Adoption of Cloud-Based Smart Grids: Insights from Oman's Electricity Sector

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Abstract

Cloud computing technology offers key advantages for smart grid applications, especially for electric companies with industry expertise. However, implementing cloud-based solutions for smart grids requires careful consideration of several critical factors. This research aims to identify the primary factors influencing electricity companies' the adoption of cloud-based solutions in smart grids in Oman. An in-depth interview was conducted with field experts to develop a comprehensive model that will potentially be a key reference source for guiding the adoption and implementation of cloud-based smart grids in Oman and beyond. This research is espoused by the technology organization environment (TOE) framework and the diffusion of innovation (DOI) theory. The model identifies ten key factors that impact the adoption of smart grid cloud-based (SGCB) solutions in utilities in Oman. By understanding the significance of these factors, utility companies can make well-informed decisions about implementing cloud-based solutions for smart grids. This research serves as a valuable resource, guiding the adoption of this technology in the electricity sector. It also contributes to smart grid advancement and optimization within utility companies.

Keywords: Smart grid; Cloud solutions; TOE framework; Innovation factors; Utility advancements

1. Introduction

Electrical power has become a game-changer in fuelling economic activity and the heartbeat of any meaningful transformative innovation. With the realization of the importance of electric power as a catalyst for human development, energy demand has increased [1]. The increased demand has strained many existing power grids, reducing the efficiency of power generation, communication, and distribution. As a result, there is a huge debate and engagement on innovations surrounding the attainment and sustainability of energy security, efficiency, and availability. Many innovations in electrical power systems have centred on the use of Information and Communication Technologies (ICTs) which aim to optimize control and monitoring processes within the smart grid. However, the adoption and use of ICTs have the dual effect of increasing power demand while also enhancing access to crucial technological information [2]. A smart grid is an innovation in electrical networks for improving energy transmission, conservation, and distribution. It usually delivers electricity from the power plant to businesses, homes, or other destinations [3]. Thus, digital technologies and systems (e.g., computers, sensors, automated motors, logic units, intelligent relays, and Remote Terminal Units) are in crucial demand for sensing transmission lines, which makes the smart grid the most suitable solution for ensuring efficient monitoring, control, and management of electricity distribution networks [4].

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Technology has been a positive change agent in electrical power systems. However, the extensive use of Wireless Sensor Network (WSN) communication standards in smart grids has rapidly increased security threats [5]. Man-in-the-middle attacks, denial of service, information theft, natural disasters, and cyberattacks are examples of security threats that may lead the smart grid system to failure. One more challenge is the geographical distribution of electricity plants and communication between them. Actions have been taken based on the load capacity of each plant [6]. Correspondingly, the use of the Internet and cloud-based applications to support business development is expected to be an essential area for technological innovation and industry investment [7]. Smart grids hosted by cloud computing can solve issues like enhanced security, big data analysis, and fog computing support, and provide comprehensive dashboards for service providers and their customers [8]-[10]. Cloud computing deployment models can be applied in different scenarios in the smart grid environment. Cloud computing technology uses ubiquitous resources that smart grid users and stakeholders may access. In this way, internet users can communicate with multiple cloud servers simultaneously, enabling cloud computing to use smart grid applications [7]. Moreover, cloud computing services can support high-speed infrastructure, fast processing, user accessibility, application integrity, and quality-stable technologies [5]. Those services and demands can develop enormous potential for smart grid applications to be hosted on cloud computing [6].

Consequently, the development of a mechanism for a novel security infrastructure along with cloud computing is required [11]. However, the smart grid enables collecting and monitoring all data and information, providing an extensive PC and network infrastructure that eludes expanded situational mindfulness and allows enhanced control and coordination [4]. In real-time frameworks and applications, this combination environment is key [12]. For those in the electricity companies, this key is essential to face their challenges. A reliable and dynamic infrastructure is needed to build a smart grid architecture that is ideal for smart networks due to their versatility, prudential, and adaptability attributes [13].

This research aims to understand the status of electricity companies in the Sultanate of Oman regarding the adoption of smart grid cloud-based (SGCB) technology. As mentioned in the Oman Power and Water Procurement Report 2018, the increasing power demands play a central role in improving the efficiency of the power system in the national network [14]. Therefore, the improvement of smart grids and the use of cloud computing offer many opportunities and avenues to improve demand response and enhance demand-side management (DSM) [15]. The expected investment in smart grid infrastructure within the MENA countries is $9.8 billion by 2024 [16], including distribution automation SCADA (Supervisory Control and Data Acquisition), smart meters AMI (Advanced Metering Infrastructure), and smart city technology. While the integration of cloud-based technologies into smart grids has been identified as a potentially effective means of surmounting obstacles, this study's significance comes from its focused investigation of the adoption dynamics within Oman's power firms. By resolving the complexities around the implementation of a smart grid cloud-based (SGCB), this study contributes to the larger conversation about how to improve energy efficiency and dependability in the area. Policymakers, business professionals, and technology developers will be able to make well-informed decisions that support Oman's expanding power needs and its goals of having a resilient and sustainable energy infrastructure thanks to the findings, which are expected to provide insightful information.

This study focuses on the Sultanate of Oman's electrical companies and explores every aspect of deploying cloud-based smart grid solutions. Integration of progressive technology options in contemporary electrical power design and implementation is of cardinal importance as it directly contributes to the Sustainable Development Goals (SDG7, SDG13) and is in line with the Paris Agreement. Given that Oman, just like many other countries, is committed to energy efficiency, clean energy, and zero-net carbon emissions by 2030, smart grids are one of the potential technologies that will likely contribute to the broader call for energy transition. The results of this research, espoused upon the realities surrounding SGCB adoption for Oman's Electricity Sector, will be highly applicable to the Omani context and other contextually similar environments. For the successful implementation of the proposed research model, theoretical perspectives drawn from the Diffusion of Innovation theory (DOI) and the Technology Organization Environment (TOE) framework have been synthesized. Moreover, the factors influencing electricity companies' SGCB adoption have been identified and evaluated.

