Sudan University of Science & Technology

Faculty of Computer Science and Information Technology

Integrated Framework For Green ICT:

Energy Efficiency by Using Effective

Metric and Efficient Techniques

For Green Data Centres

إطار عمل متكامل بإستخدام تقنيات فعالة وصديقة للبيئة

لترشيد الطاقة المستهلكة وزيادة كفاءة

مراكز بيانات تكنولوجيا الإتصالات والمعلومات

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DEDICATION

To the soul of my mother

To the soul of my father

To my wife

To my family

To the people who add meaning to my life

To everyone who has supported me during this research

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Abstract

All over the world, nations are concerned about the challenge of sustainable energy, energy efficiency effects on society, environment and the economy. This research develop a green ICT solutions to increase energy efficiency and sustainability in data centers. Focusing on achieving high energy efficiency for green data centre, an energy efficient framework (RAIN) for energy efficiency assessment and management has been developed. Additionally, the author used Fixed to Variable Energy Ratio (FVER) as a suitable metric, to demonstrate ability and sensitivity from the effect of changes in energy workload efficiency. The tool and its technique were validated through analysis of several data sets gathered from ICT data centres in Sudan, Saudi Arabia and Pakistan. The innovative assessment tool, indicators and techniques will enable ICT data centres to monitor, measure, assess and manage energy efficiently for Green data centers. The implementation of the proposed framework proved that RAIN could achieve an average **of 50%** saving of a data centre's total energy consumption, consequently leading to performance-optimisation of ICT infrastructure services enabling users to concentrate on business, cutting ICT operations costs, reducing indirectly emissions of carbon dioxide (CO_2) and minimising its carbon footprint. The proposed framework compared by other green framework and provides not only covers the understanding of different aspects of green ICT, but may also be used as a tool to evaluate techniques required to put green ICT into action.

الملخص

ظل العالم مهتما بقضايا ضمان استمرار الطاقة وسبل المحافظة عليها وترشيد استخدامها واثر ذلك على البيئة والمجتمع والاقتصاد. وهذا الاهتمام ظل في تزايد بالرغم من زيادة الادوات التي تساعد في تحكم استهلاك الطاقة المستخدمة في مراكز تكنولوجيا المعلومات والاتصالات. هذه الدراسة تقدم حلا تقنيا للمحافظة على الطاقة وترشيد استهلاكها وذلك بتبني اطار عمل يسمي RAIN لتوفير استهلاك الطاقة في مراكز استضافة البيانات في مؤسسات المعلومات والاتصالات. تسلط الدراسة الضوء على تحقيق أكبر قدر ممكن لزيادة فاعلية هذه المراكز وذلك بتبني تكنولوجيا صديقة للبيئة. استخدم الباحث **FVER** كمعيارا مناسبا يستطيع قياس مقدار الطاقة المستهلكة والجزء الذي تم ترشيده. يعتبر هذا المعيار من أكثر المعايير فاعلية لأنه يستطيع قياس مدى تأثير البرامج والتطبيقات الحاسوبية علي زيادة استهلاك الطاقة في مراكز البيانات.

تم اختبار فاعلية وكفاءة إطار العمل وادواته بتحليل مجموعة من البيانات والقراءات تم رصدها وتجميعها من مراكز تكنولوجيا المعلومات والاتصالات في السودان والسعودية وباكستان. اثبت تحليل البيانات قبل وبعد تطبيق اطار العمل مدي فاعليته ودوره المباشر في توظيف استهلاك الطاقة في مراكز البيانات مما يؤدي لترشيد استخدامها حيث وصل متوسط مستوي الترشيد الي **٥٠%** من جملة الطاقة المستهلكة. مما سبق يمكن لاطار العمل RAIN ادارة مراكز استضافة البيانات في مؤسسات المعلومات والاتصالات وكذلك تحسين كفاءة الإداء لها مما يؤدي لتقليل التكلفة الكلية للخدمات المقدمة وهذا بدوره سيفيد المستخدم بصورة مباشرة وذلك بتقليل تكلفة التشغيل. ومن الفوائد الغير مباشرة لاطار العمل RAIN خفض انبعاث ثاني اكسيد الكربون كنتيجة فعلية لتقليل استهلاك الطاقة في هذه المراكز.

كما يمكن استخدام هذا الاطار كأداة لتقييم وادارة تقنيات وتطبيقات برمجيات الاتصالات المستخدمة في مراكز البيانات والمعلومات وبالتالي ترشيد استهلاك الطاقة الكلية في قطاع المعلومات والاتصالات.

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List of Abbreviations

ICT	Information Communication Technology
CO_2	Carbon Dioxide
QoS	Quality of Service
EAC	Energy Aware Computing
RAIN	Rating, Analysis, Implement and Note
IT	Information Technology
FVER	Fixed to Variable Energy Ratio
SLA	Service Level Agreement
KWh	Kilowatt per Hour
GHG	Green House Gas
DC	Data Center
VM	Virtual Machine
UPS	Uninterruptable Power Supply
RES	Renewable Energy supply
DCSG	Data Center Specialist Group
PUE	Power Usage effectiveness
CC	Cloud Computing
LEED	Leadership in Energy and Environment Design
DVFS	Dynamic Voltage/frequency scaling
DCiE	Data Center Infrastructure Effectiveness
DCeP	Data Center Energy Productivity

DPPE	Data Center Performance Per Energy
DC FVER	Data Center Fixed to Variable Energy Ratio
ROI	Return On Investment
PDU	Power Distribution Unit
NCPI	Network Critical Physical Infrastructure
EPA	Environment Protection Agency
DCPI	Data Center Physical Infrastructure

CHAPTER ONE

INTRODUCTION

This chapter is explores in details the main parts which define and explain in detail the information system research. This chapter presents the problem statement of the research, hypothesis, philosophy behind the research, research methodology that was adopted to increase the energy efficiency and reduce carbon emission indirectly by enabling green ICT framework using different green ICT techniques.

1.1 Purpose of The Research

Data centers are currently consuming amount of energy which reduce the benefits of the owners and in same way producing CO_2 gases that are very hazardous to the environment [69]. According to a report published by climate group and global e-sustainability initiative SMART 2020, the growth in emissions from ICT with increase from 3% of total global emissions in 2009 to 6% by 2020 [70]. The research explores the importance of green ICT in reducing energy consumption, operation costs and environment friendly in data centers. The major goal of this research is to formulate an energy efficient and low carbon enabler green ICT framework based on virtualization, right sizing, efficiency data center buildings and green metrics to reduce the operation costs for owners and end users by managing and reducing power consumption the operators can reducing operators bills.

1.2 Problem Background

The current research conducted a deep critical literature review to examine the fragmented knowledge about energy efficiency in the data centers in cloud computing technology.

First, the investigated literature showed that there were some gaps in previous researches. First of all, the focus of most of their studies in the area of energy efficiency in data centers has been only focused on one part of the data center (Servers applications, job scheduling, building, or hardware). This approach may be due to difficulties in measuring the energy efficiency in the data center.

Second, the previous techniques and approaches lacked several features like quality of services (QoS) performed against energy efficiency.

Third, the reduction of the energy consumption is not measured in a highly effective way, because current metric did not measure software influence and IT equipment factors. So, there is lack of appropriate metric for measuring the value of energy efficiency take into account the change in the IT workload.

Fourth, despite the enormous body of literature in studying the effect of energy efficiency in data centers in cloud computing, lack of a unified framework for integrating different aspects and features of the changes in the software that run on the data center and the effect of the software on the energy efficiency in the data centers in cloud computing. So, the field of energy efficiency in the data centers appears to be in need of further development and coherence.

The required framework should provide a platform on top of which the green cloud could be built. The framework from Energy Aware Computing (EAC) point of view will improve the efficiency of cloud systems and their data centers and the clouds themselves will produce naturally efficient and focused centers of computation, advancing the pursuit of green computing.

From the above, it can be concluded that data center managers should, when considering energy efficiency framework, take into account all the three dimensions of energy efficiency parts (application, building, and hardware). Additionally, the framework consider the changed social network applications load as an effective factor in elevating energy consumption by the data centers, as well as meeting energy efficiency.

1.3 Limitations and Open Issues:

The investigated of the literature showed that there are some gaps in previous works. First of all, the focus of most of studies in the area of energy efficiency in data centers has been on one part of the data center (either Servers or application or building or hardware). This approach may be due to difficulties in measuring the energy efficiency in the data center. Despite the enormous body of literature in studying the effect of energy efficiency in data centers in cloud computing, the lack of a standard framework for integrating different aspects and features of the changing in the software that run on the data center and the effect of the software on the energy efficiency in the data centers. Additionally, none of the current applied energy efficiency frameworks considered the social network applications (Facebook, twitter, YouTube, …) as a vital related factor in elevating energy consumption, as well as high potential for energy efficiency.

The field of energy efficiency in the data centers seems to be in need of further development and coherence. The previous techniques and approaches lack several features like QoS and performance against energy efficiency. Additionally, the reduction or increase of the energy consumption is not measured by suitable metric. The need for a comprehensive and integrated framework (RAIN) provides a platform on top of which the Green Cloud could be built. The development of such framework practices from Energy Aware Computing will improve dramatically the efficiency of Cloud systems and their data centers and Clouds themselves will produce naturally efficient and focused centers of computation, advancing the pursuit of green computing. The required integrated data center energy efficiency framework should be also applied in different types of data centers including public, private and hybrid. The existence of such framework will offer a great powerful capability to deal with service levels and resources management. The required data center Energy Efficiency framework will offer improvement in scalability, elasticity, simplicity of management, delivery of cloud services and better reduction in data centers energy consumption taking into consideration the QoS for the user services.

Our literature review on the common energy efficiency metrics which are currently in use by data centers reveals that none of these metrics are meeting the prior criteria.

From the above, it can be concluded that data center managers should, when considering energy efficiency framework, take into account all three dimensions of energy efficiency parts (Data center, Building, Software) and choose appropriate metric. Additionally, consider the social network applications as a vital related factor in elevating energy consumption, as well as high potential for energy efficiency.

1.4 Problem Statement

The data center is the most active part in an ICT, it provides processing resources and hosting resources which supports different platforms. Data centers are connected with thousands of servers, run applications for end users to meet their needs and to achieve large business goals. For low operation costs, recently organizations switch to cloud services specially e-businesses, which are in need of a data center to perform their jobs. All over the world data centers consume around 40,000,000 MWhr per year [71], unfortunately figure 1.1 shows that most of the part of this energy is wasted due to lack of efficiency in data centers and data center building. The problems with the current ICT data centers are:

1-The lack of integrated and coherent green ICT framework to manage energy efficiency techniques like virtualization, right sizing to increase energy efficiency and reduce operation costs including servers applications, job scheduling, building, and hardware taking into account the QoS.

2-The lack of appropriate metric for measuring the value of energy efficiency taking into consideration the change in the IT workload including social media applications .

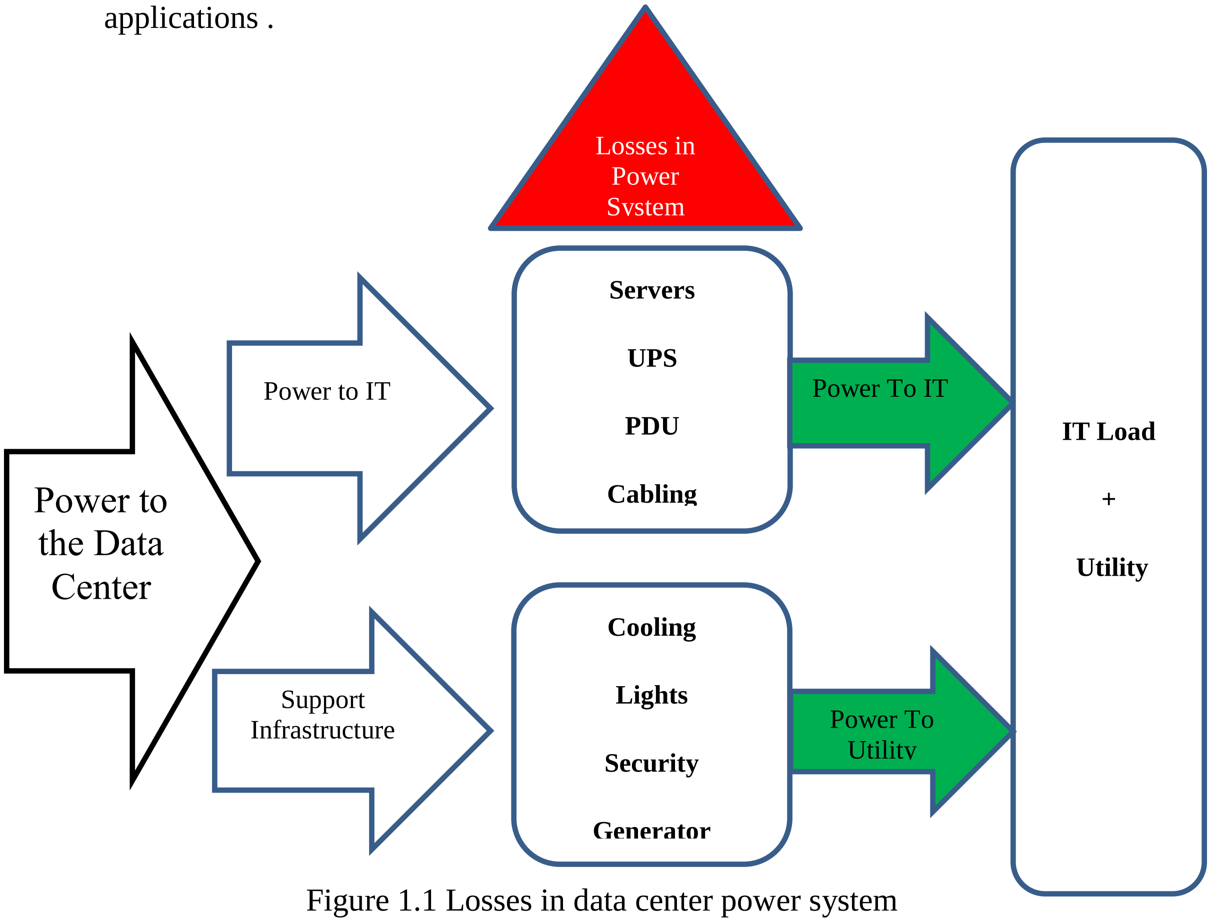

Figure 1.1 Losses in data center power system

1.5 Questions/Hypothesis/Philosophy

1.5.1 Questions

1. How to minimize fixed and variable energy consumption in data centers in order to increase energy efficiency and reduce operation costs?
2. How to select a suitable and effective green metric?
3. How green ICT framework will be helpful to achieve energy efficient and green data centers?
4. How to calculate energy efficiency level?

1.5.2 Hypothesis

1. The proposed energy efficiency framework will help cloud computing providers to reduce data centers operational cost.
2. Implementation of integrated and coherent green cloud computing framework in data centers will lead to increase in the utilization of data centers.
3. The measurement of energy efficiency would help data center managers to effectively manage data centers energy consumption.
4. A suitable metric would help to develop energy efficiency.

1.5.3 Philosophy

The main philosophy of our research is based on an economic form to develop mechanics of marketing between cloud providers and customers by reducing the end user costs and minimizing the carbon dioxide footprint indirectly.

1.6 Research Objectives

The main aim of this research is to reduce data centers energy consumption in two dimensions operation costs and eco-friendly environment. Other objectives are:

1. To increase energy efficient in the data centers and low cost operation.
2. To develop and implement integrated and coherent green cloud computing framework in data centers that will increase the data centers utilization.
3. To set criteria to identify suitable and effective green metrics to deal with change in workload.
4. To calculate and evaluate overall energy efficiency, productivity and

costs savings including ICT equipment for different Tiers data center.

1.7 Research Scope

1. The research focuses on different Tier level data centers in Sudan, Saudi Arabia and Pakistan currently under enormous power consumptions and generating huge amount of CO_2 emissions.
2. The research applies Fixed to Variable Energy Ratio (FVER) metrics for measuring the efficiency of Tier level data centers as specified in the analysis of several case studies.

1.8 Research Significance

The research helps data center managers to put energy efficiency and green data centers into action, to reduce the operation costs for both, owner and users by reducing the energy consumption and CO_2 emissions. The research drive different Tiers data center in different countries (Sudan, Saudi Arabia and Pakistan) to hold back energy challenges by switching to a new technology of energy efficiency and sustainable environment.

The research also helps data center managers to adopt the new world attention and concern in green ICT and global environment by reducing overall CO_2 emissions (Carbon Footprints), that has become very hazardous for environmental sustainability and global warming.

The research support ICT businesses to implement Green ICT in their operations to make them sustainable. The research also helps ICT businesses to become greener by supporting environment friendly community and follow service level agreements (SLA) between stakeholders and ICT businesses.

1.9 Research Methodology

The main goal of this research is to implement suitable technologies to put green computing into action to reduce total costs of ownership and to increase return on investment. Green ICT solutions help the firm to reduce energy in ICT operations, and increase significant benefits of an ICT sustainability business. The research was performed on tier level data centers in Sudan, Saudi Arabia and

Pakistan. The research is divided in three main phases to achieve desired objectives. Figure 3.2 show the detail about the three phases.

1.9.1 Phase1: Development energy efficiency framework

In investigating the previous research the focus was mostly on the findings of articles and the methods used to achieve energy efficiency. Although this review targets energy efficiency in data centers in the cloud technology as the main audience and explores theoretical and empirical issues relevant to scientific research. To study the academic literatures on the effects of energy efficiency on the data centers, the related impact of journal, international conferences and universities research database was used to search for these keywords: 1) Green data centers, 2) Energy efficiency in the data centers, 3) Green technology, 4) Reduce energy and Co_2 emission. We searched in the title, abstract and keywords of the papers. It led to **684** papers with all the results. We depended on specific conditions to choose the suitable papers.

For the industry to make real progress at any data center, efficient metric is needed to be part of a measurement methodology designed to calculate a reasonable and fair approximation of the total environmental and financial cost of the service provided at the data center. Measuring energy consumption of data centers has become a significant concern of all data centers stakeholders to meet the end-users agreement. The energy efficiency metric is a tool used to measure energy efficiency in data centers. The most important challenge in the data centers industry is the limitation of effective standard energy efficiency metrics, which supports improvement energy efficiency.

1.9.2 Phase 2: Analysis and evaluating green ICT framework

In this phase the proposed framework (RAIN) was analyzed and evaluated to determine its real effect in increasing the energy efficiency in data centers and reduce overall operation costs. The framework was tested and evaluated by applying:

I. Performing case studies: The proposed green ICT framework, when implementing green data centers, was tested in different tier level data centers in Sudan Tier 4, Saudi Arabia Tier 3 and Pakistan Tier 2. Three case studies were performed in hot area in different countries by different data center tier to evaluate different components of proposed framework in Tier II, Tier III and Tier VI level data centers in Pakistan, Saudi Arabia and Sudan alternatively. The part of energy efficiency in the framework deal with measuring operational costs, total cost of ownership and other benefits after implementing server virtualization, right sizing and green data center building standard (LEED).

II. Applying regression analysis approach: To prove the liner relationship between the productivity of the data center in specific time (hour) and the energy consumed (kWh) to finish this work. The data collected by various means was analysed. Regression analysis technique was applied thoroughly to analyze collected data in a manageable form.

The research approach investigates the implementation of proposed green IT framework RAIN in different tier level data centers based on different categories classified according to the following components:

I. Energy Efficiency Calculations
II. Productivity.
III. Green Metrics.
IV. Carbon Emission

1.9.3 Phase 3: Maintenance and finalized framework

In phase 3 after implementing our framework (RAIN) and analyzing the results generated after performing the detailed testing and analysis of the proposed green ICT framework in phase 2, the maintenance, if needed can be implemented, then restructured and redesigned to meet the required standards. The analysis phase results helps to improve the proposed framework, so that it became easier for data center managers to adapt and manage according to their limitations and recommendations to maximize efficiency in terms of energy saving and CO_2 emissions and at the same time achieve a maximum performance of the data center.

Finally a complete energy efficient and green ICT framework was developed to achieve the main objectives, which was highlighted in this research.

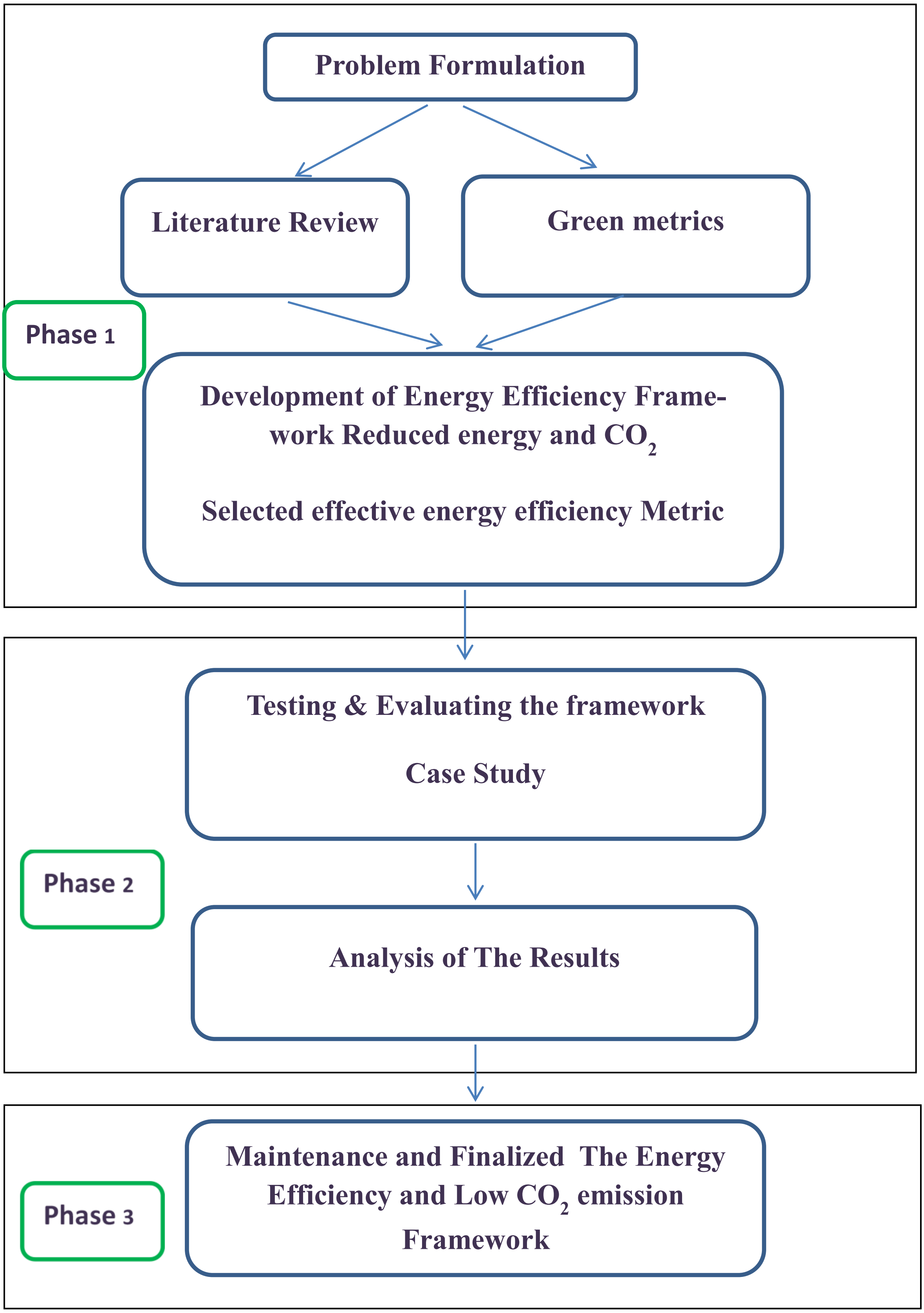

Figure 1.2 Operational research framework

CHAPTER TWO

BACKGROUND

2.1 Overview

Traditionally, the development of computing systems has been focused on performance improvements driven by the demand of applications from consumer, scientific, and business domains. However, the ever-increasing energy consumption of computing systems has started to limit further performance growth due to overwhelming electricity bills and carbon dioxide footprints. To identify open challenges in the area and facilitate future advancements, it is essential to synthesize and classify the research on power- and energy-efficient design conducted to date. In this study, we discuss causes and problems of high power/energy consumption, and present a taxonomy of energy efficient design of computing systems covering the hardware, operating system, virtualization, and data center levels. We survey various key works in the area and map them onto our taxonomy to guide future design and development efforts.

The growing of social applications and e-business need to increase the number of data centers. However, the combination of global warming and inconstant climate make the cost of energy a major challenge for the sustainability of the e-business [1]. Computer specialists expect that data centers technology is the optimal choices for next generation systems. Google managers and engineers expect that if energy consumed continues ascending, that drive to energy cost will be more than infrastructure cost. Energy consumption cost will influence to end user that pay as usage cloud resources and services. Also more power consumption requires more cooling, and that affects the environment in a negative way by producing more carbon dioxide (CO_2). Data centers are a binding form, for example, an IBM data center consumes 20 MW which is almost equal to 22,000 US building energy consumption [2], and equivalent to 0.5% of the whole world's energy. Gartner’s annual report acknowledged that the information and communication technology (ICT) costs on 2009 decreased by 5.2%, but the costs on 2010 have increased by 3.3% [3]. The ICT manufacture will enter a renewed growth phase and take place as tops Gartner’s list of 10 strategic technologies in 2010 and will become the main technology in the coming years [3].

Figure 2.1 shows the energy consumed by the data center parts, so increasing in energy efficiency in a few percentage of the energy consumption means saving a significant amount of money and increasing the profits.

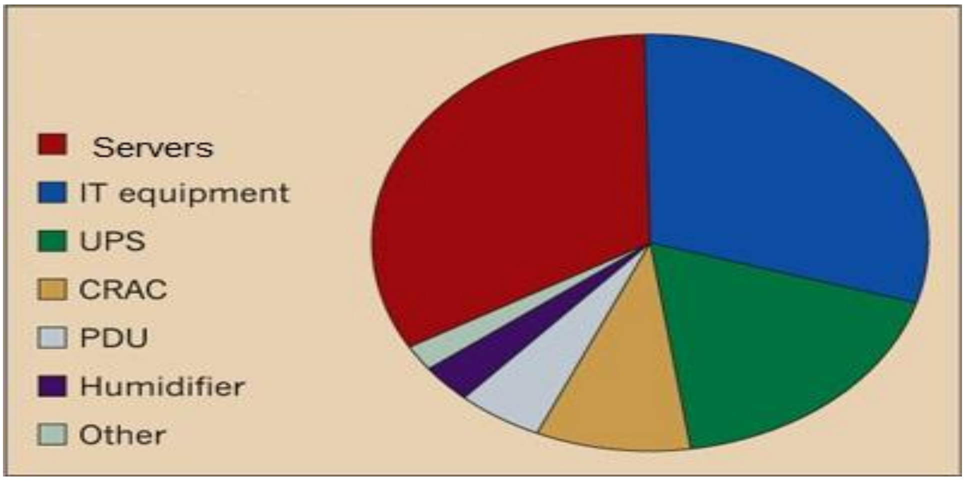

Figure 2.1: Energy Consumed in Data Center [20]

Energy consumption in hosting Internet services is becoming a pressing issue as these services scale up. Information communication technology (ICT) could play an essential role in decreasing energy consumed by data centers and at the same time generate new business opportunities. Energy Efficiency is one of the vital challenges of the ICT businesses, where environmental sustainability is becoming mandatory for energy management in data centers. Reduced cost of energy for data centers is imperative from an economic and sustainable perspective. Without the need for drastic changes in the city's physical structure.

2.2 ICT and Energy Consumption

As Information Communication Technology (**ICT**) improves corporate effectiveness, so energy expenditure in data centres is simultaneously also increasing. ICT could play an essential role in decreasing consumption, while at the same time generating business opportunities. During the life cycle of a data centre, most energy (~80%) is used during the operational stage; the impact of user behaviour and real-time control, only 20% [21]. Focused on the perfection of energy efficiency through innovative ICT applications is the so-called 'Green Data Centres or 'Smart Data

Centres’. It has spawned a vision, detailed best practice examples and identified and structured research/development targets of ICT method , its models, applications and systems to support future energy efficiency in the built environment [22]. ICT has potential to facilitate lower energy use and greenhouse gas (GHG) emissions. According to studies [23], ICT can reduce on a global one fifth of the ICT sector’s own emissions, which is 15% of total global emissions in a ‘business as usual’(scenario for 2020). According to GeSi (2008), the ICT could help to improve energy efficiency [24].

Energy consumption costs influences an end-user who must pay for usage cloud resources and services. Moreover, consumption of extra power requires more cooling – negatively affecting the environment through production of extra CO_2. Cloud computing is compatible with differing users’ demands and has three types of access structure -network, public cloud/private cloud and hybrid cloud [25].

Software is another issue to be considered when discussing green ICT [12]. Software behaviour is affecting computing workload and resource usage and has influenced energy consumption and core computing resources – particularly in utility equipment [11]. Publications worldwide print software issues to enhance awareness. Whether driven by consumer demand, business, economic, social or politics, the green movement has grown; domestic and international organisations are adopting it [12].

While green ICT influences business and the environment, data centre managers can play a principal role in increasing energy efficiency by following a green ICT framework, to reduce huge amount of energy while reducing global warming through the cutting of CO_2 emission [14].

2.3 Measure Energy consumptions in Data Center

People sometimes use power and energy in synonymously. But power and energy mean two different things. Power can be thought of the rate at which energy can expended. Power is the instantaneous measurement of the use of electricity, like a 100-watt light bulb or what something can do. Energy is the total quantity of work performed. Energy is using of the power over a period of time, like 100-watt bulb being lit for one hour.

2.3.1 Data center

Data center is a corner stone of the infrastructure of cloud computing approach by which a variety of information and communication technology (ICT) services are built. They extend the ability of centralized repository for computing, hosting, storage, management, monitoring, networking and deployment of data. With the rapid increase in using data centers, there is a continuous increase in the energy consumption [14]. Data center beside consumed energy also produces carbon dioxide and that riddled with IT inefficiencies. Data center major components are thousands of servers; however these servers consume huge energy without performing useful work. Data centers today are homes to a vast number and a variety of applications with diverse resource demands and performance objectives. There are many models to support energy efficiency in data center; the most important model is virtualization. Cloud computing supports virtualization like resources (i.e. computes, storage, and network capacity). The most basic one is at Virtual Machine (VM) level where different applications can be executed within their containers or operating systems running on the same machine hardware. Platform level enables seamless mapping of applications to one or more resources offered by different cloud infrastructure providers. Virtual machines (VMs) are a logical slit of physical resources, and it is the heart of virtualization. In data centers, the number of physical machines can be reduced using virtualization by consolidating virtual appliances onto shared servers. This can help to improve the efficiency of ICT systems. The advantages are simple, it allows multiple virtual machines to be run on a single physical machine in order to provide more capability and increase the utilization level of the hardware. It always increases efficiency; it allows you to do more work with less ICT equipment [2]. The worldwide agitation to achieve ecological, business and environmental sustainability is starting to redraw industrial landscape. The current status of global warming, ecological deterioration and the severity of its potential consequences explain the over whelming popularity of environmental initiatives across the world. Environmental impact of ICT under the banner of “Green ICT” has started being discussed by academia, media and government. Since 2007 when the Environmental Protection

Agency (EPA) submitted a report to the US Congress [2] about the expected energy consumption of data centers. The main objective of Green ICT is to increase energy efficiency and reduce CO_2 emissions [13]. Energy usage and carbon footprint are the features most commonly discussed and measured to determine how green a Data Center is; however, other elements warrant attention as well. Other green details to consider include the following:

Generator emissions: Standby generators, used to keep a Data Center running when commercial power fails, consume fuel when in operation and can emit a range of pollutants including nitrogen oxides, hydrocarbons, carbon monoxide, carbon dioxide, and particulate matter. Knowing the consumption and emissions of your Data Center generators provide greater insight into the facility's environmental impact.

Heat waste: Most strategies regarding Data Center temperatures focus on how to best remove hot server exhaust from the hosting environment yet pay little attention to the ultimate disposition of Data Center heat waste. If your Data Center cooling system is highly efficient and does a superb job of keeping equipment cool but raises temperatures outdoors, how green is it really? Hot building exhaust is blamed for increasing the severity of several undesirable environmental and health problems including air pollution, heat-related illnesses, deteriorated water quality, and increased energy consumption during summer evenings. The phenomenon known as heat islands is discussed further in Chapter 3, "Green Design and Build Strategies."

Water consumption: Major Data Centers consume millions of gallons/liters of water per month through standard cooling processes as hot water is vaporized from a Data Center's cooling tower and has to be replaced. (Water used to replace what has evaporated is known as makeup water.) Although this consumption hasn't received the same level of attention from governments and the public in recent years as energy use and carbon emissions, removing such large amounts of water from local supplies is a tremendous environmental impact.

Energy consumption in the data center is classified into two types of energy consumptions:

Fixed energy consumption: this energy is consumed by the equipment running the data center like: cooling, lighting and power delivery.

Variable energy consumption: this energy is consumed by the equipment that responsible for data processing like: ICT equipment and servers.

2.4 Power Consumption in the Data Centers

The power delivered to the data center throw main electricity utility supply or generators in case of a breakdown, or throw renewable energy supply (RES) and feeds the switchgear. Within the switchgear the transformer resized the voltage. The suitable voltage feeds the UPS that is also fed by EG in case of a breakdown. Table 2.1 and figure 2.2 show the component of the data center and the consumption rate for each equipment. IT equipment is responsible for 50% of energy cost in the data center. Air conditioners and water pumps consumed 25% of the data center power. Air movement like fans and air pumps is responsible for 12% of energy cost in the data center. Internal transformer and transformerless UPS is responsible for more than 10% of total energy cost in the data center. Lighting and other is responsible for more than 3% of the overall data center power.

Table 2.1 The distribution of power in data center [80]

Cost	**Component**	**Sub-Components**
50%	ICT equipment	Servers, Routers, Switches, Loud balances, Cabinets, CPU, memory and storage systems.
25%	Cooling	Air conditioners and water pumps.
12%	Air movement	Fans and air pumps.
10%	Transformer/ UPS	internal transformer and transformerless UPS .
3%	Lighting	Lighting and other

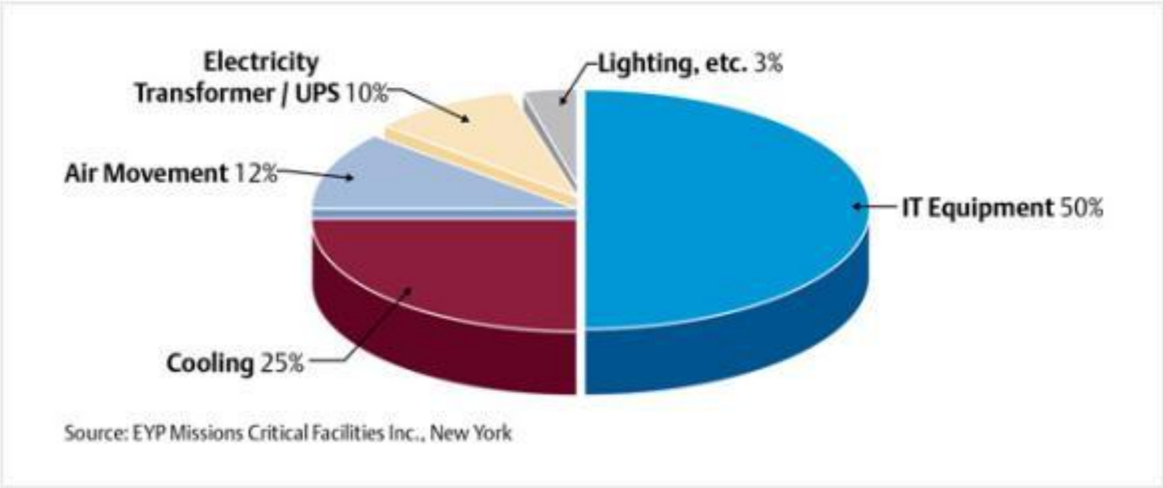

Figure 2.2 Sources of data center energy consumption [81]

Figure 2.3 shows the levels of consuming energy in the data centers. Fixed energy is the energy consumed by the devices without executing any program. Variable energy is the difference between fixed energy and the energy required to execute the program or energy required to do the job. Table 2.2 interprets and clarifies the fixed energy and variable energy.

