

إدارة الطاقة والتقاط الكربون في المملكة العربية السعودية

Energy Management and Carbon Capture in Saudi Arabia

Prepared by:

Fahd Awadh Alharbi

Supervised by:

Dr. Al Faisal Abdulhameed Mohammad

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List of Content

Contents

Acknowledgments.....	ii
List of Content	iii
Tables and charts.....	Error! Bookmark not defined.
Chapter One: Introduction	1
1.1 Background	1
1.2 Problem statement	2
1.3 Significance of the research	3
1.4 Research Aims and objectives.....	4
1.5 Research Questions:	5
1.6 Hypothesis:.....	5
1.7 The scientific theory used to prepare the research:	5
Chapter 2: previous Studies	7
2.1 Introduction:	7
2.2 Previous Studies	8
2.3 Literature Review	10
Chapter Three: Research Methodology	14
1.3 Introduction	14
2.3 Research approach.....	14
2.3 Research design.....	14
4.3 Sample	14
5.3 Data collection.....	15
6.3 Validity and Reliability:	15
7.3 Data Analysis	15
8.3 Study Determinants	16
10.3 Ethical Considerations.....	16
Chapter 4: Practical Study.....	17
4-1 Data Analysis.....	17
4.1.1 Introduction	17
4.1.2 Results	17
4.1.3 Effectiveness of Energy Management Techniques	19
4.1.3 Performance of Carbon Capture Systems	20
4.1.4 Economic Benefits	22

4.1.5 Challenges and Opportunities	24
4.1.6 Association Among Energy Management Techniques, Carbon Capture Systems, Economic Benefits, and Challenges and Opportunities	26
4-2 Research Findings	28
4-3 Research Recommendations	30
References:.....	32
Appendixes	37
Questionnaire	38
Arabic abstract	41
English abstract.....	42

Tables and charts

Figure (4.1): Participants gender.....	18
Figure (4.2): Participants age	18
Figure (4.3): Participants Nationality	19
Table 1: Demographic Characteristics	17
Table 2: Effectiveness of Energy Management Techniques (Descriptive Statistics)	19
Table 3: Performance of Carbon Capture Systems (Descriptive Statistics)	20
Table 4: Economic Benefits (Descriptive Statistics)	22
Table 5: Challenges and Opportunities (Descriptive Statistics)	24
Table 6: Matrix of Correlations	26

Chapter One: Introduction

1.1 Background

Over the past few decades, Saudi Arabia has seen considerable increases in population and urbanization, which has resulted in a notable rise in energy consumption, especially in the residential sector. There are a number of issues that come with the growing energy use in residential structures, such as increasing load on the power system, higher greenhouse gas emissions, and decreased energy efficiency. There is a rising demand for cutting-edge energy management systems that can maximize energy usage and improve efficiency in residential buildings in order to solve these issues and encourage sustainable energy practices (Abubakar & Dano, 2020).

The energy management systems market had a noteworthy valuation of USD 35.54 billion in 2021 on a global scale. In the upcoming years, the field is anticipated to increase at a noteworthy 13.4% annual pace. Electric utility grids use EMS to track and improve the efficiency of the electric transmission system. (Energy Management Systems Market Size, 2022). Beyond this, though, their reach encompasses a broad spectrum of energy network applications, including scheduling and generation management. The system is built using a real-time data operating system in order to meet its objectives of increased power efficiency. It is not unexpected that these cutting-edge technologies are extensively employed in a variety of industries, including IT, telecom, and energy, given their versatility. Energy management in particular has seen a significant transformation as a result of digitalization in business and industrial processes. The outstanding efficiency benefits of this move towards modernizing energy methods are contributing to its expanding relevance (Alghassab, 2024).

In addition to having no public debt and a strong positive trade balance, Saudi Arabia has recently had significant GDP growth (Samargandi 2017). Saudi Arabia's overall energy usage

per person in 2011 was more than three times higher than the world average (6.5 tons of oil equivalent per person in Saudi Arabia compared to 1.9 tons globally). The need to comply with international duties to guarantee a safe environment for sustainable development planning is large and complicated, driven by the fast population growth, robust GDP, and ongoing demand on natural resources.