2. Related Work

The utilization of cloud computing is experiencing swift expansion, aligning with the rise of smart grids. Cloud computing facilitates the integration process between data and communication technologies for electricity delivery over the power grid [17]. Communities within the smart grid ecosystem, encompassing customers, program managers, technicians, and various stakeholders, are increasingly embracing cloud computing, either as end-users or providers of cloud services. Industrial electricity is known for accepting cutting-edge technologies before other industries do. For example, electric utilities in Oman were among the first companies to employ mainframe computers in the 1980s [18]. As Oman's economy has grown and electricity needs have increased, it has required significant investment in new generation capacity. Since 2004, the liberalization of the electricity sector has placed significant emphasis on private sector participation. There are two major factors contributing to the liberalization

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process: clear and comprehensive reform legislation, and effective regulatory oversight by the Authority for Electricity Regulation (AER) [19]. In Oman's main interconnected system (MIS), the private sector now owns 100% of the power generation capacity, and efforts are underway to privatize other network companies. Oman will be the first country in the Middle East Gulf region to privatize its electricity transmission and distribution sectors [15]. However, cloud computing adoption for electric utilities has been slow in the industry. This is surprising considering that cloud technologies can greatly enhance smart grid capabilities, and the ability to segregate data is a significant advantage [6].

Cloud computing can be used to manage the energy in the architecture of the smart grid. The model is proposed by using cloud computing technologies in the smart network area and investigates how cloud computing plays a convincing role in DSM among a group of Smart Energy Hubs. Moreover, it facilitates ongoing data streaming through various options and sources, supporting dynamic and differentiated applications [20]. IaaS comprises the entire infrastructure of the resource collected from the services to the hardware platforms that support them, whereas PaaS is positioned as a top IaaS by adding it only up to one layer, which causes incorporation for further developing intelligent grid cloud applications with a computing framework [21].

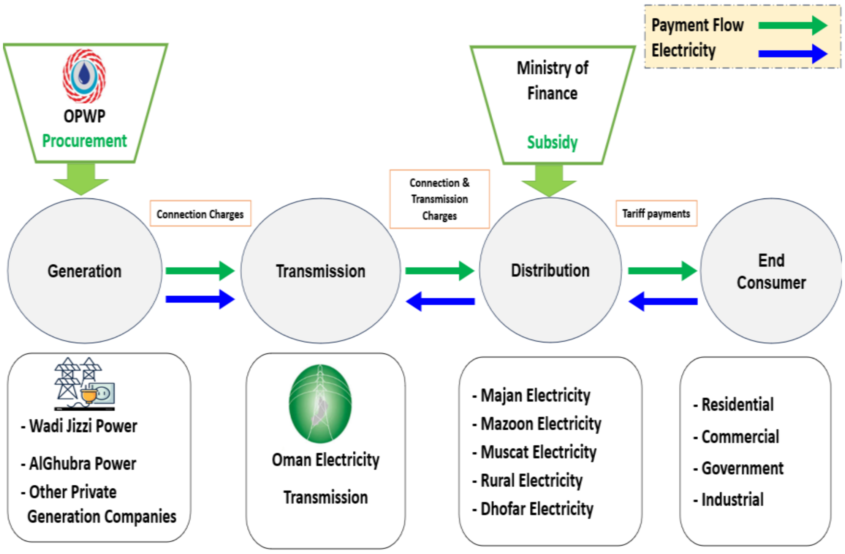

Figure 1. Electricity Sector in Oman (Source: [22])

Figure 1 presents the electricity companies in the Sultanate of Oman and their hierarchy as per the Authority for Electricity Regulation (AER) [22]. In “OPWP’s 7-Year Statement” (2018 – 2024) [23], Since 2000, Oman's electrical industry has required large investments in additional generation capacity to meet the nation's expanding demand for power as well as its expanding economy. Thus, private sector involvement in the generation of power and water was given a lot of weight when the electrical industry was liberalized. Currently, the private sector owns 100% of generation capacity in Oman’s main interconnected system. The Main Interconnected System ("MIS") in the north of Oman; the Rural System of the Rural Areas Electricity Company ("RAEC"); and the Dhofar Power System ("DPS"). Both the production and consumption of electricity are dynamic processes. It becomes increasingly difficult to optimize a large network of dispersed assets because of these changes, posing new difficulties for power utilities. For companies within a country, using grid power data for strategic purposes is very important in increasing operational efficiency and being cost-effective [24]. Energy consumption patterns analysis by companies helps in optimizing resource allocation, reducing costs, and promoting environmental sustainability. Additionally, the analysis assists in demand prediction and promotes dynamic reactions to grid fluctuations, ensuring stability and dependability. Through compliance with regulations regarding energy buying decisions and by responding to competitive pressures, companies can integrate grid power data into their strategic planning processes. The integration of the decision-making process with the grid power data is critical for future-oriented businesses operating under rapidly changing energy environments that align with sustainable goals thereby enhancing their resilience.

In a comprehensive review of renewable energy sources, researchers stated that the limits of a country's grid power system frequently include inadequacies in energy circulation, outdated infrastructure, and sensitivity to interruptions [25]. These problems might cause power interruptions and impede the incorporation of renewable energy sources. By combining new technology with established power systems, it may be possible to overcome constraints and improve overall dependability and efficiency. Traditional power grids may function much better

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when cutting-edge technology is included [26]. A recent survey report showed that 99% of enterprises realized substantial technical benefits from adopting cloud technology, and 77% of total enterprises employed public cloud in some capacity [27]. The benefits of cloud computing, such as its flexibility, scalability, cost-effectiveness, and accessibility, have led to its adoption in a wide range of applications and addressing real-life problems. According to the same research, 81% of enterprises thought that working in the cloud would enable them to grow their businesses more effectively than on-premises technology. Furthermore, the difficulties of integrating smart grid technologies and handling massive data without cloud support may result in abandoned possibilities for optimization and progress. Adopting cloud computing is vital for addressing these constraints and creating a more versatile and robust energy system.