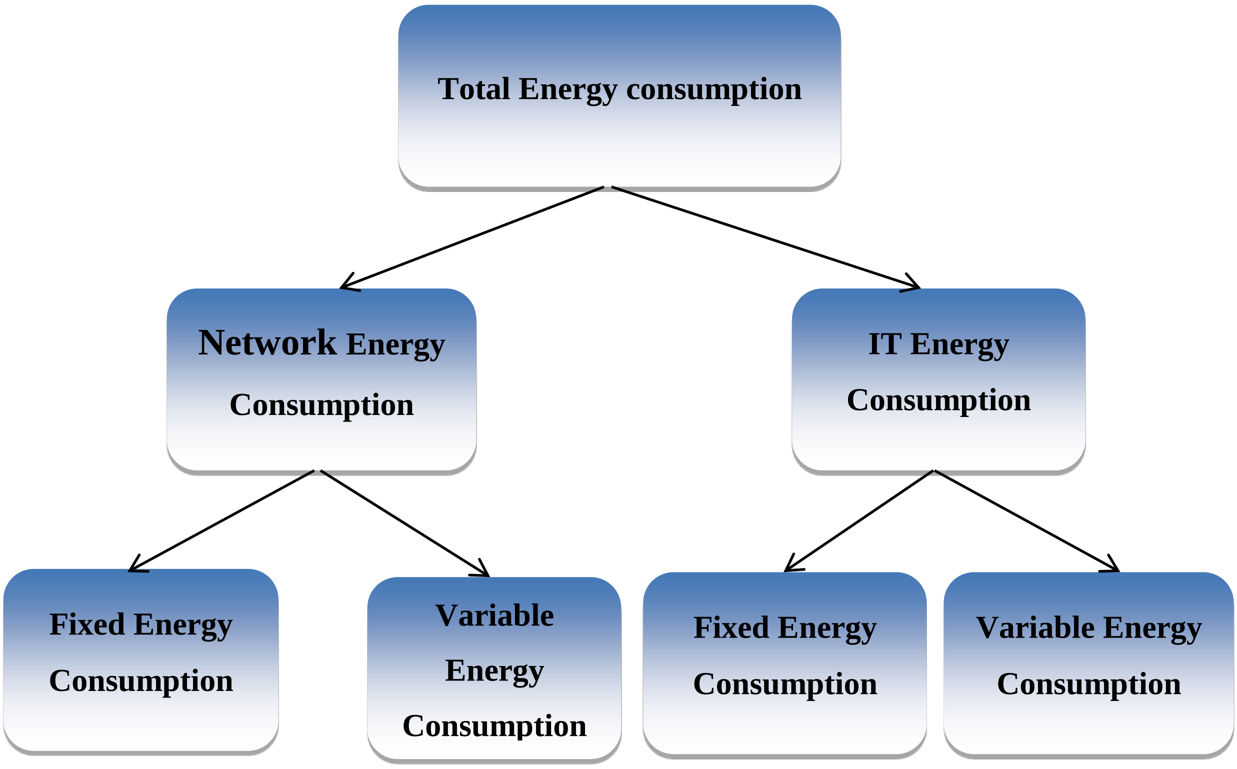

Figure 2.3 Levels of energy consumption in the data centers

Table 2.2 Interpret and clarify the fixed and variable energy

Data Center	Comment
Real Data Center	> 70% of energy consumption is fixed and not affected by workload, < 30% is related to workload.
Ideal Data Center	~0% of energy consumption is fixed, ~100% related to work delivered

The more of these Data Center elements that you measure, the more opportunities to make your server environment greener that you uncover. Tips on reducing the impact of these features are provided in Chapter 4 and Chapter 5.

2.4.1 Carbon footprint

Environmental impact is the other issue of data centers. The amount of carbon dioxide (CO_2) produced as part of the running operation of the hardware equipments. Carbon dioxide is one of a handful of substances dubbed greenhouse gases that trap heat from the sun and warm the Earth. That warming effect is necessary to a certain degree. Without it, the Earth's mean surface temperature would be 2 degrees Fahrenheit (19 degrees Celsius) rather than today's 57 degrees Fahrenheit (14 degrees Celsius). Many scientists and environmentalists today are concerned that human activity is causing such problems, prompting them and various government agencies worldwide to call for reductions in carbon dioxide emissions [26].

2.5 Energy Efficiency and Green ICT Framework for Data Centres

While most industrial countries aggressively pursue the effect energy use in centres, there was limited documentation on the developing countries' efforts, in spite of evidence of significant data centre projects in developing countries - particularly in Africa [13]. However, at the same time, companies in developing countries needed to adopt new technology services in the short term, while taking into account high reliability, performance, efficiency, operational costs and availability requirements as important challenges [14].

2.5.1 Energy Efficiency

Using technology to decrease the energy consumed by the data centers in order to produce the same amount of services [14]. Latest effective technology named Virtualization could be used to reduce energy consumed and increase the utilisation ratio to achieve energy-efficient data centres, by providing different solutions such as server consolidation, migration, load balancing, energy efficiency measurements and green metrics to determine inefficiencies in a data centre [15]. Data centre virtualization increased the utilisation ratio of different servers in data centres by up to 50% or even more [16], saving huge energy and reducing CO_2 emission. The green ICT has moved from the theoretical to the practical, ICT operators and leaders being challenged to construct new data centre or develop existing units with energy-efficient advantages, sustainable materials and other environmental perks [16]. It was important to evaluate energy use in regulatory mechanisms applied in the context of developing countries [14]. Such evaluation helped in developing green data frameworks for different tier level centres [15].

Based on our literature review we realized that the lack of and need for an integrated data center energy efficiency framework which consider the social network applications as a vital related factor in elevating energy consumption, as well as high potential for energy efficiency. The framework provides a platform on top of which the Green Cloud could be built. The framework practices from Energy Aware Computing will improve the efficiency of Cloud systems and their data centers and Clouds themselves will produce naturally efficient and focused centers of computation, advancing the pursuit of green computing. The required integrated data center energy efficiency framework should be also applicable in different types of data centers including public, private and hybrid. The existence of such framework will offer a great powerful capability to deal with service levels and resources management. The required data center Energy Efficiency framework will offer improved in scalability, elasticity, simplicity for management, delivery of cloud services and better reduction in data centers energy consumption taking into consideration the QoS for the user services.

Energy performance: Energy use of a data center building under standardized conditions [82].

2.6 Green Metric

In a few years the Power Usage Effectiveness (PUE) metric has full focus as the measure of efficiency for a data centre [16]. However, there was still no consensus metric as standard for ICT or software efficiency and most energy efficiency measurements stopped at ICT energy [17]. The Fixed to Variable Energy Ratio (FVER) metric developed by British Computer Society's Data Centre Specialist Group (DCSG), has five levels. FVER avoid the weaknesses of PUE by providing a high value diagnostic metric for ICT equipment and utility equipment and software energy consumption in the centre.

CHAPTER THREE

LITERATURE REVIEW

The Current State of Energy Efficiency In

Data Centers

3.1 Introduction

According to Cooper's taxonomy of literature reviews [28], the main goal of this review is to identify critical issues central to the field, questions that have been the focus of previous research and topics that have been neglected. Also, the current research tries to specify some methodological problems which have prevented the formation of an integrated body of knowledge in the field.

The Cloud Computing (CC) approach has grown in popularity [26] where an organization achieved high profits by selling computer resources including both software and hardware. The cloud computing technique is complex and consists of a number of heterogeneous technologies [18]. However, as the cloud computing environment is growing in number and providing many levels of services. The backbone of cloud computing is the data center, it consists of a huge number of servers connected together. These data centers consume a large amount of energy to deliver the services to the customer. The cloud computing providers can control the cloud computing services to unburden the task of managing infrastructure, while cloud computing providers expand the number of servers in their data centers due to the increase in service requests. With this increasing need, their energy consumption increases significantly. Reducing the operational cost while satisfying the service level agreement (SLA) [27], becomes an important issue in order to increase the benefits for cloud computing providers and reduce the carbon emissions CO_2. On the other hand, the aggregated demands for different services are dynamic over time.

The increasing in energy efficiency in a few percent of the energy consumption means saving a significant amount of money and increasing the profits.

Energy consumption in hosting Internet services is becoming a pressing issue as these services scale up. There are different solutions to increase energy efficiency like:

1- Finding ways to distribute workloads to each processor core and efficiently reduce energy consumption is of vital importance, especially for real-time systems. Recently, The efficient load balancing and scheduling technique is increasing significantly. Some techniques are closely related to the efficiency of the whole cloud computing facilities like: the job scheduling and resource management. One such very important and necessary concept is that of load balancing. This importance arises because load balancing balance between the efficiency and performance of data center. There are many load balancing algorithms available, but the relevant point regarding this is how these algorithms are effectively used. An effective load balancing algorithm regards to data centers, that one in which the jobs requested from the user are completed within the minimum period of time.

2- The main emphasis on the cloud computing is given to the resource management and the job scheduler. The goal of the job scheduler is to maximize the resource utilization and minimize the processing time of the jobs. Existing approaches of data center scheduling doesn't give much emphasis on the performance of a data center scheduler in processing time parameter. Schedulers allocate resources to the jobs to be executed using the First come First serve algorithm.

ICT could play an essential role in decreasing energy consumed by data center's buildings and at the same time generate new business opportunities. Energy Efficiency is one of the vital challenges of the building sector and ICT businesses, where environmental sustainability is becoming mandatory for energy management in building and data centers. Reducing the cost of energy for buildings and data centers is imperative from an economic and sustainable perspective. Without the need for drastic changes in the city's physical structure.

According to Cooper's taxonomy of literature reviews [28], the main goal of this review is to identify critical issues central to the field, questions that have been the focus of previous research and topics that have been neglected. Also, the current research tries to specify some methodological problems which have prevented the formation of an integrated body of knowledge in the field.

3.2 Literature Review Methodology

While investigating the previous works the focus is mostly on the findings of articles and the methods used to achieve energy efficiency. Although this review targets energy efficiency in data centers in the cloud technology as the main audience and explores theoretical and empirical issues relevant to scientific research.

To study the academic literature on the effects of energy efficiency on the data centers, the related impact journal, international conferences and universities researches database was used to search for these keywords:

1) Green data centers,

2) Energy efficiency in the data centers,

3) Green technology,

4) Reduce energy and CO_2 emission.

We searched in the title, abstract and keywords of the paper. It led to 684 papers as the results. We have depended on specific conditions to choose suitable papers. First, we filtered this list based on journal name and impact. Second, we evaluated the main objective of the paper. Third, reviewed the abstract that should be increased energy efficiency by using specific techniques. Fourthly, investigated the reference sections of the paper to include potential articles. The results of proceeding filtering produced a list of 40 articles. Table 1, Table 2, Table 3 and Table 4 provides a summary of selected papers based on procedures described. The organizations of this chapter are as follows: In the next section we investigated some issues with the current state of the literature. Next, provided some gabs and suggestions for future research.

3.3 Energy Efficiency Levels

In recent years, the energy efficiency has attracted the attention of data center's researchers. In the literature review below, a proudly previous research investigated energy efficiency in data centers in three levels:

I. **Data center level:**, migration, consolidation and reconfiguration. Cooling, heating, lighting and utility.

II. **Hardware level:** Hardware management, provisioning and turn on/off servers.

III. **Application level:** skip/execute, scheduling and load balance activity.

3.3.1 Data center level: This level can be divided into two sub levels:

I. Data center (migration, consolidation and reconfiguration).

Song et al.[29], the author developed an adaptive and dynamic model, operating system-base for efficient sharing of a server by optimizing resources (CPU and memory) between virtual machines.

Bo Li, Jianxin et al.[30], the author developed an energy saving on-line placement model, based on a balance of workload by distributing it in a virtual machine to achieve a least number of nodes to execute that load. So the workloads are replaced, and resized. However, the migration and relocation of VMs for matching application demand can impact the QoS service requirements of the user.

Rajkumar Buyya et al.[31], the author proposed (a) architectural principles for energy-efficient management of Clouds; (b) energy efficient resource allocation policies and scheduling algorithms considering quality-of-service expectations, and device power usage characteristics; and (c) a novel software technology for energy-efficient management of Clouds.

Anton Beloglazov et al. [32], the author proposed a novel technique for dynamic consolidation of VMs based on adaptive utilization thresholds, which ensures a high level of meeting to the Service Level Agreements (SLA). He validates the high efficiency of the proposed technique across different kinds of workloads using workload traces from more than a thousand Planet Lab servers.

Saurabh Kumar Garg et al. [33], the author proposed a Green Cloud framework, which make Cloud green from both user and provider's perspective. The framework relies on two main components, Carbon Emission and Green Cloud.

Uddin et al. [34], the author developed a tool to improve the performance and energy efficiency of data centers. He divided data center components into different resource pools depending on different parameters. The framework highlights the importance of implementing green metrics like power usage effectiveness (PUE) and data center effectiveness and carbon emission calculator to measure the efficiency of the data center. The framework is based on virtualization and cloud computing. The tool was to increase the utilization of the data centers from 10% to more than 50%.

Meenakshi Sharma et al. [35], the author firstly presented an analysis of different Virtual machine(VM) load balancing, a new VM load balancing algorithm has been proposed and implemented in a Virtual Machine environment of cloud computing in order to achieve better response time and reduce cost.

Xin Lia et al. [36], the authors proposed a virtual machine placement algorithm named EAGLE, which can balance the utilization of multidimensional resources and thus lower the energy consumption. Experimental results show, that EAGLE can reduce energy as much as 15% more energy than the first fit algorithm.

Elgelany et. al. [37], the authors investigated recent research that concentrated on energy efficiency approach and obtained some important conditions, to achieve green cloud computing by reducing energy consumption and emissions of carbon dioxide (CO_2) in data centers and represent open challenges. The author found that there is an urgent need for an integrated energy efficiency framework for green data centers, which combines IT architecture with specific activities and procedures that lead to energy efficiency putting into account the social network applications.

Nada et. al. [38], the authors investigated previous frameworks that focus on energy efficiency and show the pros and cons of that framework. The analysis process found that the current available frameworks have some drawbacks that are the reason why there is an urgent need for an integrated criterion for selecting and adopting an energy efficiency framework for data centers. Additionally, the authors highlighted the importance of the identification of efficient and effective energy efficiency metric that can be used for the measurement and determination of the value of data center efficiency and their performance.

Table 3.1 Energy efficiency data center level:
migration, consolidation and reconfiguration Techniques

No	Author	Year	Approach	Adv+	Limitation
1	Song	2007	Optimizing resources	Deal with dynamic load	Waiting times are high
2	Bo Li	2009	A balance of workload	Online Model	Impact on Quality-of-service
3	Rajkumar Buyya	2010	Manage resource allocation policies and scheduling	Quality-of-service	No parameter to indicate CO2 emission
4	Beloglazov	2010	Dynamic consolidation of VMs	Meeting the Service Level Agreements (SLA)	No suitable metric to show the energy efficiency level
٥	Saurabh Kumar Garg	2011	Green Cloud framework	Good in reduce energy, pricing and time	Increase the network traffic
6	Uddin	2012	Virtualization	Increase the utilization ratio	Did not concern to dynamically load
7	Meenakshi Sharma	2012	VM load balancing	Good in reduce energy, pricing and time	Much calculation needs more time to take a decision
8	Xin Lia	2013	Virtual machine placement	Can balance the utilization of multidimensional resources	Did not concern on performance
9	Elgelany	2013	Investigated previous energy efficiency work in a critical way	Represent open challenges	-
10	Nada	2014	Investigated previous frameworks in critical view	Show the drawbacks of the current frameworks	-

II. Data center (buildings) level: cooling, heating and lighting

Lawrence Berkley National Laboratory (LBNL) [59], the research team in LBNL investigated studies on 14 data centers in the USA and found that power demand of data centers are in the range of 120–940 W/m2, while the power demands typically drawn by commercial office spaces lie in between 50 and 110 W/m2.

S. Greenberg et. al.[60]. The author developed a set of ''best-practice'' technologies for energy efficiency of data center buildings. He optimized central chiller plants,' free cooling'' from air-side or water side economizers, improved uninterruptible power supplies, high-efficiency computer power supplies.

Yiqun Pan et. al. [61], the author developed energy simulation models with Energy Plus for two office buildings in a R&D center in Shanghai, China to evaluate the energy cost savings of green building design options compared with the baseline building.

A Von Ketelhodt et. al. [62]. The author Surveyed 250 SMEs in Cape Town and found that the prevailing methods of changing electricity consumption behavior: information campaigns, increasing prices, and providing rebates for energy savings, have had limited results and are unsustainable when applied to SMEs.

Yiqun Pan et. al, [63]. The author investigated the energy use of two data centers in commercial buildings in Shanghai and concluded that data centers were high energy consuming areas in commercial office buildings. He improved equipment efficiencies compared to ASHRAE minimum, several system enhancements and design options, e.g., under-floor air distribution system, ice storage, air-side free cooling.

Laura Keys et. al. [64]. The author conducts a survey of several small clusters of machines in search of the most energy-efficient data center building block targeting data intensive computing. The author evaluates the performance and power of single machines from the embedded, mobile, desktop, and server spaces. The author builds five-node homogeneous clusters of each type and run Dryad, a distributed execution engine, with a collection of data-intensive workloads to measure the energy consumption per task on each cluster. In this collection of data-intensive workloads, the author achieved an average of 80% more energy-efficient than a cluster with embedded processors and at least 300% more energy-efficient than a cluster with low-power server processors.

Anna Kramers et al. [65]. The author developed in-depth study and forms part of current research into urban sustainable. He developed a methodological approach that integrated actors and measures in describing a process of change. The research focused on ICT solutions for energy efficiency and a sustainable technique of managing and using buildings in the existing built environment.

Abhinandan et al. [66]. The author proposed an effective model, to automate the scheduling of meetings in a way that uses available meeting rooms in an energy efficient manner, while adhering to time conflicts and capacity constraints. The researcher investigated a number of scheduling algorithms, ranging from greedy to heuristic approaches, and reduced energy up to a 70%.

Michael et al. [67]. The author investigated seven famous sustainable rating systems–BREEAM, CASBEE, GREEN GLOBES, GREEN STAR, HK-BEAM, IGBC Green Homes and LEED by the perceptions and opinions of stakeholders in Nigeria certified in green building rating systems in an attempt to select and adapt a green building rating system for Nigeria. The result of his research showed that the green building rating Leadership in Energy and Environmental Design (LEED), which is the dominant system in the United States and Canada is appropriate for Nigeria because it helps customers determine environmental performance, with strong base, large investments and proven advantages scored the highest with 80 points out of 100 points.

Long Phan et al. [68]. The author developed energy simulation code, Energy Plus. He investigated the effects of wall boundary conditions, climatic locations, supply air temperatures, and volume flow rates, on the energy consumption and thermal performance of a popular data center model. To achieve energy efficiency he used data center model having 1120 servers distributed in four rows of rack. He investigated under two major climatic conditions–hot and humid (Miami, FL), and cool and humid (Chicago, IL). The researcher proposed a multi-zone modeling approach to resolve the hot and cold aisles in the data center, evaluated the proposed model he compared to existing well-mixed single zone model. Using the multi-zone approach that is believed more reasonable, both monthly and annual overall energy consumptions as well as cooling load were analyzed under various boundary conditions. The simulation results showed that the thermal performance of the data center is significantly affected by locations or climatic conditions. The effects of location and wall boundary conditions are particularly appreciable during the summer and winter seasons. An optimal supply temperature of 11.8◦ C, and air flow rate of 2.5 m^3 /s were found to be most preferred selections for the data center model.

Table 3.2 Energy efficiency technique: data center buildings: cooling, heating, lighting and utility.

No	Author	Year	Approach	Adv+	Limitation
1	Lawrence Berkley National Laboratory (LBNL)	2003	Investigated studies	Found that the data centers is Power demand	-
2	S. Greenberg	2006	Cooling	Economized	Depend on free air and water
3	Yiqun Pan	2008	Cooling, heating, lighting and utility	Compared with the baseline building	Two office buildings is small building
4	A Von Ketelhodt	2008	Surveyed 250 SMEs	Previous techniques are unsustainable when applied to SMEs	Limited results
5	Yiqun Pan	2008	Cooling	Concluded that data centers were high energy consuming	Concerned with cooling only
6	Laura Keys	2010	Cooling, heating, lighting and utility	Energy consumption per task	High complexity
7	Anna Kramers	2011	Cooling, heating, lighting and utility	Integrated actors	-
8	Abhinandan	2012	Cooling, heating, lighting and utility	Reduced energy up to a 70%	High complexity
9	Michael	2013	Investigated seven famous sustainable rating	Showed that the green building rating is (LEED)	-

10	Long Phan	2014	Cooling and hot	Multi-zone modeling	High complexity

3.3.2 Hardware level: hardware management, provisioning and turn on/off servers:

Gong Chen et. al. [39]. The author developed unique properties, performance, and power models of connected servers, based on a real data trace collected from the deployed Windows Live Messenger. The researcher design server provisioning and load dispatching algorithms by using the models and study subtle interactions between them. He showed that the developed algorithms can save a significant amount of energy without sacrificing user experiences.

Abdelsalam H. Maly et al.[40], the author investigated a new model for a power efficient technique to increase the management of Cloud computing environments. The author formulated the resource management problem in the form of an optimization model to introduce energy consumption by the Cloud.

Huang, Li et al.[41], the author introduced dynamic resource management hardware-base. Using dynamic setting for the frequency and voltage of the processor during running time to set the CPU in original design power. As long as CPU works with minimum voltage, the energy consumption can directly be saved. However, the complexity of resource management make the benefits not large enough.

Haiyang Qian et. al. [42]. The author developed a multi-time period optimization model for saving the energy consumed by the data center to reduce total operational cost, he combined two factors: 1) Dynamic Voltage/Frequency Scaling (DVFS), 2) turning servers on/off over a time horizon. He showed the impact of the granularity of the duration of the time slots and frequency options for optimal solutions. He presented parametric investigated on the varying cost of turning servers on/off and power consumption.

Vinicius Petrucci et. al. [43]. The author investigated and evaluated an approach for energy and performance management in virtualized data center. The main objective of the researcher is to reduce energy consumption in the data center while meeting performance requirements. The author contributions are: (1) an effective way of modeling energy consumption and the capacity of the servers even under heterogeneous and changing workloads, and (2) an optimization strategy based on a mixed integer programming model for achieving improvements in energy-efficiency, he considered about performance guarantees in the data center. The researcher developed optimization model, he addressed application workload balancing and the often ignored switching costs due to frequent and undesirable turning servers on/off and VM relocations. The results showed the effectiveness of the developed approach. The researcher experiments showed that the proposed approach conserves about 50% of the energy required by a system designed for peak workload scenario, with little impact on the applications' performance goals. Also, to achieve QoS he used prediction strategy.

Shailesh S.Deore et al.[44], the author introduced an energy-efficient scheduling scheme technique. Workloads were distributed on a minimum physical machine, using new state pause, resume, and teleport-in state. To avoid changing the status of an idle node to power on and that required an amount of energy we can use pause state, or teleport-in the state, and resume state to achieve a reducing amount of energy. However, This scheme was not used effectively in Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a service (SaaS) of cloud computing.

Wang et al.[45], the author proposed mechanism to support maximizing resource utilization by using active and idle energy consumption by finish time minimization. This mechanism reduces the power consumption by allowing spare servers to be in an idle state. This mechanism put into account QoS of cloud data center.

Tan Lu et. al. [46]. The author proposed novel dynamic provisioning techniques decentralized, simple to implement and deal with wasting energy by servers when the idle server needs to react. The author investigated the dynamic provisioning problem and developed online solutions. The author used "divide-and-conquer" technique to achieve the optimal solution.

Tuan Phung-Duc et. al. [47]. The authors investigated the existence of a trade-off between power consumption and delay performance when idle servers reactive. The author used M/M/c queue with setup time for which they present a decomposition property by solving difference equations. In this research the author used an alternative technique, he obtained explicit expressions for partial generating functions, factorial moments joint distribution of the number of active servers and the system. The author proposed a new formula which showed that the number of waiting customers under the condition that all servers are busy has the same distribution with the sum of two independent random variables.

Kuangyu Zheng et. al. [48]. The author proposed PowerNetS, a power optimization strategy that leverages workload correlation analysis to jointly minimize the total power consumption of servers and the DCN. The new PowerNetS is based on the key observations that the workloads of different servers and DCN traffic flows do not peak at exactly the same time. The researcher introduced that more energy savings can be achieved, especially if the workload correlations are considered in the server and traffic consolidations. Additionally, the PowerNetS technique considered the DCN topology during server consolidation, which leads to less inter-server traffic and thus more energy savings and shorter network delays. The author implemented PowerNetS on a hardware test bed composed of 10 virtual switches configured with a production 48-port Open Flow switch and 6 servers. The experiment showed that the results with many web sites like: Wikipedia, Yahoo, and IBM traces demonstrate that PowerNetS can save up to 51.6% of energy for a data center. The authors simulation results came when he used 72 switches and 122 servers.

Table 3.3 Energy efficiency technique hardware level: hardware management, provisioning and turn on/off servers.

No	Author	Year	Approach	Adv+	Limitation
1	Gong Chen	2008	Server provisioning	Considered performance and power	Ignored QoS
2	Abdelsalam	2009	Resource management	Forecasting the resource utilization	High complexity consumed time
3	Minsu Huang	2009	Power-Low for idle servers	O(n) complex, Low complexity	An idle servers to power on that required an amount of energy
4	Haiyang Qian	2011	Servers on/off	Deal with the idle server needs to react	DVFS impact on the data center performance
5	Vinicius Petrucci	2011	Hardware management	Deal with the servers under heterogeneous and	Ignored switching costs

				changing workloads	
6	Shailesh S.Deore	2012	Pause, resume, and teleport-in	Avoid changing the status of an idle mode	Not used effectively in (IaaS), (PaaS) and (SaaS)
7	Zhiming Wang	2012	Maximizing resource utilization	Concern account QoS	Much job performance take amount of time Sleep-in-Waking up-ready.
8	Tan Lu	2012	Dynamic provision-ing	Deal with the idle server needs to react	Ignored QoS Limited metric
9	Tuan Phung-Duc	2014	Estimate the minimal number of active resources	Deal with power consumption and delay performance	Have a higher order of computational com-plexity
10	Kuangyu Zheng	2014	Hardware manage-ment	Less inter-server traffic	Ignored changing in workload

3.3.3 Application level: skip/execute, scheduling and load balance activity:

Nguyen Quang Hung et al.[49], the author proposed to host selection policies, named MAP (minimum of active physical hosts) and MAP-H2L, and four algorithms solving the lease scheduling problem. Those algorithms reducing 7.24% and 7.42% energy consumption than an existing greedy mapping algorithm. On their simulations show that energy consumption decreased by 34.87% and 63.12% respectively.

Jiandun Li et al.[50], the author introduced a hybrid energy-efficient scheduling model based on private clouds to minimize response time, balance workload that when data center is executed in a minimum energy mode, produce an algorithm for pre-power and least load. They are concentrated on load balancing, migration on state-base of VM. If response time decreases, then also energy decreases. However, this technique loses significant energy in migration.

S. Kontogiannis et al.[51], the research team developed a unique mechanism called Adaptive Workload Balancing algorithm (AWLB) for cloud data center based web systems which deals with agents into two dimensions the web data center and web servers. AWLB algorithm also supports protocol specification for signaling purposes among web switch and data center nodes and also utilizes other protocols such as SNMP and ICMP for its balancing process. Performance gains are shown from tests of AWLB against known balancing Least Connections (LC) and Least Loaded (LL) algorithms.

Nidhi Jain et al. [52]. Load balancing is one of the important challenges in data centers, which is required to distribute the dynamic workload across multiple servers to ensure that no server is overwhelmed. It is the heart of utilization of resources and contributes in enhancing the performance of the system. The main role of load balancing is to reduce the resource consumption, which will further reduce energy consumption and carbon emission rate. The author investigated the existing load balancing techniques in the data centers. He further analyzed these techniques from energy consumption and carbon emission perspective.

Pinky et al. [53]. The author developed an efficient job scheduling algorithm to maximize the resource utilization and minimize processing time of the jobs. He investigated an optimization algorithm for scheduling the queue of the jobs, he used the various scheduling algorithms Shortest Job First, First in First out, Round robin. The job scheduling system is responsible to choose the best and suitable server in a data center for user jobs. The research idea focused on management and scheduling system, by generating job schedules for each server in the data center, taking static restrictions and dynamic parameters of jobs and machines into consideration. He but into account when used various scheduling algorithms the performance criteria to be improved e.g. response time, throughput. He used MATLAB tool and the parallel computing toolbox.

San Hlaing et al. [54]. The author developed sustainable data center framework (SDC), to increase energy efficiency for the data center, as a sustainable solution for the next generation data center. He proposed framework by using machine learning technology based resource prediction, to performed and handling dynamic workload matter. He estimated future energy demand and CO_2 emission to provide a dynamic energy management process. On the other hand the researcher considered the service level agreement (SLA) violation, as the one of the sustainability factors. He developed a simulation environment and evaluated the proposed framework.

Keng-Mao et al. [55]. The researcher developed a novel scheduling algorithm. The algorithm based on real-time multi core systems to balance the computation loads and save energy. The proposed algorithm simultaneously considers multiple criteria, a novel factor, and task deadline, and is called power and deadline-aware multi core scheduling (PDAMS). The research experiment showed results, that the developed algorithm reduced energy consumption by up to 54.2% and the deadline times missed, as compared to the other scheduling algorithms.

Antony et al. [56]. The researcher developed and implemented an approach to effectively introduce controller and balancer into the data centers of a cloud computing. The author used different mechanisms to achieve energy efficiency, by which each task is optimally assigned to a virtual machine. He used effectively, the task priority algorithm.

Shikha et al. [57]. The author developed and designed an architectural framework, decentralized, scalable, adaptive, and distributed algorithms for load balancing across resources for data-intensive computations on data center environments. He used job migration algorithm which is a Load Balancing Algorithm.

Andrei et al. [58]. The author investigated cloud computing and showed that it widely being adopted by many companies because it allows to maximize the utilization of resources. However, the challenges of cloud computing system like complexity in the existence of many cloud providers makes it infeasible for the end user the optimal or near-optimal resource provisioning and utilization, especially in the presence of uncertainty of very dynamic and unpredictable environment. The researcher developed an adaptive load balancing algorithm. He formulated the problem and proposed an adaptive load balancing algorithm for distributed computer environments. The researcher evaluated the energy efficiency of proposed solutions in the domain of VoIP computations on federated clouds.

Table 3.4 Energy efficiency technique: application level: skip/execute, scheduling and load balance activity

No	Author	Year	Approach	Adv+	Limitation
1	Nguyen Quang	2011	Job scheduling	Deal with dynamic load	High complexity
2	Jiandun Li	2011	Load balancing, migration	Deal response time	Loses significant energy in migration
3	S. Kontogi-annis	2011	Load balancing	Deals with agents into two dimensions	Increase the internet traffic that impact on QoS
4	Nidhi Jain	2012	Load balancing	Enhancing the performance	Limited metric
5	San Hlaing	2012	Resource prediction	Deal with dynamic load	High complexity
6	Keng-Mao	2014	Job scheduling	Real-time multi core systems	High complexity
7	Antony	2014	Introduce controller and balancer	Increase the performance	High complexity
8	Pinky	2014	Job scheduling	Increase the performance	High utilization lead to introduce CO_2
9	Shikha	2014	Load balancing	Decentralized, scalable, adap-tive, and distributed algorithms	Data-intensive computations
10	Andrei	2014	Load balancing	Deal with distributed computer environments	VoIP high computa-tions

CHAPTER FOUR

PRPOSED SOLUTION (I)

GREEN METRIC: FIXED TO VARIABLE ENERGY RATIO (FVER)

4.1 Introduction

To make real progress at any data center, efficient metric is needed to be part of a measurement methodology designed to calculate a reasonable and fair approximation of the total environmental and financial cost of the service provided at the data center. Measuring energy consumption of data centers has become a significant concern of all data centers stakeholders to meet the end-users agreement. The energy efficiency metric is a tool used to measure energy efficiency in data centers. The most important challenge in the data centers industry is the limitation of effective standard energy efficiency metrics, which supports improvement energy efficiency [17].

4.2 Energy Efficiency Measurement and Metrics

The measuring of energy is the most important on the Data Center. The data center operator is concerned about how much power the facility has and how much power is consumed by ICT equipment and network infrastructure such as cooling and lighting. There are many reasons to measure energy consumption in the data center:

- **Energy is a Data Center's most important resource**: the small form factor and big energy demands of today's high performance servers means the most data centers will run out of power well before cabinet space or cooling. So, the operators aren't interested in green data center, but measuring energy consumed by the data center is important to understand the optimal capacity of the ICT room.

- **Power is the common element for the Data Center infrastructure**: Air movement, cabinets and lighting are all different parts in the data center infrastructure. So, different that they're are installed and maintained by personnels that were trained in separate disciplines, they all need power to run. Measuring energy consumption creates a common standard by which you can tell how much each is drawing for the overall Data Center Capacity.

- **Power consumption is the most expensive operational cost of a Data Center**: By measuring the specific energy usage of various Data Center components and applying the regional cost of electricity, you know the true monthly expense of the consumption of those components. This enables you to target which Data Center subsystems have the potential to save you the most energy and the most money through efficient improvements.

- **Power consumption reflects the environmental impact**: The amount of power that a Data Center uses in a day determines how much the quantity of carbon emissions it is responsible for.

Figure 4.1 show the big picture of green data center and highlighted the important parts that directly influences in energy efficiency. Because of these four conditions, green Data Center improvements that conserve energy provide some of the largest benefits to your business. Measuring power in your Data Center is, therefore, also the best way to appraise that value and understand the real impact of those green improvements.

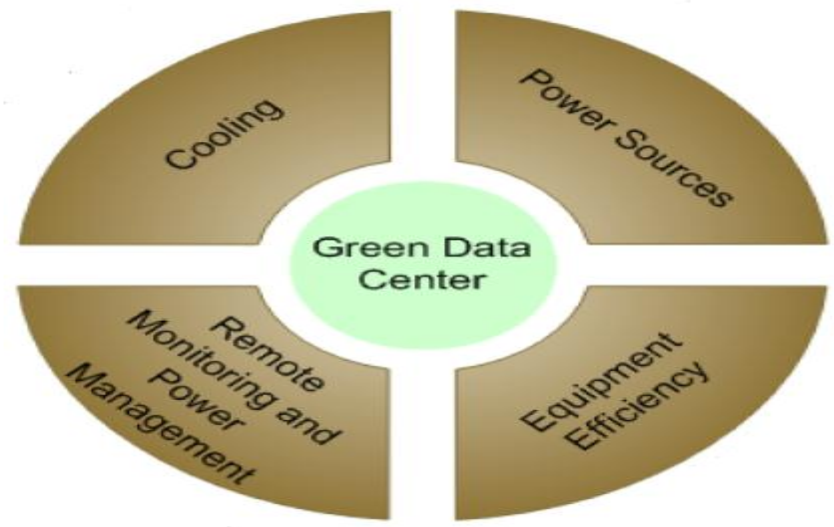

Figure 4.1 The big picture of green data center [75]

Globally, the energy consumption of data centers is on a continuous increase [88]. It is predicted that the energy operations cost will continue to double every five years between 2005 and 2025 [89]. These increase will leads to higher emission of CO_2 that reflects negatively on global warming and environmental health. Measuring energy consumption of data centers has become a significant concern of all datacenters stakeholders to meet end-users agreement [90]. Energy efficiency metric is a tool used to measure energy efficiency in data centers [91]. The most important challenge in the data centers industry is the limitation of effective standard energy efficiency metrics, which support improving energy efficiency [92], [93]. For an effective energy efficiency assessment of data centers and its components, we need to assess the effectiveness of the used metrics to measure the energy efficiency of data centers. To determine whether these metrics are effective or not we need to assess these metrics against its intended goals and under a range of common use of cases to determine the values of its effectiveness in terms of reporting, targets, education, analysis and decision support [94].

4.2.1 Alternative energy efficiency metric

In the last few years data center operators have adopted Power Usage Effectiveness (PUE) metrics as the measure of energy efficiency for the mechanical and electrical infrastructure of the data center. The process of assessment has submitted a focus and comparable measure of performance, which has enabled data centers operators to make substantial improvements. However, until now there is no consensus about ICT or software energy efficiency and most energy efficiency measurements stop at the ICT power cord. According to previous research on the currently used energy efficiency metrics which were used for the assessment of energy efficiency in data centers. In our thesis we decided to use the Fixed to Variable Energy Ratio (FVER) metric instead of PUE metric to measure the data centers energy efficiency. The reason behind our choice to favor the FVER metric is that it combines and meets all the needed criteria for better energy efficiency assessment in data centers, listed in table 4.1, including the usage of ICT and software applications in data centers [95]. Figure 4.1 depicts the difference between FVER and PUE and Table 4.1 represents the different Goals of energy efficiency metrics including PUE, DCiE, FVER, and DCeP where:

$$\text{Power Usage Effectiveness (PUE)} = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}} - - - (1)$$

$$\text{Data Center Infrastructure Effectiveness (DCiE)} = \frac{1}{\text{PUE}} - - - - (2)$$

$$\text{Fixed to Variable Energy Ratio (FVER)} = 1 + \frac{\text{Fixed Energy}}{\text{Variable Energy}} - - (3)$$

$$\text{Data Center Energy Productivity (DCeP)} = \frac{\text{Useful Work Produced}}{\text{Total Data Center Energy Consumed over time}} - - (4)$$

4.2.2 The characteristics of the metrics

The significant shorter lifetime of the ICT equipment and software compared to that of the mechanical and electrical infrastructure also present issues [96]. The optimisation methods and economic balances we have developed and used for the mechanical and electrical equipment with a service life of up to 20 years do not easily translate to software and ICT equipment, which we may retain for only a couple of years. This difference in lifetime has grown in the last few years at the rate of which ICT equipment refresh has accelerated with the widespread adoption of virtualisation and commodity computing technologies. It is now normal for an operator to include efficiency in the selection of new ICT equipment, whether in terms of system power requirements and efficiency for their workload or the consolidation ratio they will achieve against their current generation of equipment.