The state-owned oil firm Saudi Aramco has produced far more greenhouse gas emissions over the last 50 years than any other major petroleum corporation worldwide. Saudi Arabia remains isolated in the global endeavor to decrease greenhouse gases (GHGs) despite a recent decline in emissions owing to the COVID-19 epidemic. The country shows a very limited capacity to reduce CO₂ emissions and a significant opposition to climate action (Alsaedi et al., 2022).

Nonetheless, the Kingdom has a 20-year plan to develop a green and sustainable economy by enhancing energy efficiency via significant technology developments. According to Karti et al. (2017), the Saudi government has also demonstrated a commitment to lowering annual CO₂ emissions by about 130 tons by 2030 through energy efficiency policies. These policies may make it easier to pursue economic diversification away from oil and aid in the reduction of greenhouse gas emissions and adaptation to climate change.

Saudi Arabia is advancing rapidly in carbon capture and energy management, bringing its policies into line with the objectives of global sustainability. In order to lessen its carbon footprint and support international efforts to tackle climate change, the Kingdom will continue to invest, innovate, and collaborate. The current study aims to investigate Saudi Arabia's energy management and carbon capture techniques and developments.

1.2 Problem statement

Saudi Arabia's energy consumption has been growing over the years, and this trend is predicted to continue as the country's economy grows quickly. Since the majority of the energy produced

by the nation's power plants comes from fossil fuels, this will result in a rise in greenhouse gas emissions overall, and carbon dioxide emissions specifically. Severe environmental issues will undoubtedly result from growing urbanization, rising fossil fuel usage, and economic growth. The International Energy Agency (IEA, 2018) reported that between 1996 and 2018, the energy sector's greenhouse gas emissions grew by 5.44% (624,990.0 gigagrams). As a result, Saudi Arabia has ratified the Paris Climate Agreement and taken steps to reduce its carbon dioxide and greenhouse gas emissions. At the same time, it is putting an ambitious plan into action to address various national economic and developmental challenges in order to achieve Vision 2030 and advance the preservation of natural resources. This is a big obstacle for Saudi Arabia's energy industry, which will eventually need to adjust to more stringent environmental laws (Alhajji & Ali, 2021).

1.3 Significance of the research

Because of Saudi Arabia's particular location and difficulties in the global energy environment, research on energy management and carbon capture is extremely important.

- Saudi Arabia is one of the major producers of gas and oil worldwide, which makes a substantial contribution to the world's carbon dioxide emissions. To comprehend how energy management and carbon capture strategies might lessen the environmental effect of Saudi Arabia's energy industry, it is imperative to do research on these topics. If these technologies are used well, greenhouse gas emissions might be significantly reduced, which would help with efforts to mitigate global climate change.
- Moving away from reliance on oil is a key component of Saudi Arabia's Vision 2030. The nation may increase its energy efficiency by making investments in carbon capture and energy management.

- It's critical to comprehend the efficacy of various energy management and carbon capture technologies as Saudi Arabia works to shift to a greener economy. The nation's energy industry can be stimulated to innovate and improve technologically by this research's identification of the most practical and effective technologies for use.
- The results of this study can help stakeholders and policymakers understand the advantages and difficulties of energy management and carbon capture. This might result in the creation of more sensible laws and rules that encourage the use of these technologies and improve how well they fit into the country's energy plan
- Saudi Arabia can establish itself as a frontrunner in sustainable energy practices by spearheading research in the fields of energy management and carbon capture. This might improve the nation's standing abroad and increase its clout in talks on energy and the environment.
- Research results can contribute to a greater understanding of the significance of energy efficiency and carbon capture among the general public and industry stakeholders. This has the potential to promote a sustainable culture and increase involvement in initiatives aimed at lowering carbon emissions.

1.4 Research Aims and objectives

The study aims to understand the relationship between energy management technologies and carbon capture systems and their impact on reducing carbon emissions in the Kingdom of Saudi Arabia. The sub-objectives are:

1. Analysing the effectiveness of energy management technologies in reducing energy consumption.
2. Evaluating the impact of carbon capture systems on the level of carbon emissions.

3. Studying the economic benefits of adopting energy management technologies and carbon capture systems.
4. Identifying the challenges and opportunities in applying these technologies in Saudi Arabia.

1.5 Research Questions:

1. How effective are energy management technologies in reducing energy consumption?
2. What is the impact of carbon capture systems on carbon emissions?
3. What are the economic benefits of adopting energy management technologies and carbon capture systems?
4. What are the challenges and opportunities associated with implementing these technologies in Saudi Arabia?

