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Reducing the Carbon Footprint of E-Government Systems in Kuwait: Sustainable Computing Strategies for Green Digital Transformation and Environmental Governance

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ABSTRACT

The expansion of e-government has been on the increase to provide more public services to citizens, facilitate government interactions, and encourage citizen participation. The increased use of digital governance systems necessitates higher levels of computing power to manage the increasing computing requirements. In turn, this higher computing power requirement generates more energy consumption which results in more carbon emissions. With Kuwait currently undergoing modernization through various plans are currently in place; therefore, adopting sustainable computing to reduce the carbon footprint of e-government systems through environmental governance in public sector is a necessity. The present study therefore aims to identify and adopt sustainable computing solutions that could minimize carbon footprint of e-government systems in Kuwait. A mixed-methods approach will be employed whereby energy consumption of IT infrastructure in government (quantitative) will be analyzed and in-depth interviews with relevant stakeholders (qualitative) will be conducted. Expected results from this study will lead to the development of a framework for sustainable e-government architecture as well as proffering recommendations for digital environmental governance in the public sector in Kuwait.

Key words: E-government, Carbon footprint, Sustainable, Green, Digital governance, Kuwait, Energy.

1. INTRODUCTION

Information and communication technologies (ICT) are rapidly changing the ways governments deliver their public services by implementing information systems and other electronic solutions. The terms electronic government (e-government), online government (e-gov), and digital government (digital gov) are used to describe how governments at all levels are increasingly using digital platforms, online services, and integrated information systems to improve the efficiency, enhance the accessibility, increase transparency, and improve responsiveness of public services. These services, which are often delivered on an on-going basis through web portals and other digital platforms, can include services such as the online licensing of vehicles, the payment of taxes, health services managed through health information systems, identity management systems, and other services that are increasingly being delivered through smart city platforms. The United Nations E-Government Survey 2024 reports on the rapid development of digital government around the world, and highlights the ways in which governments are using ICT to improve the way in which public services are managed and delivered in order to enhance administrative efficiency and to provide improved services to citizens. The report finds that there has been significant progress towards improved digital government maturity worldwide, with many countries undertaking digital transformation in order to improve the public services that they deliver [1].

E-government is often associated with economic and operational advantages. However, the environmental impacts of large-scale digital infrastructure have so far largely been ignored. Digital solutions offer many advantages, such as reducing the use of paper, transport and administration. However, the necessary equipment such as data centers, cloud services, communication networks and cooling systems are highly energy-consuming. As a result, they require a lot of electricity and lead to greenhouse gas emissions, thus increasing the carbon print of public digital services. Data centers and the digital transmission networks are increasingly consuming a higher share of the global electricity, according to the International Energy Agency (IEA). This is due to the growing computing power and the increasing use of cloud services [2].

The growing digital system's environmental impacts have lately attracted the focus of many researchers in the area of sustainable computing, or green computing. Green computing is an emerging area that seeks to design new models of computational systems and their management in an energy

efficient way in order to reduce their environmental impacts. All the different stages in the life cycle of the computing systems are considered in sustainable computing, including design, deployment, usage, and even retirement of the systems. To reduce the energy consumption of the large IT systems, many solutions have been recently proposed. These solutions include the virtualization of the servers, the scheduling of workloads based on the energy-aware consumption of the workloads, the dynamic resource management, and the energy efficient management of the cloud computing systems. Research has shown that with the proper management of the resources in the virtualized cloud data centers, it is possible to save a lot of power while maintaining the level of service for the users (Beloglazov; Buyya, 2010) [3]. In addition to that, green computing is also used in order to improve the environmental sustainability and organizational efficiency of companies by adopting the best environmental friendly practices and methods to IT in organizations without causing any harm to the environment [4] [5], this area is referred to as Green IT.