There are also other metrics such as SPECPower and labeling such as Energy Star which purchasers were already using to guide their selection of ICT equipment. This means that there is little ICT equipments, particularly servers, which are substantially energy less efficient than the market benchmark. This competitive market and high refresh rate left little value to be added by a metric which reports the "ICT work efficiency" of a data center as this is a constantly moving target and such a metric would inevitably be more of a measure of the operators refresh rate which was constrained by many issues other than ICT energy efficiency.

For a while the data center operators and designers have embraced PUE as the measure of efficiency for the electrical infrastructure of the data center. The process of measurement has provided a focus and comparable measure of performance which has allowed many operators to make improvement in energy efficiency.

Metrics should be simple and easy to understand for anyone instead of complex terms found using mathematical formulas**.**

4.2.3 Comparison between the green metrics

In the last few years operators have adopted PUE metrics as the measure of energy efficiency for the mechanical and electrical infrastructure of the data center. The process of assessment has submitted a focus and comparable measure of performance, which has enabled data centers operators to make substantial improvements. However, at present , no consensus about ICT or software energy efficiency and most energy efficiency measurements stopped at the ICT power cord. According to table 4.3 we prefer the Fixed to Variable Energy Ratio (FVER) metric, which could be used to measure the data centers energy efficiency instead of PUE. The reason behind our choice in favoring of the FVER metric is that it combines and meets all the needed criteria for better energy efficiency assessment in data centers, listed in table 4.1, including the usage of ICT and software applications in data centers [94]. Figure 4.3 depicts the difference between FVER and PUE and table 4.1 represents the different Goals of energy efficiency metrics including PUE, DCiE, FVER, and DCeP which shows the covers of all metric criteria by FVER metric.

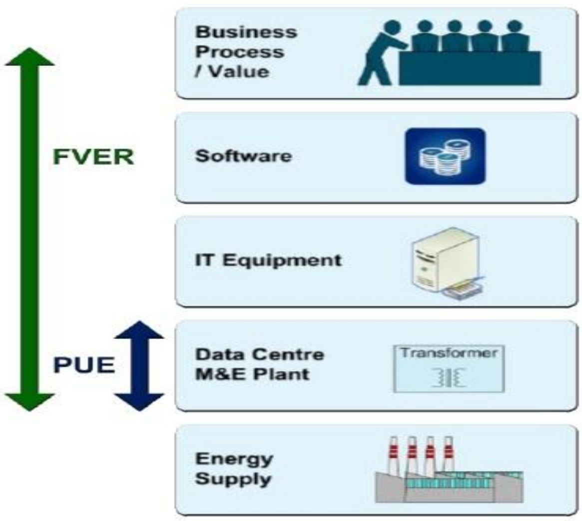

Figure 4.2 FVER Vs PUE [97]

Table 4.1 Goals of energy efficiency metrics [94]

No	Goal	PUE	FVER	DCeP
1	Provide a clear, preferably intuitive understanding of the measure.	Y	Y	
2	Provide a clear, preferably intuitive direction of improvement.		Y	Y
3	Describe a clearly defined part of the energy to useful work function of the ICT services.		Y	Y
4	Be persistent, i.e. the metrics should be designed to be stable and extensible as the scope of efficiency measurement increases, rather than confusing the market with rapid replacement.	Y	Y	
5	Demonstrate the improvements available in a modern design of facility.		Y	
6	Demonstrate the improvements available through upgrade of existing facilities using more efficient M&E systems.		Y	
7	Provide a clear, preferably intuitive understanding of the impacts of changes.		Y	Y
8	Be reversible, i.e. it should be possible to determine the energy use at the electrical input to the data center for any specified device or group of devices within the data center.	Y	Y	Y
9	Be capable of supporting 'what if' analysis for ICT and data center operators in determining the energy improvement and ROI for improvements and changes to either the facility or the ICT equipment it houses.	Y	Y	

4.3 Fixed and Variable Energy Ratio (FVER) Metric

Despite much effort by many organizations around the world we are still not closer to a "useful work" metric for data centers than we were when PUE was adopted. We suggested that by changing the way we look at ICT output metrics we can leverage much of the effort already put into metric development and in doing so we can not only mitigating the weaknesses of these previous proposals but in most cases turn these weaknesses into strengths. It is somewhat surprising that we are happy to allow our data centers to use almost the same amount of electricity when doing nothing as when delivering full "useful work" output.

The DC FVER metric leverages both existing measurement protocols developed for Data Center Performance Per Energy (DPPE) and PUE as well as the effort expended defining and testing the Green Grid productivity proxies (DCeP).

$$\text{Energy Efficiency Level} = 1 + \frac{\text{Fixed Energy}}{\text{Variable Energy}} -------- \quad (5)$$

However, to improve the energy efficiency of data centers, it is necessary to implement energy saving for both facilities and IT equipment in data centers, and therefore the PUE metric to prompt the improvement of facility power efficiency alone is not sufficient.[98].

Also Metrics should be simple and easy to understand for anyone instead of complex terms found using mathematical formulas. FVER, the Fixed to Variable Energy Ratio metric will be the next generation of data center metrics, by including the IT equipment and software as well as the data center infrastructure. FVER targets operating waste in the software, IT and M&E infrastructure and provides a complementary reporting metric to PUE. FVER can be calculate using equation 5. Figure 4.3 represents the FVER metric values, the dark green area contains the energy consumptions values from 0 to 1, which mean that the data centers is ideal or not work. The second green area contains the consumption values for the data centers are excellent energy efficiency between 1 and 1.5 FVER values. The third area is light green contains the consumption values for the data centers are better energy efficiency between 1.5 and 2 FVER values. The fourth area is yellow contains the consumption values for the data centers are acceptable energy efficiency between 2 and 4 FVER value.

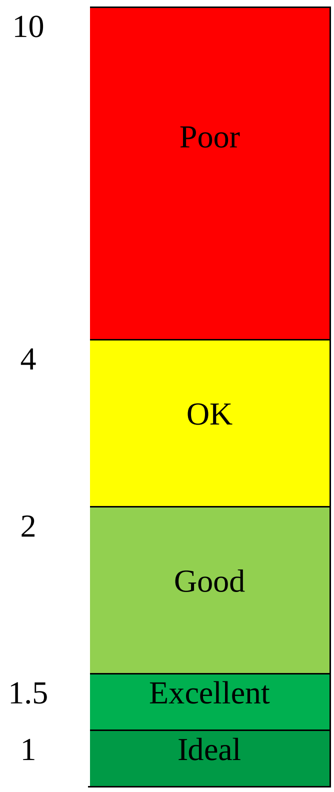

Figure 4.3 FVER values

The substantial opportunity in most current data centers is not finding additional improvement in the power efficiency when delivering peak business output, but how much power they consume to do nothing. Even with our improvements in PUE, the power draw of most data centers is still almost constant despite large fluctuations in the work being delivered.

For example: If a car used fuel at the same rate whether driving four passengers on the highway or idling stationary this would be seen as completely unacceptable. However, this is how most current data centers behave to manage energy.

The Data Center Fixed to Variable Energy Ratio metric (DC FVER) measures for the first time what proportion of data center energy consumption is variable, related to the useful work delivered, versus what proportion is fixed and allowing operators to understand how much of their energy cost is related to the work delivered and how much is a fixed burden to be eliminated.

FVER does not prescribe how each data center operator should measure the output of their data center as this measurement must vary from operator to operator, the same measure will not be effective for a supercomputer, a trading site and a web video operator. FVER instead allows each operator to select an appropriate set of proxy measures for useful work which are meaningful to their business activities. These are then normalized and combined with existing PUE measurement points of ICT, energy and total Utility energy to allow for a comparable measure of their data center performance. Off peak efficiency is of particular value to enterprise data center operators whose peak ICT work period is a relatively small part of the total time. In these cases reductions in off peak energy demand provide a direct and obvious value. FVER also carries value for data centers with less variable workloads though, as the optimization of the site for part load performance by eliminating fixed energy waste is also likely to reduce the energy consumption at high output.

FVER may be measured for the entire data center or in part by allowing service providers and customers to measure and report the metric without needing full control of the entire data center.

DC FVER is a normalized metric which provides a way for operators to understand and compare how well their energy consumption is linked to the "useful work" or business value delivered from their data center, specifically how much of their energy consumption is fixed and how much is variable with load.

Our literature review on the common energy efficiency metrics which are currently in use by data centers reveals that none of these metrics are meeting the prior mentioned criteria except FVER metric. Therefore our research is recommening FVER as a better metric to be used in the assessment of the data centers energy efficiency.

CHAPTER FIVE

PROPOSED SOLUTION (II)

ENERGY EFFICIENCY FRAMEWORK, MEASURING AND MANAGING ENERGY IN DATA CENTERS

5.1 Introduction

Energy consumption cost and environmental effect are dynamic challenges to data centers. Data centers are promising areas in distributing computing. Data centers are the backbone of cloud computing [74]. They continue to be challenging problems to energy efficiency. The growth of social applications and e-businesses provided the need to increase the number of data centers [75]. However, the combination of global warming and inconstant climate makes the cost of energy a major challenge for the sustainability of e-business [76]. Data center beside of consumed energy also produced carbon dioxide that riddled with IT inefficiencies. IDC annual report find that cloud computing reached $42bn in 2012 and revenue cloud will be $150bn in 2013 [77].

There are many models which support energy efficiency in data center, the most important model is virtualization [78]. Cloud computing supports virtualization resources (i.e. computes, storage, and network capacity). The most basic one is at Virtual Machine (VM) level, where different applications can be executed within their containers or operating systems running on the same machine hardware. Platform level enables seamless mapping of applications to one or more resources offered by different cloud infrastructure providers. Virtual machines (VMs) are a logical slit of physical resources, and it is the heart of virtualization. In data centers, the number of physical machines can be reduced using virtualization by consolidating virtual appliances onto shared servers. This can help to improve the efficiency of ICT systems. The advantages are simple, it allows multiple virtual machines to be run on a single physical machine in order to provide more capability and increase the utilization level of the hardware. It always increases efficiency, it allows you to do more work with less ICT equipment [77].

5.2 Data Centers Architecture

Each data center architecture can be divided into two parts:

I. **ICT equipment (Critical equipment)**: This equipment is responsible for data processing and delivery.

II. **Network equipment (non-critical equipment)**: This equipment is responsible for running the data center. Like cooling, lighting and power delivery.

Data center can be classified into 4 different design categories [79]. Tier 1 to Tier 4 data center is a standardized methodology used to define the data center and define the data center availability:.

I. **Tier 1** = Non-redundant capacity components and guaranteeing 99.671% availability.

II. **Tier 2** = Tier 1 + Redundant capacity components and guaranteeing 99.741% availability.

III. **Tier 3** = Tier 1 + Tier 2 + Dual-powered equipment and multiple uplinks and guaranteeing 99.982% availability..

IV. **Tier 4** = Tier 1 + Tier 2 + Tier 3 + all components are fully fault-tolerant including uplinks, storage, chillers, HVAC systems, servers etc. Everything is dual-powered and guaranteeing 99.995% availability.

Figure 5.1 show that Tier 4 data center was considered as the most robust and less prone to failures. Tier 4 was designed to host mission critical servers and computer systems, with fully redundant subsystems (cooling, power, network links, storage, etc) and compartmentalized security zones controlled by biometric access controls methods. Naturally, the simplest is a Tier 1 data center used by small businesses or shops.

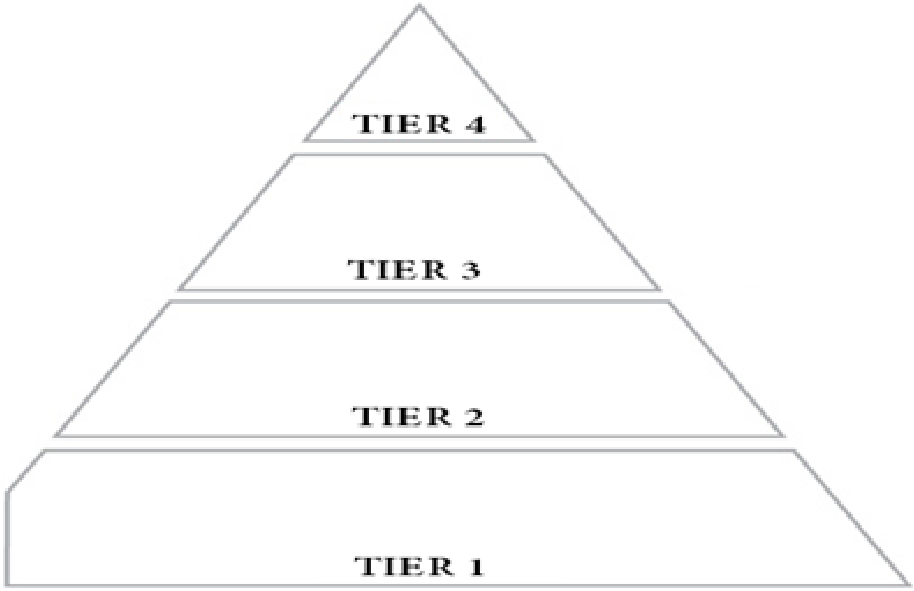

Figure 5.1 Data center Tiers

Each Tier presenting advantages and disadvantages according to energy consumed and availability of the data center. Figure 5.2 highlights the effect of the data center Tier into energy consumption and quality of services (QoS).

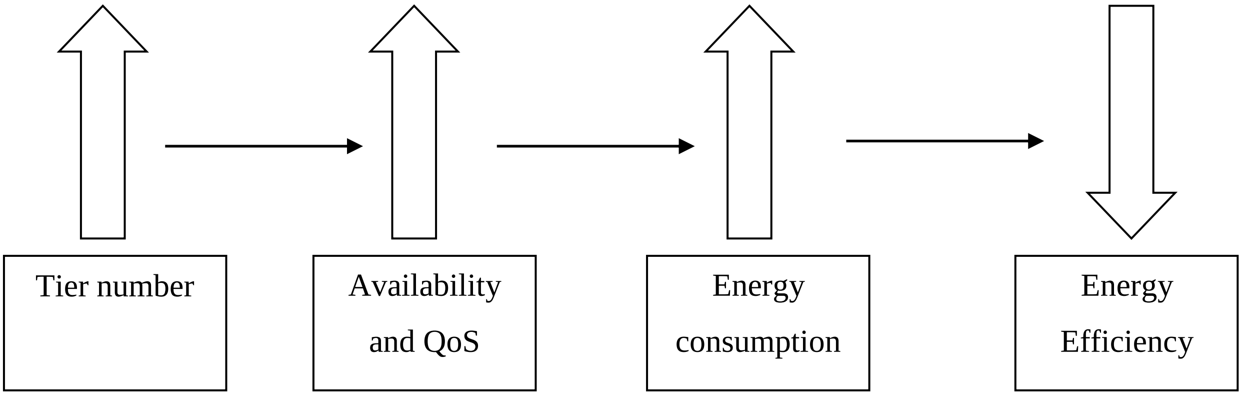

Figure 5.2 The serious effect of data center Tier into energy consumption

These classification will help to measure:

I. Data center performance.

II. Investment.

III. ROI (return on investment).

The data center architecture consist of many units, figure 5.3 show this units:

I. **Transformer/UPS**: Uninterruptable power supply (UPS) is responsible for providing power supply.

II. **Emergency Generators (EG)**: is responsible for providing the necessary power when data center in case of a breakdown.

III. **Switchgear (mechanical equipment)**: this unit is responsible for distributing mechanical equipment and electrical equipment through UPS.

IV. **Pump Room**: is responsible for pumping the chilled water, that will be used in cooling.

V. **PDU**: Power Distribution Units (PDU) is responsible for distributing power to the IT equipment.

VI. **IT room**: located inside the data center, contained computers, servers, routers, switches and cabinets.

VII. **Cooling modules**: computer room air conditions (CRAC) is responsible for cooling and air flow in the IT room.

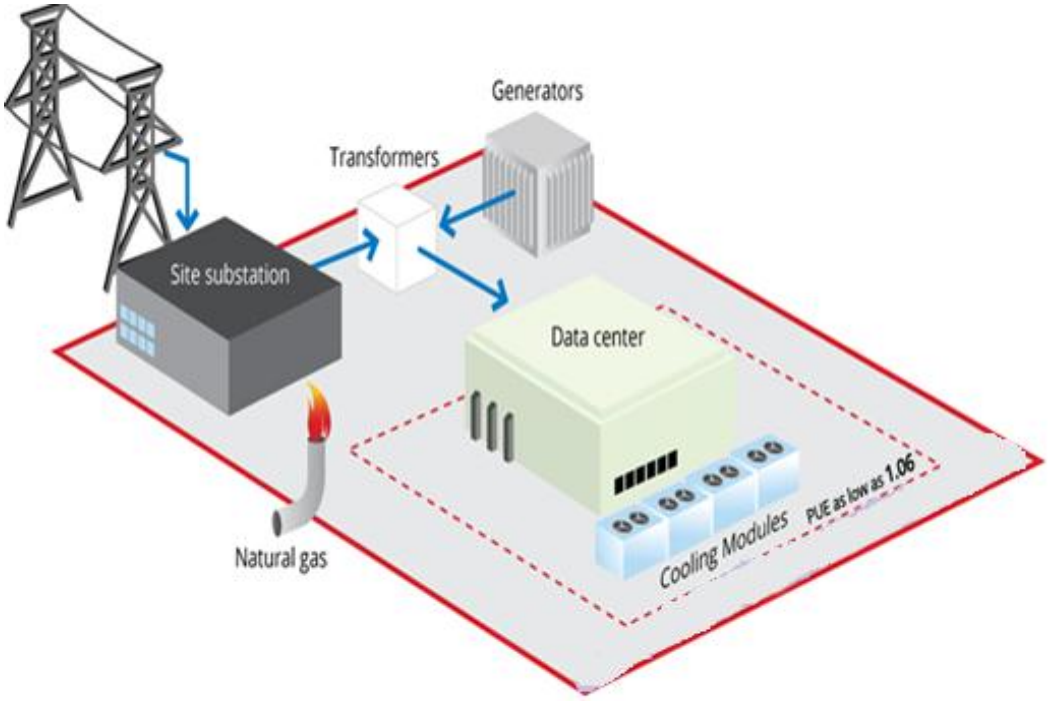

Figure 5.3 Data center architecture [48]

5.2.1 Types of energy losses in the data centers

The energy loses in the data center was influenced by:

I. Input workload to the data center.

II. Environmental factors (outdoor temperature, humidity, etc).

According to the workload we can categorize the losses into three types:

I. **Fixed losses:** this type of losses happen even when there is no workload in the data center (no-load). Usually related to Network-Critical Physical Infrastructure (NCPI).

II. **Variable losses**: this type of losses depends on the rate of workload and environmental conditions. Increase in workload mean increase in energy losses.

5.3 Energy efficient Technique in the Data Centers

Recently, many software approaches have significantly assisted and contributed to energy efficiency by reducing energy consumption and achieving energy efficiency. Software and hardware were the two approaches that complement each other. Cloud computing has different techniques to solve energy-efficient problem in order to minimize the impact of cloud computing on the environment. This techniques deal with energy efficiency consumption like virtualization, hardware base, operating systems base and data centers. Some new features arise like energy performance, and time wise. However, the concerns should be the swap problem between energy consumer and performance.

We need to separate between two terms:

I. **Energy efficiency**: This term mean executing the same amount of workload and consume low level of energy.

II. **Energy savings**: Consume low level of energy without taking into account the useful work (reduce QoS).

A cording to taxonomy techniques in Figure 5.4 that classified the levels of energy efficiency technique to three level: Hardware, datacenter and application.

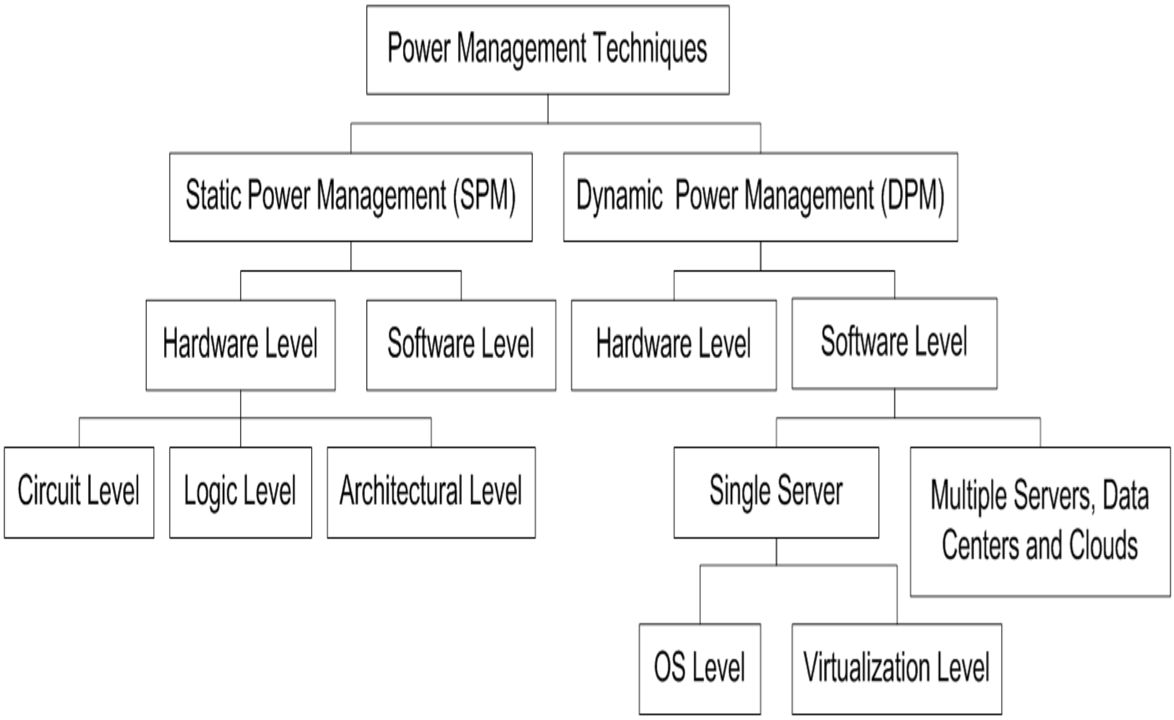

Figure 5.4 Taxonomy of energy management techniques [82]

I- **Hardware level**: hardware level include servers, network devices, Uninterruptible Power System (UPS), cooling system , generators and power distribution unit (PDU).

II- **Data center level**: the data center is a cornerstone of the infrastructure of cloud computing approach on which a variety of Information and Communication Technology (ICT) services were built. They extended the ability of centralized repository for computing, hosting, storage, management, monitoring, networking and deployment of data. With the rapid increase in the capacity and size of data centers, there is a continuous increase in the demand of energy consumption. Data center which consumed energy also produced carbon dioxide that were riddled with ICT inefficiencies. Data center major components are thousands of servers, however these servers consumed huge energy without performing useful work.

III- **Application Level**: there is no doubt that ICT has exploded in different areas, making human lives better, there work easer and several many services. In these days the on-line application like community, social networks and search engines software's are intensively used by users and professionals. However, all this on-line applications have been contributing to energy consumption and emission of CO_2, which has negative impact to environmental problems. These applications run among internet into huge amount of data centers and other IT infrastructures [83]. Energy efficiency for data centers is a renewed challenge and dynamic complex issue because storage data and computing applications are increasingly every day. Social application such as Facebook, YouTube and twitter are popular internet based applications. They served dynamic requests to millions of customers, it is very hard to predict whose access and interaction patterns. Also, these applications created by independent analysis and developers, the features of these applications are dynamic workload and from different locations in the world. In order to reduce power consumption by data centers that executed the application we must keep QoS and resource consumption at suitable levels. However, on-line application websites developers did not take into account when creating social applications energy efficiency [84].

Efficiency in some parts of the data center is important moreover to reduce energy consumption. However, to achieve greening ICT the overall data center design must be efficiency. Driving the data center to a green data center is a complicated operation, so greening data center can be achieved in two stages:

I. **Customization of the data center operation (operation costs)**: The operation costs attract full attention of the data center operators and owners as well as influences to costs of the service. It is responsible for the changes in the data center operations towards efficiency. The operation costs is related to network and IT equipment.

II. **Ideal planning actions (Planning Actions)**: the planning actions is responsible for transforming the overall data center operations to more efficiency. The efficiency of the data center can be achieved by developing new technology and management techniques.

The energy efficiency is achieved when we minimize (increase the efficiency) the fixed and variable energy in the data center.

5.4 Green ICT

The data center is an important element in the ICT infrastructure. Also, it is the big energy consumer in the ICT infrastructure. Environmental impact of Information Communication Technology (ICT) under the banner of "Green ICT" has being discussed by academia, media and governments. Since (2007), when the Environmental Protection Agency (EPA) submitted a report to the US Congress about the expected energy consumption of data centers, Green IT has received growing attention. The overall objective of Green IT is to increase energy efficiency and reduce CO_2 emissions [85].

The data center is the most active part in an ICT, which provides processing resources and hosting resources which supports different platforms. All over the world data centers consumes around 40,000,000 MWhr per year [71], unfortunately most part of this energy is wasted due to lack of efficient data center design. Figure 5.5 show the effect of good practice of green data center for gas emission. To make data center greener there are two ways:

I. First improve energy efficiency of data center,

II. Second use clean energy supply.

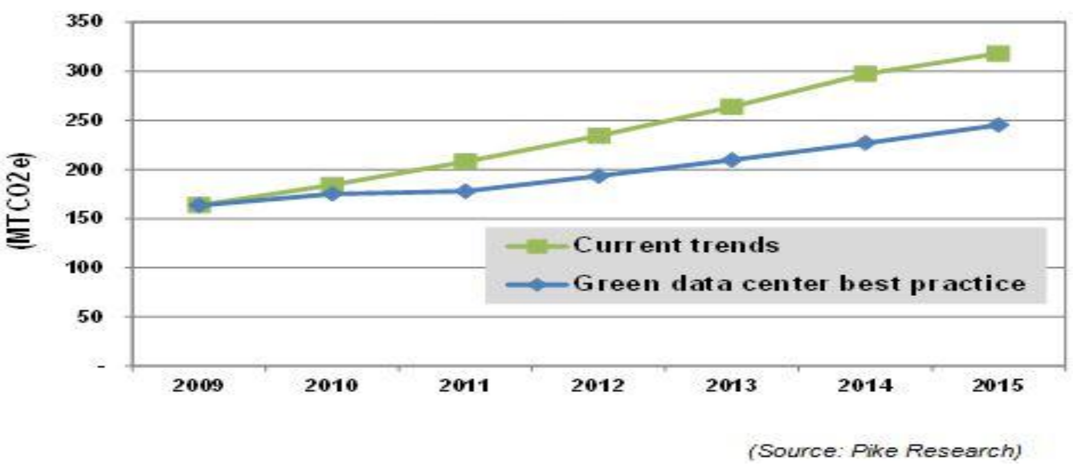

Figure 5.5 Green Data Center [86]

Data center has different techniques to solve energy-efficient problem to minimize the impact of data centers on the environment. This techniques deal with energy efficiency consumption like virtualization, hardware base, operating systems base and data centers. Some new features arise like energy performance, and time wise. However, the concerns should be to swap problem between energy consumer and performance. The current status of global warming, ecological deterioration and the severity of its potential consequences explains the overwhelming popularity of environmental initiatives across the world. Figure 5.6 shows that there has been an unprecedented increase on the level of concern regarding climate change and environmental sustainability. In recent years, business organizations have witnessed a global intention of employing environment friendly products and technologies to counter global warming and achieve environment friendly and sustainable businesses. The overall objective of green IT is to increase energy efficiency and reduce CO_2 emissions [87].

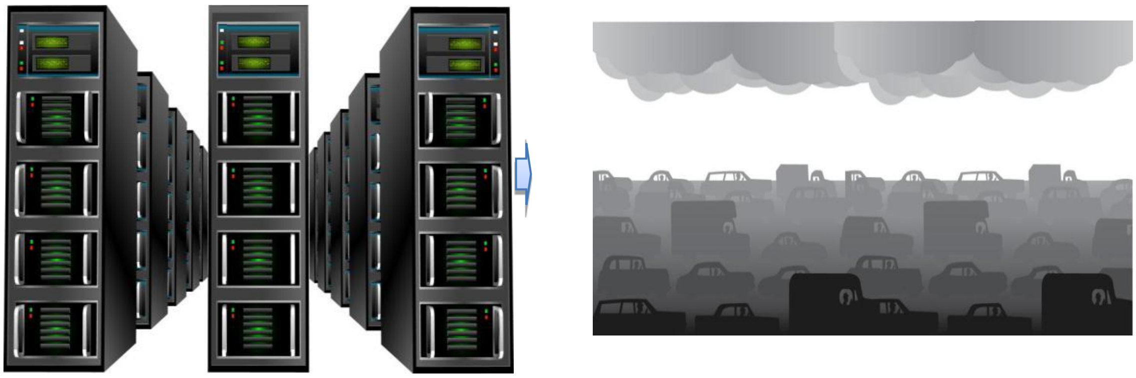

Figure 5.6 The impact of the data center in the environment

The effect of Energy efficiency in data centers exceeds the environment and energy costs to achieved a number of benefits, figure 5.7 show the value of these benefits:

- Increase the hardware lifetime.
- Reduce operational spending of the firm.
- Reduce hardware maintenance.

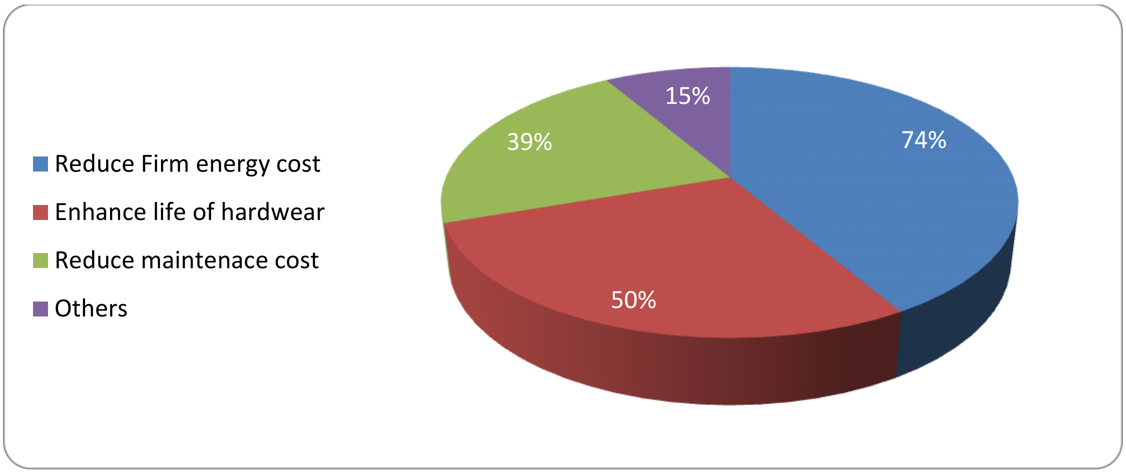

Figure 5.7 Reasons for adopting green ICT

5.5 The Proposed Solution: Integrated Green ICT Framework for Data Centers

Reducing energy consumption and emissions of carbon dioxide (CO_2) in data centers represent open challenges and driving the future research work for green data centers. Our Literature review reveals that there is an urgent need for integrated energy efficiency framework for data centers which combines a green ICT architecture with specific activities and procedures that led to minimal impact on total operation costs in the data centres and less CO_2 emissions. The required energy efficiency framework should also consider the social network applications as a vital related factor in elevating energy consumption, as well as high potential for energy efficiency. The framework provides a platform on top of which the Green Cloud could be built. The framework practices from Energy Aware Computing (EAC), improve the efficiency of Cloud systems and their data centers and Clouds themselves will produce naturally efficient and focused centers of computation, advancing the pursuit of green computing.

The integrated data center energy efficiency framework is also applicable in different types of data centers including Tier 1, Tier 2, Tier 3 and Tier 4. The framework will offer a great powerful capability to deal with service levels and resources management, improved in scalability, elasticity, simplicity for management, delivery of cloud services and better reduction in data centers energy consumption taking into consideration the QoS for the user services.

The framework is called RAIN which deals with both hardware and software by using:

I. Virtualization,

II. Rightsizing and

III. Green metrics.

Which could be used and implemented in complex data centers. The framework deal with important problems and challenges highlighted previously. The proposed Green data center framework provides an overall model to help data center managers to implement Green IT solutions in their existing or new data centers, to make them energy efficient and friendly green environmental data centers. In addition, the proposed data center framework we introduced a green metric based model to analyze all data centers main component measurements, including building, ICT infrastructure, UPS and the performance of the data center in terms of energy efficiency and CO_2 emissions and benchmarked all of these measurements. The proposed Green data center framework consists of four phases to be followed to properly implement the Leadership in Energy and Environmental Design (LEED) standard [99] which has been developed by the US Green Building Council. The LEED for building - consists of a set of rating systems for the design, construction and operation of high performance green buildings and data centers [100]. The LEED including sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality and the right sizing for UPS and virtualization for data center [101]. LEED buildings or centers have 4 Levels of certifications which ranked from Certified, Silver, Gold, and Platinum [102]. The RAIN applies metrics to measure the efficiency of the data center in terms of energy efficiency and CO_2 emissions. The proposed Green ICT framework using virtualization technology and green metrics should be used and followed by data center managers to implement green initiatives in their data center to make it more energy efficient and green.

The **RAIN** consists of the following four phases as figure 5.8 show:

I. **R**ating.

II. **A**nalysis.

III. **I**mplementation.

IV. **N**ote and Evaluation**.**

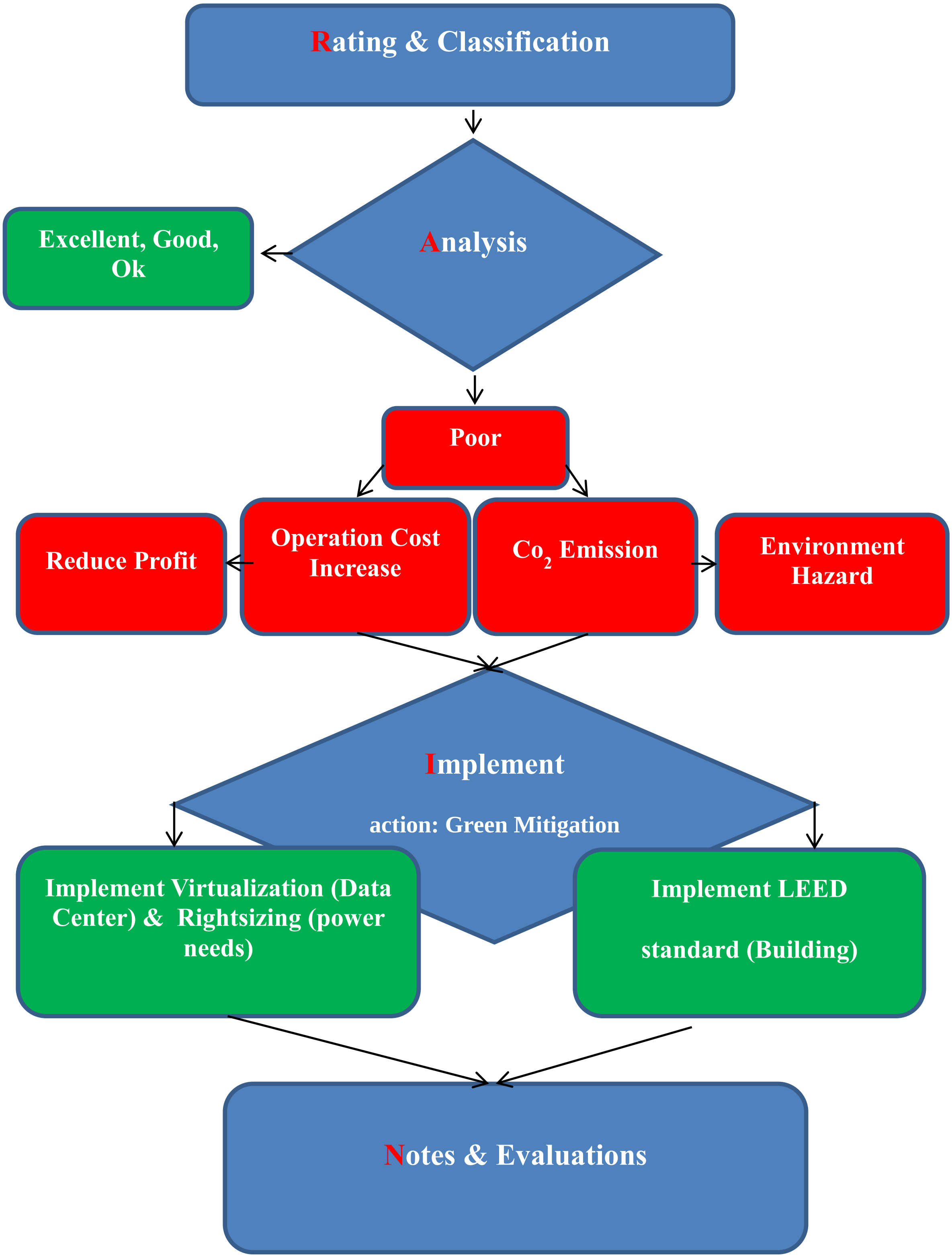

Figure 5.8 The green ICT framework (RAIN)

5.5.1 Rating

The first phase of RAIN is developed to identify, categorize, measure and order the components of the data center that consumes energy (Building, IT and UPS). Usually, Data centers consist of many different parts and devices, data center components are performing different tasks to meet the end user demands. These parts should be classified into measurable units depending on the energy consumed, so that different green metrics can be applied to measure their performance and energy efficiency of each part separately and then to calculate the total efficiency of data center, because it is difficult to evaluate and assess the efficiency of the whole data center collectively.