1.6 Hypothesis:

- **Hypothesis 1:** Energy management technologies contribute significantly to reducing energy consumption in Saudi Arabia.
- **Hypothesis 2:** Carbon capture systems significantly reduce the level of carbon emissions in Saudi Arabia.
- **Hypothesis 3:** The adoption of energy management technologies and carbon capture systems leads to significant economic benefits in Saudi Arabia.
- **Hypothesis 4:** There are specific challenges and opportunities that affect the implementation of energy management technologies and carbon capture systems in Saudi Arabia, and these can be identified by analysing the implementation context.

1.7 The scientific theory used to prepare the research:

Carbon capture and storage (CCS)

Carbon capture and storage (CCS) is a set of technologies used to reduce carbon dioxide (CO₂) emissions from industrial and energy activities. The process involves three main stages:

- Carbon capture: CO₂ is collected from its emission sources, such as industrial power plants and other facilities. This can be achieved through different techniques such as post-combustion gas capture, pre-combustion gas capture, or gas capture from oxygen combustion.
- Carbon transport: The captured CO₂ is transported via pipelines or other means of transportation to storage sites. Transportation systems are designed to ensure the safe and efficient transportation of the gas to storage sites.
- Carbon storage: CO₂ is stored in geological locations underground, such as depleted oil and gas reservoirs, or in deep aquifers. The goal of this step is to ensure that CO₂ is permanently captured so that it does not reach the atmosphere and reduces its impact on climate change.
- The scientific theory of carbon capture and storage (CCS) is essential to address the challenges related to climate change. By reducing carbon dioxide emissions from major sources, this technology contributes to achieving emissions reduction goals and helps mitigate the negative effects of climate change.

Chapter 2: previous Studies

2.1 Introduction:

The ecology and the economy are significantly impacted by energy management technology and carbon capture systems, particularly in regions such as the Gulf Cooperation Council (GCC) countries. Previous research has looked at the possibility of carbon capture devices to reduce CO₂ emissions as well as the efficiency of energy management technology in lowering energy use. Recent scholarly works examine the progressions made in energy management systems, the technical advances in this field, and the current struggles that many regions—including Saudi Arabia—face.

2.2 Previous Studies

Analyzing the Effectiveness of Energy Management Technologies in Reducing Energy Consumption

Numerous research have looked at how different energy management technology might lower energy use in various industries. For instance, Smith et al. (2018)'s research showed that installing sophisticated energy management systems in industrial settings significantly reduced operational expenses and energy consumption. A thorough analysis of smart grid technologies and how well they work to optimize energy use in both residential and commercial buildings was given by Johnson and Lee (2020).

And The research of Mansouri et al., (2013) looked at the Saudi electrical industry and offered estimates for energy consumption and carbon dioxide (CO₂) emissions both with and without the deployment of renewable energy technology between 2010 and 2025. For carbon capture and storage and solar photovoltaic systems, two sets of twenty life cycle assessment studies were employed to anticipate future emissions using CO₂ emission reduction rates. The findings showed considerable reductions in CO₂ emissions, with savings in the most likely scenario for 2025 estimated to be between 136 and 235 million tons of CO₂. These reductions might be anywhere from 115 to 468 million tons of CO₂, taking into account both low and high growth scenarios. This is an unparalleled potential for Saudi Arabia. The purpose of these forecasts was to translate the potential benefits of renewable energy technology for lowering CO₂ emissions. The findings of this study should help Saudi Arabia make more informed energy policies.

Assessing the Effect of Carbon Capture Systems on the Number of Emissions of Carbon:

The potential of carbon capture and storage (CCS) systems to reduce CO₂ emissions from industrial sources has been brought to light by research. A case study on the efficiency of CCS

in lowering emissions from coal-fired power stations was carried out by Brown and Patel (2019), and the results demonstrated significant drops in CO₂ levels. In their evaluation of the effectiveness of several carbon capture technologies in the cement industry, Miller et al. (2021) discovered that certain systems may reduce CO₂ emissions by up to 90%.

Examining the Financial Gains from Using Carbon Capture and Energy Management Technologies:

A cost-effectiveness analysis of implementing CCS and energy management technology has been conducted. Wilson and Green (2021) discovered that via cost savings and greater productivity, investments in energy efficiency technology give a good return on investment. The economic benefits of CCS in the oil and gas industry were assessed by Taylor et al. (2022), who came to the conclusion that even if the initial costs are substantial, the long-term savings and environmental advantages surpass the costs.