Cloud computing has a transformative impact on grid power networks and offers many benefits in terms of efficiency and scalability. By leveraging cloud-based services, power users can optimize their operations through real-time data processing, predictive analytics, and seamless communication. Cloud facilitates the integration of smart grid technology, enabling utilities to effectively monitor and manage power supply. It increases the reliability of the network by providing a central location for monitoring, control, and maintenance. In addition, cloud computing enables the use of advanced algorithms and machine learning models for demand forecasting and energy efficiency. This not only improves resource efficiency but also contributes to the sustainability and resilience of the entire electricity system, paving the way for smarter and more efficient energy systems. Despite the potential benefits, several challenges impede the widespread adoption of SGCB solutions. Organizations transitioning to SGCB often experience initial hurdles related to integration complexities, data security concerns, and regulatory compliance issues. The deployment of cloud computing in smart grids requires significant investment in infrastructure and expertise to manage the transition smoothly [28]. Moreover, interoperability between existing systems and cloud platforms poses technical challenges that need careful consideration. Furthermore, the dynamic nature of cloud technologies necessitates continuous updates and adaptations to meet evolving industry standards and customer expectations. Despite these challenges, SGCB adoption promises substantial benefits such as enhanced operational efficiency, improved resource management, and scalability which are crucial for meeting the growing demands of modern energy systems [29].

3. Models for Technology's Adoption

For enterprises to understand and predict the factors that influence evolving technology adoption, some models are of significant help. [30] articulates the widely used theoretical constructs including the Technology Acceptance Model - TAM (Perceived Usefulness; Perceived Ease of Use); Theory of Reasoned Action - TRA (attitudes, social norms, and perceived behavioral control); Diffusion of Innovations - DOI (social networks; communication channels); Technology Organization Environment - TOE (technological, organizational, and environmental factors); Model of PC Utilization - MPCU (users' individual characteristics); and Social Cognitive Theory - SCT (role of self-efficacy, outcome expectations, and goals) [31].

In business environments, models such as DOI and TOE play an essential role in revealing all aspects of technology adoption. They not only identify the factors that influence or hinder the acceptance of new technology but also help formulate strategies for their implementation. The DOI theory explains technology adoption based on characteristics such as relative advantage, compatibility, complexity, observability, and trialability, which influence the likelihood and speed of adoption. The DOI hypothesis, first articulated by E.M. Rogers in 1962, is commonly used to explain and predict innovation adoption, DOI theory is limited in its ability to handle environmental factors influencing adoption behavior adequately [32]. In contrast, the TOE framework was used for this study because it includes both technological and non-technological elements, as well as environmental impacts, all of which are important in understanding adoption at the organizational level [33]. The TOE framework considers three dimensions: the technological capabilities available to the firm, the organization’s internal readiness, and external environmental pressures such as competition and regulation.

A more comprehensive model can likely be created by integrating aspects of DOI and TOE features. The resultant model takes into consideration individual as well as organizational variables that affect adoption decisions [34]. This work presents a combined approach that utilizes DOI and TOE to effectively assess technology adoption. The paper includes the TOE's key features and how they vary compared to the DOI. The study discusses how the recommended approach can better represent the adoption of technology, particularly cloud computing.

4. Research Methodology

This investigation uses a descriptive research approach to get a thorough and precise insight into the characteristics, behavioral patterns, or views within a certain group or phenomenon. The process represents extensively documenting and explaining the subject, as well as collecting data using methods such as interviews, investigations, and record analysis. The acquired data is then thoroughly analyzed and reported using statistical methods or qualitative procedures [35].

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The primary goal is to gather useful insights and form relevant conclusions regarding the research topic. This is achieved by proposing a model for determining the level of adoption of Smart Grid Cloud-Based (SGCB) technologies in Oman's utilities industry. The deductive technique was chosen for this study because it is well-suited to assessing a specified set of hypotheses taken from existing theories and frameworks, namely the Technology Organization Environment (TOE) framework and the Diffusion of Innovation (DOI) theory [36]. Furthermore, this study demonstrates a link between survey-based research and non-probability sampling. Using a non-probability sampling approach requires researchers to have prior knowledge of the target population to ensure that qualified experts are selected. In this study, non-probability expert sampling is used to reduce uncertainty and aid in the identification of research findings. Furthermore, online surveys were sent and gathered from electrical companies [37]. Moreover, this research uses several statistical techniques and software, such as SmartPLS and Structural Equation Modelling (SEM) for analyzing data. SEM is a widely used statistical method in information systems [38]. It enables researchers to test hypotheses and examine relationships between observed and latent variables. It offers advantages over other methods, including the ability to adjust theoretical models, consider measurement errors, and calculate more accurate representations of functional relationships [39].

A. Developing the Questionnaire

During the pilot analysis, an English-language structured questionnaire was designed to test the factors that influence SGCB adoption in Oman's electricity companies. To ensure the reliability and accuracy of the items (questions) and to assess the intended constructs, researchers adapted the questions from the TOE framework, DOI theory, and expert interviews. Incorporating insights from interviews not only enhances the validity of the factors but also enriches the model with valuable field experience [40]. A wide range of constructs (factors) were included in the questionnaire, including Technology Readiness, Top Management, Competitive Pressure, Regulatory, Relative Advantage, Compatibility, Security, Cost Savings, Real-Time Response, and Fog Computing. Furthermore, the construction and design phase involves item scale planning, reaction design, development, and resources. The questionnaire is divided into two sections. The first section (Section A) is demographic information consisting of six MCQs. The second section (Section B) consisted of 28 MCQs in eleven groups, each addressing a specific construct (factor). Both sections are in Appendix A.