Some of the major data center parts are:[103]

I. Servers and Racks.
II. Storage devices.
III. Uninterruptible power supplies (UPS).
IV. Switch gear.
V. Chillers.
VI. Air conditioners and lighting.
VII. Direct expansion (DX) units.
VIII. Generators.
IX. Distribution losses external to the racks.
X. Power distribution units (PDUs).
XI. Batteries.

Recently, there has been a lack of standard to categorize data center components into measurable units so that green metrics could be applied to each part separately to measure their performance [99]. This research proposes a metric based energy efficiency model to categorize data center components into measurable units and then applying green metric for each part so that their efficiency can be measured and benchmarked. In this phase the framework gives each element a separate ranking (priority) which depends on its contribution to the whole energy consumption in the data center. After giving the task order (Rank), the framework will deal with these orders as follows:

I. Data center energy consumption (Hardware + Software + Building).

II. Carbon CO_2.

III. Performance.

The reporting measures and metrics are defining the energy efficiency and performance of the center at a given point of time (per hour). To show changes in energy and productivity these measures are inherently sensitive and their values are changeable [94]. Analysis measurement and metrics have the opposite requirement and should be as stable as possible for each data center and as independent as possible of the varying ICT workloads and ICT equipments contained within the facility to support effective decision making and planning [95].

5.5.2 Analysis

The second phase of RAIN was based on the energy efficiency model which was depicted in Figure 5.8 The main role of energy measurement and analysis is to find the value of the metrics, when it represents the case of inefficient energy usage, then a decision has to be taken to reduce the energy consumption. During this phase, energy efficiency in the different parts of the data center should be calculated and benchmarked. There are several metrics available for the measurement of energy efficiency, this is why we selected the Fixed to Variable Energy Ratio (FVER) instead of Power Usage Effectiveness (PUE) as a better metric for the assessment of the data centers energy efficiency, which is based on certain required criteria including the usage of ICT and software applications in data centers [87]. FVER metric helps to break the data center down into manageable chunks. Figure 5.12 shows the 4 levels of FVER efficient green ranges: 1, 1 – 1.5, 1.5 – 2 and 2 – 4 and the inefficient values from 4 – 10 which is not acceptable. The Data Centre Fixed to Variable Energy Ratio metric (DC FVER) measures proportion of data center energy consumption, which was related to the useful work delivered, versus what proportion is variable, allowing operators to understand how much of their energy cost is related to the work delivered and how much is a fixed burden to be eliminated. After classification and rating, the next phase is to determine the suitable metrics for benchmarking. But unfortunately, due to the lack of both standard metric and benchmarking, there were no agreed metrics, this framework proposes the following metrics that were considered as industry standard in measuring the energy efficiency and CO_2 emissions: data center (FVER metrics), building (LEED standards), matching the sizing,

CO_2 (CO_2 calculator) and performance/productivity (FVER $_{proxy}$ metrics). All these metrics are calculated by the three formulas below:

$$\text{Fixed to Variable Energy Ratio (FVER)} = 1 + \frac{\text{Fixed Energy}}{\text{Variable Energy}} \quad -(6)$$

$$\text{FVER(ICT)} = 1 + \frac{\text{Fixed Energy}}{\text{Variable Energy}} - - - - - - - - - - - - - - (7)$$

$$\text{FVER(Utility)} = 1 + \frac{\text{Fixed Energy}}{\text{Variable Energy}} - - - - - - - - - - - - - (8)$$

$$\text{W(hour)} = \text{a.W1} + \text{b.W2} + \text{c.W3} + \text{d.W4} - - - - - - - - - - - - (9)$$

Where

W_{hour} = Total work in the measured hour.

A, b, c, d = The relative weighting.

W_1, W_2, W_3, W_4 = Counted productive actions of different platforms.

5.5.3 Implementation

In this step the framework puts green ICT into action by implementing a procedure called **Green Mitigation**. This procedure contains different actions depending on the values of the metrics in a second step (analysis). Green mitigation gets one of the two decisions depending on the metric values:

I. Implement virtualization on data center and
II. Right sizing power needs. Or Implement LEED standards for data center building (Fixed Energy).

I. **Server virtualization (The engine behind energy efficiency)**: IT virtualization is responsible for physical network, server, and storage resources. Virtualization increased the ability to utilize and scale compute power. Virtualization has become the technology behind the increase of cloud computing technology [104]. While the benefits of this technology and service delivery model are well known, understood, and increasingly being taken advantage of, and their effects on the data center physical infrastructure (DCPI). It has become popular in data centers since it provides an easy mechanism to cleanly partition physical resources, allowing multiple applications to run in isolation on a single server. It categorizes volume servers into different resources pools depending on the workloads they perform, and then server consolidation is applied. This technique decouples software from hardware and splits multiprocessor servers into more independent virtual hosts for better utilization of the hardware resources. Figure 5.9 shows how server virtualization implemented by allowing services to be distributed in one processor. With server consolidation, many small physical servers are replaced by one larger physical server to increase the utilization of expensive hardware resources, reducing the consumption of energy and emission of CO_2 [102].

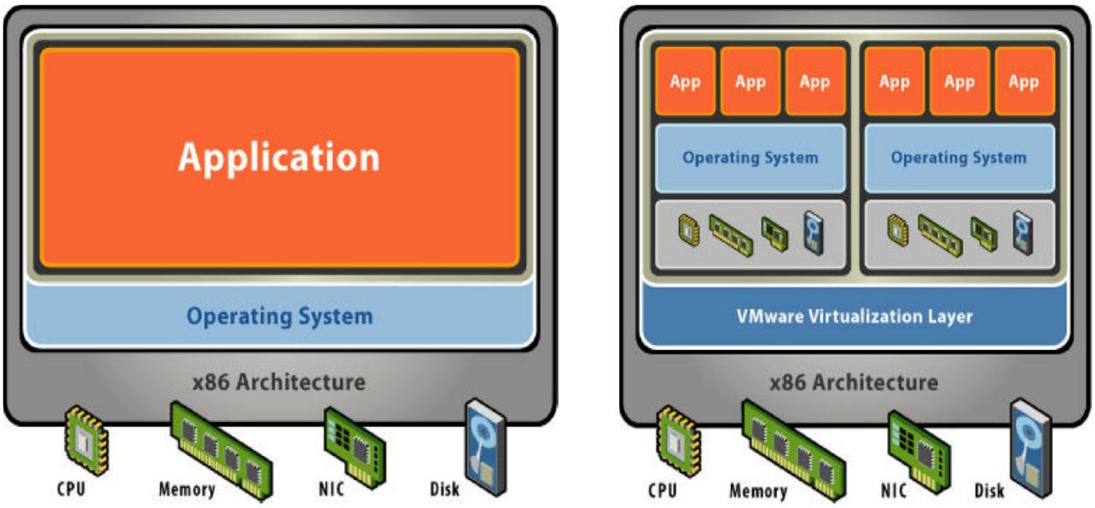

Figure 5.9 Before and after virtualization environment in single server

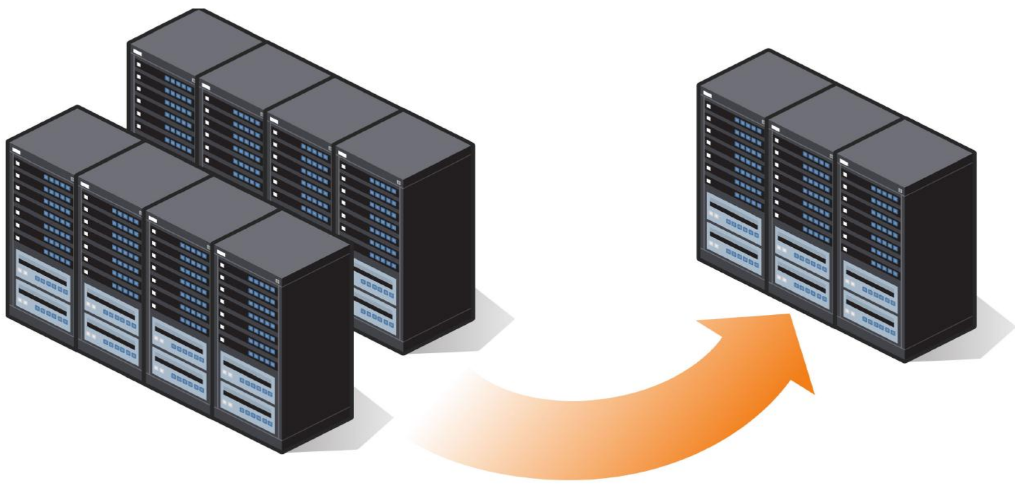

Figure 5.10 Before and after virtualization in the data center

Figure 5.10 shows before implement virtualization rack and after implementing the virtualization in the data center. This technique reduced more than 60% in the data center footprint, by reducing the components that consume energy we can decrease the energy consumption by the data center.

II. **Leadership in Energy and Environmental Design (LEED)**: the United States Green Building Council (USGBC) is a non-profit organization that promotes and certifies environmentally friendly buildings and is committed to fostering and furthering green building efforts worldwide and to enabling members to be a part of those efforts. The USGBC developed the LEED (Leadership in Energy and Environmental Design) The entire building can be certified as an environmentally friendly facility — this includes office space. Look for LEED Platinum Certification as the highest mark a facility can obtain today. From there, see if their office space is designated as "A" Class to not only support the customers — but also provide a comfortable working environment. LEED certification, internal data center operations can speak volumes as to how green a data center really is. Ensuring that air flow is well controlled and that hot/cold aisle containment is deployed by your organization wherever possible. Efficient aisle control as well as good airflow management can really help a data center remain environmentally conscious. [33]. LEED Rating System present many benefits to the data center building:

a) LEED addresses complete lifecycle of the building.

b) LEED present 4 Levels of satisfaction.

c) Steps to LEED international Certification.

d) A sample checklist.

e) Available resources on line.

Building and certifying a green data center or other facility can be expensive up front, but long-term cost savings can be realized on operations and maintenance. Another advantage is the fact that green facilities offer employees a healthy, comfortable work environment. In addition, green facilities enhance relations with local communities and environmental society. There is increase pressure from environmentalists and, increasingly, the general public for governments to offer green buildings in data centers and non-commercial buildings. Based on the table 1, the green building rating systems LEED was rated the highest with 80 points, Green star was rated second with 69 points [103].

Table 5.1 International benchmark in energy efficiency of data centers buildings

No	Variables	LEED	BREEAM	Green Home	Green Star
1	Popularity & Influence (10)	10	10	5	6
2	Availability (10)	8	8	5	8
3	Methodology (15)	10	12	10	8
4	Applicability (20)	13	13	9	10
5	Data Collecting (10)	8	8	4	9
6	Accuracy & Verifying (10)	8	8	6	6
7	User friendliness (10)	10	8	4	8
8	Development (10)	8	8	6	8
9	Result Presentation (5)	5	4	2	3
Total Score (100)		80	79	51	67

III- Rightsizing: Many companies after adopting cloud computing find themselves with power infrastructures that are either too small or too big for their real needs.

Companies with too small power restricted by having insufficient electrical capacity for peak loads, driving to system failover. Repetition of failover will increase the downtime, which lead to lower employee productivity and reduced profitability. While, too small power infrastructure can also restrict the expansion of the data center in the future, because companies must make expensive power system upgrades to add new hardware.

Having too big power capacity is not better than having too small. Power more than the actual real needs will directly affect the organizations operational costs, maintenance and floor space.

Every company should right-size their power consumption to match their real needs.

A right sized power infrastructure: present high energy efficiency for current operating data center by providing appropriate power capacity to deal with real needs. [107].

5.5.4 Note and Evaluation

This phase deals with the evaluation of the effectiveness of the selected solution. The evaluation is done by measuring the energy and the performance of the data center regularly from time to time using the selected metrics; this is done by performing the following two steps:

I. Collect and categorize data (Network data, ICT equipment data).

II. Data Analysis using energy efficiency and CO_2 emission calculators.

In this phase, as depicted in Figure 4.15 data center managers need to collect data regularly related to energy usage, carbon emissions, utilization ratio and all categories of equipment for the data center. After collecting the required data, analysis should be performed by using different tools like **Data Center Energy Savings Calculator by Schneider electrical company**. This tool will generate output on the basis of comparison between performance and power. Any changes on the data centre's operation will change metrics value and will enable clear note to the direction (positive or negative) to implement the RAIN framework. This process should be repeated until a maximum efficiency in terms of power of performance is achieved.

CHAPTER SIX

DATA COLLECTION AND ANALYSIS

Introduction

Sudan telecommunication Group (STG) is the biggest telecommunications and Internet service provider company in Sudan. The company is responsible for the construction and maintenance of Sudan's telecom infrastructure. Generally the data center of Sudatel takes 200m x 100m area and consists of many components such as the racks, servers, UPS, switches, router, cooling units, lighting units and monitoring sensors for the environment. There are also ,one or two monitor devices for data gathering, which are executing a software that collects the energy consumption data from the data center component devices and acts accordingly.

6.1 The Electricity Costs

The increase of energy demand and costs is the main motivations behind the research. So, because over the world the energy consumed, demand and need is increasing. The nations use energy as the essential component in developing. Table 6.1 show the behavior of the increasing in the demand and the costs of electricity in Sudan where data was collected , figure 6.1 highlights the energy demands and costs in the Sudan in the period from 2000 to 2016.

Table 6.1 The demand and the costs of energy in Sudan 2000–2016 [108]

Year	Consumption in MW	Price per $/kWh	% Price/kWh
2000	391	0.0256	0%
2002	439.2	0.0256	0%
2004	419.1	0.0280	10%
2006	565.7	0.0280	0%
2008	546.2	0.0280	0%
2010	673	0.0280	0%
2012	536	0.0765	150%
2014	673	0.0765	0%

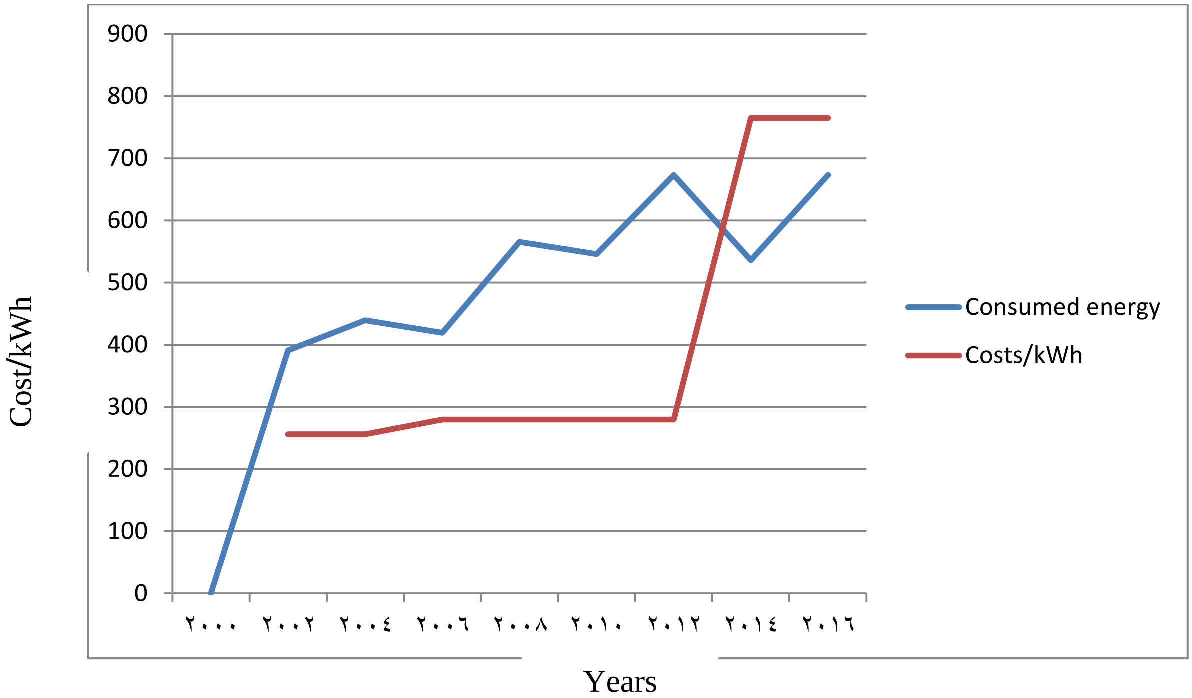

Figure 6.1 The increase in demand and costs of energy in Sudan

Figure 6.1 shows our historical data for electricity costs. The demand and costs for energy increased in higher rate during the last ten years and is expected to increase in the future .Table 6.2 and figure 6.2 shows the comparison of the costs of energy per cent for each kWh, between Sudan and many countries, while the table 6.2 and the figure 6.2 highlights the consumption of energy in all of the world and especially in Sudan which increased as well as the cost in Sudan. Globally, the energy demand is growing, in a rate of %2 - %2.6 annually. The Arab countries demands growth is about three times more % 6 - % 8 [109].

Table 6.2 Electricity cost among Arab countries

Country	Cost cent per kWh
Morocco	12.1
Tunis	11.0
Jordan	9.0
Sudan	7.6
UAE	5.0
Egypt	2.7
Syria	1.7
KSA	1.4

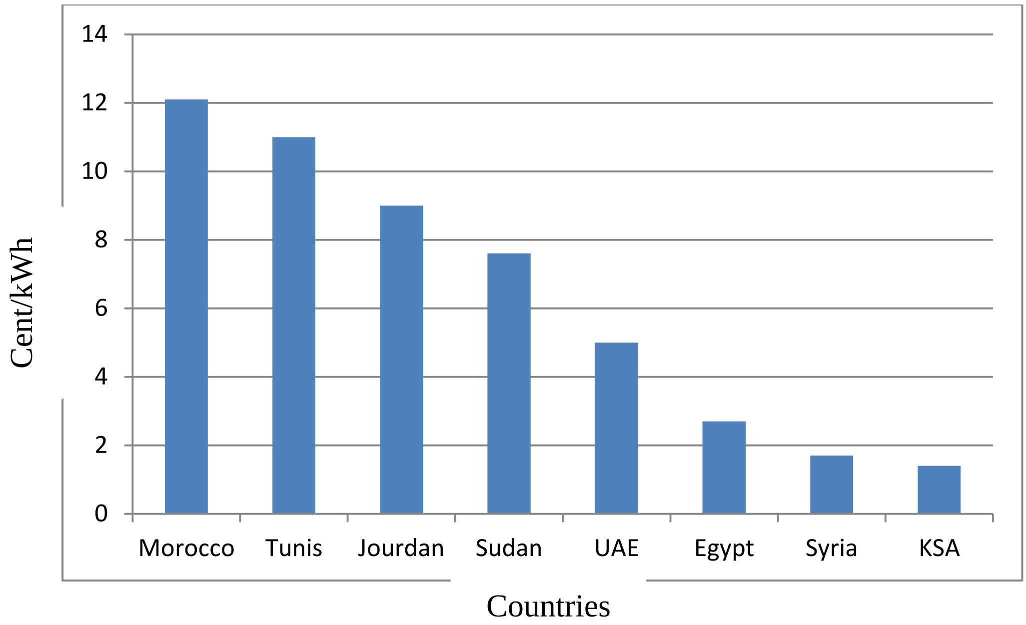

Figure 6.2 The costs of energy in Arab Countries

6.2 Data Collection

The collected data saved in files is in the standard format (.xlsx). Each value of energy consumed represented by a single row in the files. Each row consists of a number of columns, which contains a number (integer and real), these columns are coordinated by excel cell program format. The total number of rows is 24 data lines. Each row contains 11 columns. From this 24 rows, we calculated the consumed energy (kWh), this value is divided into two different parts, part one is IT devices consumed energy and part two is utility devices consumed energy. The gathered data stored in the database for future reference.

To determine the equipment responsible for the energy waste, implement the proposed solution (RAIN framework), and evaluate the influence of RAIN frame-work in energy consumption five steps was performed:

1- **Calculating the energy values:** Calculated energy consumed by the data center.

2- **Targeting the energy waste:** using FVER calculator to targeting the waste equipment part and the energy consumed real cost. FVER calculator developed by Data Centre Specialist Group (DCSG).

3- **The energy consumption after implement RAIN framework:** calculating energy consumption values by implement the integrated green framework RAIN using data center efficiency Schneider simulation developed by Data Centre Specialist Group (DCSG) for Schneider electric company (more details in Appendix A), to produce the energy consumption after adjusting the simulator options by choosing appropriate options that deal with the RAIN framework options.

4- **Analysis the energy consumption values by using FVER metric:** Using FVER metric calculator by insert the energy values in FVER metric calculator (Excel file), this calculator automatically after insert the energy consumed value which influenced by many factors it calculated $FVER_{IT}$ fixed and variable value and also calculated $FVER_{utility}$ fixed and variable values (more details in Appendix A).

5- **Calculating Co_2 emissions:** Calculated CO_2 emission by using the calculator software that called **the data center carbon calculator** developed by Data Centre Specialist Group (DCSG) for Schneider electric company.

6.3 Case Study I: Sudatel (SCG) Data Center

To investigate the behavior of real energy consumption in the data centers, we used an expert team consists of electrical and network engineers, of Sudatel Telecom Group (STG). The team traced the values of energy that consumed by the Sudatel data center. The trace was completed in the period of January to May 2014. The data was collected for different seasons. The outside temperature was between 15 – 25 from January to February and 25 – 40 from March to May. The values of energy consumed by the data center taken during the data center was running (has not stopped). They accounted records from the data center, which was collected in different days in 24 hours, in each hour the team took value of energy consumed by the data center. The team collected the data on workdays (Sunday – Thursday) and on weekend days (Friday – Saturday).

The ProLiant DL585 server is a powerful, 4U enterprise server incorporating technologies that extend the capabilities of industry-standard x86 computing. This server provides high performance and the capability of running both 32-bit and 64-bit applications simultaneously with no performance penalty when using an operating system that supports 64-bit extensions. This is possible because the x-86-64 instruction set architecture is a superset containing the x86-32 instruction set architecture (HP, 2006). Intel® Xeon® processor E5-2600 v2 product family offers increased performance, improved security and efficiency; ideal for demanding workloads. HP Smart Memory, with speeds up to 1866MHz, prevents data loss and downtime with enhanced error handling while improving workload performance and power efficiency. GPU compute support to maximize performance HP Smart Cache, a controller-based caching solution, caches hot data onto lower latency SSDs providing up to 4x better workload performance. The data center power capacity is classified as Tier4, which power capacity is 4 MW and comprised of 300 racks, the power capacity of each rack is 7 kW. Each rack contained 8 servers; the total number of servers was 300 racks × 8 servers with a total number of servers 2400.

1- Calculating the energy values:

We investigated the energy consumed by Sudatel Data center from a different point of view. We use data center efficiency Schneider simulation, because this simulation present many options to analyze the data center energy consumptions, inputs section were we insert the total power capacity of the data center and the IT power capacity then choose a property options as figure 6.3 shows the simulator options, so the output section automatically present inefficiency of the data center in the IT component and the utility component the carve shows the efficiency level in dark area.

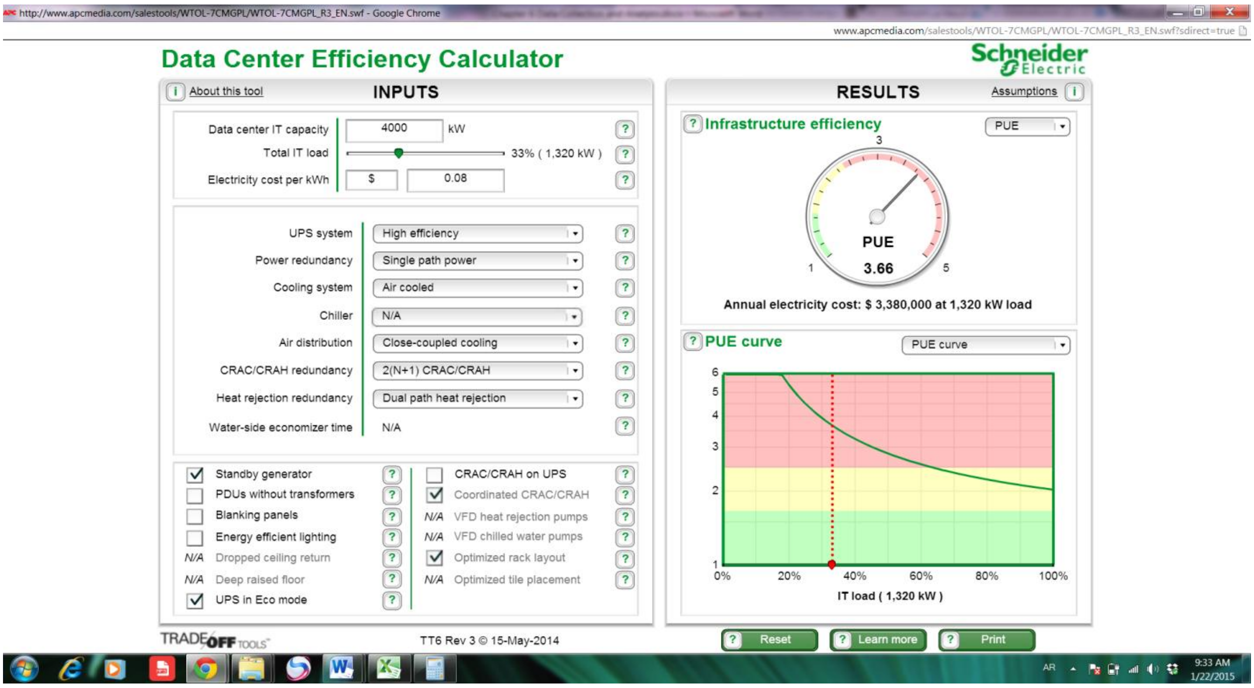

Figure 6.3 IT loads compared with utility load using PUE metric

The simulator has ability to view the energy waste in many points of view. Figure 6.4, show the power system losses, so in output section the simulator automatically shows the parts which loose energy in the data center.

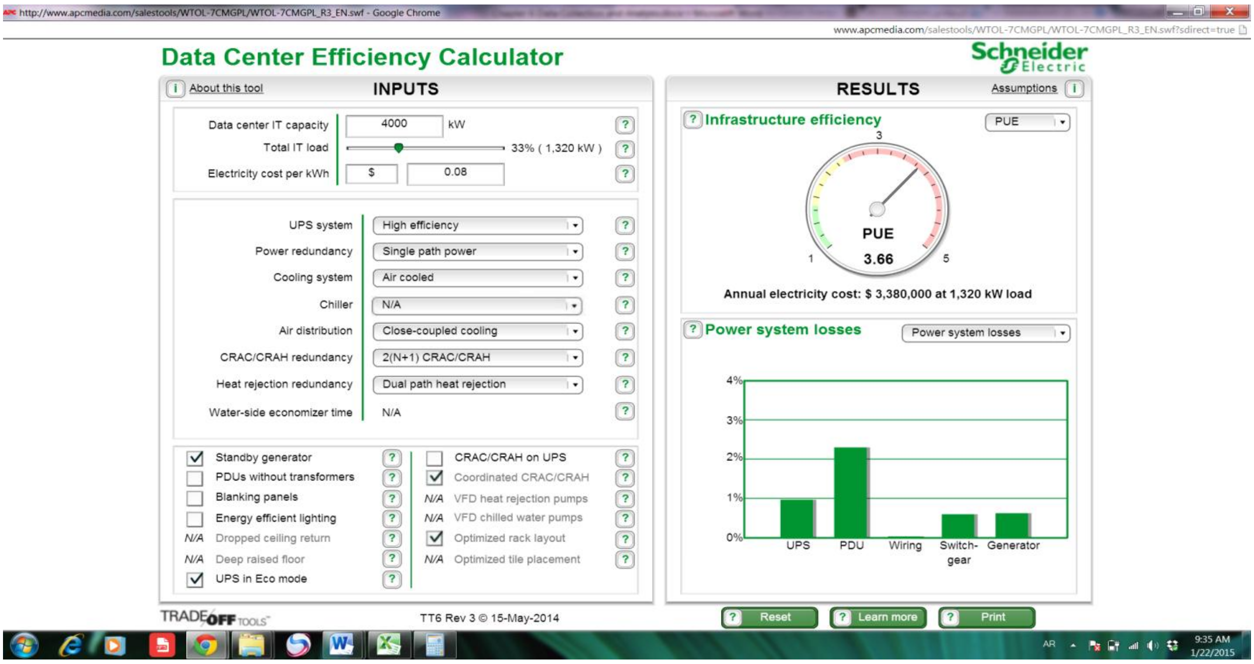

Figure 6.4 The power system losses in Sudatel data center

The data center power capacity is classified as Tier4, which power capacity is 4 MW and comprised of 300 racks, the power capacity for each rack is 7 kW. Each rack contained 8 servers; the total number of servers was 300 racks × 8 servers with total number of servers 2400. The total IT load and costs for one rack per year.

can be calculated as:

1 rack consumed = 7kwh

Total hours in annual = 24 h x 365 days = 8,760 h

Energy consumed annual= 7kwh x 8,760 hrs = 43,800 kWh

Cost annual = 43,800kWh x $0.76/kWh = $33,288

To calculate the total IT load and costs per year (300 Racks):

IT load annual = 43,800 kWh x 300 = **13140000**kWh/ year

Total IT cost annual = 13140000kWh x $0.076 = **$998,640**

Calculating for all racks/h:

IT energy consumed = 7 kWh x 300 rack = **2100** kWh

IT energy cost = 2100 kWh x $0.076 = **$159,600**

The total IT load and costs for one rack per year we can calculate as:

To calculate the total IT load and costs per year (300 Racks):

IT load annual = 43,800 kWh x 300 = **13,140,000**kWh/ year

Total IT cost annual = 13140000kWh x $0.076 = **$998,640**

Table 6.3 Energy consumption by IT equipment

Item	Energy consumption kWh	Costs/$	CO_2 Emission
Rack/day	7	127.68	37,926 Tons
Rack/Year	43,800	33,288	
IT/Year	13,140,000	9,986,400	

2- **Targeting the energy waste part:**

We noticed that the energy consumption increased during the workdays over the holidays, and there is a relation between energy consumption during the same day and the work load. The relationship was the increase of energy consumption when the workload was increasing. The value taken at night is lower than the one taken at midday. Figure 6.5 shows how energy consumption has different values during one day, the points show the values of energy consumption in a day, the green points show low energy consumption values, most of them in the early morning 1 – 8 o’clock, and the black points show higher energy consumption values, these white points show a low level of energy efficiency and high energy consumptions values, most of them were in the period between 2 o’clock in the afternoon and 9 o’clock at night.

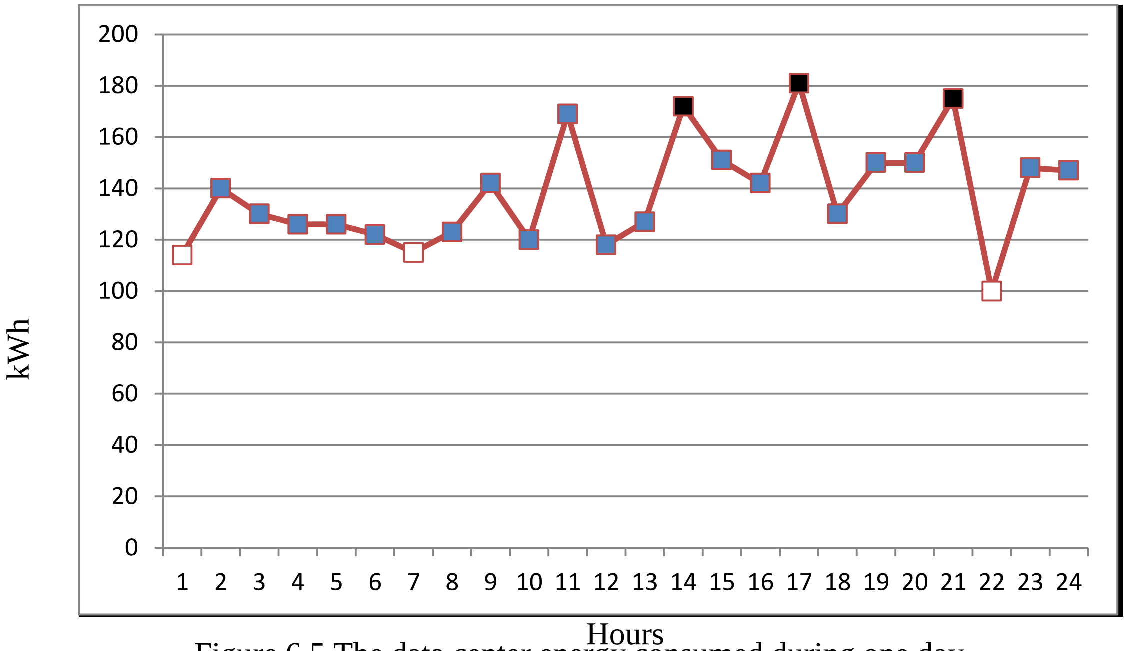

Figure 6.5 The data center energy consumed during one day

Table 6.4 Interpret and clarify the fixed and variable energy

Data Center	Comment
Real Data Center	> 81% of energy consumption is fixed and not affected by workload, < 19% is related to workload.
Ideal Data Center	~0% of energy consumption is fixed, ~100% related to work delivered

Figure 6.6 shows the Sudatel data center consumed a large amount of energy when in no-load status (75 kWh). The Sudatel data center uses a large amount of electricity when in no-load (no program loaded). The ideal data center consume near zero energy when there is no-load or when idle and the energy consumed increases when delivering useful work or services, to perform 100% useful work or services the data center consume 100% energy.

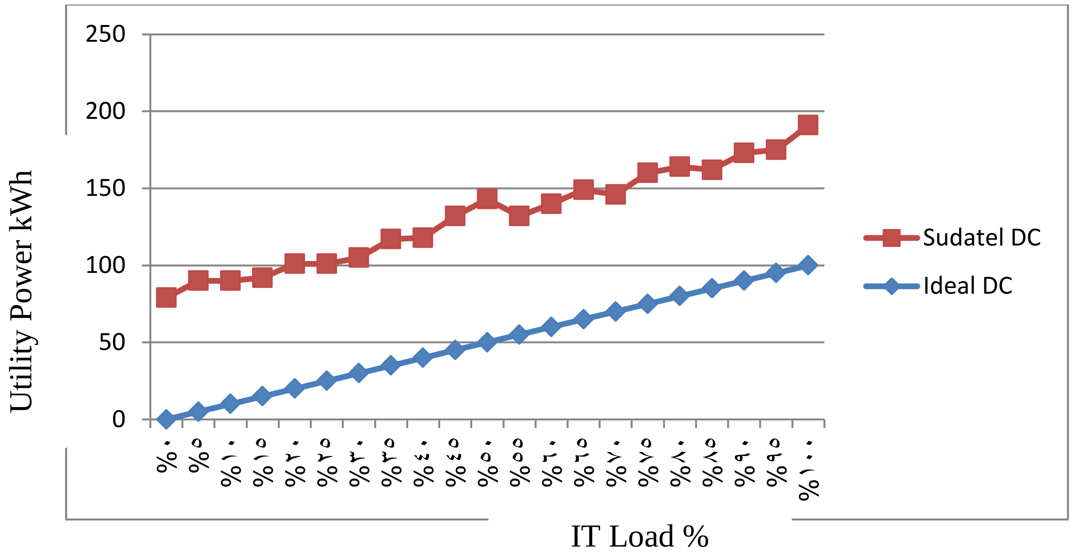

Figure 6.6 Ideal data center vs real data center

The value of FVER metric calculated by simulation, which developed by Data Centre Specialist Group (DCSG) in USA, this simulation accept the changing in workload, virtualization, right-sizing and data center building values and automatically calculate the energy consumed value before and after implement the proposed solution the framework (RAIN), which influenced by many factors, the simulation help to calculated FVER $_{IT}$ fixed, variable value, FVER $_{utility}$ fixed and variable values (more details in Appendix A). The Sudatel data center showed a variation in energy consumption of the data center between the workday and weekend day. The workday and the end week day loads are shown in figure 6.7, figure 6.8 and figure 6.9.