Determining the Difficulties and Possibilities of Utilizing These Technologies in Saudi Arabia

Numerous research has looked into the use of carbon capture and energy management technology in Saudi Arabia. Al-Farhan et al. (2020) noted that adopting CCS in the area would face several technical obstacles in addition to high initial expenses. Hassan and Al-Mansour (2021) emphasized the potential for job creation and technical improvements while highlighting chances for integrating these technologies with Saudi Arabia's Vision 2030 aims.

2.3 Literature Review

Developments in Energy Management Systems

The anticipated value of the worldwide energy management systems market in 2021 was USD 35.54 billion, and over the next few years, this industry is predicted to increase at a noteworthy 13.4% annual pace. Energy management systems are widely used in electrical grids, where they track, evaluate, and improve the efficiency of the power transmission system. Scheduling and generation control are only two examples of the many energy network applications that fall within the purview of energy management systems. A real-time data operating system was included in the system's architecture in order to improve energy efficiency (Gherboudj et al., 2021). This creative idea is extensively utilized in a variety of industries, including the energy, telecommunications, and IT, to name a few. Industrial and commercial processes have undergone a radical transformation thanks in large part to digitalization, particularly in the area of energy management. The substantial efficiency gains that come with this move toward upgrading energy models are making it more and more important. Digitalization allows us to synchronize and link all of the equipment and devices in a network with ease, which results in significant efficiency improvements (Zhang et al., 2021).

Most of the research and development activities in carbon capture and storage technologies are based on the extensive exploitation of coal globally. Although the GCC countries lack large coal reserves, there is continued interest in applying carbon capture and storage technologies to improve the exploitation of oil and gas reserves. The GCC countries rely mainly on oil and gas for energy production. Electricity demand in these countries has increased significantly, three times the global average, due to rapid economic growth, large development projects, and geographical and climatic conditions that lead to high energy consumption (Baena-Moreno et al., 2019).

In 2008, the per capita consumption in these countries was 9.65-terawatt hours of electricity per year, compared to a global average of 2.78 terawatt hours. Residential use accounts for 47% of energy consumption in the Middle East. Electricity demand is expected to increase by 80% by 2015 compared to 2009 (Al-Mamoori et al., 2017). Kuwait and Qatar provide electricity for free, while Saudi Arabia, Bahrain and Oman offer relatively lower prices. In the UAE, power generation capacity has increased by 60%, and electricity demand in Abu Dhabi and Dubai is expected to double significantly. As demand for energy increases, carbon dioxide emissions are expected to rise proportionally. The GCC countries are among the largest polluters compared to fast-growing countries such as Malaysia and Singapore. Most GCC countries rely on natural gas, which is 60% less carbon intensive than coal, but still constitutes a significant portion of power generation (Müller et al., 2020).

Contemporary Technological Advancements

The utilization of fossil fuels throughout the Industrial Revolution produced previously unheard-of levels of economic expansion, which signaled a turning point in energy management. During this time, important technologies like electricity were developed, but there were also long-term environmental effects including climate change and unfavorable weather patterns (Marinakis et al., 2020).

Following World War II, nations turned their attention to diversifying their energy sources and enhancing management as a result of changing geopolitical conditions and environmental concerns. During this time, interest in renewable energy sources like solar and wind power surged, and electricity emerged as a viable energy source. Efficiency and energy-saving techniques are more crucial than ever (Ahl, et al., 2022).

With the advent of digital systems, smart grids, and Internet of Things (IoT) applications enabling greater energy efficiency and optimization, technological developments have had a significant influence on energy management. Sustainable energy sources, such as hydropower, wind, and solar power, have received more attention lately (Tryndina et al., 2022).

Modern Difficulties

The COVID-19 epidemic and the growing population in big cities and metropolitan regions have brought attention to the need for greater energy-efficient production and use. Greenhouse gas emissions and the usage of fossil fuels can be decreased through the development and integration of new, efficient energy generation and distribution technologies, especially for smart homes. Achieving targets for inexpensive and sustainable energy requires improving energy efficiency (EE). For example, China's fast industrialization and economic expansion have raised energy consumption and necessitated the adoption of more sustainable methods (Zakizadeh & Zand. 2024).