The challenge of sustainability faces many obstacles in the Gulf region of very high ambient temperatures, a culture of air conditioning and the challenge of digitalization. Kuwait has made a lot of progress in its digital transformation and has set up several national initiatives to modernize public services and to increase efficiency of government services. A lot of online portals for government services as well as online platforms for public services have been launched to administrate a variety of administrative services [10]. The digitalization of services puts a lot of pressure on servers and data storage as well as on computer networks. Above all it puts a lot of pressure on cooling systems. While there is a growing amount of research on the subject of e-government and carbon emissions, there is a lack of research on how to manage the negative effects of e-government on the environment. There is a lack of research on the subject in Kuwait as well as on possible solutions to the problem of the environmental damage that is caused by e-government in Kuwait.

There is a major research gap when combining the fields of e-government and environmental sustainability, particularly in the context of less developed countries, oil-rich countries and Kuwait in particular. Most studies that focus on e-government attempt to measure the quality of provided services, to prevent cyber threats, to gauge the degree of citizens' adoption and use of provided services through e-government platforms, or to discuss aspects of governance in order to enable the digital framework and tools. In contrast to these existing studies, very few studies can be found that attempt to measure the energy efficiency and carbon footprint of public sector computing using sustainability metrics. Furthermore, there is a severe lack of frameworks that are geared towards specific geographical regions and incorporate the principles of sustainable computing within the frameworks that support the government's digital transformation [8][9].

Lack of research on sustainable computing for reducing the carbon footprint of e-government services and ensuring their performance is one of the problems tackled by this research. It identifies the sources of e-government infrastructure emissions and assesses the potential of technology and governance to reduce them. The research presents a framework for green digital governance aimed at making the national digital strategy environmentally sustainable. The study will be beneficial for policy makers, IT managers, and practitioners in sustainability as it will introduce a holistic approach to design and develop greener e-government services and applications that deliver effective services while keeping their environmental impact minimum.

The remainder of this paper is structured as follows. Section 2 reviews related work. Section 3 presents the details of the proposed Methodology. Section 4 discusses the proposed framework. Finally, Section 5 concludes the paper**.**

2. RELATED WORK

This prospective Lack of research on sustainable computing for reducing the carbon footprint of e-government services and ensuring their performance is one of the problems tackled by this research. It identifies the sources of e-government infrastructure emissions and assesses the potential of technology and governance to reduce them. The research presents a framework for green digital governance aimed at making the national digital strategy environmentally sustainable. The study will be beneficial for policy makers, IT managers, and practitioners in sustainability as it will introduce a holistic approach to design and develop greener e-government services and applications that deliver effective services while keeping their environmental impact minimum.

However, the energy required by these digital systems leads to increased energy consumption and environmental impact in the form of greenhouse gas emissions. The report by International Energy Agency, Energy-Related Carbon Emissions from Global Energy System [2][7], outlines energy consumption by data centers and telecommunications infrastructure worldwide as well as the indirect carbon dioxide emissions that they generate. A very large e-government project that operates 24/7/365 that requires a lot of processing power can have a considerable energy consumption and generate considerable greenhouse gas emissions.

A number of solutions have been proposed to mitigate the effects of IT growth. In the paper Green IT principles, Murugesan [4] outlines the basic principles of Green computing including increasing the efficiency of computers and IT systems and their use i.e. through virtualization. Efficient server hardware has recently been developed, but electricity consumption by data centers is increasing sharply. This is due in part to the rapidly increasing number of services that are being offered on the Internet, as reported by Koomey [5]. The key to combating these effects lies with smart IT management.

Searching for advanced sustainable computing solutions to saving energy by using virtualization and cloud optimization.

Beloglazov and Buyya [3] presented a new energy-efficient management and allocation of resources in virtualized environments. Hilty and Aebischer [6] discuss the integration of sustainability objectives into the ICT-governance. They stress to include environmental objectives when designing technology as well as when making policies.

Green computing has recently been linked to public sector digital transformation and its potential to cut emissions through the modernization of IT infrastructure and carbon aware computing [11][12]. However, there is a lack of research into sustainable computing strategies and digital environmental governance for e-government systems in the Gulf region, specifically in Kuwait where the high temperatures increase the cooling energy required to maintain the working temperature of computers. This paper aims to address this gap through a critical review of strategies for reducing the carbon footprint of the IT infrastructure and services provided by e-government in Kuwait.