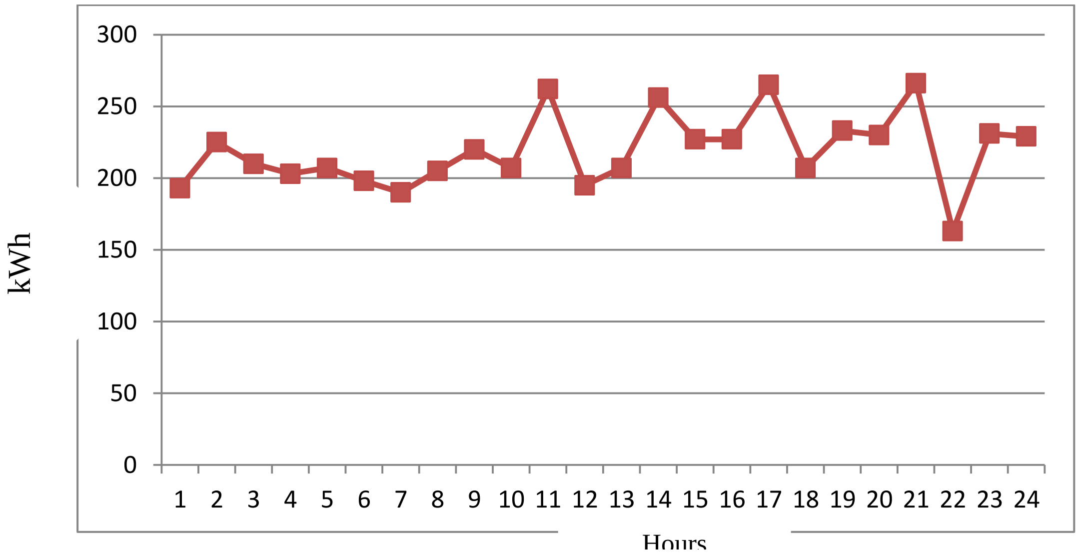

Figure 6.7 The energy consumption during work day

We noticed early morning from 1 – 8 Am the data center consumed low level of energy, because at this period of time there is no users use the applications in the data center. At 9 Am o'clock the work day began and the users started to use the software on the data centers, so that the energy consumption began to varying depends on the users activities, until the mid of night 24 pm o'clock and when the user reduced using software in the data center the energy consumption decreased.

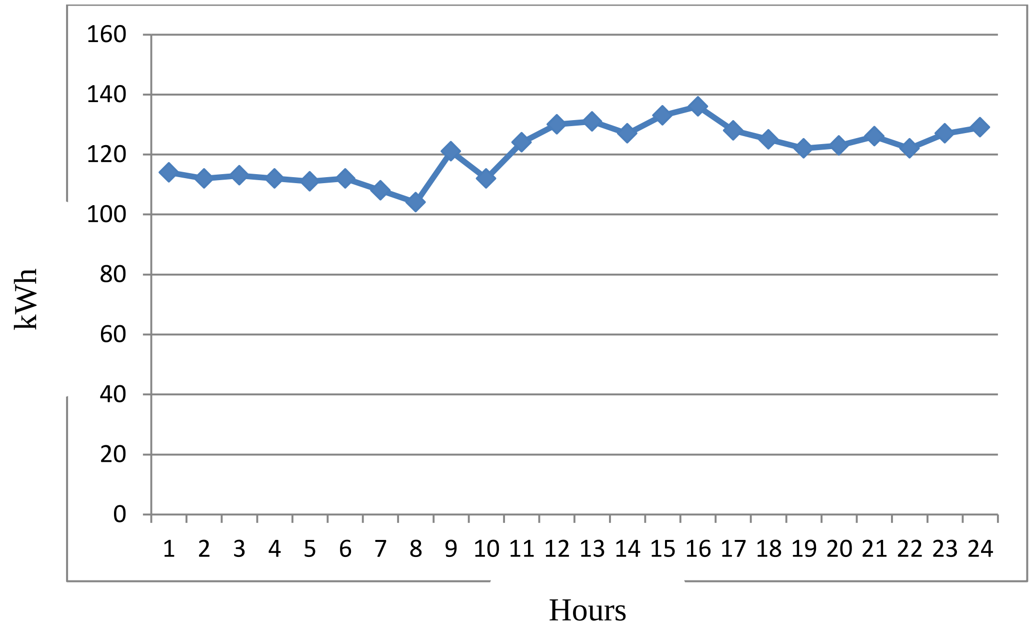

Figure 6.8 The energy consumption during weekend day

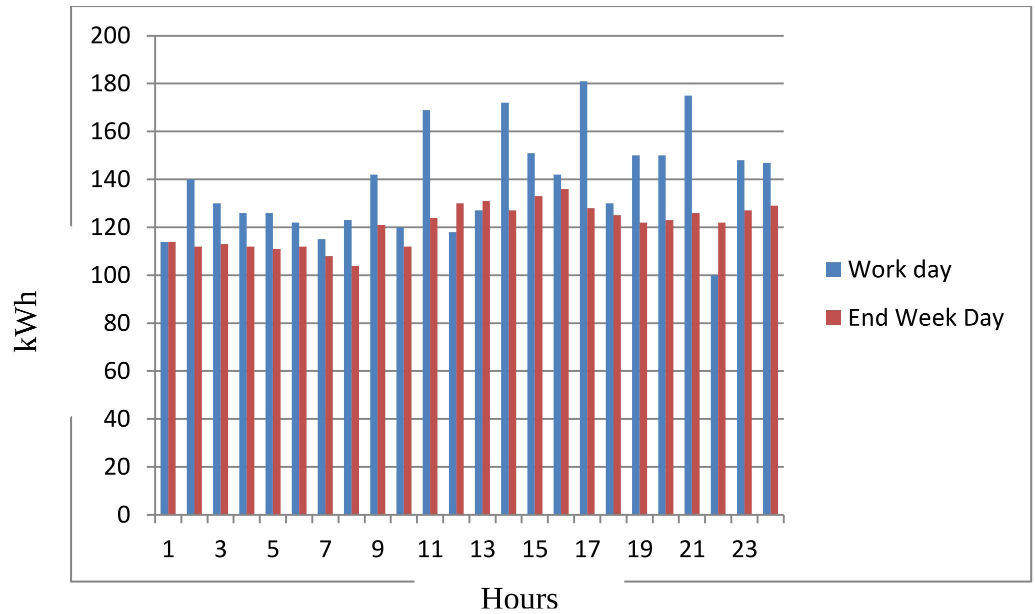

Figure 6.9 Measured weekend day and work day output

We can start from the data center was doing half or less as much useful work at 03:00 pm or 15:00. The measurement can include:

I. User interactions (telephone, web service).

II. Database transaction process.

To calculated variable energy we can use equation 1. FVER measure energy efficiency by dividing the fixed energy (energy consumed by the data center in no-load) to variable energy (energy consumed by the data center to deliver useful work) by equation 2.

From table 6.5 and figure 6.9 we can take many points to see that the data center is covered by fixed energy consumption.

Table 6.5 Utility power vs productivity (work output)

Element	Midday	Midnight
Work output	97%	6%
Utility power	100%	81%

From table 6.5, when we compared utility power with work output from midday to midnight the Sudatel data center was still using 81% of that power to produce just 6% of the work output. With a small calculation we can find that the data center consumed more than 70% of energy consumption when idle. That means 75% of data center energy consumption is fixed.

From equation 2 we can calculate the initial value for FVER from these two values by: The value 4.3 in FVER degree in poor area. Of course to improve the measure we will calculate 24 hourly values in weekday and 24 hourly values in a weekend day. This calculation appears in figure 6.9 and figure 6.10. To make full investigation of data center energy efficiency, we used a simple spreadsheet (Excel file) to calculate FVER by using the values recorded. We have calculated both utility and IT energy consumed by the Sudatel data center. We calculated IT equipment and software and another covering the software by comparing the IT equipment to measure work load. Then we can calculate the FVER for the whole of Sudatel data center by comparing the utility energy to measure work load. Table 5.6 shows the FVER metric values at the IT and utility equipment:

Table 6.6 The FVER (IT) and FVER (utility) value

Metric	Value
FVER(IT)	3.5
FVER (utility)	6.8

From table 6.6 and figure 6.10 we can note that, 5.8 (6.8 – 1) parts of energy consumption which are fixed. However, this value is less than the optimal value.

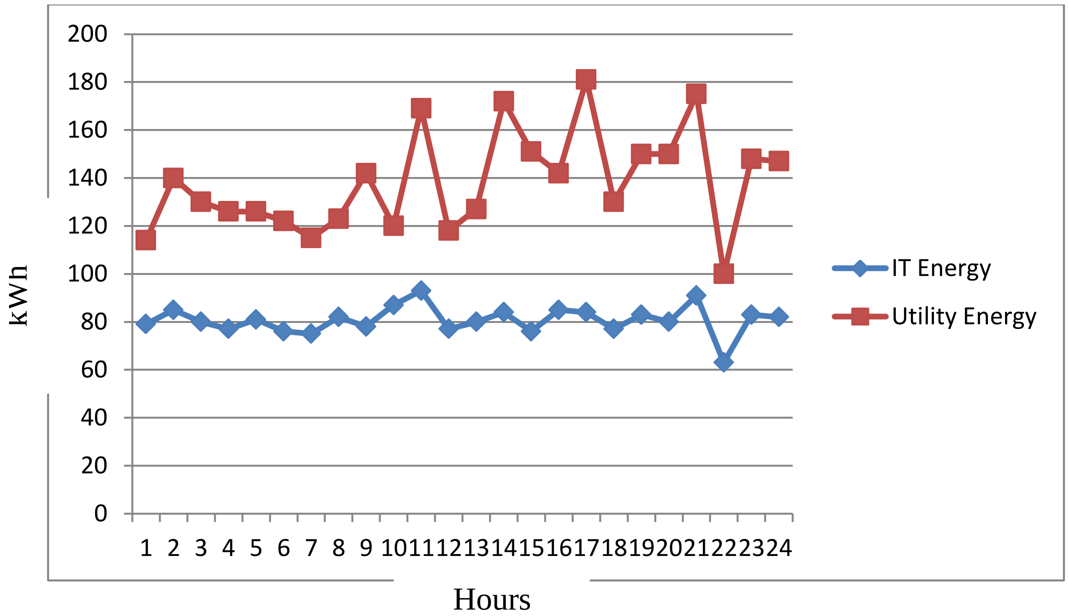

Figure 6.10 The energy consumption IT power and total utility power

We can use equivalently many statistical analysis methods, like linear regression. We can produce two values by using linear regression, the slope and intercept. The slope in our case energy consumption with productivity. The intercept is an estimate of energy consumption when the data center is idle. From figure 6.13 we can conclude table 6.7.

Table 6.7 Intercept and slope of IT and Utility energy

Measure	Intercept	Slope
IT energy	0.67	0.27
Utility energy	0.70	0.12

We can conclude to value in table 6.8, which shows fixed variable energy rations for Sudatel data center using the linear regression statistical model.

Table 6.8: FVER metric calculate using linear regression models

Metric	Value
FVER (IT)	3.5
FVER (Utility)	6.8

The key steps to measure the data center productivity (work output) are the selection of suitable productivity proxy, this proxy are highest application activities and consumed much energy from the data center and are stood as behalf of other applications that has less activities and less energy consumption.

To measuring the productivity and power values taken per specific time (each hour), giving proxy data and acting on behalf of small values. Measuring work output by FVER, depend on select suitable productivity proxies. These proxies will be responsible for all values. Productivity calculated by combining proxies, which full measurement of the entire data center and a weighting activity which calculating by the operators by selected a relative weight for each application depends on the application activities. Table 6.9 presents the activity weighting in Sudatel data center. For each hour the activity calculated by:

Where

W_{hour} = Total work in the measured hour.

A, b, c, d = The relative weighting.

W_1, W_2, W_3, W_4 = Counted productive actions of different platforms.

Table 6.9 Activity weighting in Sudatel data center

Activity	Weighting
Telephone user interaction	3
Web user interaction	2
Database user interaction	4
Financial interaction	50

Table 6.10 and table 6.11 shows productivity and energy consumed to produce work. Table 5.9 presents the percentage of productivity, the IT and the utility energy consumed to produce the work. We noticed that there is a waste of energy, by consuming 95% kWh to producing just 80% work and consuming 93% to producing 100% work.

Table 6.10 Weighted productivity and energy consumption

Hour	Weighted productivity	IT energy (kWh)	Utility energy (kWh)
10:00	79.7	87	120
11:00	85.1	93	169
12:00	68.9	77	118
13:00	84.7	80	127
14:00	68.6	84	172
15:00	79.5	76	151

Table 6.11 shows productivity, IT and utility energy converted to percentages to present the values we used to calculate FVER.

Table 6.11 Percentage productivity and energy consumption

Hour	Productivity	IT energy	Utility energy
10:00	93.7%	93.5%	66.3%
11:00	100.0%	100.0%	93.4%
12:00	81.0%	82.8%	65.2%
13:00	99.5%	86.0%	70.2%
14:00	80.6%	90.3%	95.0%
15:00	93.4%	81.7%	83.4%

Figure 6.11 and figure 6.12 presents the IT consumption in the data center, which reflects the increased energy consumption against producing the work (productivity). The FVER metric show at 0% productivity the energy consumed by

the data center is about 70% (fixed energy), this value reflects the waste of energy consumed to perform nothing load (0 load) and consumed 82% of total energy to produce 100% work. The variable energy is about 12%.

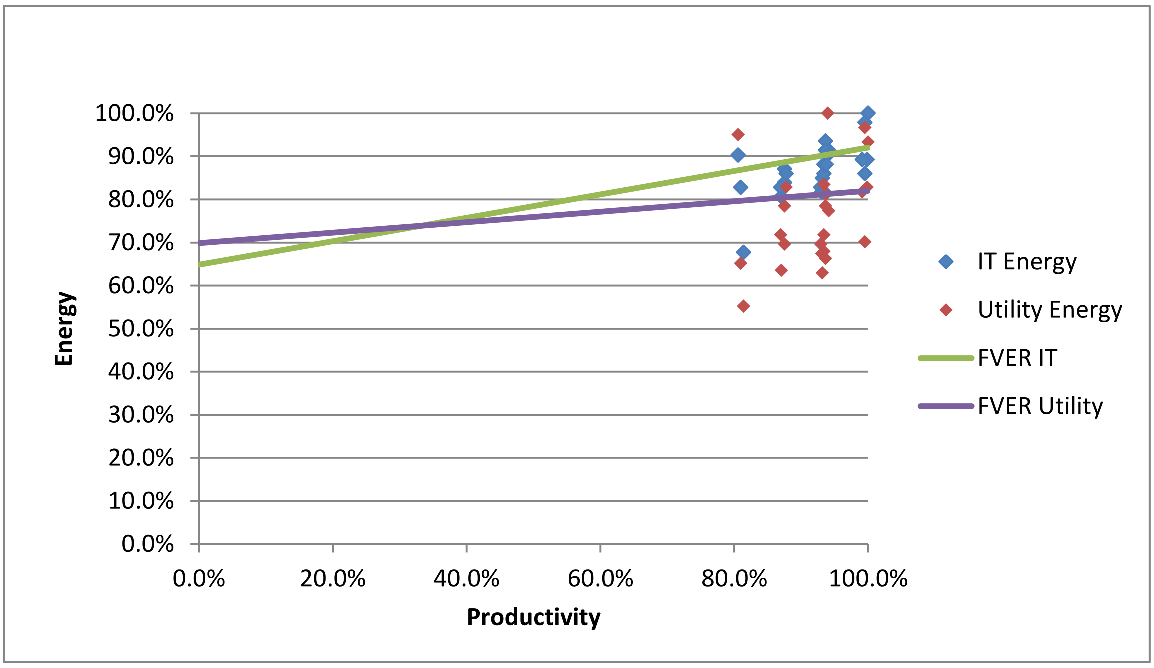

Figure 6.11 The Sudatel data center FVER plots 24 hourly

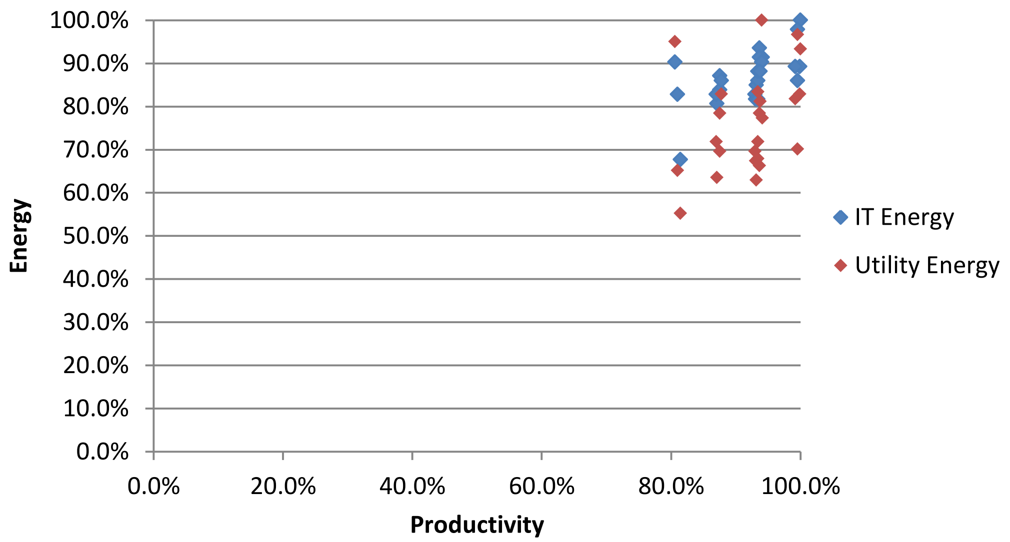

Figure 6.12 The Sudatel productivity vs IT and utility energy consumption 24 hourly

3- The energy consumption values after implement RAIN framework:

To implement the integrated green framework RAIN we adjusted the data center efficiency simulation options to deal with RAIN options and that present the changing in the energy consumption after implemented the framework (RAIN) by reducing the energy consumed by the data center. Figure 6.13 shows the simulation result after implementing the framework RAIN. Figure 6.13 shows the simulator options, so the output section automatically present reducing in energy consumed by the data center after implement the integrated green framework and shows the efficiency of the data center in the IT component and the utility component the carve shows the efficiency level in.

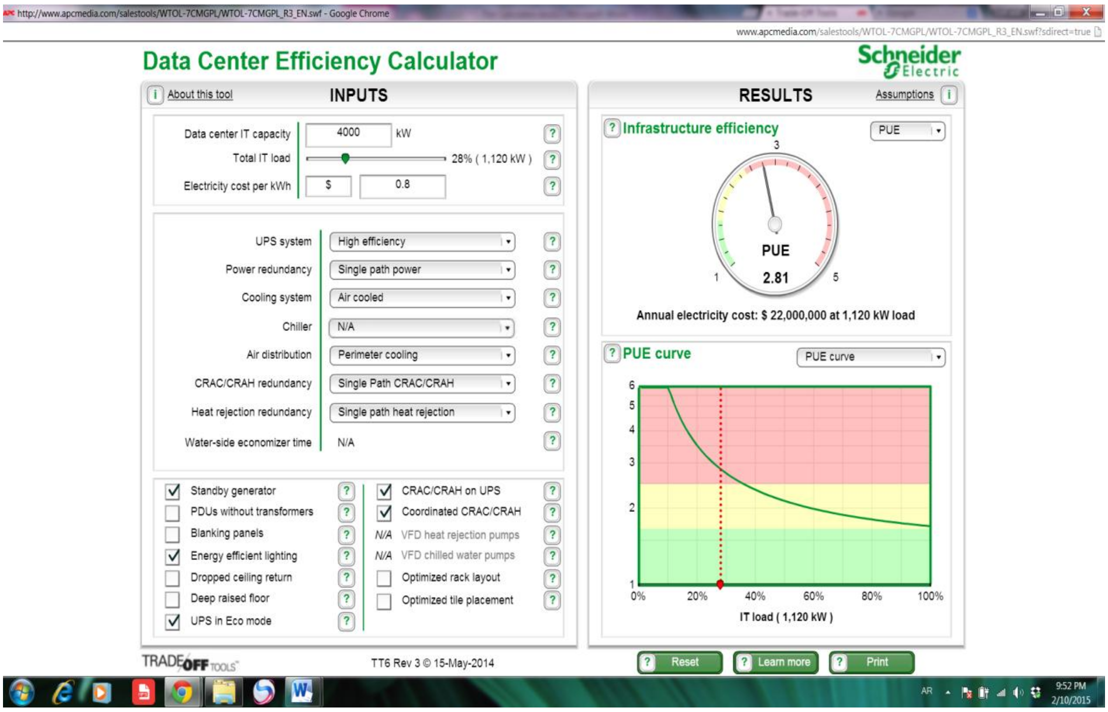

Figure 6.13 Show the effect of the framework (RAIN) on the power system losses

4- Analysis the energy consumption values after using RAIN:

We analyze the updated version of the Sudatel data center by using FVER calculator, which took value at 24 hours on a weekday and 24 hours for the weekend day figure 6.14 shows the new value. For evaluation our results we can implement the linear regression analysis model.

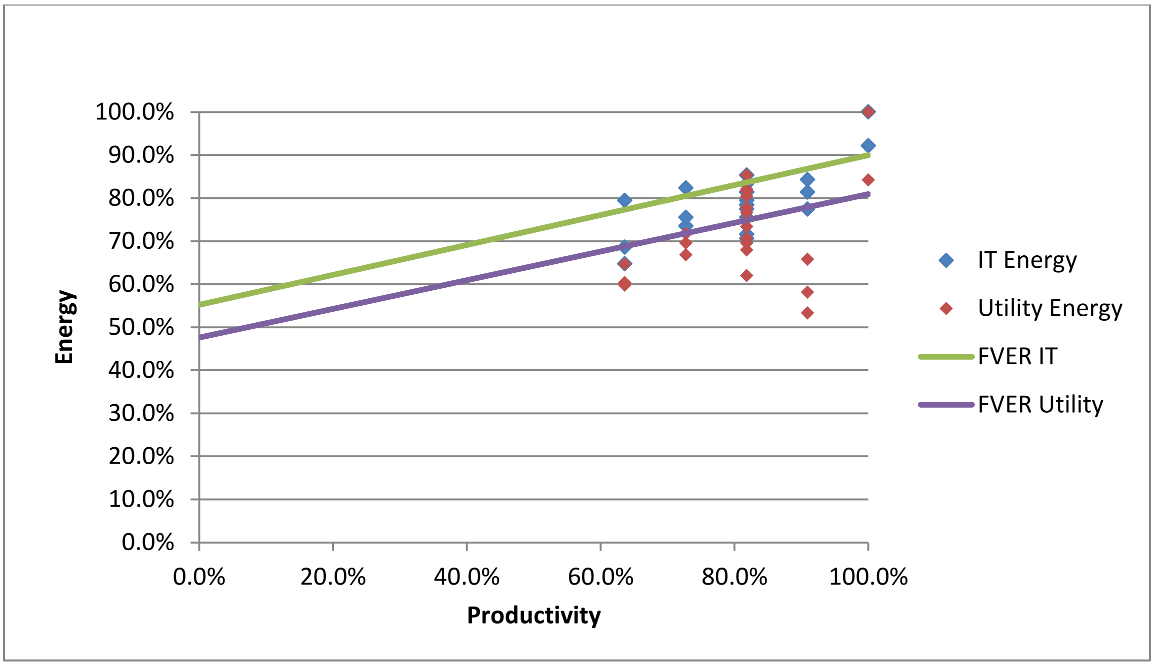

Figure 6.14 Sudatel data center after implementing RAIN

After implementing RAIN the data center recorded the following values for FVER metrics, in table 6.12:

Table 6.12 The IT and utility equipment value after RAIN

Metric	Value
FVER (IT)	2.6
FVER (utility)	2.4

By analysis table 6.12, we can understand in the easy way, that fixed energy is only 1.4 (2.4 – 1) and IT energy

We can produce two values by using linear regression, the slope and intercept. From figure we can conclude table 6.13.

Table 6.13 The intercept and slope after implementing RAIN

Measure	Intercept	Slope
IT energy	0.56	0.34
Utility energy	0.47	0.33

We can conclude to value in table 6.14, which show fixed to variable energy rations for Sudatel data center using the linear regression statistical model.

Table 6.14 FVER metric calculate using linear regression model

Metric	Value
FVER (IT)	2.6
FVER (Utility)	2.4

As a conclusion of our practical case study process, we can see that FVER metric is able to compare the Sudatel data center before and after implementing our new proposed framework (RAIN) in table 6.15. Also, it has ability to measure the productivity proxies after updating the data center to reflect the IT services produced and the IT efficiency is achieved. Table 6.15 shows the development in the FVER measurement, in IT equipment from 3.5 to 2.6 (40%), and in utility equipment from 6.8 to 2.4 (60%).

Table 6.15 Sudatel data center IT and utility energy before and after RAIN

Metric	DC before	DC after	Energy Efficiency
FVER (IT)	3.5	2.6	40%
FVER (utility)	6.8	2.4	60%

5- Calculating CO_2 emissions:

The increasing in energy efficiency reflected in energy consumption as well as the operating costs. The main feature in energy efficiency is maintains, reducing of the energy consumption and keeping the quality of service in his account. The data center carbon calculator developed by Schneider can show the electricity savings by implementing the RAIN framework in table 6.1, which calculating the amount of electricity saving, electricity costs, cutting in CO_2 emissions and the amount in savings in equivalent machine like cars. This value calculated in one year, five years and ten years.

Table 6.16 Sudatel data center energy Savings After Implement RAIN

	KW of Electricity 	**Electricity Costs** 	**CO_2 Emissions** 	**Equivalent To** 
1 Year	28,032,000 kW	21,304,320 USD	16,903 Tons	3,189 Cars
5 Years	140,160,000 kW	106,521,600 USD	84,515 Tons	15,946 Cars
10 Years	280,320,000 kW	213,043,200 USD	169,030 Tons	31,892 Cars

6.4 Case Study II: Aljouf University – Saudi Arabia

This data center is Tier III, Located in main campus Building, Sakaka Aljouf – Saudi Arabia. Total covered space: Rack area 1000 Sq. Ft. Total racks 50 racks expandable to 100.

1- **Calculating the energy values**:

Figure 6.17 shows the FVER $_{IT}$ and FVER $_{utility}$. Table 6.17 highlights the energy consumption value.

Table 6.17 The FVER IT and utility value

Metric	Value
FVER (IT)	1.4
FVER (Utility)	7.3

2- **Targeting the energy waste**:

This value shows the IT equipment energy consumption is in the green area, according to the FVER measurement and show utility equipment energy consumption is in the red area (poor). The FVER metric highlighted and traced the path to determine the wasted in the energy. In order to achieve energy efficiency in this data center, we need to implement the framework in utility part.

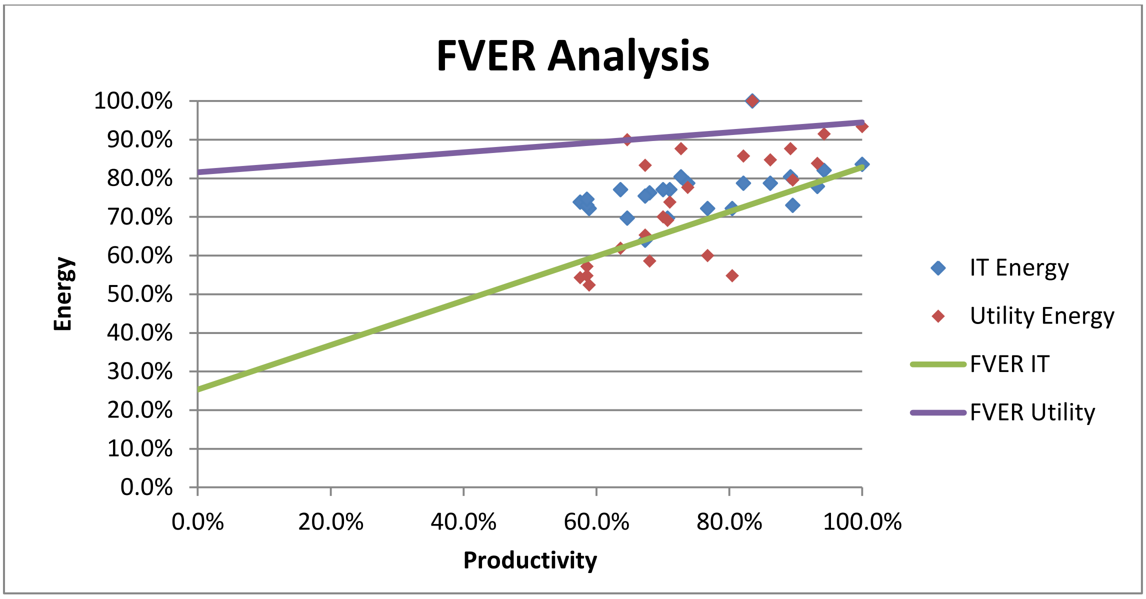

Figure 6.15 Aljouf university data center for FVER $_{IT}$ and FVER $_{utility}$ value

3- The energy consumption after implement RAIN framework:

To implement the integrated green framework RAIN we adjusted the data center efficiency simulation options to deal with RAIN options and that present the changing in the energy consumption after implemented the framework (RAIN) by reducing the energy consumed by the data center. Figure 6.16 shows the simulation result after implementing the framework RAIN and shows the simulator options, so the output section automatically present reducing in energy consumed by the data center after implement the integrated green framework and shows the efficiency of the data center in the IT component and the utility component the carve shows the efficiency level.

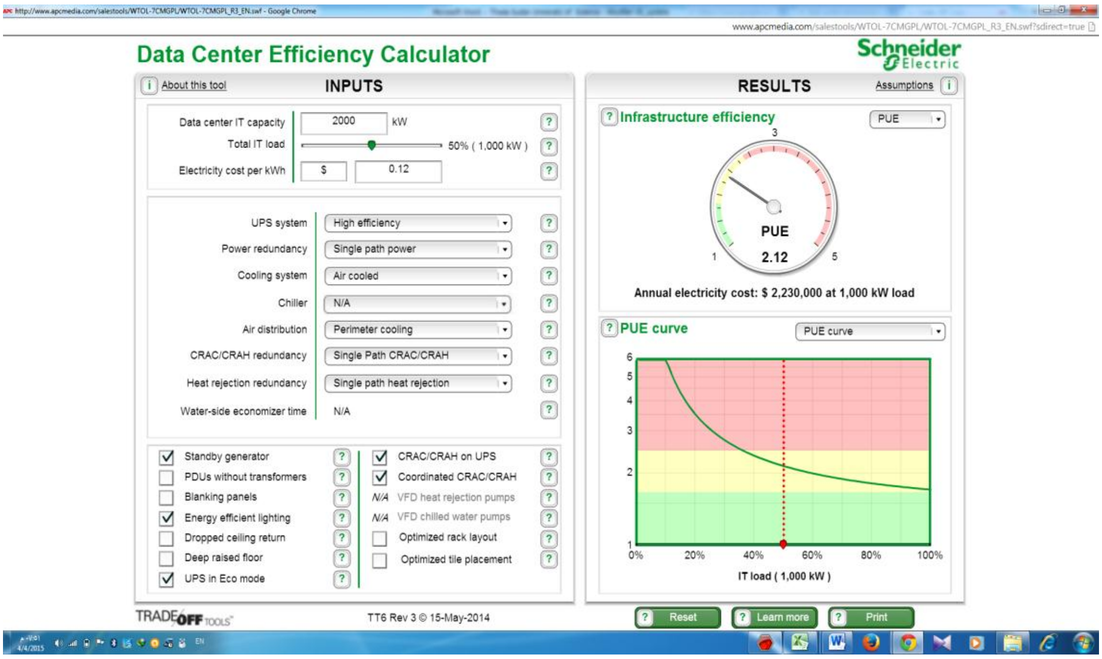

Figure 6.16 Aljouf University DC: The effect of the framework (RAIN)

4- Analysis the energy consumption values after using RAIN:

The RAIN proves a high degree of fitness and ability to improve data center in many versions (Tier x). The FVER metric shows compatibility with different Tier data center. This metric measures Tier III data center, after implementing the RAIN framework, which reflects the energy efficiency achieved. In order to improve energy efficiency, we should determine the path of waste the energy. After determining the part which wasted energy we implement the RAIN framework. Figure 6.17 shows the effect of RAIN in reducing energy consumed, when the data center with no load (fixed energy). The RAIN reduced the IT energy consumption about 20% and utility energy consumption about 74%, table 6.18 reflect this improvement.

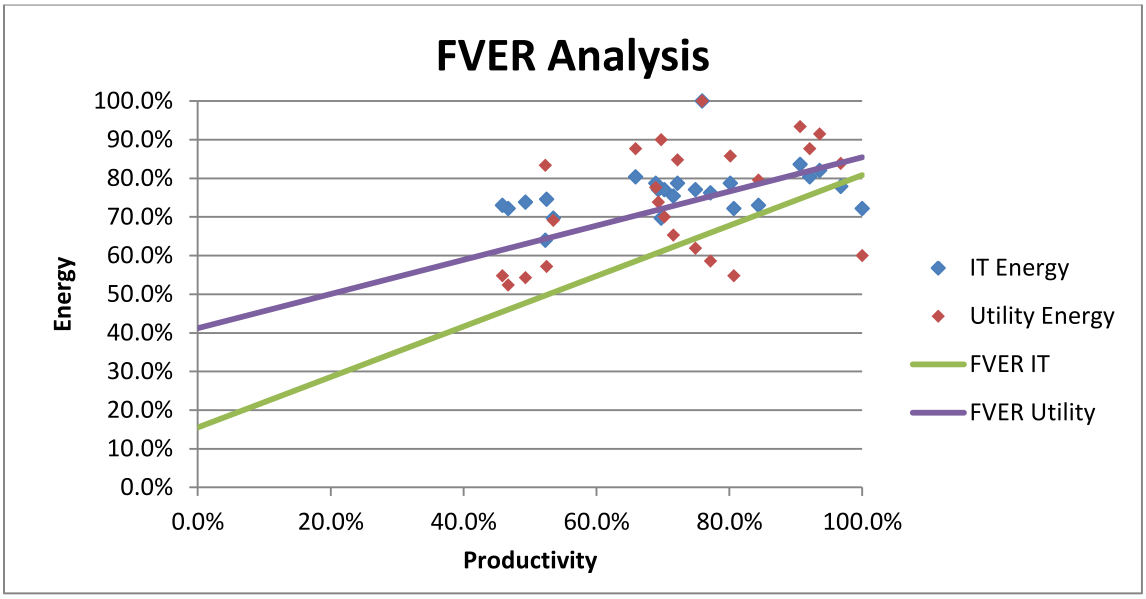

Figure 6.17 Aljouf university DC energy consumption after implementing RAIN framework

Table 6.18 Aljouf university DC before and after implementing RAIN framework

Metric	DC before	DC after	Energy Efficiency
FVER (IT)	1.5	1.2	20 %
FVER (utility)	7.3	1.9	74 %

We can produce two values by using linear regression, the slope and intercept. From figure 6.18 we can conclude table 6.19.

Table 6.19 The intercept and slope after implementing RAIN

Measure	Intercept	Slope
IT energy	0.15	0.65
Utility energy	0.40	0.45

We can conclude to value in table 6.20, which show fixed to variable energy rations for Aljouf data center using the linear regression statistical model.

Table 6.20 FVER value using linear regression model

Metric	Value
FVER (IT)	1.2
FVER (Utility)	1.9

5- Calculating Co_2 emissions:

The increasing in energy efficiency reflected in energy consumption as well as the operating costs. The main feature in energy efficiency is maintains, reducing of the energy consumption and keeping the quality of service in his account. The data center carbon calculator developed by Schneider in figure 6.18 can show the electricity savings by implementing the RAIN framework in figure , which calculating the amount of electricity saving, electricity costs, cutting in CO_2 emissions and the amount in savings in equivalent machine like cars. This value calculated in one year, five years and ten years.