Recognized measurement tools like Likert Scales, specifically the 5-point Likert scale ranging from 1 "strongly Agree" to 5 "strongly Disagree," were employed to enhance the survey's efficiency and quality. This type of questionnaire was chosen due to its widespread usage and uncertainty in more than seven questions [41]. A Google Form has been prepared and shared with stakeholders in AOI (a utility company in Oman) via email and social media applications. Participants in this study were selected from Oman's electricity companies based on their expertise in technology readiness, top management support, competitive pressure, regulatory support, relative advantage, compatibility, security, cost savings, real-time response, and fog computing. Participants had to have positions that gave insight into SGCB adoption, be able to give demographic information, be fluent in English, and be willing to fill out the structured questionnaire. In Table 1, the item scales are illustrated that were used to evaluate the impact of selected factors on SGCB adoption. The final row of the table contains SGCB adoption, which supports the research hypotheses (H1-H10).

Table 1: Factors Influencing SGCB Adoption

Constructs	Items (Questions)	Source
Technology Readiness	**TC1:** The Company recognizes how to use IT in operations and processes. **TC2:** The Company has enough skills and experts to implement SGCB.	[42]
Top Management	**TM1:** Top management is ready to take financial and organizational risks of SGCB adoption. **TM2:** Top management has strong attention to processes that can improve IT and the corresponding applications	[43] & [44]
Competitive Pressure	**CP1:** The SGCB was adopted by other companies, which pushed the organization to adopt it as well. **CP2:** The organization believes that SGCB has positively impacted industry competition.	[42] & [47]

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Regulatory	**RS1:** The current regulations and rules are enough to preserve organizations' rights to use cloud computing. **RS2.** As per country's laws and regulations, cloud computing is legal.	[45] & [46]
Relative Advantage	**RA1:** Using SGCB is faster than traditional ways of managing related applications. **RA2:** Using SGCB provides an efficient way to manage operations. **RA3:** Using SGCB will increase organizational productivity. **RA4:** Using SGCB improves operation quality.	[42] & [50]
Compatibility	**CO1:** Using SGCB aligns with the firm's values and culture. **CO2:** Using SGCB is compatible for organization work style. **CO3:** Using SGCB is integrated into the firm's business cycle. **CO4:** Using SGCB is compatible with current organization software and hardware.	[42], [45], [48] & [49]
Security	**SC1:** The Company is concerned about information security in SGCC. **SC2:** The Company has concerns about privacy when using cloud computing for operations. **SC3:** The customer has privacy concerns about using cloud-based applications.	[49], [51] & [52]
Cost Saving	**CS1:** SGCB maintenance costs are lower than in-premises applications. **CS2:** The SGCB benefits over time are higher than the initial adoption cost. **CS3:** Using SGCB will reduce energy and environmental costs.	[48] & [53]
Real-Time Response	**RT1.** Cloud computing supports prompt response for DMS and SCADA applications in the smart grid. **RT2:** Cloud computing supports smart grid transactions without delay.	[54] & [55]
Fog Computing	**FC1.** SGCB supports sensors through fog services. **FC2:** Cloud computing analytics services support fog data structures.	
SGCB Adoption	**SA1:** How far has your firm progressed in adopting SGCB? **SA2:** If your organization decides to adopt SGCB in the future, when could that happen?	[48]

The Authority for Electricity Regulation (AER) in the Sultanate of Oman has defined the authorized entities responsible for power distribution, transmission, and generation [54]. This study focuses on six Omani electricity companies (MJEC, MEDC, MZEC, RAECO, OETC, and DPC) operating under Nama ownership [55] and AER authority, as they are actively involved or have expressed interest in SGCB applications. Specifically, the study concentrates on the distribution and transmission departments encompassing IT, SCADA, OAM, DCC, and GIS. The questionnaire was administered to a group of 86 experts from electricity companies. The participants included senior security engineers, GIS heads and engineers, technical services supervisors, and SCADA engineers. Out of the responses received through Google Forms, 76 were deemed valid for analysis. Three responses were excluded due to insufficient experience, and two were inconsistent. In total, 71 responses were evaluated and analyzed, resulting in a 93% response rate. This response rate is considered acceptable, meeting the recommended sample size requirement of at least 70 out of 86 individuals [57].

B. Research Model and Hypotheses

The research model and corresponding hypotheses related to various constructs (factors) are discussed, as depicted in Figure 2. The proposed model suggests a positive influence of the constructs derived from the Technology Organization Environment (TOE) framework and Diffusion of Innovation (DOI) theory on the adoption of Smart Grid Cloud-Based (SGCB) solutions by Omani electricity companies. Hypotheses H1 to H4 pertain to the TOE framework, while hypotheses H5 to H8 focus on DOI characteristics. Hypotheses H9 and H10 were formulated based on interviews conducted with six international electric companies: Schneider Electric, PSI, Siemens, OSI, ABB, and General Electric.

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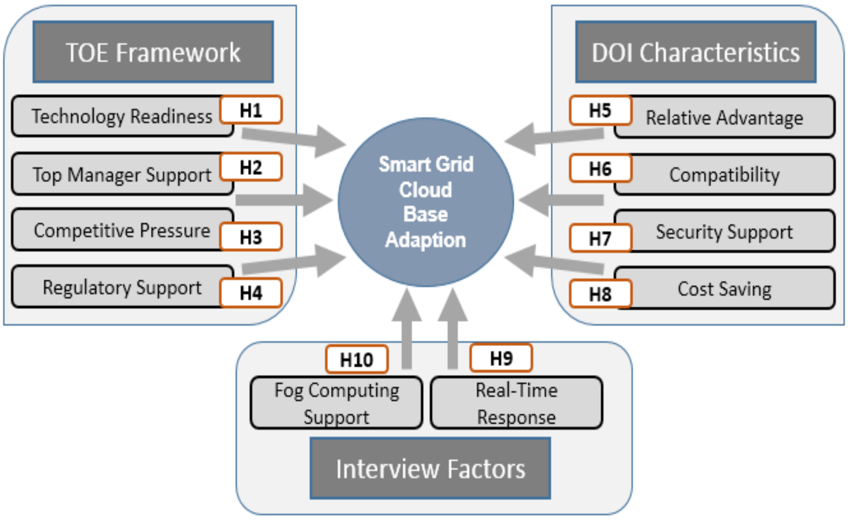

Figure 2. Purposed Research Model for the adoption of cloud computing in Smart Grid

1. TOE Context Hypothesis

The TOE framework encompasses the internal and external perspectives through which a firm identifies a problem, explores potential solutions, and ultimately selects among alternatives.