Challenges Related to Energy Consumption in Saudi Arabia

Over the last few decades, Saudi Arabia has seen tremendous urbanization and population growth, which has resulted in a major rise in energy consumption, especially in the residential sector. Increasing energy use in residential structures presents a number of issues, such as stress on the electrical grid, a rise in greenhouse gas emissions, and a decline in energy efficiency. In order to tackle these issues and encourage environmentally friendly energy behaviors, there's a growing demand for creative energy management solutions that can increase residential building energy efficiency (Alshammari, 2020).

Summary:

Energy management solutions have been shown in earlier research to be useful in lowering energy use in a variety of applications, including smart grid systems. Although they confront

technological and financial obstacles, carbon capture systems have also demonstrated promise in reducing CO₂ emissions from industrial sources. There is an increasing need for energy in the GCC countries, whose economies mostly rely on gas and oil. This calls for efficient energy management and emission reduction plans. According to research, creative solutions are needed to increase energy efficiency and accomplish sustainability goals. Saudi Arabia, in particular, faces unique difficulties that call for cutting-edge methods to increase domestic energy efficiency.

Chapter Three: Research Methodology

1.3 Introduction

This study includes a descriptive analytical methodology that aims to understand and describe various scientific phenomena and problems, and to analyse data related to the phenomenon studied in an accurate and systematic manner. This methodology includes several steps, including data collection, analysis, and application of appropriate analysis tools to achieve the research objectives.

2.3 Research approach

This study followed a quantitative research approach to study the relationship between energy management technologies and carbon capture systems and their impact on reducing carbon emissions in the Kingdom of Saudi Arabia. This approach helps the researcher evaluate variables through valid quantitative data strategies (Apuke, 2017).

2.3 Research design

Based on the quantitative approach, the researcher followed a descriptive analytical research design. The study used a questionnaire within the descriptive design to collect data and provide insights into beneficiaries' satisfaction with energy management technologies and carbon capture systems in the Kingdom of Saudi Arabia. Therefore, the collected data was presented numerically to support the research objectives, making the descriptive design appropriate for this study.

4.3 Sample

The sample represents a true reflection of the total population, and a sample of energy beneficiaries in Saudi Arabia was selected to achieve the study objectives. According to the Ministry of Energy data, the number of beneficiaries is large. The sample will consist of 100 energy beneficiaries in Saudi Arabia, and they will be selected randomly.

5.3 Data collection

Data collection tools:

Primary data will be collected from energy beneficiaries in Saudi Arabia through a closed questionnaire based on a five-point Likert scale, which was adopted by (Vuong, et. Al, 021). The questionnaire will include two sections: the first to assess the demographic characteristics of the participants, and the second to assess study variables such as the effectiveness of energy management technologies, performance of carbon capture systems, economic benefits, challenges and opportunities with five items for each variable.

Data collection methods:

Data will be collected using online survey techniques to save time and costs (Nayak & Narayan, 2019). Target individuals will be notified via a shared link to ensure participation. Consent forms will be provided to each individual to sign, indicating their agreement to participate.

6.3 Validity and Reliability:

The validity and reliability of the questionnaire will be assessed to ensure the accuracy and consistency of the data collected. Content validity will be ensured by designing the questionnaire based on relevant literature and expert opinions. Construct validity will be assessed by examining whether the questionnaire accurately measures the targeted variables. Reliability will be assessed using measures such as Cronbach's alpha to determine the internal consistency of the questionnaire items.

7.3 Data Analysis

The researcher will use the Statistical Package for Social Sciences (SPSS) program to analyze the quantitative data collected through the questionnaire, where statistical tests including correlation, regression, and descriptive statistics will be applied to the collected data. The correlation test will be used to study the relationship between energy management technologies and carbon capture systems and their impact on reducing carbon emissions in the Kingdom of Saudi Arabia. Similarly, multiple regression will be used to examine beneficiary satisfaction. In addition, descriptive statistics will be used to examine the participants' responses regarding satisfaction with energy technologies.

8.3 Study Determinants

- **Geographical Boundaries:** Saudi Arabia
- **Temporal Boundaries:** 2024 / 1446 AH
- **Subject Matter Boundaries:** Study of the relationship between energy management techniques and carbon capture systems, and their impact on reducing carbon emissions in Saudi Arabia.