2.1. Research Objectives

1. Measure energy consumption and carbon emissions of selected Kuwaiti e-government systems. Rationale: Baseline carbon assessment is necessary.
2. Identify major emission sources within digital infrastructure. Rationale: Enables targeted interventions.
3. Evaluate sustainable computing strategies. Rationale: Determines practical reduction methods.
4. Develop governance recommendations. Rationale: Supports long-term sustainable digital

3. METHODOLOGY

This research employs a mixed-method approach. The methodological approach of the research will provide an assessment of sustainable computing and its effect upon decreasing e-government's carbon footprint in Kuwait. The quantitative analysis will show the energy being consumed by systems as well as the emissions of greenhouse gases that are being produced as a result of such consumption. In addition to the quantitative assessment, the research will also present an assessment of current governance and the many challenges there are to implementing green e-government. The qualitative assessment will investigate the many technical as well as policy features of green e-government in Kuwait in great detail.

The proposed framework assumes that sustainable computing practices directly influence carbon emission reduction in e-government systems, while digital environmental governance acts as an enabling factor for implementation, the proposed framework displays in the following (Figure 1).

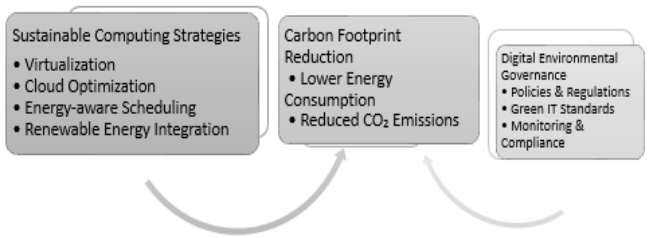

Figure 1: Proposed Framework

The framework consists of:

1) Independent Variables (IV) include of Virtualization level (X1), Cloud optimization (X2), Cooling efficiency (X3), and Renewable energy usage (X4)
2) Moderating Variable: include Digital environmental governance (M)
3) Dependent Variable (DV): include Carbon footprint reduction (Y).

a) Mathematical Equations

Carbon Emission Calculation, and Carbon releases are estimated using:

$$CO2=E\times EF$$

Where:

CO2 = Carbon emissions (kg CO_2)

E = Energy consumption (kWh)

EF = Electricity emission factor (kg CO_2/kWh)

Energy Consumption Model

Total energy consumption is calculated as:

$$E_{total}=E_{server}+E_{cooling}+E_{network}$$

Where:

E_{server} = Server energy consumption

$E_{cooling}$ = Cooling system energy

$E_{network}$ = Network infrastructure energy

b) Carbon Reduction Percentage

$$CR(\%)=((CO_{2before}-CO_{2after})/\ CO_{2before})\times 100$$

Where:

$CO2_{before}$ = Emissions before optimization

$CO2_{after}$= Emissions after optimization

c) Hypothesis Development

Based on prior literature, the following hypotheses are proposed:

- Main Hypothesis

H1: Sustainable computing strategies significantly reduce the carbon footprint of e-government systems in Kuwait.

- Sub-Hypotheses

H1a: Higher virtualization rates significantly reduce energy consumption.

H1b: Cloud optimization significantly lowers server-related carbon emissions.

H1c: Improved cooling efficiency significantly reduces total infrastructure emissions.

H1d: Renewable energy integration significantly decreases overall carbon footprint.

H2: Digital environmental governance positively moderates the relationship between sustainable computing and carbon reduction.