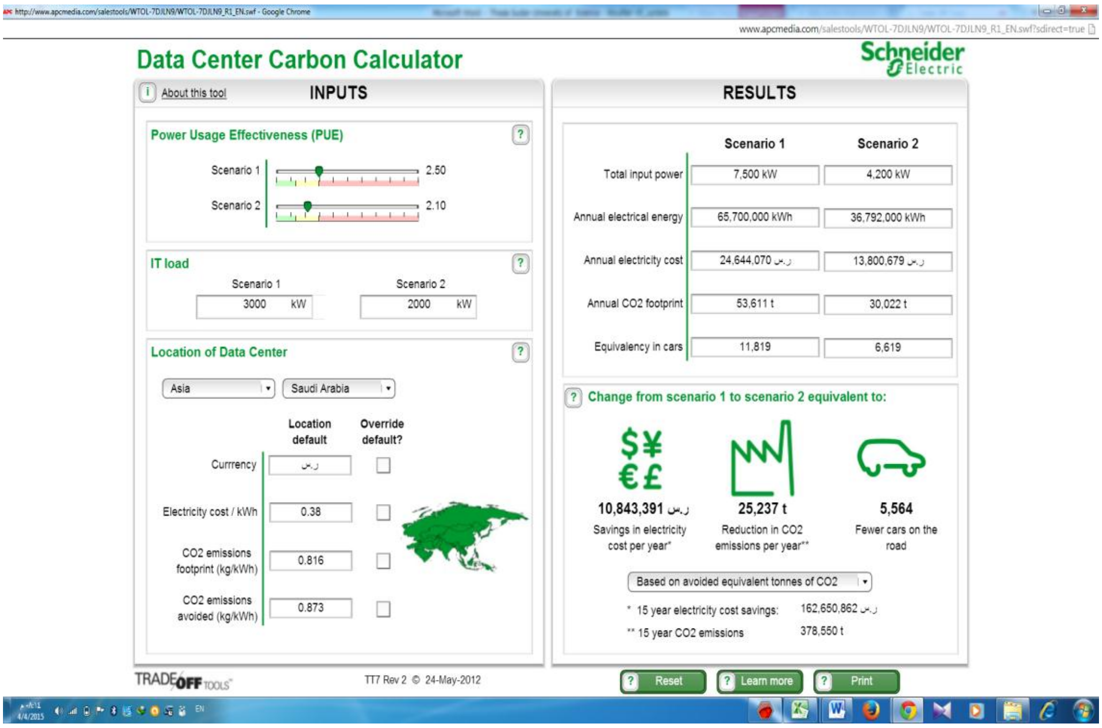

Figure 6.18 The carbon calculator for Aljouf DC before and after RAIN

6.5 Case Study III: PTCL Bank - Pakistan

This data center is Tier II, Located in CTH Building I.I Chundrigar Road Karachi – Pakistan, PTCL company. Total covered space: Rack area 5000 Sq. Ft. Total racks 150 racks expandable to 300.

1- Calculating the energy values:

Figure 6.21 shows the FVER $_{IT}$ and FVER $_{utility}$. Table 6.21 highlights the energy consumption value.

Table 6.21 PTCL FVER $_{IT}$ and FVER $_{utility}$ value

Metric	Value
FVER (IT)	1.3
FVER (Utility)	2.8

2- Targeting the energy waste:

This value shows the IT equipment energy consumption is in the green area, according to the FVER measurement and show utility equipment energy consumption is in the red area (poor). Figure 6.19 show how the FVER metric highlighted and traced the path to determine the wasted in the energy. In order to achieve energy efficiency in this data center, we need to implement the framework in utility part.

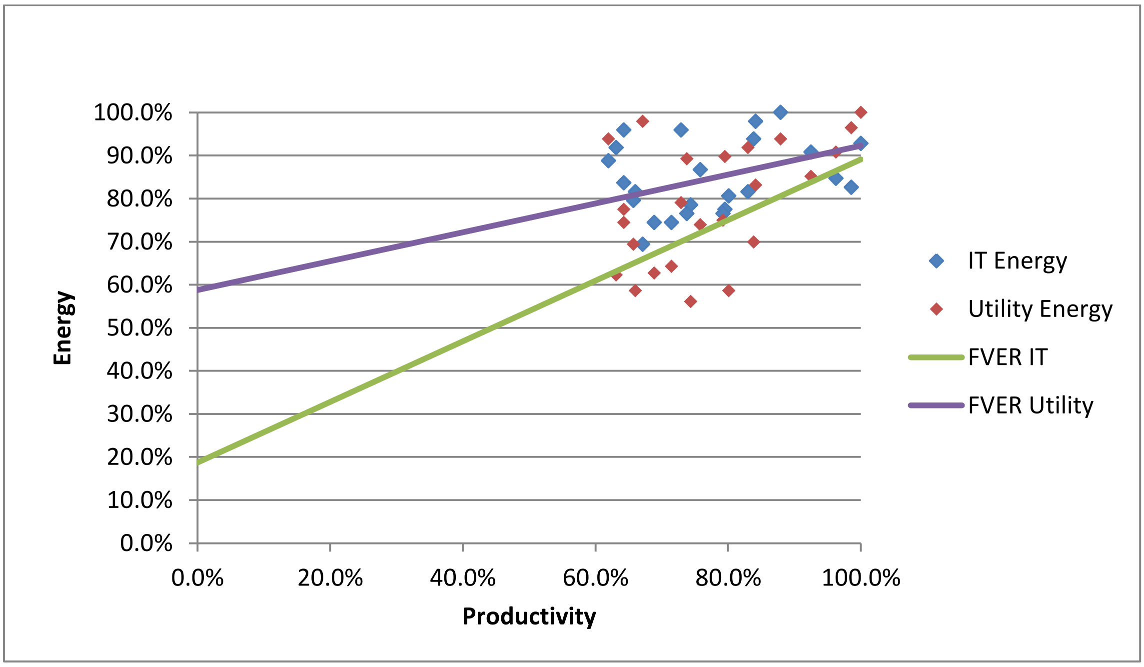

Figure 6.19 PTCL DC FVER $_{IT}$ and FVER $_{utility}$ value

3- The energy consumption after implement RAIN framework:

To implement the integrated green framework RAIN we adjusted the data center efficiency simulation options to deal with RAIN options and that present the changing in the energy consumption after implemented the framework (RAIN) by reducing the energy consumed by the data center. Figure 6.20 shows the simulation result after implementing the framework RAIN and shows the simulator options, so the output section automatically present reducing in energy consumed by the data center after implement the integrated green framework and shows the efficiency of the data center in the IT component and the utility component the carve shows the efficiency level.

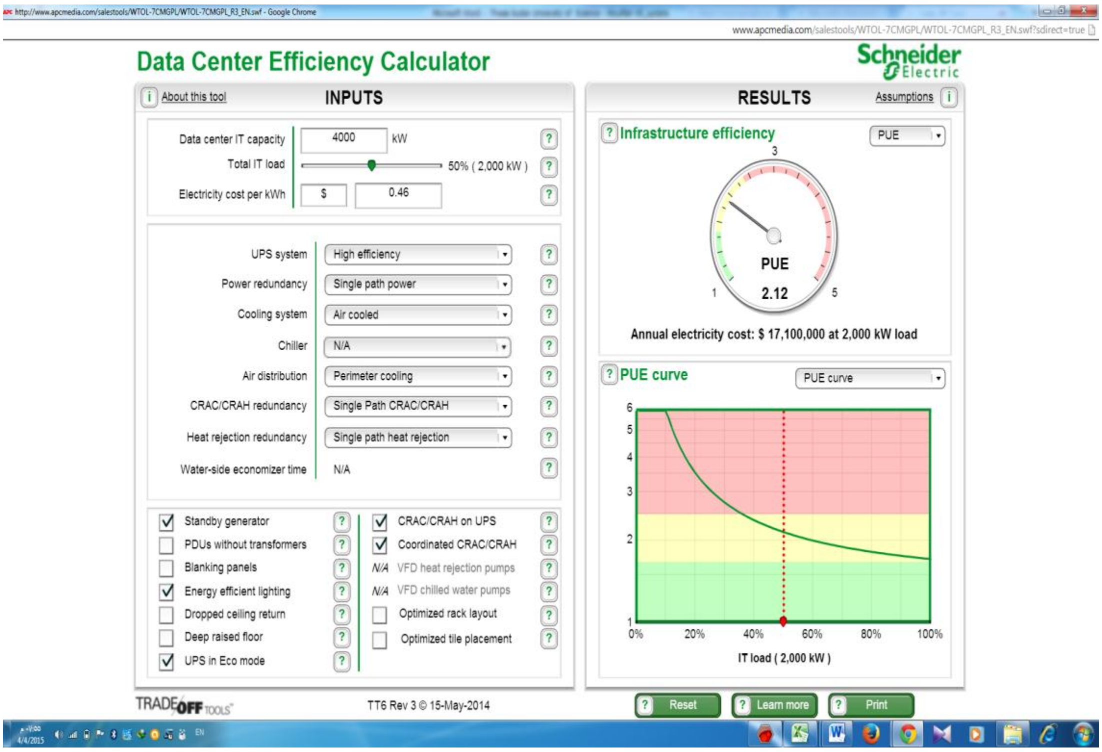

Figure 6.20 PTCL DC after implement RAIN framework

4- Analysis the energy consumption values after using RAIN:

The RAIN proves a high degree of fitness and ability to improve data center in many versions (Tier x). The FVER metric shows compatibility with different Tier x data center. This metric measures Tier II data center, after implementing the RAIN framework, which reflects the energy efficiency achieved. In order to improve energy efficiency, we should determine the path of waste the energy. After determining the part we implement the RAIN framework. Figure 6.21 shows the effect of RAIN in reducing energy consumed, when the data center with no load (fixed energy). The RAIN reduced the IT energy consumption about 16% and utility energy consumption about 33%, table 6.22 reflect this improvement.

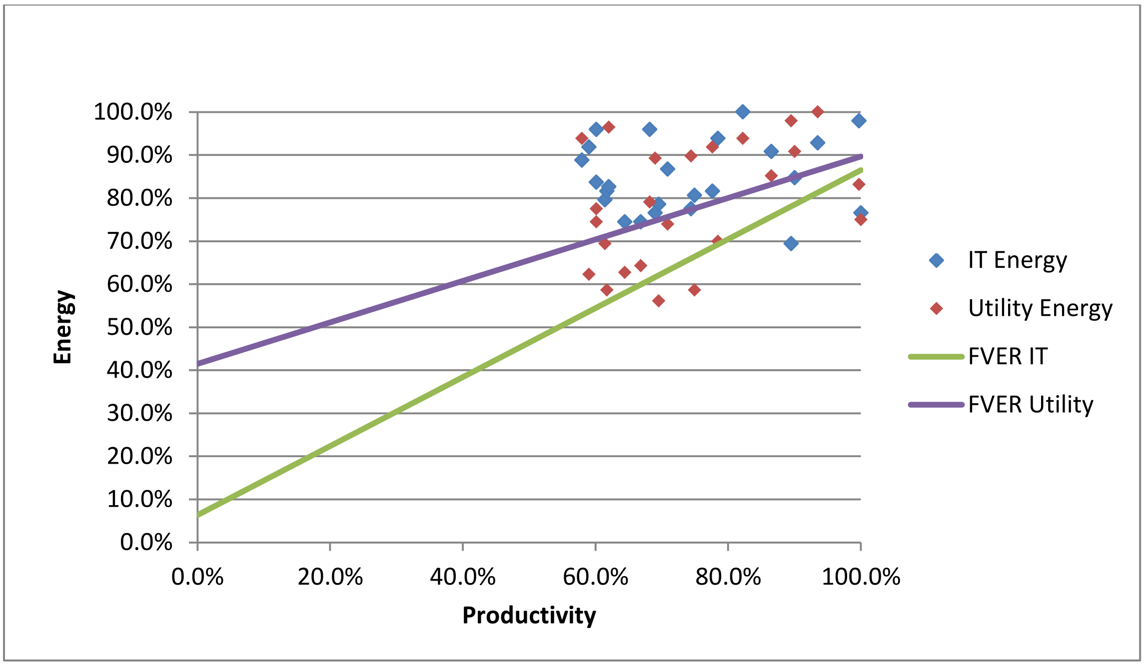

Figure 6.21 PTCL DC energy consumption after implementing RAIN framework

Table 6.22 PTCL data center IT and utility energy before and after RAIN

Metric	DC before	DC after	Energy Efficiency
FVER (IT)	1.3	1.1	16%
FVER (utility)	2.8	1.9	33%

We can produce two values by using linear regression, the slope and intercept. From figure we can conclude table 6.23.

Table 6.23 The intercept and slope after implementing RAIN

Measure	Intercept	Slope
IT energy	0.05	0.9
Utility energy	0.40	0.5

We can conclude to value in table 6.24, which show fixed to variable energy rations for Sudatel data center using the linear regression statistical model.

Table 6.24 FVER metric calculate using linear regression models

Metric	Value
FVER (IT)	1.1
FVER (Utility)	1.9

5- Calculating Co_2 emissions:

The increasing in energy efficiency reflected in energy consumption as well as the operating costs. The main feature in energy efficiency is maintains, reducing of the energy consumption and keeping the quality of service in his account. The data center carbon calculator developed by Schneider can show the electricity savings by implementing the RAIN framework in figure 6.22, which calculating the amount of electricity saving, electricity costs, cutting in CO_2 emissions and the amount in savings in equivalent machine like cars. This value calculated in one year, five years and ten years.

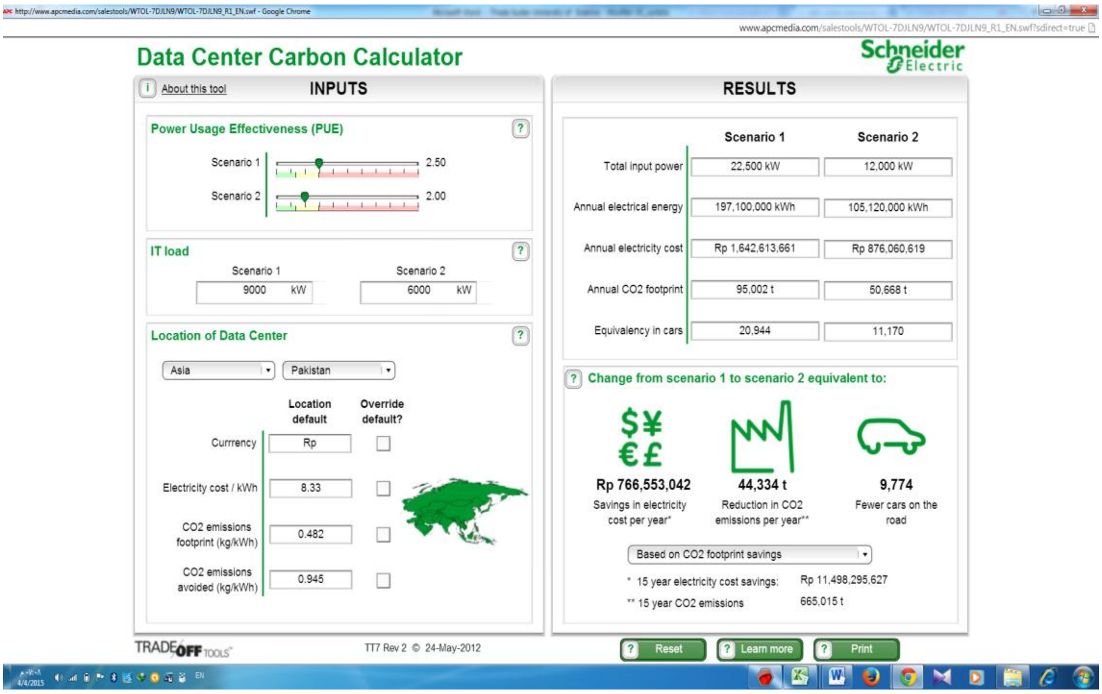

Figure 6.22 Carbon calculator for PTCL DC before and after RAIN

6.6 The Stability of Proxy Measurements Over the Time

Although developing existing data centers by implementing RAIN takes some time to implement. But, the FVER metric still has the ability to track, measure and compare the changes in the data centers before and after RAIN and presents the increasing in efficiency for different data centers tier. Table 6.25 show the impact of RAIN in different data centers tier in different countries.

Table 6.25 The influence of RAIN in different data centers tier

DC	Metric	Before RAIN	After RAIN	Energy Efficiency ratio
Sudatel (Sudan)	FVER (IT)	3.5	2.6	40%
	FVER (utility)	6.8	2.4	60%
JU (KSA)	FVER (IT)	1.5	1.2	20%
	FVER (utility)	7.3	1.9	74%
PTCL (Pakistan)	FVER (IT)	1.3	1.1	16%
	FVER (utility)	2.8	1.9	33%

6.7 The Impact of Outdoor Temperature

The issue of variation in outdoor temperature is effected in some data centers, by record a higher than actual connection between productivity and all the data center power. In most data centers the IT productivity recorded low value overnight, when the outdoor temperature is cool. This issue can be solved by restricting the $FVER_{utility}$ to the lower value of the $FVER_{IT}$.

CHAPTER SEVEN

CONCLUSION, CONTRIBUTIONS AND FUTURE DIRECTIONS

Introduction

This chapter is an overview of the overall research. It presents the contribution and future direction of this research. It is the summary of the green ICT framework RAIN, for implementing and putting into action green data centers, which was discussed in the previous chapters. As a result of this research a comprehensive critical investigation of the literature review relating to energy efficiency frameworks and common energy efficiency metrics disclosed that none met any suggested criteria to achieve accurate measurement of center's energy efficiencies. The FVER metric was adopted here, rather than what more was usually used when based on certain required criteria including usage of ICT and software applications. Thus FVER was a more suitable metric for assessment of energy efficiency. The proposed framework RAIN developed and. The validation analysis for the collected data sets from three centres in three countries (Tier 4 in Sudan, Tier 3 in Saudi Arabia and Tier 2 in Pakistan) proved that the implementation and usage of RAIN achieved an average **50%** saving of the center's total energy consumption. The evaluation results showed the proposed framework provided high stability, a better energy-efficiency rate and was more accurate in tracing fluctuations of energy consumption of ICT equipment than the previously developed energy efficiency frameworks. The complete formulation and development of green IT framework was given in section 5.6 in chapter 5.

7.1 Conclusion

The objectives mentioned in chapter 3 (problem statement) shows that the research targets were achieved by using scientific methods and procedures to achieve the desired goals of study. The objectives achieved were:

1- Development of energy efficient, by reducing energy consumption and indirectly reducing CO_2 emissions and re enabler green ICT framework (RAIN), The framework has been developed by taking into account clear understanding of different aspects of implementing green and energy efficient data centers as tools to evaluate the techniques needed to put green IT into action. It reduced total operation costs and increased business performance by coordinating green ICT policies to bridge the gap between ownership, climate, environment and energy experts and policy makers.

2- Develop propose framework deal with different techniques like server virtualization, power right sizing, green data center buildings and suitable green metrics to enable costs saving in data centers to make them green, energy efficient and environment friendly. The framework increased the productivity by including the IT equipment and software in the data center efficiency measurement whilst allowing each operator to select an output, productivity measure which usefully represents their data center and business activity. The framework implemented in different data centers tier in different countries like: Sudan, Saudi Arabia and Pakistan and most importantly using Metrics based energy efficiency model. The complete formulation and development of the proposed Solution: Green Framework for Data Centers (RAIN) is given in section 5.6 in chapter 5. The author developed and validated a green ICT energy efficiency management framework named RAIN. The validation analysis for the collected data sets from three data centres in three countries (Tier IV in Sudan, Tier III in Saudi Arabia and Tier II in Pakistan) proved that the implementing and usage of RAIN can achieve an average **50%** saving of the centres' total energy consumption.

3- Set criteria to identify suitable and effective green metrics to deal with changes in workload, defining a guide line, which composed of nine important properties to be adopted by data center owners and managers for selecting any energy efficiency metrics. The criterion is explained in section 4.4.2 in chapter 4. It is set as benchmarks and track the energy efficiency to improve the performance of data centers in terms of energy efficiency. FVER may be measured for the entire data center or in part of the data center, allowing service providers and customers to measure and report the metric without needing full control of the entire data center.

4- Calculate and evaluate overall energy efficiency, productivity and costs savings including ICT equipment for different Tiers data center by implementing three case studies in different countries (Sudan, Saudi Arabia and Pakistan) in different tier level data centers (Tier 4, Tier 3 and Tier 2) respectively. Case studies are described in detail in chapter 6.

Case Study 1: Implementation of Integrated green framework (RAIN) using Fixed to Variable Energy Ratio (FVER) metrics to measure energy consumption by IT and utility equipment. The metric present fixed and variable energy in IT & utility equipment energy consumption and efficiency of data center: A case study in Sudan. Key Findings:

I. By calculating the waste energy and using suitable metric (FVER) to determine the equipment that responsible for that waste in energy the importance of green metrics and their contribution in implementing energy efficiency and green data centers designed for maximum energy efficiency with the lowest operation costs and environmental influence was highlighted.

II. Implementing Fixed to Variable Energy Ratio (FVER) metrics in one of the tier level data center in Sudan clearly presents the IT consumption in the data center, which reflected the increased energy consumption against producing the work (productivity). The FVER metric show at 0% productivity the energy consumed by the data center is about 70% (fixed energy), this value reflects the waste of energy consumed to perform in idle state (0 load) and consumed 82% of total energy to produce 100% work. The variable energy is about 12%. This values shows that data center is lacking energy efficiency value in poor area. The FVER metric highlighted and traced the path to determine the waste in energy. In order to achieve energy efficiency in this data center, we need to implement the framework in IT and utility part.

Case Study 2:

Implementation of Integrated green framework (RAIN) using Fixed to Variable Energy Ratio (FVER) metrics to measure energy consumption by IT and utility equipment. The metric present fixed and variable energy in IT equipment energy consumption and efficiency of data center: A case study was in Saudi Arabia. Key Findings:

I. By calculating the waste energy and using suitable metric (FVER) to determine the equipment that responsible for that waste in energy the importance of green metrics and their contribution in implementing energy efficiency and green data centers designed for maximum energy efficiency with the lowest operation costs and environmental influence was highlighted.

II. Implementing Fixed to Variable Energy Ratio (FVER) metrics in one of tier level data center in Saudi Arabia clearly shows that data center lacks energy efficiency as a result the value of $FVER_{IT}$ was 1.4 and $FVER_{Utility}$ was 7.4, IT equipment energy consumption was in the green area, according to the FVER measurement it showed utility equipment energy consumption was in the red area (poor). The FVER metric highlighted and trace the path to determine those wasted in the energy. In order to achieve energy efficiency in this data center, we need to implement the framework in utility part.

Case Study 3:

Implementation of Integrated green framework (RAIN) using Fixed to Variable Energy Ratio (FVER) metrics to measures energy consumption by IT and utility equipment. The metric present fixed and variable energy in IT equipment performance of data center: A case study in Pakistan. Key Findings:

I. By calculating the waste energy and using suitable metric (FVER) to determine the equipment that responsible for that waste in energy the importance of green metrics and their contribution in implementing energy efficiency and green data centers designed for maximum energy efficiency with the lowest operation costs and environmental influence was highlighted.

II. Implementing Fixed to Variable Energy Ratio (FVER) metrics in one tier level data center in Pakistan clearly shows that data center lacks energy efficiency as result the value of $FVER_{IT}$ was 1.3 and $FVER_{Utility}$ was 2.8, IT equipment energy consumption was in the green area, according to the FVER measurement and showed utility equipment energy consumption was in the red area (poor). The FVER metric highlighted and trace the path to determine the waste in the energy. In order to achieve energy efficiency in this data center, we need to implement the framework in utility part.

7.2 Research Contribution

The main contribution of this research is developing green ICT framework for implementing green and energy efficient data centers. It involves the development of sub models and frameworks that adopted different phases and techniques highlighted in the main framework. The theoretical contribution of the research towards the development of main framework are listed and explained below:

I. Integrated Framework for green ICT: energy efficiency using effective metric and efficient techniques for green data centers.
II. Metrics based energy efficiency model.
III. Specifications to select green metrics.
IV. To calculate and evaluate overall energy efficiency, productivity and costs savings including ICT equipment for different Tiers data center.

7.3 Future Directions

Although all positive contributions have been achieved, there are still some limitations of this research that guide to organize for future research. Future work could using right-sizing overall all data center instead of virtualization and SMART autonomous framework, may be using AI algorithm to manage data center energy efficiency.

7.4 Concluding Remarks

Research on green data centers is generally split in different areas, which ensures a better understanding of the field. The main contribution of this research is achieving high energy efficiency for green data centre (**average 50%**), an energy efficient framework **RAIN** for energy efficiency assessment and management has been developed. The tool and its technique were validated through analyses of several data sets gathered from ICT data centres in Sudan, Saudi Arabia and Pakistan. The innovative assessment tool, indicators and techniques will enable ICT centres to monitor, measure, assess and manage energy efficiently for Green Cloud. The proposed green framework **RAIN** implementation proved that it could achieve energy efficiency by enabling green data centers, consequently, leading to performance-optimisation of ICT infrastructure services enabling users to concentrate on business, cutting ICT operations costs, as indirect effective can be reducing carbon dioxide (CO_2) emissions and minimising its carbon footprint. The proposed framework provides not only understanding of different aspects of Green ICT, but may also be used as a tool to evaluate techniques required to adopted Green ICT.

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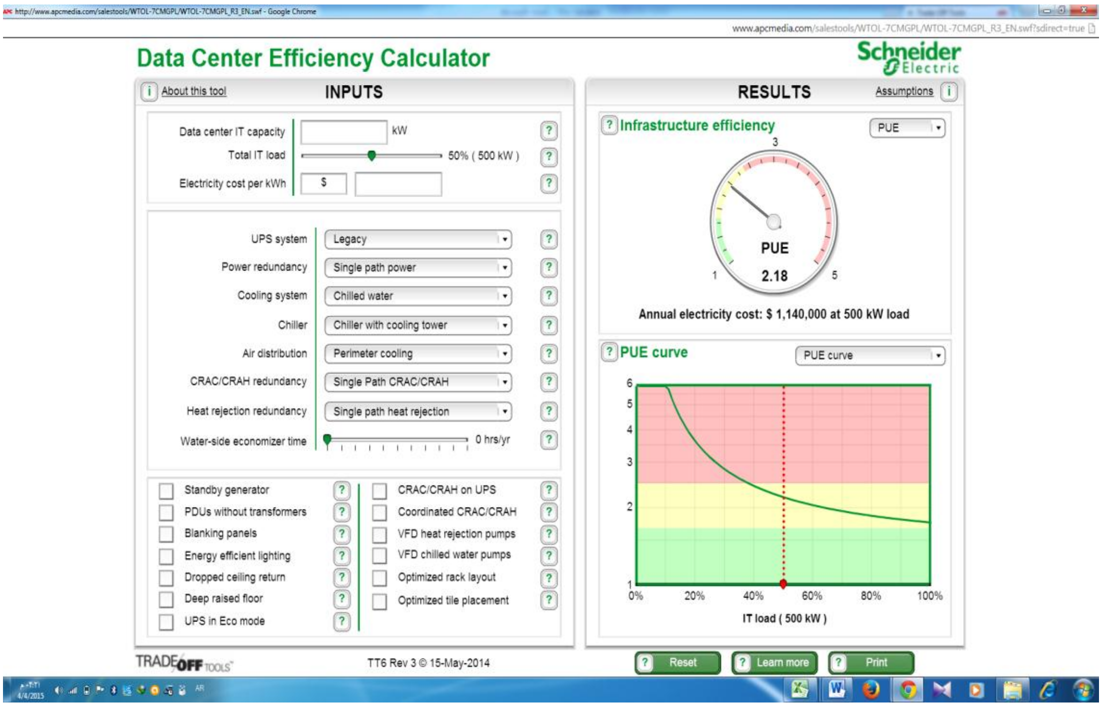
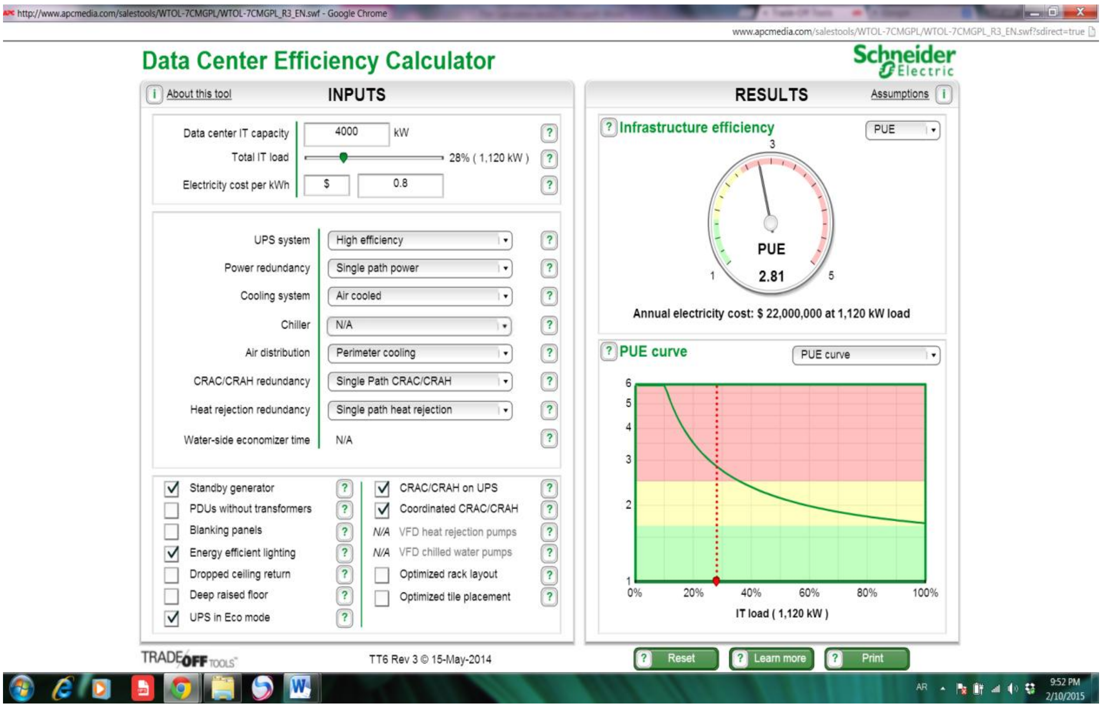
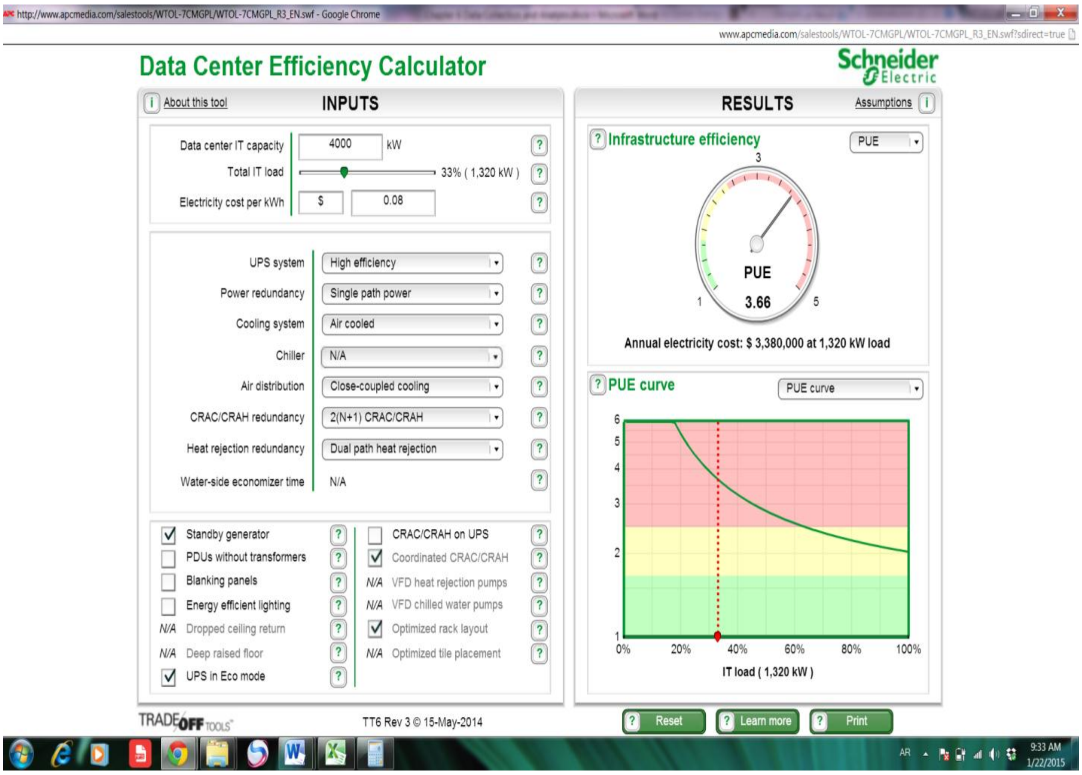
Appendix A