- Technology Readiness: This concept refers to an organization's technical expertise and infrastructure, with a particular focus on its ability to accept cutting-edge technology. Entities who have sophisticated IT skills and expertise in utility control systems, such as cloud computing and SCADA system knowledge, are more likely to incorporate Smart Grid Cloud-Based (SGCB) solutions [42].

  ○ **H1**: Technology Readiness positively influences SGCB adoption.

- Top management support: The backing of top-level management plays an essential role in technology adoption. Its support is the most critical factor for cloud computing adoption. It includes the allocation of resources, re-engineering of processes, and creation of effective methods, service integration, and structural support [43] & [44]. In short, top management would facilitate or limit new technology implementation.

  ○ **H2**: Top management support will positively impact the SGCB adoption.

- Competitive pressure: This factor refers to competition between industry firms. The adoption of cloud computing to support enterprise solutions is often a tactical requirement for success in the marketplace where competitive pressure is high [42]& [47].

  ○ **H3**: Competitive pressure will positively affect the adoption of SGCB.

- Regulatory support: It refers to governmental support for local organizations. Government regulations can inspire or depress firms [45] & [46]. For example, in Oman, all electricity companies must comply with the AER standards (e.g., it requires them to maintain a copy of firms' data in local data centers).

  ○ **H4**: Regulatory support will positively impact the SGCB adoption.

2. DOI Context Hypothesis

The DOI factors are used in most studies related to this kind of technology adoption.

- Relative advantage: This term is used in innovation and technology adoption. It is used to evaluate the benefits of a newly developed service or technology compared to existing alternatives. Therefore, it describes whether a new offer is perceived as superior to its competitors [42] & [50].

  ○ **H5**: Relative advantage positively affects the SGCB adoption.

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- Compatibility: Compatibility refers to "the degree to which the technology suits the potential adopter's current qualities, past practices, and current needs" [58]. For technology adoption to be successful, system compatibility must be ensured [42],[45],[48] & [49]. The complexity of a new technology, for example, will harm its adoption.
  - **H6**: Compatibility will positively influence SGCB adoption.
- Security Support: WSNs' wireless communication standards are widely used in smart grids, increasing security threats. Security is characterized as the security of information, server farms, and services. Cloud computing providers guarantee to protect organizations' information better than they do [49], [51] & [52].
  - **H7**: Security Support affects SGCB adoption positively.
- Cost savings: the aim is to optimize Demand Side Management (DSM) and achieve cost savings through improved load management and efficient resource allocation by leveraging cloud computing [48] & [53]. It examines the interaction between service organizations and demand response capabilities in Smart Energy Hubs (SEHs), to reduce the energy load per customer. This hypothesis has been developed to examine the cost-saving potential of cloud computing, as it is presumed that it will influence adoption positively.
  - **H8**: Cost savings positively influence SGCB adoption by electricity companies.

3. Interview Context Hypothesis

Through interviews with six foreign firms, two further factors particular to energy companies that are not addressed by the DOI and TOE models were identified as affecting SGCB adoption. The input of major power firms such as Siemens, ABB, Schneider Electric, OSI, and General Electric was critical in identifying these factors.

- Real-Time Response: Smart grid solutions require fast real-time response networks [54] & [55]. It's crucial for SCADA and DMS applications. Cloud computing promises fast transactions. However, high Internet traffic or a single node failure can slow down the response time.
  - **H9**: Real-time response has a positive impact on SGCB adoption.
- Fog Computing Support: It enables new technologies by reducing latency, processing data closer to the edge, and seamlessly integrating with cloud computing. It offers fast response times, improved user experience, and a unified computing infrastructure for implementing new technologies. SGCB rely heavily on fog computing [54] & [55].
  - **H10**: Fog computing support positively influences SGCB adoption.

5. Data Analysis

In this section, the data collected is analyzed in accordance with the research model. The study results are presented, and an evaluation of the proposed model is conducted to fulfill the study objectives. The section outlines the model requirements and utilizes SmartPLS 3.2.8 for data analysis.

A. Data Collection

As previously stated, a total of 71 responses were evaluated and analyzed from six Omani electricity companies (MJEC, MEDC, MZEC, RAECO, OETC, and DPC), and departments (IT, SCADA, OAM, DCC, and GIS). The collected data was exported to CSV format and underwent a cleaning process to enhance reliability. Mandatory answers were ensured, and inconsistent responses were excluded. Based on the questionnaire in Appendix A, the demographic information of the respondents is presented in the following Figures: 3 A, B, C, D, E, and F.

