the DSS to meet specific energy goals and addressing various issues such as thermal profiling, cloud computing and virtualization. This research has the broader impact of achieving sustainable systems for a greener planet. All this constitutes the essentials for funding by NIST TIP.

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