The efficiency data center Schneider simulation



The data center efficiency Schneider simulation




Data Center Efficiency Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Assumptions
Data center IT capacity
4000
kW
Total IT load
33% (1,320 kW)
Electricity cost per kWh
$
0.08
UPS system
High efficiency
Power redundancy
Single path power
Cooling system
Air cooled
Chiller
N/A
Air distribution
Close-coupled cooling
CRAC/CRAH redundancy
2(N+1) CRAC/CRAH
Heat rejection redundancy
Dual path heat rejection
Water-side economizer time
N/A
Standby generator
PDUs without transformers
Blanking panels
Energy efficient lighting
N/A Dropped ceiling return
N/A Deep raised floor
UPS in Eco mode
CRAC/CRAH on UPS
Coordinated CRAC/CRAH
N/A VFD heat rejection pumps
N/A VFD chilled water pumps
Optimized rack layout
N/A Optimized tile placement
Infrastructure efficiency
PUE
3.66
Annual electricity cost: $ 3,380,000 at 1,320 kW load
PUE curve
0%
20%
40%
60%
80%
100%
IT load (1,320 kW)
TRADEOFF TOOLS
TT6 Rev 3 © 15-May-2014
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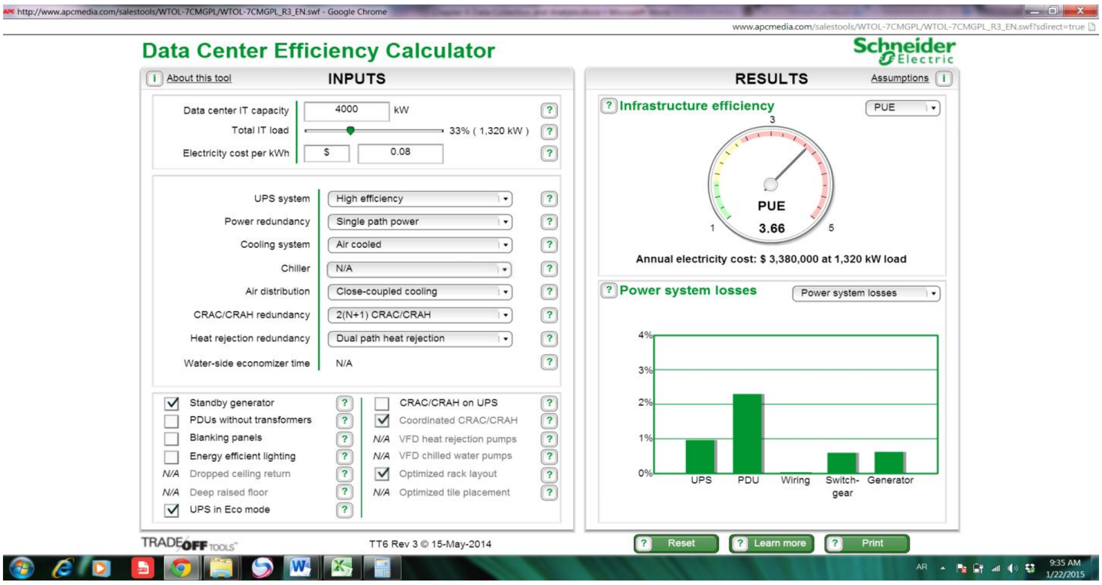
Data Center Efficiency Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Assumptions
Data center IT capacity
4000
kW
Total IT load
33% (1,320 kW)
Electricity cost per kWh
$
0.08
UPS system
High efficiency
Power redundancy
Single path power
Cooling system
Air cooled
Chiller
N/A
Air distribution
Close-coupled cooling
CRAC/CRAH redundancy
2(N+1) CRAC/CRAH
Heat rejection redundancy
Dual path heat rejection
Water-side economizer time
N/A
Standby generator
PDUs without transformers
Blanking panels
Energy efficient lighting
N/A Dropped ceiling return
N/A Deep raised floor
UPS in Eco mode
CRAC/CRAH on UPS
Coordinated CRAC/CRAH
N/A VFD heat rejection pumps
N/A VFD chilled water pumps
Optimized rack layout
N/A Optimized tile placement
Infrastructure efficiency
PUE
3.66
Annual electricity cost: $ 3,380,000 at 1,320 kW load
Power system losses
4%
3%
2%
1%
0%
UPS
PDU
Wiring
Switch-gear
Generator
TRADEOFF TOOLS
TT6 Rev 3 © 15-May-2014
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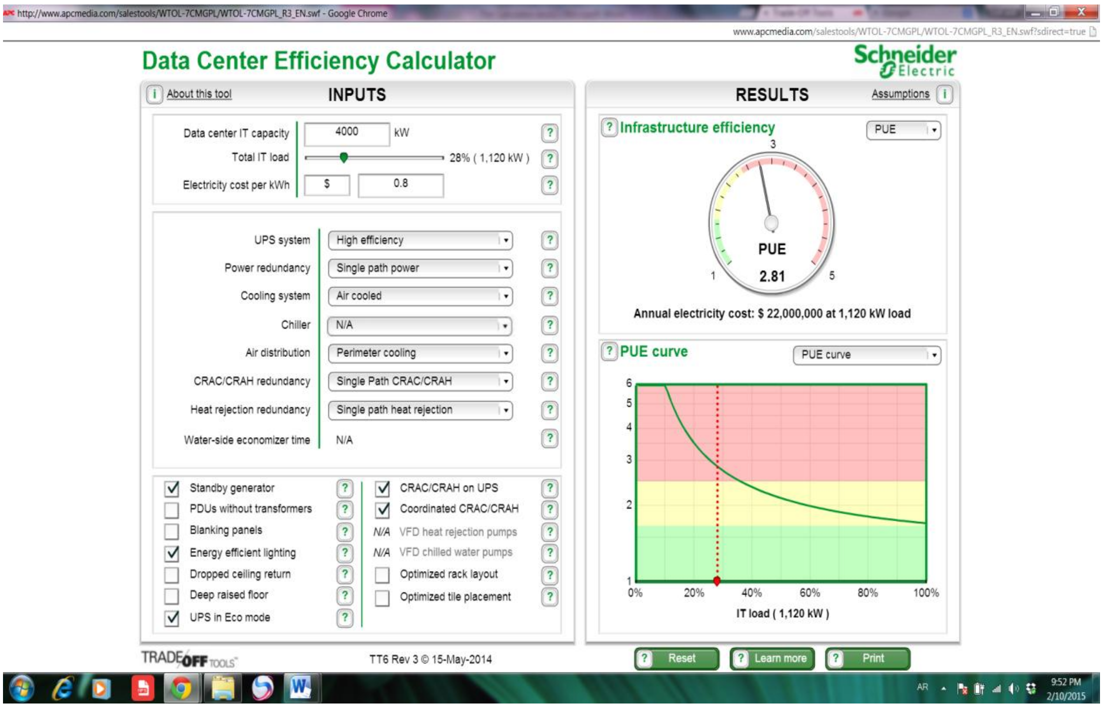
Data Center Efficiency Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Assumptions
Data center IT capacity 4000 kW
Total IT load 28% (1,120 kW)
Electricity cost per kWh $ 0.8
UPS system High efficiency
Power redundancy Single path power
Cooling system Air cooled
Chiller N/A
Air distribution Perimeter cooling
CRAC/CRAH redundancy Single Path CRAC/CRAH
Heat rejection redundancy Single path heat rejection
Water-side economizer time N/A
Standby generator
PDUs without transformers
Blanking panels
Energy efficient lighting
Dropped ceiling return
Deep raised floor
UPS in Eco mode
CRAC/CRAH on UPS
Coordinated CRAC/CRAH
N/A VFD heat rejection pumps
N/A VFD chilled water pumps
Optimized rack layout
Optimized tile placement
Infrastructure efficiency
PUE
PUE 2.81
Annual electricity cost: $ 22,000,000 at 1,120 kW load
PUE curve
IT load (1,120 kW)
TT6 Rev 3 © 15-May-2014
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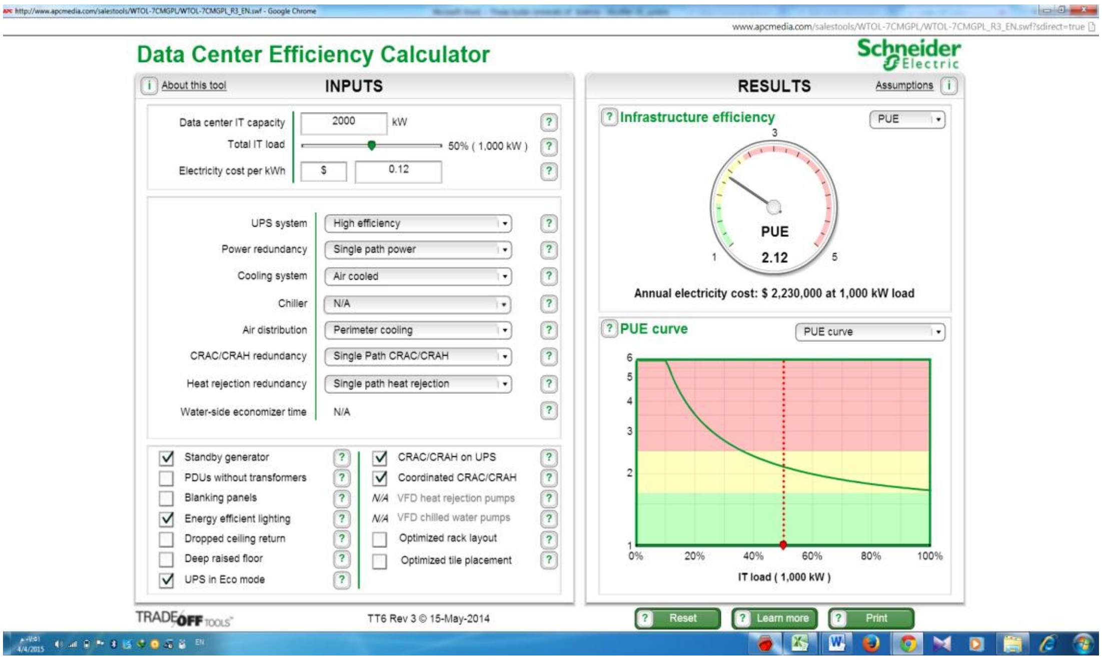
Data Center Efficiency Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Assumptions
Data center IT capacity 2000 kW
Total IT load 50% (1,000 kW)
Electricity cost per kWh $ 0.12
UPS system High efficiency
Power redundancy Single path power
Cooling system Air cooled
Chiller N/A
Air distribution Perimeter cooling
CRAC/CRAH redundancy Single Path CRAC/CRAH
Heat rejection redundancy Single path heat rejection
Water-side economizer time N/A
Standby generator
PDUs without transformers
Blanking panels
Energy efficient lighting
Dropped ceiling return
Deep raised floor
UPS in Eco mode
CRAC/CRAH on UPS
Coordinated CRAC/CRAH
N/A VFD heat rejection pumps
N/A VFD chilled water pumps
Optimized rack layout
Optimized tile placement
Infrastructure efficiency
PUE
PUE 2.12
Annual electricity cost: $ 2,230,000 at 1,000 kW load
PUE curve
IT load (1,000 kW)
TT6 Rev 3 © 15-May-2014
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Learn more
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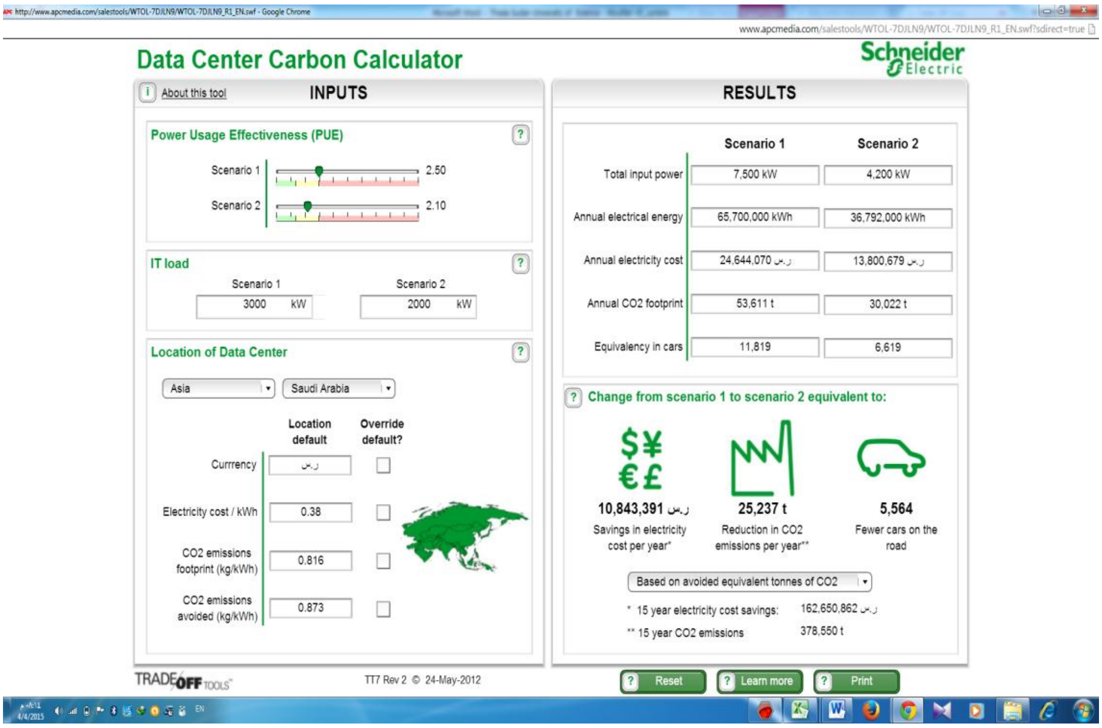
Data Center Carbon Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Power Usage Effectiveness (PUE)
Scenario 1
2.50
Scenario 2
2.10
IT load
Scenario 1
3000 kW
Scenario 2
2000 kW
Location of Data Center
Asia
Saudi Arabia
Location default
Override default?
Currrency
Electricity cost / kWh
0.38
CO2 emissions footprint (kg/kWh)
0.816
CO2 emissions avoided (kg/kWh)
0.873
Scenario 1
Scenario 2
Total input power
7,500 kW
4,200 kW
Annual electrical energy
65,700,000 kWh
36,792,000 kWh
Annual electricity cost
Annual CO2 footprint
53,611 t
30,022 t
Equivalency in cars
11,819
6,619
Change from scenario 1 to scenario 2 equivalent to:
10,843,391
Savings in electricity cost per year*
25,237 t
Reduction in CO2 emissions per year**
5,564
Fewer cars on the road
Based on avoided equivalent tonnes of CO2
* 15 year electricity cost savings: 162,650,862
** 15 year CO2 emissions 378,550 t
TT7 Rev 2 © 24-May-2012
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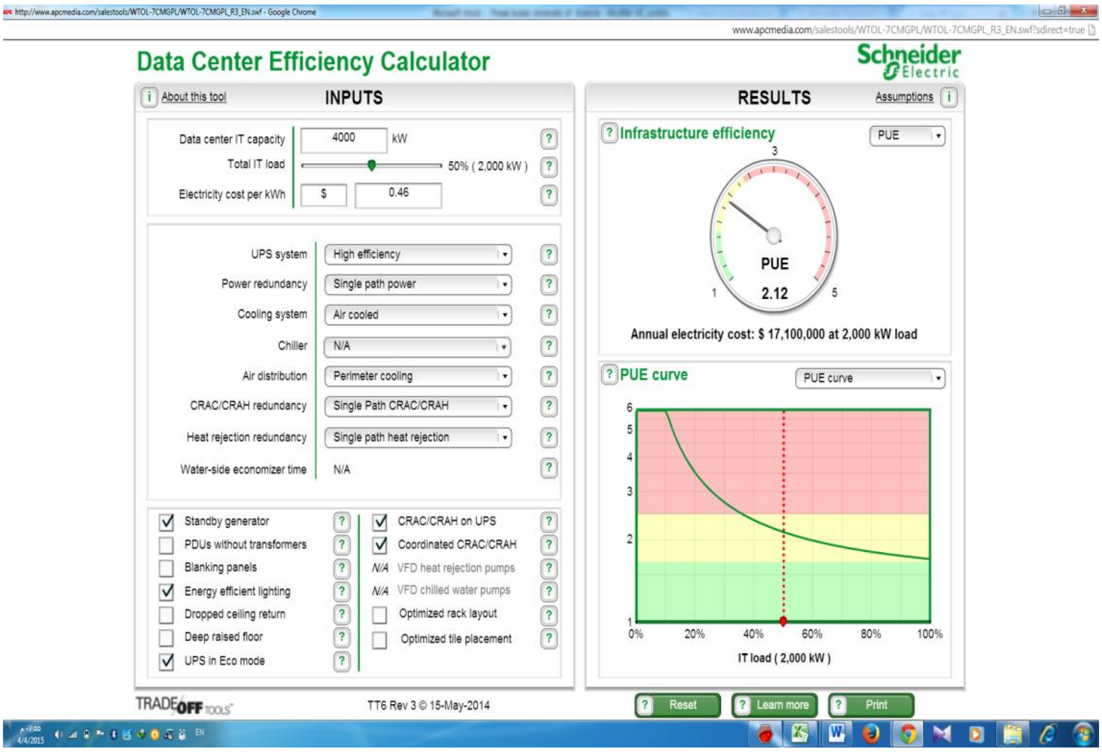
Data Center Efficiency Calculator
Schneider Electric
About this tool
INPUTS
RESULTS
Assumptions
Data center IT capacity
4000 kW
Total IT load
50% (2,000 kW)
Electricity cost per kWh
$ 0.46
UPS system
High efficiency
Power redundancy
Single path power
Cooling system
Air cooled
Chiller
N/A
Air distribution
Perimeter cooling
CRAC/CRAH redundancy
Single Path CRAC/CRAH
Heat rejection redundancy
Single path heat rejection
Water-side economizer time
N/A
Standby generator
PDUs without transformers
Blanking panels
Energy efficient lighting
Dropped ceiling return
Deep raised floor
UPS in Eco mode
CRAC/CRAH on UPS
Coordinated CRAC/CRAH
VFD heat rejection pumps
VFD chilled water pumps
Optimized rack layout
Optimized tile placement
Infrastructure efficiency
PUE
2.12
Annual electricity cost: $ 17,100,000 at 2,000 kW load
PUE curve
IT load (2,000 kW)
TT6 Rev 3 © 15-May-2014
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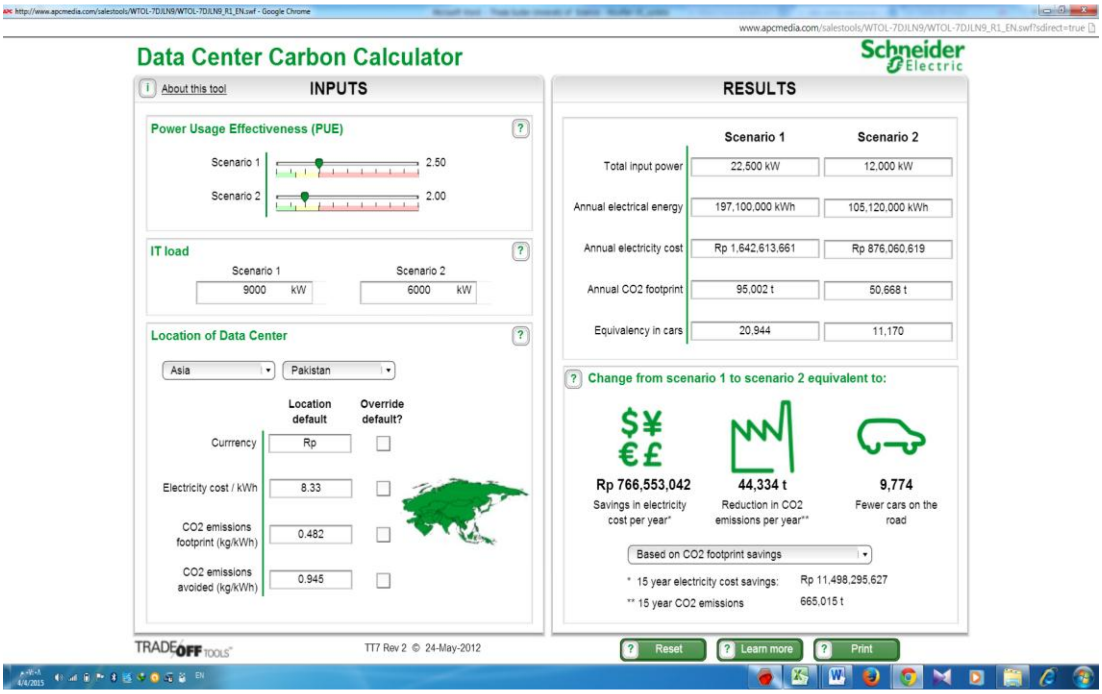


The data center efficiency Schneider simulation present many options to analysis the data center energy consumptions like (for more details look Appendix A):

I. Energy consumed by the data center.

II. The cost of energy consumed.

III. The component of the data center that consumed energy in inefficient way.

IV. The impact to the environment.

V. UPS system.

VI. Power redundancy.

VII. Cooling system.

VIII. Chiller.

IX. Air distribution.

X. CRAC/CRAH redundancy.

XI. Heat rejection.

XII. Water side economizer time.

XIII. Support many green metrics.

XIV. Energy allocation.

XV. Power system losses.

XVI. Cooling system losses.

XVII. Cost allocation.

XVIII. Cooling system costs.

When we insert the total power capacity of the data center and the IT power capacity and choose a property options as the figure shows the simulator options and the output value.

Data collected from Sudan, Saudi Arabia and Pakistan:

Dear Colleagues

Energy efficiency (Green Technology) is the solution of high operation costs for the data centers all over the world.

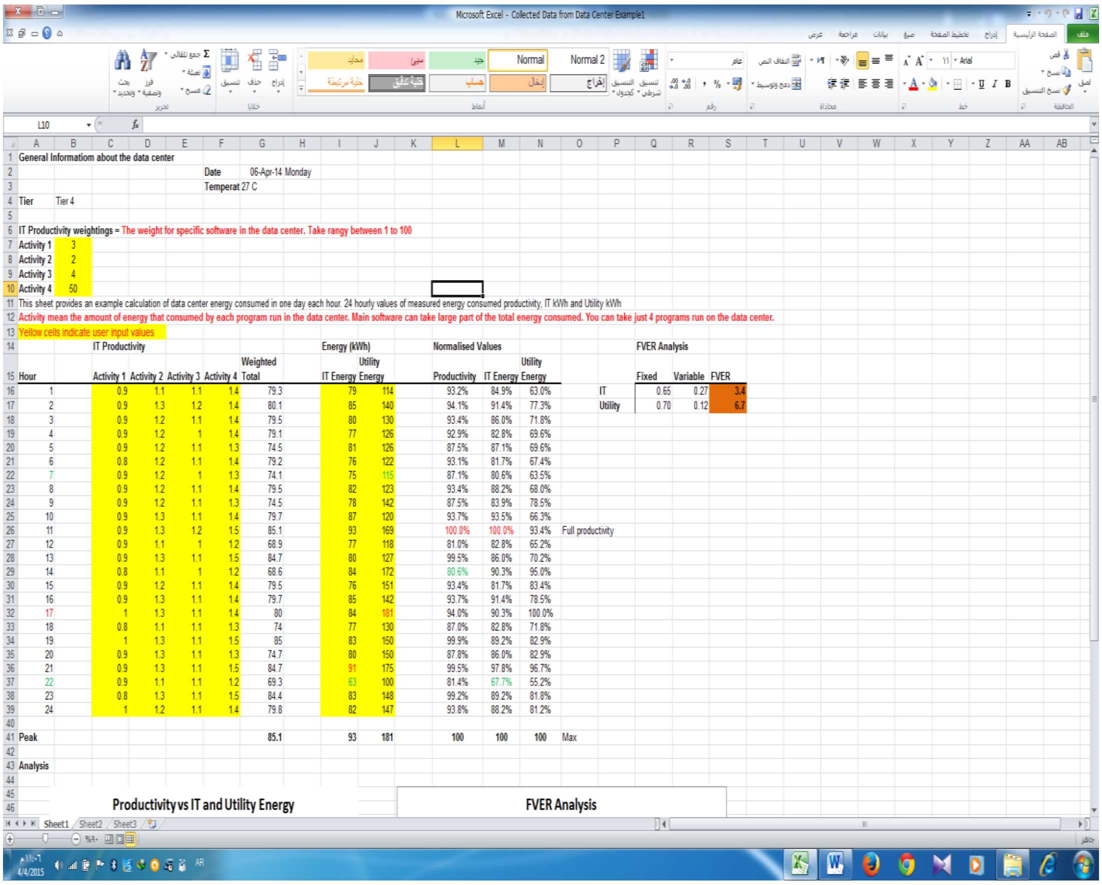
We developed an energy efficiency framework to assess and manage energy for green data centers. Now we are in the data collection, evaluation and validation of our proposed Green Data Centers Framework.

We are collecting data about electricity consumption in data centers from different countries for the framework evaluation.

So I wonder if you please can help us to get in touch with some data centers in your country to fill out the attached form which include the data center electricity consumption in different times during the day and different days during the week.

We also attached one example of the data sheet which has been collected from the Data Center in Sudan.

Your collaboration is greatly appreciated



General Informatiom about the data center

Date 06-Apr-14 Monday

Temperat 27 C

Tier Tier 4

IT Productivity weightings = The weight for specific software in the data center. Take rangy between 1 to 100

Activity 1	3
Activity 2	2
Activity 3	4
Activity 4	50

This sheet provides an example calculation of data center energy consumed in one day each hour. 24 hourly values of measured energy consumed productivity, IT kWh and Utility kWh

Activity mean the amount of energy that consumed by each program run in the data center. Main software can take large part of the total energy consumed. You can take just 4 programs run on the data center.

Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values			
Hour	Activity 1	Activity 2	Activity 3	Activity 4	Weighted Total	IT Energy	Utility Energy	Productivity	IT Energy	Utility Energy	
1	0.9	1.1	1.1	1.4	79.3	79	114	93.2%	84.9%	63.0%	
2	0.9	1.3	1.2	1.4	80.1	85	140	94.1%	91.4%	77.3%	
3	0.9	1.2	1.1	1.4	79.5	80	130	93.4%	86.0%	71.8%	
4	0.9	1.2	1	1.4	79.1	77	126	92.9%	82.8%	69.6%	
5	0.9	1.2	1.1	1.3	74.5	81	126	87.5%	87.1%	69.6%	
6	0.8	1.2	1.1	1.4	79.2	76	122	93.1%	81.7%	67.4%	
7	0.9	1.2	1	1.3	74.1	75	115	87.1%	80.6%	63.5%	
8	0.9	1.2	1.1	1.4	79.5	82	123	93.4%	88.2%	68.0%	
9	0.9	1.2	1.1	1.3	74.5	78	142	87.5%	83.9%	78.5%	
10	0.9	1.3	1.1	1.4	79.7	87	120	93.7%	93.5%	66.3%	
11	0.9	1.3	1.2	1.5	85.1	93	169	100.0%	100.0%	93.4%	Full productivity
12	0.9	1.1	1	1.2	68.9	77	118	81.0%	82.8%	65.2%	
13	0.9	1.3	1.1	1.5	84.7	80	127	99.5%	86.0%	70.2%	
14	0.8	1.1	1	1.2	68.6	84	172	80.6%	90.3%	95.0%	
15	0.9	1.2	1.1	1.4	79.5	76	151	93.4%	81.7%	83.4%	
16	0.9	1.3	1.1	1.4	79.7	85	142	93.7%	91.4%	78.5%	
17	1	1.3	1.1	1.4	80	84	181	94.0%	90.3%	100.0%	
18	0.8	1.1	1.1	1.3	74	77	130	87.0%	82.8%	71.8%	
19	1	1.3	1.1	1.5	85	83	150	99.9%	89.2%	82.9%	
20	0.9	1.3	1.1	1.3	74.7	80	150	87.8%	86.0%	82.9%	
21	0.9	1.3	1.1	1.5	84.7	91	175	99.5%	97.8%	96.7%	
22	0.9	1.1	1.1	1.2	69.3	63	100	81.4%	67.7%	55.2%	
23	0.8	1.3	1.1	1.5	84.4	83	148	99.2%	89.2%	81.8%	
24	1	1.2	1.1	1.4	79.8	82	147	93.8%	88.2%	81.2%	
Peak					85.1	93	181	100	100	100	Max

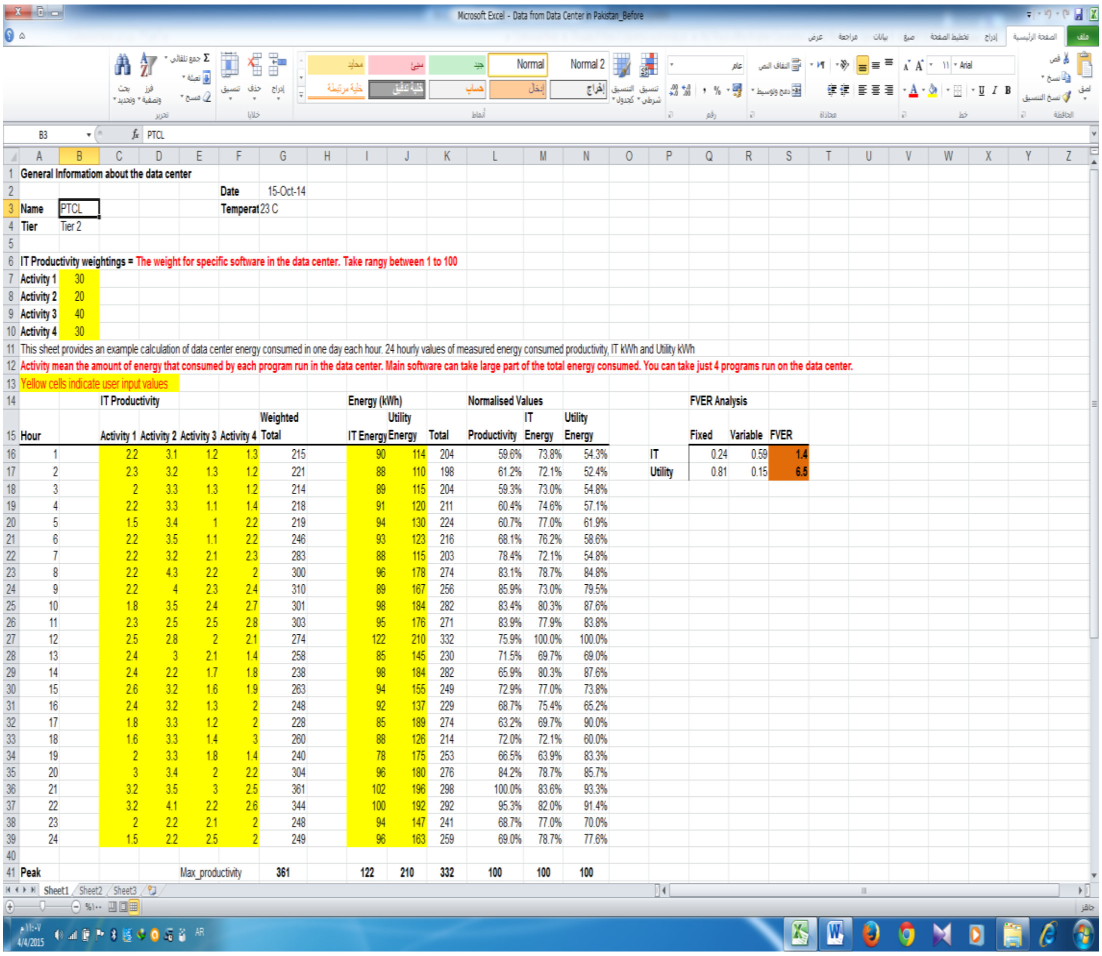
FVER Analysis

	Fixed	Variable	FVER
IT	0.65	0.27	3.4
Utility	0.70	0.12	6.7

Analysis

Productivity vs IT and Utility Energy

FVER Analysis



Microsoft Excel - Data from Data Center in Pakistan_Before

General Informatiom about the data center

Date 15-Oct-14

Name PTCL — Temperat 23 C

Tier Tier 2

IT Productivity weightings = The weight for specific software in the data center. Take rangy between 1 to 100

Activity 1	30
Activity 2	20
Activity 3	40
Activity 4	30

This sheet provides an example calculation of data center energy consumed in one day each hour. 24 hourly values of measured energy consumed productivity, IT kWh and Utility kWh

Activity mean the amount of energy that consumed by each program run in the data center. Main software can take large part of the total energy consumed. You can take just 4 programs run on the data center.

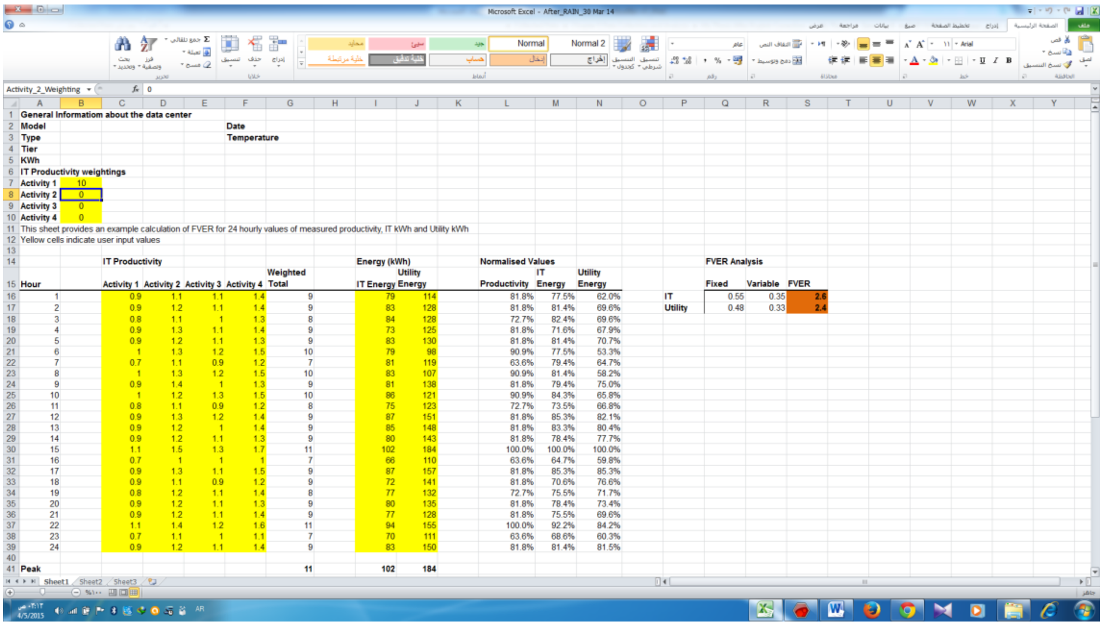
Yellow cells indicate user input values

Hour	IT Productivity Activity 1	Activity 2	Activity 3	Activity 4	Weighted Total	Energy (kWh) IT Energy	Utility Energy	Total	Normalised Values Productivity	IT Energy	Utility Energy
1	2.2	3.1	1.2	1.3	215	90	114	204	59.6%	73.8%	54.3%
2	2.3	3.2	1.3	1.2	221	88	110	198	61.2%	72.1%	52.4%
3	2	3.3	1.3	1.2	214	89	115	204	59.3%	73.0%	54.8%
4	2.2	3.3	1.1	1.4	218	91	120	211	60.4%	74.6%	57.1%
5	1.5	3.4	1	2.2	219	94	130	224	60.7%	77.0%	61.9%
6	2.2	3.5	1.1	2.2	246	93	123	216	68.1%	76.2%	58.6%
7	2.2	3.2	2.1	2.3	283	88	115	203	78.4%	72.1%	54.8%
8	2.2	4.3	2.2	2	300	96	178	274	83.1%	78.7%	84.8%
9	2.2	4	2.3	2.4	310	89	167	256	85.9%	73.0%	79.5%
10	1.8	3.5	2.4	2.7	301	98	184	282	83.4%	80.3%	87.6%
11	2.3	2.5	2.5	2.8	303	95	176	271	83.9%	77.9%	83.8%
12	2.5	2.8	2	2.1	274	122	210	332	75.9%	100.0%	100.0%
13	2.4	3	2.1	1.4	258	85	145	230	71.5%	69.7%	69.0%
14	2.4	2.2	1.7	1.8	238	98	184	282	65.9%	80.3%	87.6%
15	2.6	3.2	1.6	1.9	263	94	155	249	72.9%	77.0%	73.8%
16	2.4	3.2	1.3	2	248	92	137	229	68.7%	75.4%	65.2%
17	1.8	3.3	1.2	2	228	85	189	274	63.2%	69.7%	90.0%
18	1.6	3.3	1.4	3	260	88	126	214	72.0%	72.1%	60.0%
19	2	3.3	1.8	1.4	240	78	175	253	66.5%	63.9%	83.3%
20	3	3.4	2	2.2	304	96	180	276	84.2%	78.7%	85.7%
21	3.2	3.5	3	2.5	361	102	196	298	100.0%	83.6%	93.3%
22	3.2	4.1	2.2	2.6	344	100	192	292	95.3%	82.0%	91.4%
23	2	2.2	2.1	2	248	94	147	241	68.7%	77.0%	70.0%
24	1.5	2.2	2.5	2	249	96	163	259	69.0%	78.7%	77.6%
Peak			Max_productivity		361	122	210	332	100	100	100

FVER Analysis

	Fixed	Variable	FVER
IT	0.24	0.59	1.4
Utility	0.81	0.15	6.5

Sheet1 Sheet2 Sheet3



Microsoft Excel - After_RAIN_30 Mar 14

General Informatiom about the data center

Model — Date

Type — Temperature

Tier

KWh

IT Productivity weightings

Activity 1	10
Activity 2	0
Activity 3	0
Activity 4	0

This sheet provides an example calculation of FVER for 24 hourly values of measured productivity, IT kWh and Utility kWh

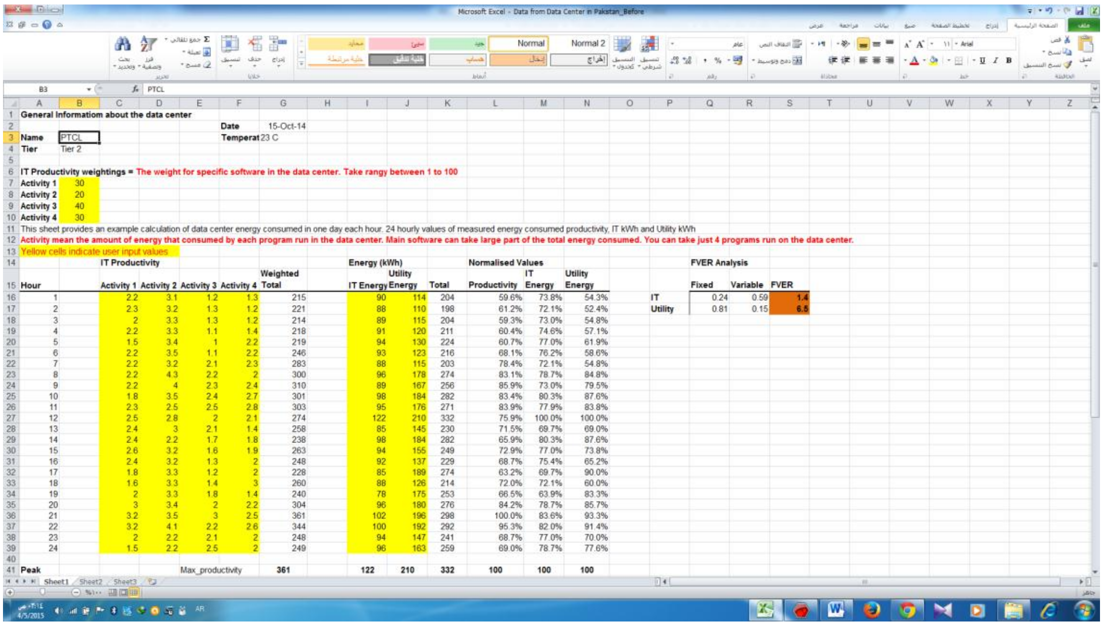
Yellow cells indicate user input values

Hour	IT Productivity Activity 1	Activity 2	Activity 3	Activity 4	Weighted Total	Energy (kWh) IT Energy	Utility Energy	Normalised Values Productivity	IT Energy	Utility Energy
1	0.9	1.1	1.1	1.4	9	79	114	81.8%	77.5%	62.0%
2	0.9	1.2	1.1	1.4	9	83	128	81.8%	81.4%	69.6%
3	0.8	1.1	1	1.3	8	84	128	72.7%	82.4%	69.6%
4	0.9	1.3	1.1	1.4	9	73	125	81.8%	71.6%	67.9%
5	0.9	1.2	1.1	1.3	9	83	130	81.8%	81.4%	70.7%
6	1	1.3	1.2	1.5	10	79	98	90.9%	77.5%	53.3%
7	0.7	1.1	0.9	1.2	7	81	119	63.6%	79.4%	64.7%
8	1	1.3	1.2	1.5	10	83	107	90.9%	81.4%	58.2%
9	0.9	1.4	1	1.3	9	81	138	81.8%	79.4%	75.0%
10	1	1.2	1.3	1.5	10	86	121	90.9%	84.3%	65.8%
11	0.8	1.1	0.9	1.2	8	75	123	72.7%	73.5%	66.8%
12	0.9	1.3	1.2	1.4	9	87	151	81.8%	85.3%	82.1%
13	0.9	1.2	1	1.4	9	85	148	81.8%	83.3%	80.4%
14	0.9	1.2	1.1	1.3	9	80	143	81.8%	78.4%	77.7%
15	1.1	1.5	1.3	1.7	11	102	184	100.0%	100.0%	100.0%
16	0.7	1	1	1	7	66	110	63.6%	64.7%	59.8%
17	0.9	1.3	1.1	1.5	9	87	157	81.8%	85.3%	85.3%
18	0.9	1.1	0.9	1.2	9	72	141	81.8%	70.6%	76.6%
19	0.8	1.2	1.1	1.4	8	77	132	72.7%	75.5%	71.7%
20	0.9	1.2	1.1	1.3	9	80	135	81.8%	78.4%	73.4%
21	0.9	1.2	1.1	1.4	9	77	128	81.8%	75.5%	69.6%
22	1.1	1.4	1.2	1.6	11	94	155	100.0%	92.2%	84.2%
23	0.7	1.1	1	1.1	7	70	111	63.6%	68.6%	60.3%
24	0.9	1.2	1.1	1.4	9	83	150	81.8%	81.4%	81.5%
Peak					11	102	184			

FVER Analysis

	Fixed	Variable	FVER
IT	0.55	0.35	2.6
Utility	0.48	0.33	2.4

Sheet1 Sheet2 Sheet3



Microsoft Excel - Data from Data Center in Pakistan_Before

General Informatiom about the data center

Date 15-Oct-14
Name PTCL
Temperat 23 C
Tier Tier 2

IT Productivity weightings = The weight for specific software in the data center. Take rangy between 1 to 100

Activity 1	30
Activity 2	20
Activity 3	40
Activity 4	30

This sheet provides an example calculation of data center energy consumed in one day each hour. 24 hourly values of measured energy consumed productivity, IT kWh and Utility kWh

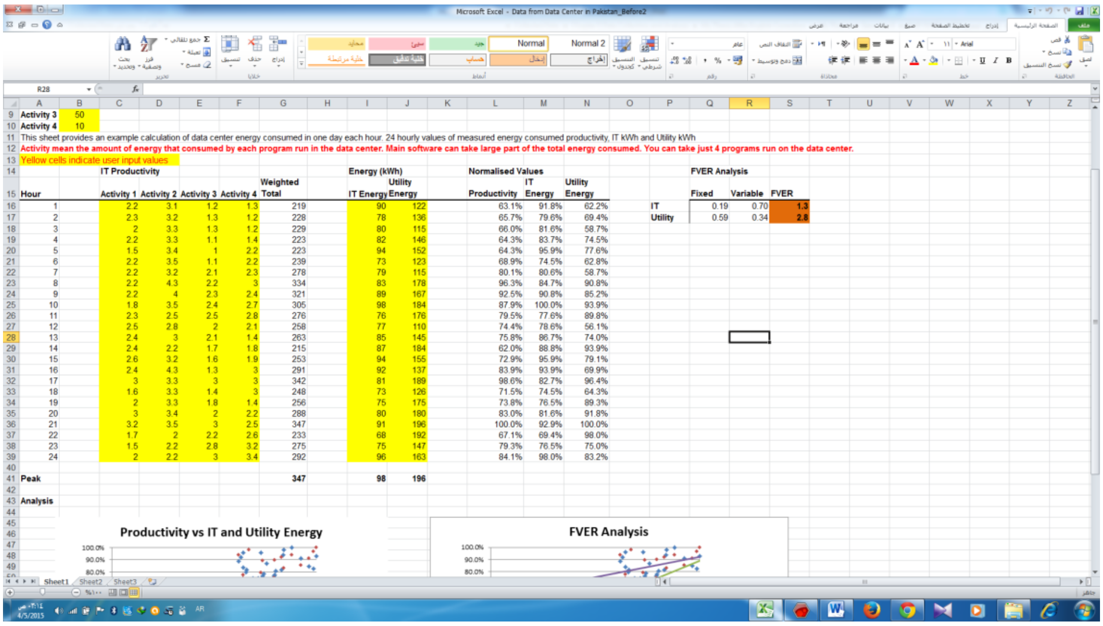
Activity mean the amount of energy that consumed by each program run in the data center. Main software can take large part of the total energy consumed. You can take just 4 programs run on the data center.