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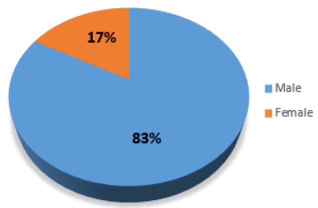
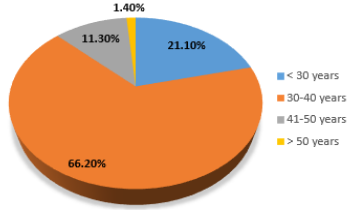
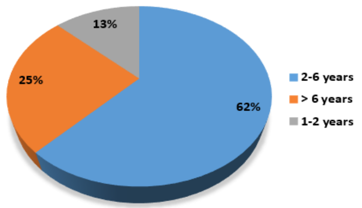


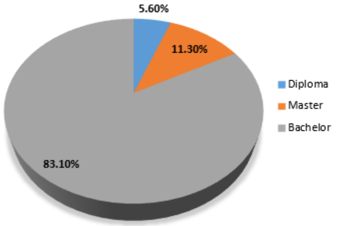
(A) Gender



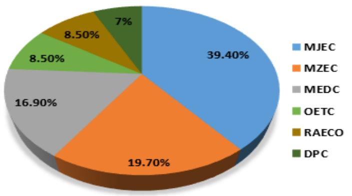
(B) Age



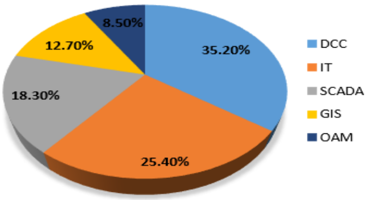
(C) Experience Level



(D) Education Level



(E) Participated Companies



(D) Participated Departments

Figure 3. Demographic Information of Respondents

B. Proposed Model Evaluating

Validating constructs is crucial when developing a survey. In the context of testing hypotheses and developing reliable measures, construct validity refers to the degree to which measurement elements accurately capture the concept of interest [59-61]. It also refers to how they can be translated into actual measurements. To evaluate construct validity, it is imperative to consider other aspects, such as convergent validity. It examines the degree to which multiple measures of the same construction are correlated. Alternatively, discriminant validity looks at the extent to which measures of different constructions are not correlated.

In this regard, the Average Variance Extracted analysis (AVE) measures convergent validity by comparing the latent variables' variance with measurement error. To obtain AVE values in SmartPLS, you typically need to estimate a Partial Least Squares Structural Equation Model (PLS-SEM) and examine the results. By squaring and summing the standardized loadings of the indicators associated with a latent variable, AVE values are calculated. Each AVE should have a higher R-square than the relationship between the elements involved in the analysis [62]. As will be discussed next, the hypothesis suitability and construct reliability were verified using the above measurement techniques.

C. Initial Loading Model

Using SmartPLS software, measurement items have been assigned to their corresponding factors within the suggested model as shown in Figure 4. The factors are represented by blue circles and the related items (questions) by yellow rectangles. The values shown between them represent convergent validity. The R-square values for each factor exceeding 0.60 indicate the validity of the items [62]. Additionally, the loaded factors show that all the items are strongly associated with their hypotheses. Additionally, item values exceeding 0.70 for all beliefs indicate high cross-loading for each factor.

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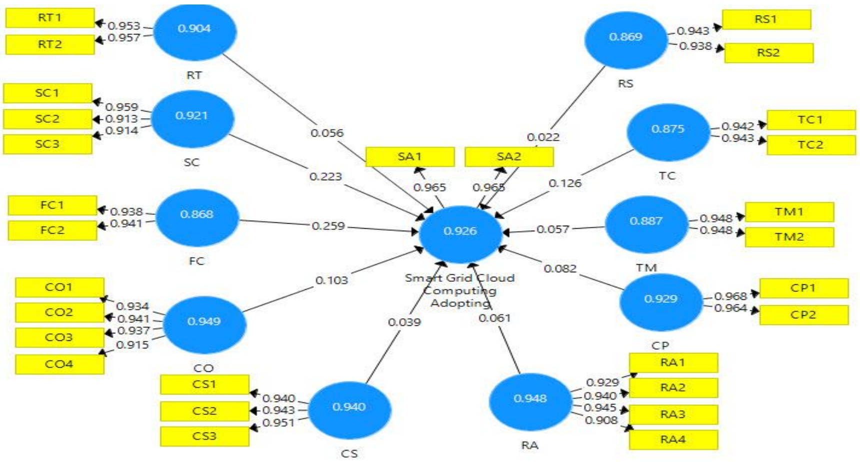

Figure 4. SmartPLS software with constructs loading.

D. Proposed Model Reliability and Validity Test

The reliability test assesses the reliability of the proposed constructs. Common methods to test construct reliability include composite reliability and Cronbach's alpha. These analyses provide insights into the consistency and reliability of the measurement scale associated with the construct. In general, both Cronbach's alpha value and the composite reliability value should be above 0.70 to indicate a reliable measurement scale [63].

The Cronbach Alpha test yields values ranging from 0 to 1. A value close to one signifies high construct reliability, while a value nearing zero suggests low reliability. As mentioned earlier, a reliability score of 0.70 or higher is generally deemed as reliable [64]. Cronbach Alpha formula is shown in Eq.1.

$$\propto = \left(\frac{n}{n-1}\right)\cdot\left(1-\frac{\sum_{i-1}^{n} S_i^2}{S_t^2}\right) \qquad (1)$$

As a reference to our results, Cronbach’s alpha categories for internal consistency are listed in Table 2.

Table 2: Cronbach’s alpha Categories

Cronbach's alpha	Internal consistency
! > 0.9	Excellent
0.8 < **!** < 0.9	Good
0.7 < **!** < 0.8	Acceptable
0.6 < **!** < 0.7	Questionable
0.5 < **!** < 0.6	Poor
! < 0.5	Unacceptable

In Figure 5, the Cronbach's Alpha results for each factor are displayed. This shows that all factors have values surpassing 0.70, confirming their acceptability.