Hypothesis Testing Model

To test the hypotheses, Multiple Linear Regression will be used.

d) Regression Model

$$Y=\beta0+\beta1X1+\beta2X2+\beta3X3+\beta4X4+\epsilon$$

Where:

Y = Carbon footprint reduction

X1 = Virtualization

X2 = Cloud optimization

X3 = Cooling efficiency

X4 = Renewable energy usage

β0= Intercept

β1...β4 = Regression coefficients

ϵ = Error term

e) Moderation Model

To evaluate governance impact:

$$Y=\beta0+\beta1X+\beta2M+\beta3(X\times M) + \epsilon$$

Where:

X= Sustainable computing strategies

M = Digital environmental governance

X×M = Interaction term

A significant interaction coefficient (β3) indicates moderation.

f) Data Collection

The quantitative dataset collected from:

- Government data centers
- Cloud service logs
- Energy consumption reports
- Cooling infrastructure measurements

3.1. Data Analysis Techniques

a. Descriptive Statistics

To calculating: Mean energy consumption, Average CO_2 emissions, and Standard deviation

b. Reliability Testing

Cronbach's Alpha for survey consistency:

c. Inferential Statistics, such as Correlation analysis, Regression analysis, ANOVA, and Hypothesis significance testing.

Decision rule:

$p < 0.05 \rightarrow$ Hypothesis accepted

$p \geq 0.05 \rightarrow$ Hypothesis rejected

d. Analytical Flow

Figure 2 and 3 illustrates the overall research methodology and pipeline adopted in this study, from data collection and carbon footprint assessment to hypothesis testing and the development of sustainable governance recommendations.

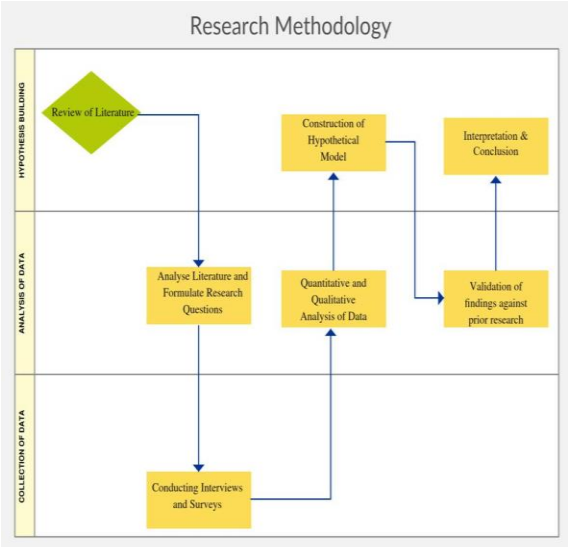

Figure 2: Research Methodology

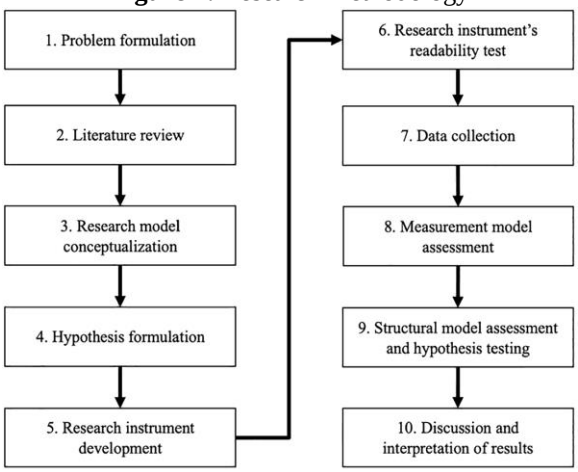

Figure 3: Research Pipe Line

4. CONCLUSION

This study addresses the environmental sustainability challenge of digital governance by measuring and managing the carbon footprint of e-government in Kuwait. Although e-government has many advantages for improving and delivering government services and citizens' interaction with government, the underlying IT infrastructure of e-government generates a huge amount of energy which in turn leads to production of greenhouse gases emissions and thus causes environmental damage. The research aims at developing a framework which would support the implementation of sustainable computing and digital environmental governance in order to minimize the environmental impact of digital governance. The study seeks to find out the impact of cloud computing, server virtualization and Green Data Centers in reducing carbon emissions while maintaining high quality of e-government services and ensuring effective environmental governance through appropriate policies and implementations.

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