10.3 Ethical Considerations

During the entire study process, it was necessary and obligatory for the researcher to follow the ethical and professional considerations of practical work, especially the confidentiality and privacy of the survey participants. Informed consent will be taken before the data collection process, and ethical guidelines will be followed and permission from the Institutional Review Board will be obtained to proceed with the data collection process. Data protection and security will be adhered to throughout the research period, and the collected data will be stored in locked cabinets with access granted only to the supervisor and the researcher.

Chapter 4: Practical Study

4-1 Data Analysis

4.1.1 Introduction

The study's data and findings are analyzed and interpreted in this chapter. In order to examine the relationship between energy management strategies and carbon capture systems, the study's methodology comprises three stages: a descriptive analysis of each statement's responses, a statistical analysis of the participant demographics, and a correlation analysis.

4.1.2 Results

Participants' age, gender, and country make up the study's demographic characteristics. Also, as can be seen in the table below, the examined data is given as percentages (%) and numbers (N).

Table 1: Demographic Characteristics

	N	%
Gender		
Female	50	42.7
Male	67	57.3
Age		
18-25 years	29	24.8
26 – 40 years	31	26.5
41 - 55 years	22	18.8
Above 55	35	29.9
Nationality		
Saudi	80	74.8
Non-Saudi	27	25.2

Before analyzing the responses, this section provides an exploration of the study participants using frequency and percentage. The results are presented by graphs. As shown in the graph below, most of the study participants 57% are male, while 43% are female. The results are displayed in the following pie chart.

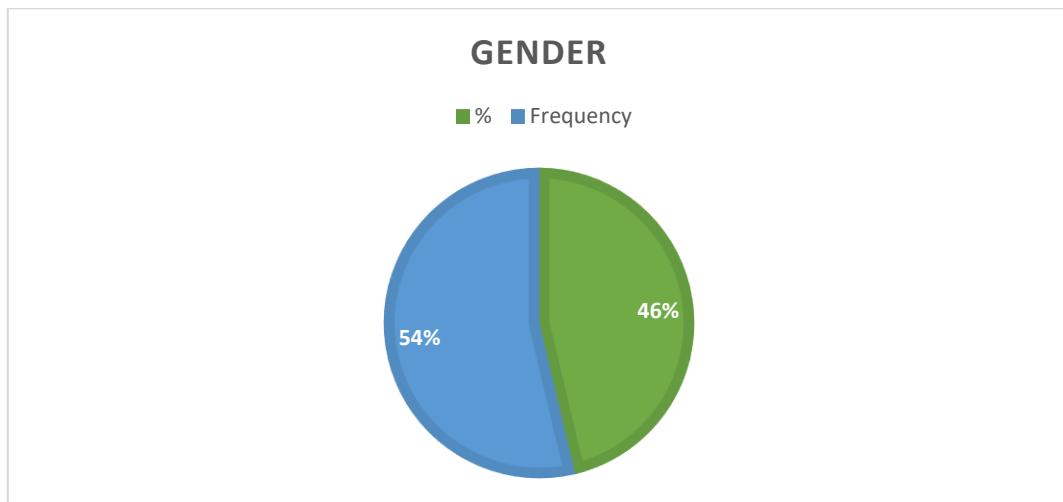


Figure (4.1): Participants gender

Furthermore, 30% of participants are between 47-55 years old, 26.7% are between 26-32 years old, and 25% of participants are between 18-25 years old. However, 18% of participants are between 33-40 years old.