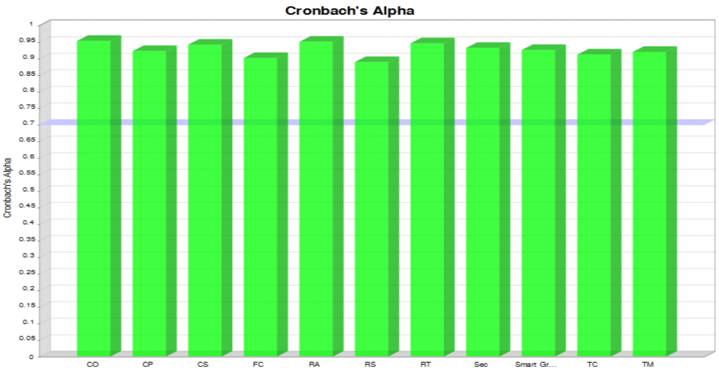

Figure 5. Cronbach’s Alpha Results

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The composite reliability measure gauges a construct's internal consistency and reliability. It focuses on evaluating the reliability of items associated with a particular construct. Typically, a composite reliability value above 0.70 indicates a high level of reliability for the feature [63]. Figure 6 depicts the Composite Reliability analysis for the proposed model. The findings reveal that all items are reliable, as their respective values exceed 0.7

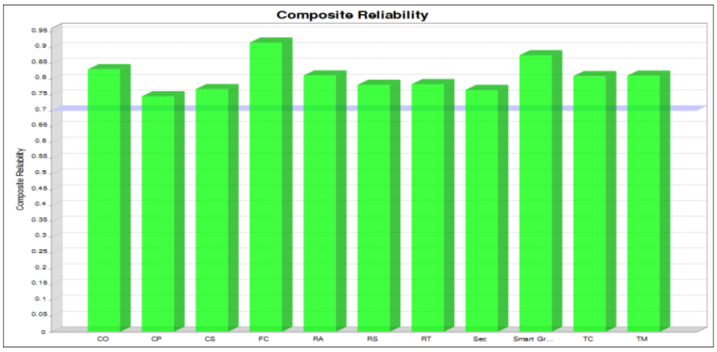

Figure 6. Composite Reliability Result

Additionally, the study also employed Average Variance Extracted (AVE) analysis. This assessment examines how much the indicators can be attributed to the shared factor. AVE values lie between 0 and 1, representing the percentage of total variation explained by the latent variable. A value exceeding 0.50 suggests the validity of both the individual variables and the factor [65]. Figure 7 illustrates the results of the AVE analysis, showing that all features and their contents surpass the threshold value of 0.50. This finding affirms the validity of all factors studied in this research.

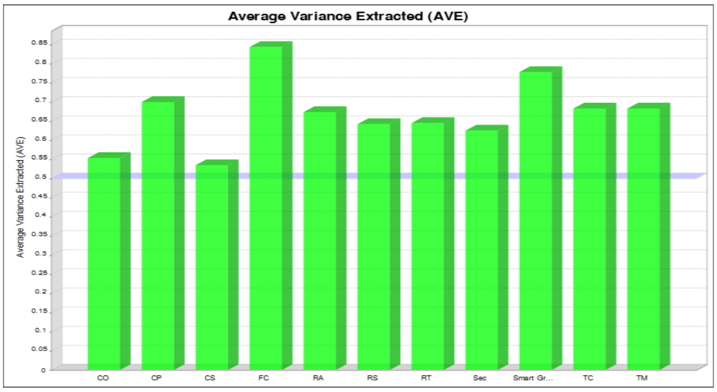

Figure 7. Average Variance Result

E. Hypothesis Evaluation

The PLS algorithm is utilized to evaluate internal consistency, discriminant validity, and construct validity. Additionally, SmartPLS software is employed to analyze coefficient paths for each factor. Subsequently, Microsoft Excel is utilized to compute T-values and R-squares, enabling the drawing of conclusive results regarding the hypotheses. The significance of the analysis is then determined based on the following process:

- Hypothesis Testing: Bootstrapping is used with T-tests to test hypotheses. A T-value greater than 2 indicates a significance hypothesis [35].
- Probability (P-value): The P-value quantitatively measures the numerical significance of construct testing. If the P-value is greater than 0.05, the target hypothesis is considered significant [39].
- Path Coefficients: Path coefficients are crucial indicators in a structural equation model (SEM) or path analysis. They represent the strength and direction of relationships between direct and indirect factors in the model. These coefficients range from -1 to 1, where a positive value indicates a positive relationship, a negative value represents a negative relationship, and the magnitude reflects the level of support for the

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adoption model. Values closer to 1 or -1 suggest a stronger influence, while values closer to 0 indicate a weaker association between the variables [66].

- R-square: R-square (R^2) is a measure used in structural equation modeling (SEM) to assess the overall effect of the proposed model constructs. It estimates the percentage of variance explained by the model's constructs in the dependent variable. R-square provides an indication of how independent constructs collectively account for the dependent variable variability. The value of R-square ranges from 0 to 1, with a higher value indicating that a larger proportion of the variance in the dependent variable is explained by the model construct [39] & [67].

Figure 8 displays the path coefficient values for each construct. Among them, Regulatory Support (RS) has the lowest value, while fog computing (FC) has the highest. In other words, FC significantly influences SGCB adoption, whereas RS has a lesser impact on the adoption process.

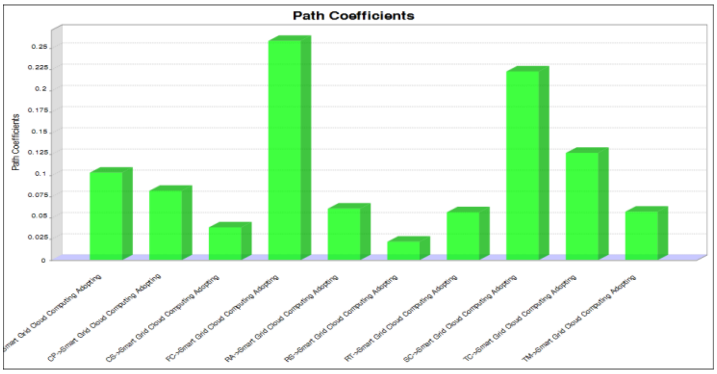

Figure 8. Patch Coefficients Result

Table 3 displays the outcomes of T-values and P-values for each construct. The T-value, path coefficients, and P-value exhibit strong correlations with the results, providing robust evidence that all hypotheses in the model supports SGCB adoption readiness.