Yellow cells indicate user input values

	IT Productivity					Energy (kWh)			Normalised Values		
Hour	Activity 1	Activity 2	Activity 3	Activity 4	Weighted Total	IT Energy	Utility Energy	Total	Productivity	IT Energy	Utility Energy
1	2.2	3.1	1.2	1.3	215	90	114	204	59.6%	73.8%	54.3%
2	2.3	3.2	1.3	1.2	221	88	110	198	61.2%	72.1%	52.4%
3	2	3.3	1.3	1.2	214	89	115	204	59.3%	73.0%	54.8%
4	2.2	3.3	1.1	1.4	218	91	120	211	60.4%	74.6%	57.1%
5	1.5	3.4	1	2.2	219	94	130	224	60.7%	77.0%	61.9%
6	2.2	3.5	1.1	2.2	246	93	123	216	68.1%	76.2%	58.6%
7	2.2	3.2	2.1	2.3	283	88	115	203	78.4%	72.1%	54.8%
8	2.2	4.3	2.2	2	300	96	178	274	83.1%	78.7%	84.8%
9	2.2	4	2.3	2.4	310	89	167	256	85.9%	73.0%	79.5%
10	1.8	3.5	2.4	2.7	301	98	184	282	83.4%	80.3%	87.6%
11	2.3	2.5	2.5	2.8	303	95	176	271	83.9%	77.9%	83.8%
12	2.5	2.8	2	2.1	274	122	210	332	75.9%	100.0%	100.0%
13	2.4	3	2.1	1.4	258	85	145	230	71.5%	69.7%	69.0%
14	2.4	2.2	1.7	1.8	238	98	184	282	65.9%	80.3%	87.6%
15	2.6	3.2	1.6	1.9	263	94	155	249	72.9%	77.0%	73.8%
16	2.4	3.2	1.3	2	248	92	137	229	68.7%	75.4%	65.2%
17	1.8	3.3	1.2	2	228	85	189	274	63.2%	69.7%	90.0%
18	1.6	3.3	1.4	3	260	88	126	214	72.0%	72.1%	60.0%
19	2	3.3	1.8	1.4	240	78	175	253	66.5%	63.9%	83.3%
20	3	3.4	2	2.2	304	96	180	276	84.2%	78.7%	85.7%
21	3.2	3.5	3	2.5	361	102	196	298	100.0%	83.6%	93.3%
22	3.2	4.1	2.2	2.6	344	100	192	292	95.3%	82.0%	91.4%
23	2	2.2	2.1	2	248	94	147	241	68.7%	77.0%	70.0%
24	1.5	2.2	2.5	2	249	96	163	259	69.0%	78.7%	77.6%
Peak			Max_productivity		361	122	210	332	100	100	100

FVER Analysis

	Fixed	Variable	FVER
IT	0.24	0.59	1.4
Utility	0.81	0.15	6.5



Microsoft Excel - Data from Data Center in Pakistan_Before2

Activity 3	50
Activity 4	10

This sheet provides an example calculation of data center energy consumed in one day each hour. 24 hourly values of measured energy consumed productivity, IT kWh and Utility kWh

Activity mean the amount of energy that consumed by each program run in the data center. Main software can take large part of the total energy consumed. You can take just 4 programs run on the data center.

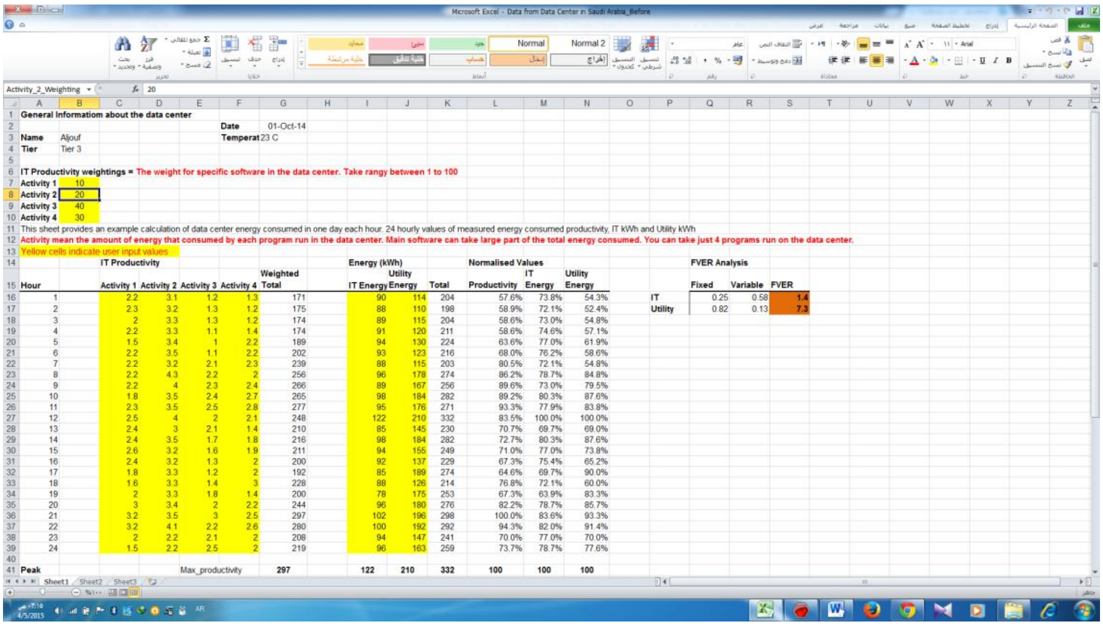
Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values		
Hour	Activity 1	Activity 2	Activity 3	Activity 4	Weighted Total	IT Energy	Utility Energy	Productivity	IT Energy	Utility Energy
1	2.2	3.1	1.2	1.3	219	90	122	63.1%	91.8%	62.2%
2	2.3	3.2	1.3	1.2	228	78	136	65.7%	79.6%	69.4%
3	2	3.3	1.3	1.2	229	80	115	66.0%	81.6%	58.7%
4	2.2	3.3	1.1	1.4	223	82	146	64.3%	83.7%	74.5%
5	1.5	3.4	1	2.2	223	94	152	64.3%	95.9%	77.6%
6	2.2	3.5	1.1	2.2	239	73	123	68.9%	74.5%	62.8%
7	2.2	3.2	2.1	2.3	278	79	115	80.1%	80.6%	58.7%
8	2.2	4.3	2.2	3	334	83	178	96.3%	84.7%	90.8%
9	2.2	4	2.3	2.4	321	89	167	92.5%	90.8%	85.2%
10	1.8	3.5	2.4	2.7	305	98	184	87.9%	100.0%	93.9%
11	2.3	2.5	2.5	2.8	276	76	176	79.5%	77.6%	89.8%
12	2.5	2.8	2	2.1	258	77	110	74.4%	78.6%	56.1%
13	2.4	3	2.1	1.4	263	85	145	75.8%	86.7%	74.0%
14	2.4	2.2	1.7	1.8	215	87	184	62.0%	88.8%	93.9%
15	2.6	3.2	1.6	1.9	253	94	155	72.9%	95.9%	79.1%
16	2.4	4.3	1.3	3	291	92	137	83.9%	93.9%	69.9%
17	3	3.3	3	3	342	81	189	98.6%	82.7%	96.4%
18	1.6	3.3	1.4	3	248	73	126	71.5%	74.5%	64.3%
19	2	3.3	1.8	1.4	256	75	175	73.8%	76.5%	89.3%
20	3	3.4	2	2.2	288	80	180	83.0%	81.6%	91.8%
21	3.2	3.5	3	2.5	347	91	196	100.0%	92.9%	100.0%
22	1.7	2	2.2	2.6	233	68	192	67.1%	69.4%	98.0%
23	1.5	2.2	2.8	3.2	275	75	147	79.3%	76.5%	75.0%
24	2	2.2	3	3.4	292	96	163	84.1%	98.0%	83.2%
Peak					347	98	196			

FVER Analysis

	Fixed	Variable	FVER
IT	0.19	0.70	1.3
Utility	0.59	0.34	2.8

Analysis



Microsoft Excel - Data from Data Center in Saudi Arabia_Before

General Informatiom about the data center

Date 01-Oct-14

Name Aljouf

Temperat 23 C

Tier Tier 3

IT Productivity weightings = The weight for specific software in the data center. Take rangy between 1 to 100

Activity 1	10
Activity 2	20
Activity 3	40
Activity 4	30

This sheet provides an example calculation of data center energy consumed in one day each hour. 24 hourly values of measured energy consumed productivity, IT kWh and Utility kWh

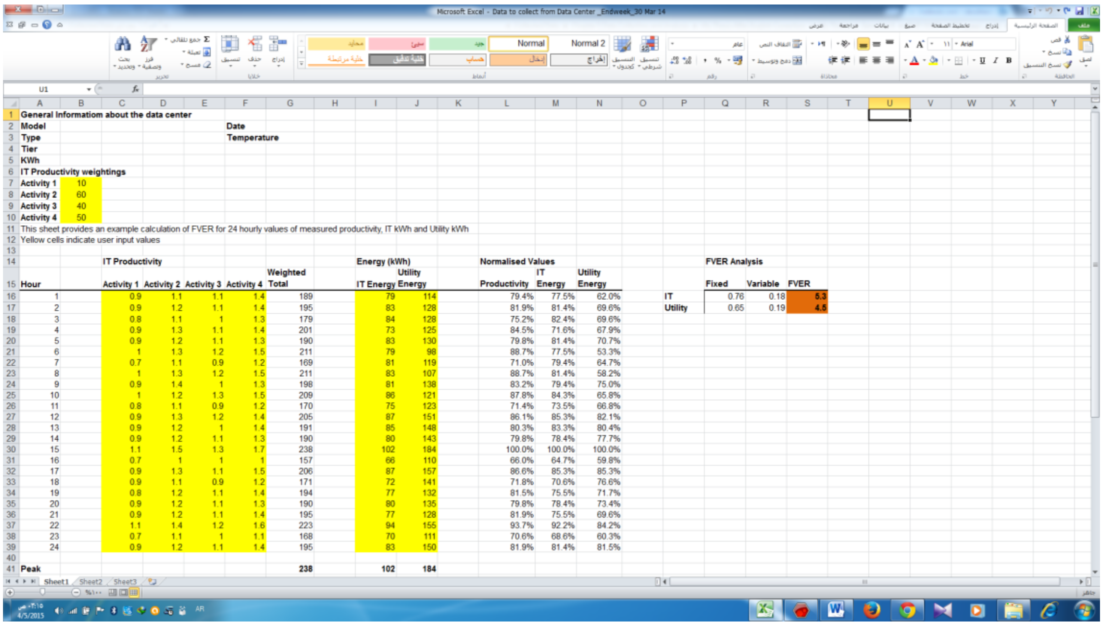
Activity mean the amount of energy that consumed by each program run in the data center. Main software can take large part of the total energy consumed. You can take just 4 programs run on the data center.

Yellow cells indicate user input values

	IT Productivity					Energy (kWh)			Normalised Values		
Hour	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Weighted Total**	**IT Energy**	**Utility Energy**	**Total**	**Productivity**	**IT Energy**	**Utility Energy**
1	2.2	3.1	1.2	1.3	171	90	114	204	57.6%	73.8%	54.3%
2	2.3	3.2	1.3	1.2	175	88	110	198	58.9%	72.1%	52.4%
3	2	3.3	1.3	1.2	174	89	115	204	58.6%	73.0%	54.8%
4	2.2	3.3	1.1	1.4	174	91	120	211	58.6%	74.6%	57.1%
5	1.5	3.4	1	2.2	189	94	130	224	63.6%	77.0%	61.9%
6	2.2	3.5	1.1	2.2	202	93	123	216	68.0%	76.2%	58.6%
7	2.2	3.2	2.1	2.3	239	88	115	203	80.5%	72.1%	54.8%
8	2.2	4.3	2.2	2	256	96	178	274	86.2%	78.7%	84.8%
9	2.2	4	2.3	2.4	266	89	167	256	89.6%	73.0%	79.5%
10	1.8	3.5	2.4	2.7	265	98	184	282	89.2%	80.3%	87.6%
11	2.3	3.5	2.5	2.8	277	95	176	271	93.3%	77.9%	83.8%
12	2.5	4	2	2.1	248	122	210	332	83.5%	100.0%	100.0%
13	2.4	3	2.1	1.4	210	85	145	230	70.7%	69.7%	69.0%
14	2.4	3.5	1.7	1.8	216	98	184	282	72.7%	80.3%	87.6%
15	2.6	3.2	1.6	1.9	211	94	155	249	71.0%	77.0%	73.8%
16	2.4	3.2	1.3	2	200	92	137	229	67.3%	75.4%	65.2%
17	1.8	3.3	1.2	2	192	85	189	274	64.6%	69.7%	90.0%
18	1.6	3.3	1.4	3	228	88	126	214	76.8%	72.1%	60.0%
19	2	3.3	1.8	1.4	200	78	175	253	67.3%	63.9%	83.3%
20	3	3.4	2	2.2	244	96	180	276	82.2%	78.7%	85.7%
21	3.2	3.5	3	2.5	297	102	196	298	100.0%	83.6%	93.3%
22	3.2	4.1	2.2	2.6	280	100	192	292	94.3%	82.0%	91.4%
23	2	2.2	2.1	2	208	94	147	241	70.0%	77.0%	70.0%
24	1.5	2.2	2.5	2	219	96	163	259	73.7%	78.7%	77.6%
Peak			Max_productivity		**297**	**122**	**210**	**332**	**100**	**100**	**100**

FVER Analysis

	Fixed	**Variable**	**FVER**
IT	0.25	0.58	1.4
Utility	0.82	0.13	7.3



Microsoft Excel - Data to collect from Data Center _Endweek_30 Mar 14

General Informatiom about the data center

Model

Date

Type

Temperature

Tier

KWh

IT Productivity weightings

Activity 1	10
Activity 2	60
Activity 3	40
Activity 4	50

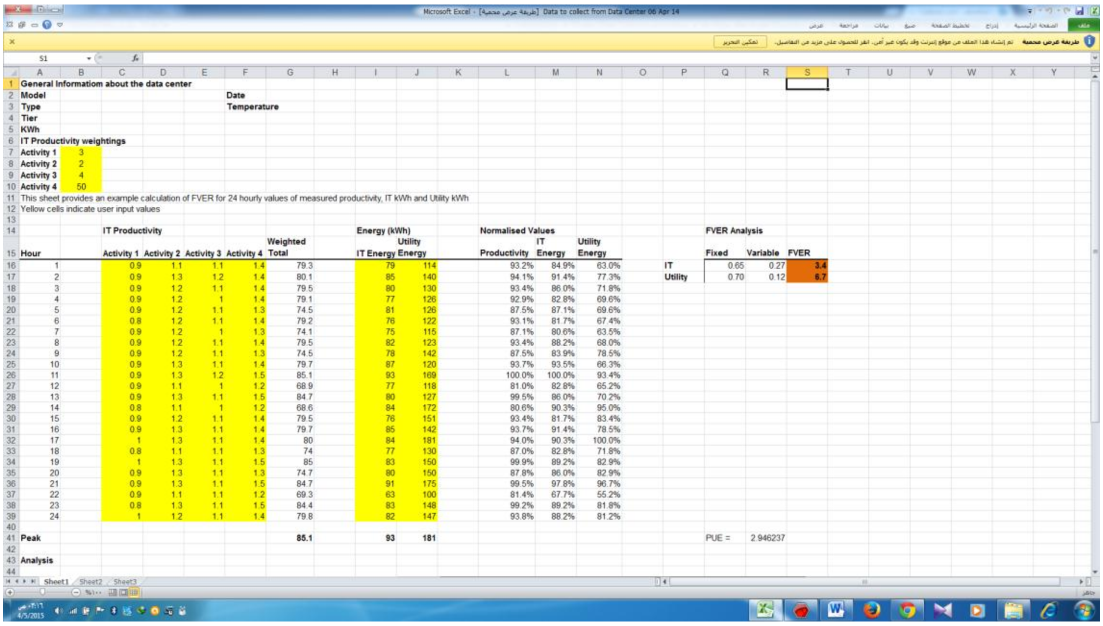
This sheet provides an example calculation of FVER for 24 hourly values of measured productivity, IT kWh and Utility kWh

Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values		
Hour	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Weighted Total**	**IT Energy**	**Utility Energy**	**Productivity**	**IT Energy**	**Utility Energy**
1	0.9	1.1	1.1	1.4	189	79	114	79.4%	77.5%	62.0%
2	0.9	1.2	1.1	1.4	195	83	128	81.9%	81.4%	69.6%
3	0.8	1.1	1	1.3	179	84	128	75.2%	82.4%	69.6%
4	0.9	1.3	1.1	1.4	201	73	125	84.5%	71.6%	67.9%
5	0.9	1.2	1.1	1.3	190	83	130	79.8%	81.4%	70.7%
6	1	1.3	1.2	1.5	211	79	98	88.7%	77.5%	53.3%
7	0.7	1.1	0.9	1.2	169	81	119	71.0%	79.4%	64.7%
8	1	1.3	1.2	1.5	211	83	107	88.7%	81.4%	58.2%
9	0.9	1.4	1	1.3	198	81	138	83.2%	79.4%	75.0%
10	1	1.2	1.3	1.5	209	86	121	87.8%	84.3%	65.8%
11	0.8	1.1	0.9	1.2	170	75	123	71.4%	73.5%	66.8%
12	0.9	1.3	1.2	1.4	205	87	151	86.1%	85.3%	82.1%
13	0.9	1.2	1	1.4	191	85	148	80.3%	83.3%	80.4%
14	0.9	1.2	1.1	1.3	190	80	143	79.8%	78.4%	77.7%
15	1.1	1.5	1.3	1.7	238	102	184	100.0%	100.0%	100.0%
16	0.7	1	1	1	157	66	110	66.0%	64.7%	59.8%
17	0.9	1.3	1.1	1.5	206	87	157	86.6%	85.3%	85.3%
18	0.9	1.1	0.9	1.2	171	72	141	71.8%	70.6%	76.6%
19	0.8	1.2	1.1	1.4	194	77	132	81.5%	75.5%	71.7%
20	0.9	1.2	1.1	1.3	190	80	135	79.8%	78.4%	73.4%
21	0.9	1.2	1.1	1.4	195	77	128	81.9%	75.5%	69.6%
22	1.1	1.4	1.2	1.6	223	94	155	93.7%	92.2%	84.2%
23	0.7	1.1	1	1.1	168	70	111	70.6%	68.6%	60.3%
24	0.9	1.2	1.1	1.4	195	83	150	81.9%	81.4%	81.5%
Peak					**238**	**102**	**184**			

FVER Analysis

	Fixed	**Variable**	**FVER**
IT	0.76	0.18	5.3
Utility	0.65	0.19	4.5



Microsoft Excel - Data to collect from Data Center 06 Apr 14

General Informatiom about the data center

Model | **Date**
Type | **Temperature**
Tier
KWh

IT Productivity weightings

Activity 1	3
Activity 2	2
Activity 3	4
Activity 4	50

This sheet provides an example calculation of FVER for 24 hourly values of measured productivity, IT kWh and Utility kWh
Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values		
Hour	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Weighted Total**	**IT Energy**	**Utility Energy**	**Productivity**	**IT Energy**	**Utility Energy**
1	0.9	1.1	1.1	1.4	79.3	79	114	93.2%	84.9%	63.0%
2	0.9	1.3	1.2	1.4	80.1	85	140	94.1%	91.4%	77.3%
3	0.9	1.2	1.1	1.4	79.5	80	130	93.4%	86.0%	71.8%
4	0.9	1.2	1	1.4	79.1	77	126	92.9%	82.8%	69.6%
5	0.9	1.2	1.1	1.3	74.5	81	126	87.5%	87.1%	69.6%
6	0.8	1.2	1.1	1.4	79.2	76	122	93.1%	81.7%	67.4%
7	0.9	1.2	1	1.3	74.1	75	115	87.1%	80.6%	63.5%
8	0.9	1.2	1.1	1.4	79.5	82	123	93.4%	88.2%	68.0%
9	0.9	1.2	1.1	1.3	74.5	78	142	87.5%	83.9%	78.5%
10	0.9	1.3	1.1	1.4	79.7	87	120	93.7%	93.5%	66.3%
11	0.9	1.3	1.2	1.5	85.1	93	169	100.0%	100.0%	93.4%
12	0.9	1.1	1	1.2	68.9	77	118	81.0%	82.8%	65.2%
13	0.9	1.3	1.1	1.5	84.7	80	127	99.5%	86.0%	70.2%
14	0.8	1.1	1	1.2	68.6	84	172	80.6%	90.3%	95.0%
15	0.9	1.2	1.1	1.4	79.5	76	151	93.4%	81.7%	83.4%
16	0.9	1.3	1.1	1.4	79.7	85	142	93.7%	91.4%	78.5%
17	1	1.3	1.1	1.4	80	84	181	94.0%	90.3%	100.0%
18	0.8	1.1	1.1	1.3	74	77	130	87.0%	82.8%	71.8%
19	1	1.3	1.1	1.5	85	83	150	99.9%	89.2%	82.9%
20	0.9	1.3	1.1	1.3	74.7	80	150	87.8%	86.0%	82.9%
21	0.9	1.3	1.1	1.5	84.7	91	175	99.5%	97.8%	96.7%
22	0.9	1.1	1.1	1.2	69.3	63	100	81.4%	67.7%	55.2%
23	0.8	1.3	1.1	1.5	84.4	83	148	99.2%	89.2%	81.8%
24	1	1.2	1.1	1.4	79.8	82	147	93.8%	88.2%	81.2%
Peak					**85.1**	**93**	**181**			

Analysis

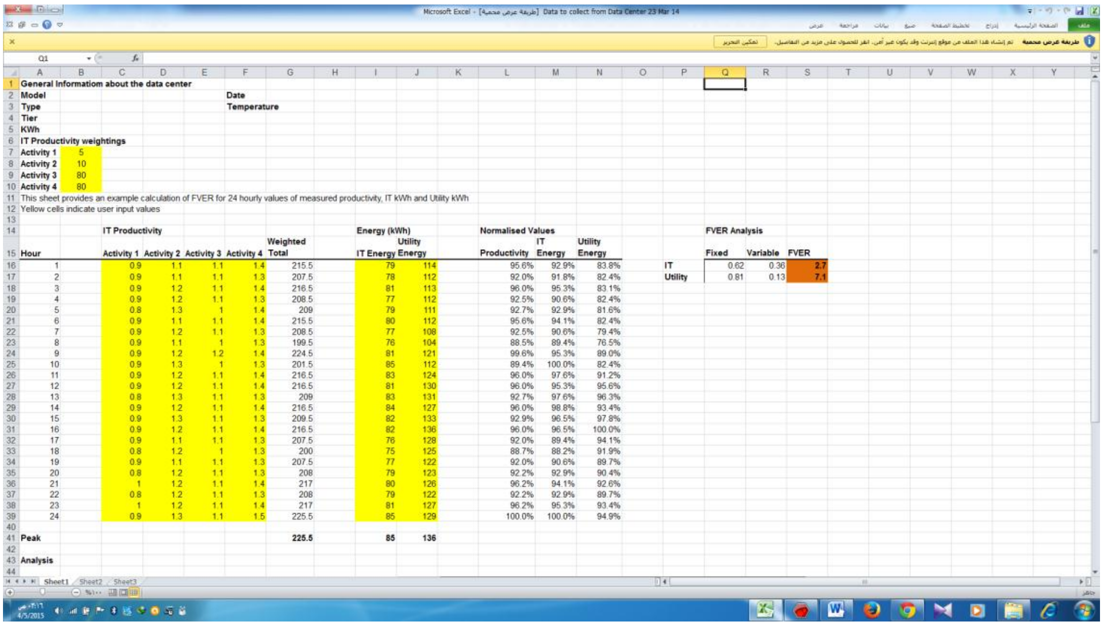
FVER Analysis

	Fixed	**Variable**	**FVER**
IT	0.65	0.27	3.4
Utility	0.70	0.12	6.7

PUE = 2.946237

Sheet1 Sheet2 Sheet3

4/5/2015



Microsoft Excel - Data to collect from Data Center 23 Mar 14

General Informatiom about the data center

Model | **Date**
Type | **Temperature**
Tier
KWh

IT Productivity weightings

Activity 1	5
Activity 2	10
Activity 3	80
Activity 4	80

This sheet provides an example calculation of FVER for 24 hourly values of measured productivity, IT kWh and Utility kWh
Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values		
Hour	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Weighted Total**	**IT Energy**	**Utility Energy**	**Productivity**	**IT Energy**	**Utility Energy**
1	0.9	1.1	1.1	1.4	215.5	79	114	95.6%	92.9%	83.8%
2	0.9	1.1	1.1	1.3	207.5	78	112	92.0%	91.8%	82.4%
3	0.9	1.2	1.1	1.4	216.5	81	113	96.0%	95.3%	83.1%
4	0.9	1.2	1.1	1.3	208.5	77	112	92.5%	90.6%	82.4%
5	0.8	1.3	1	1.4	209	79	111	92.7%	92.9%	81.6%
6	0.9	1.1	1.1	1.4	215.5	80	112	95.6%	94.1%	82.4%
7	0.9	1.2	1.1	1.3	208.5	77	108	92.5%	90.6%	79.4%
8	0.9	1.1	1	1.3	199.5	76	104	88.5%	89.4%	76.5%
9	0.9	1.2	1.2	1.4	224.5	81	121	99.6%	95.3%	89.0%
10	0.9	1.3	1	1.3	201.5	85	112	89.4%	100.0%	82.4%
11	0.9	1.2	1.1	1.4	216.5	83	124	96.0%	97.6%	91.2%
12	0.9	1.2	1.1	1.4	216.5	81	130	96.0%	95.3%	95.6%
13	0.8	1.3	1.1	1.3	209	83	131	92.7%	97.6%	96.3%
14	0.9	1.2	1.1	1.4	216.5	84	127	96.0%	98.8%	93.4%
15	0.9	1.3	1.1	1.3	209.5	82	133	92.9%	96.5%	97.8%
16	0.9	1.2	1.1	1.4	216.5	82	136	96.0%	96.5%	100.0%
17	0.9	1.1	1.1	1.3	207.5	76	128	92.0%	89.4%	94.1%
18	0.8	1.2	1	1.3	200	75	125	88.7%	88.2%	91.9%
19	0.9	1.1	1.1	1.3	207.5	77	122	92.0%	90.6%	89.7%
20	0.8	1.2	1.1	1.3	208	79	123	92.2%	92.9%	90.4%
21	1	1.2	1.1	1.4	217	80	126	96.2%	94.1%	92.6%
22	0.8	1.2	1.1	1.3	208	79	122	92.2%	92.9%	89.7%
23	1	1.2	1.1	1.4	217	81	127	96.2%	95.3%	93.4%
24	0.9	1.3	1.1	1.5	225.5	85	129	100.0%	100.0%	94.9%
Peak					**225.5**	**85**	**136**			

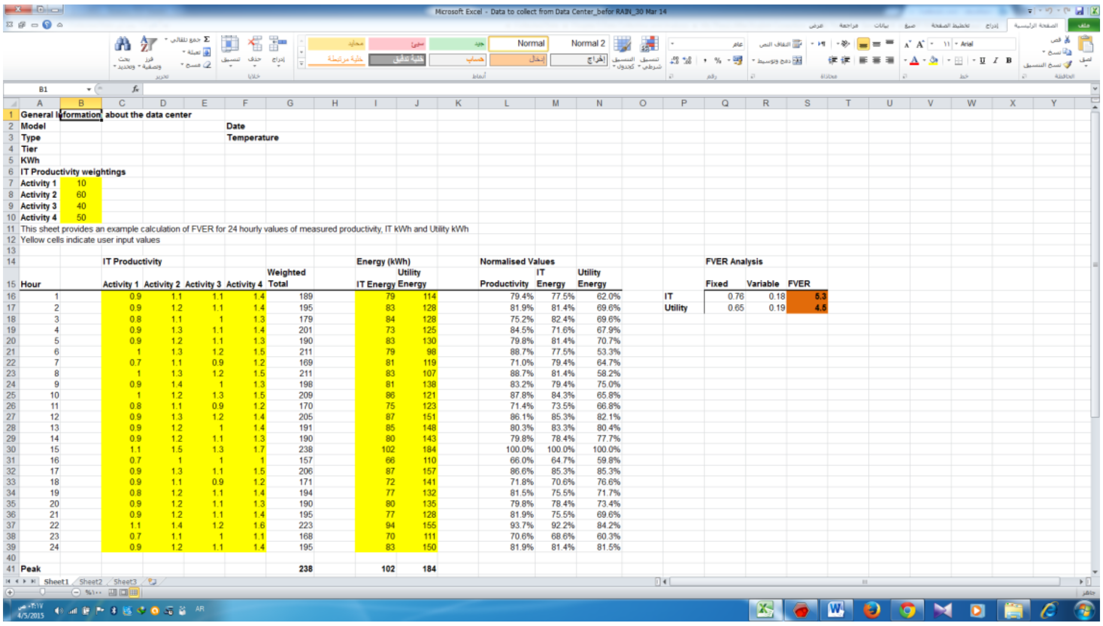
Analysis

FVER Analysis

	Fixed	**Variable**	**FVER**
IT	0.62	0.36	2.7
Utility	0.81	0.13	7.1

Sheet1 Sheet2 Sheet3

4/5/2015


Microsoft Excel - Data to collect from Data Center_befor RAIN_30 Mar 14

General Information about the data center

Model		**Date**	
Type		**Temperature**	
Tier			
KWh			

IT Productivity weightings

Activity 1	10
Activity 2	60
Activity 3	40
Activity 4	50

This sheet provides an example calculation of FVER for 24 hourly values of measured productivity, IT kWh and Utility kWh

Yellow cells indicate user input values

	IT Productivity					Energy (kWh)		Normalised Values		
Hour	**Activity 1**	**Activity 2**	**Activity 3**	**Activity 4**	**Weighted Total**	**IT Energy**	**Utility Energy**	**Productivity**	**IT Energy**	**Utility Energy**
1	0.9	1.1	1.1	1.4	189	79	114	79.4%	77.5%	62.0%
2	0.9	1.2	1.1	1.4	195	83	128	81.9%	81.4%	69.6%
3	0.8	1.1	1	1.3	179	84	128	75.2%	82.4%	69.6%
4	0.9	1.3	1.1	1.4	201	73	125	84.5%	71.6%	67.9%
5	0.9	1.2	1.1	1.3	190	83	130	79.8%	81.4%	70.7%
6	1	1.3	1.2	1.5	211	79	98	88.7%	77.5%	53.3%
7	0.7	1.1	0.9	1.2	169	81	119	71.0%	79.4%	64.7%
8	1	1.3	1.2	1.5	211	83	107	88.7%	81.4%	58.2%
9	0.9	1.4	1	1.3	198	81	138	83.2%	79.4%	75.0%
10	1	1.2	1.3	1.5	209	86	121	87.8%	84.3%	65.8%
11	0.8	1.1	0.9	1.2	170	75	123	71.4%	73.5%	66.8%
12	0.9	1.3	1.2	1.4	205	87	151	86.1%	85.3%	82.1%
13	0.9	1.2	1	1.4	191	85	148	80.3%	83.3%	80.4%
14	0.9	1.2	1.1	1.3	190	80	143	79.8%	78.4%	77.7%
15	1.1	1.5	1.3	1.7	238	102	184	100.0%	100.0%	100.0%
16	0.7	1	1	1	157	66	110	66.0%	64.7%	59.8%
17	0.9	1.3	1.1	1.5	206	87	157	86.6%	85.3%	85.3%
18	0.9	1.1	0.9	1.2	171	72	141	71.8%	70.6%	76.6%
19	0.8	1.2	1.1	1.4	194	77	132	81.5%	75.5%	71.7%
20	0.9	1.2	1.1	1.3	190	80	135	79.8%	78.4%	73.4%
21	0.9	1.2	1.1	1.4	195	77	128	81.9%	75.5%	69.6%
22	1.1	1.4	1.2	1.6	223	94	155	93.7%	92.2%	84.2%
23	0.7	1.1	1	1.1	168	70	111	70.6%	68.6%	60.3%
24	0.9	1.2	1.1	1.4	195	83	150	81.9%	81.4%	81.5%
Peak					**238**	**102**	**184**			

FVER Analysis

	Fixed	**Variable**	**FVER**
IT	0.76	0.18	5.3
Utility	0.65	0.19	4.5

Sheet1 Sheet2 Sheet3