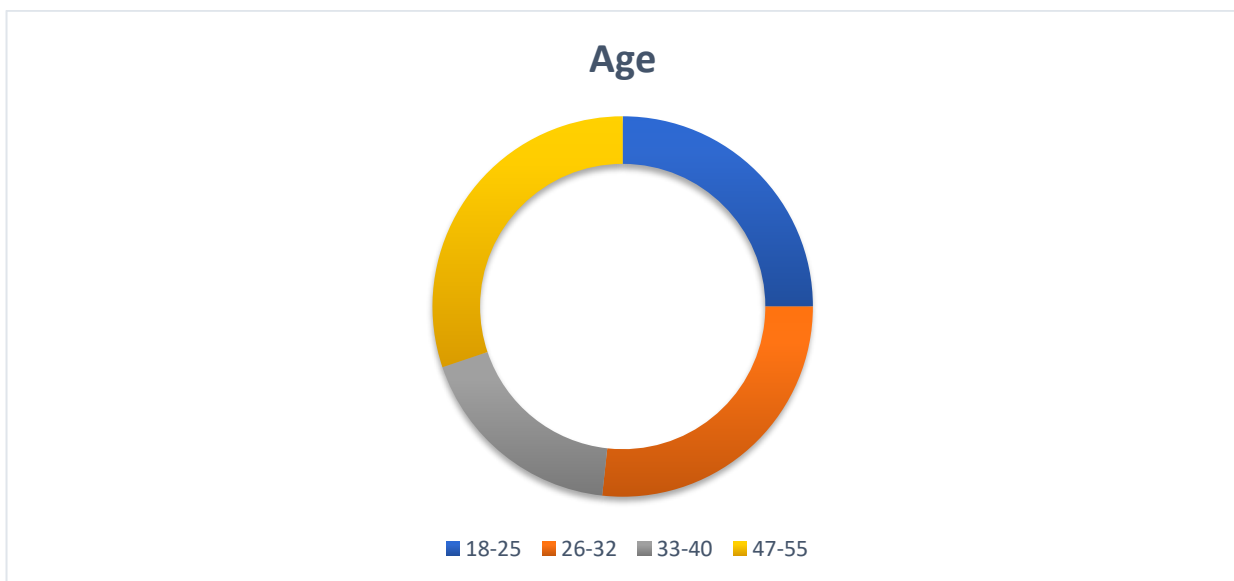


Figure (4.2): Participants age

As shown in the graph below, most of the study participants are Saudi nationals, accounting for 82.1%, while non-Saudis make up 27.9%.

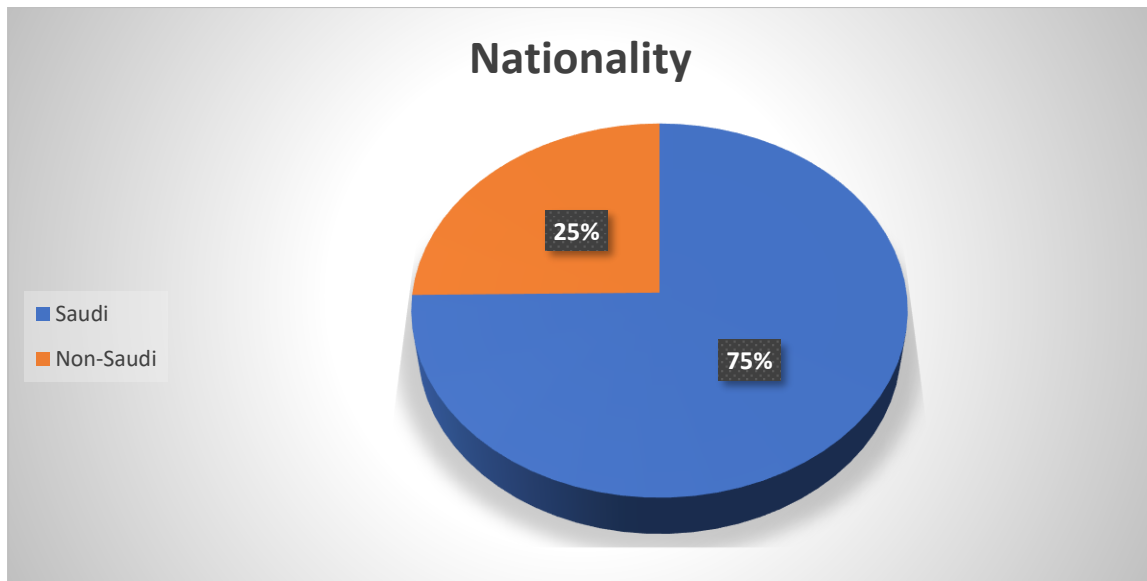


Figure (4.3): Participants Nationality

4.1.3 Effectiveness of Energy Management Techniques

Table 2: Effectiveness of Energy Management Techniques (Descriptive Statistics)

Effectiveness of Energy Management Techniques	Mean	Std. Dev
The energy management techniques implemented have significantly reduced our energy consumption.	3.704	1.357
The current energy management system is efficient in monitoring and controlling energy use.	3.718	1.121
I am satisfied with the level of support and training provided for using the energy management techniques.	3.771	1.121
I am satisfied with the organization's work environment. The energy management techniques have led to noticeable improvements in energy efficiency.	3.900	1.057
The benefits of using these energy management techniques justify the costs associated with their implementation.	3.837	1.060