Table 3: Results from the model

Hypothesis	T-Value	P-Value	Results
H1: Technology Readiness → SGCB Adoption	5.778	9.40 E-06	Support
H2: Top Management Support → SGCB Adoption	3.411	9.13 E-4	Support
H3: Competitive Pressure → SGCB Adoption	4.071	7.59 E-4	Support
H4: Regulatory Support → SGCB Adoption	1.823	3.45 E-2	Support
H5: Relative Advantage → SGCB Adoption	3.715	7.34 E-4	Support
H6: Compatibility → SGCB Adoption	5.479	4.96 E-5	Support
H7: Security Support → SGCB Adoption	6.170	5.83 E-7	Support
H8: Cost Savings → SGCB Adoption	2.241	1.21 E-2	Support
H9: Real-time Response → SGCB Adoption	3.527	8.42 E-4	Support
H10: Fog Computing Support → SGCB Adoption	6.564	1.94 E-7	Support

Consequently, the utility data analysis confirms the validity of all factors, and all ten hypotheses are validated. As a result, the R-square (alteration of diversity) attains a substantial value of 0.838.

6. Summary and Conclusion

Smart grids are crucial in utility companies, assuring useful power distribution and utilization. A strong infrastructure for both hardware and software is the basis for their effectiveness. The primary aim of this study is to create a model for assessing the readiness of Oman's electricity sector, particularly the distribution and

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transmission departments, to adopt Smart Grid Cloud-Based (SGCB) solutions. The study utilizes a descriptive research methodology and employs deductive reasoning based on relevant theories in the field. To provide a comprehensive explanation of technology adoption, the model combines the DOI (Diffusion of Innovations) and TOE (Technology-Organization-Environment) frameworks. Eight factors are derived from these frameworks, and an additional two factors are obtained from interviews with six international company representatives. In practical terms, the findings highlight three factors that should receive special attention from electricity company management: fog computing support, security support, and technology readiness.

Rigorous testing, including AVE, Cronbach's Alpha, and composite reliability measurements, confirms the validity of these factors. Data collection involved an online questionnaire distributed among six Omani electricity companies. A non-probability expert sample consisting of 71 SGCB technology experts out of the targeted 86 individuals is utilized for prompt identification of research findings and addressing any vagueness. With a response rate of 93%, the sample size meets the recommended criterion of at least 70 out of 86 participants, making it acceptable [56].

The research successfully achieved its objectives by identifying, evaluating, and validating influential factors affecting SGCB adoption. The relationships between constructs and hypotheses are validated using the PLS (Partial Least Squares) algorithm and SEM (Structural Equation Modeling) technique. The analysis results and R-square show that the proposed model is likely to assist electricity companies in Oman in fulfilling high levels of readiness for SGCB adoption through the ten factors that strongly support SGCB adoption.

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Appendix A

Section A

In this section, you will find additional information about the participants that is solely intended for analysis purposes. This information is not directly related to the main topic of the discussion.

- What is your educational background? {*Diploma, Bachelor, Master, PHD*}
- How many years of experience do you have? {*Less than one year, 1-2 Years, 2-6 Years, more than 6 Years*}
- Please select your company. {*MJEC, MEDC, MZEC, DPC, RAECO, OETC*}
- Your section or department? {*Distribution and Control, GIS, IT, SCADA, Operation and Maintenance*}
- Gender? {*Male, Female*}
- Age? {Below *30 Years, Between 30 and 40, Between 41 and 50, More than 50 Years*}

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Section B

Within this section, you will encounter a distinct question concerning your company and its utilization or plans regarding smart grid cloud-based (SGCB) applications. Please select a single response from the following options: *Strongly Agree, Agree, Neutral, Disagree, or Strongly Disagree.*

1. The company recognizes how to use IT in operations and processes.
2. The company has enough skills and experts to implement SGCB.
3. The top management is ready to take the financial and organizational risks SGCB adoption.
4. The top management has strong attention in the process that can improve information technology and corresponding applications.
5. The SGCB adopted by competitors influences the organization to adopt it as well.
6. The organization believes that SGCB has positively impacted on its industry competition.
7. The current regulations and rules are enough to conserve the organization's rights to using cloud based.
8. The use of cloud computing is legal as per the country’s regulations.
9. Using SGCB is faster than traditional ways to manage related applications.
10. Using SGCB provides an efficient way to manage operations.
11. Using SGCB will increase organizational productivity.
12. Using Cloud Computing enhanced operation quality.
13. Using SGCB aligns with firm values and culture.
14. Using SGCB is suitable with organizational work style.
15. Using SGCB is integrated with the firm business cycle.
16. Using SGCB is compatible with current organization software and hardware.
17. The company has conservation about information security in SGCB.
18. The Company concern about privacy when using cloud computing for operation.
19. The customer has a privacy concern in using cloud-based applications.
20. SGCB maintenance costs are lower than on premises application.
21. The SGCB benefits by the time is higher than the initial adoption cost.
22. Using SGCB will reduce the energy and environmental costs.
23. The SGCB supports prompt response for DMS, SCADA applications.
24. Cloud computing supports smart grid transactions without delay.
25. Sensors reading is supported by SGCB through fog services.
26. Cloud computing analytics services support the fog data structure.
27. At which level of SGCB adoption that your firm reach? {*Already adopted, Evaluated with plan to adopt, Evaluating, Evaluated without plan to adopt, Not Considered*}
28. In case your organization decides to adopt SGCB in the future? When could that happen? {*Already adopt some cloud service for smart grid implementation, Less than one month, between one to six months, More than six months, Not Considered*}

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