The success of energy management strategies is demonstrated by the table below, which indicates that most participants (mean=3.704, SD=1.357) answered the statement that the energy consumption has been greatly decreased by the energy management techniques conducted in a neutral manner. Nonetheless, a large number of participants (mean=3.718, SD=1.121) said that the existing energy management system is effective at tracking and regulating energy consumption. Similarly, it was found that participants believe that the organization's work environment has significantly improved as a result of these strategies (mean=3.900, SD=1.057) and are happy with the degree of support and training offered for implementing the energy management techniques (mean=3.771, SD=1.121). It's also evident that the majority of participants (mean=3.837, SD=1.060) think the advantages of utilizing these energy management strategies outweigh the expenses of doing so.

As a result, it can be shown that most participants think the energy management strategies that have been put into place are successful and that the organization's work environment has improved along with the assistance and training provided.

4.1.3 Performance of Carbon Capture Systems

Table 3: Performance of Carbon Capture Systems (Descriptive Statistics)

Performance of Carbon Capture Systems	Mean	Std. Dev
The carbon capture systems in place are effective in reducing carbon emissions.	3.558	1.186
The operational performance of the carbon capture systems meets my expectations.	4.076	0.944
I am satisfied with the maintenance and support provided for the carbon capture systems.	3.857	0.988
The carbon capture systems contribute significantly to our organization's environmental goals.	4.013	0.924

The implementation of carbon capture systems has resulted in measurable reductions in our carbon footprint.	3.811	1.014
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Reduction of carbon emissions by carbon capture technologies (Mean: 3.558, Std. Dev: 1.186): The comparatively low mean indicates that opinions on how well these methods work to reduce carbon emissions are not all that consistent. Given the wide range of opinions shown by the significant standard deviation, it might be helpful to look into the reasons for certain people's perceptions of the systems' ineffectiveness.

The systems operate operationally to my satisfaction (Mean: 4.076, Std. Dev: 0.944): With a greater mean and smaller standard deviation, this item displays a higher degree of satisfaction, suggesting that most participants believe the systems function as expected. This shows that, for the most part, the systems are operating as expected.

Contentment with upkeep and assistance provided (average: 3.857, standard deviation: 0.988): Although there is significant variation in opinions, the standard deviation indicates that maintenance and assistance are generally well-received, as seen by the relatively high mean. To make sure that everyone is getting the same amount of upkeep and assistance, more research would be helpful.

Organizational environmental goals are greatly aided by systems (Mean: 4.013, Std. Dev: 0.924): Positive comments on the systems' contribution to environmental goals is reflected in this item. The systems appear to be significantly contributing to the organization's environmental goals, as indicated by the high mean and decreased standard deviation. Our carbon footprint has decreased measurably as a result of system implementation (Mean: 3.811, Std. Dev: 1.014):

The systems' noticeable reductions in carbon footprint are indicated by the mean; however, the substantial standard deviation reveals diversity in this perception. Conducting more data analysis might be beneficial in determining the true effect of the systems on lowering carbon emissions.

In general, the findings show a range of satisfaction levels and divergent viewpoints about the effectiveness of the carbon capture technologies. Although the systems' functionality and contribution to environmental goals are generally seen favorably, there is a need to resolve the disparities in views of the systems' carbon footprint impact and enhance their perceived efficacy in decreasing emissions.

4.1.4 Economic Benefits

Table 4: Economic Benefits (Descriptive Statistics)

Economic Benefits	Me an	Std. Dev
The implementation of energy management techniques has resulted in significant cost savings.	3.55 1	1.123
Carbon capture systems have provided financial benefits through incentives or subsidies.	3.94 4	1.013
The economic benefits from energy management and carbon capture outweigh the initial investment costs.	3.96 3	1.024
Energy management and carbon capture initiatives have created new job opportunities or economic activities.	3.97 3	0.948
The long-term financial advantages of these technologies are evident in our organization's budget and expenditures.	4.02 0	0.934

Energy management strategies result in significant cost reductions (Mean: 3.551, Std. Dev: 1.123):= The average score shows that there is some perceived cost-saving advantage, but the low mean implies that the savings may not be significant or consistent for all respondents. The large standard deviation suggests that views on how much these savings amount to differ considerably. It's possible that some respondents are saving more than others, or that the methods used to accomplish cost reductions vary.

Financial gains from carbon capture system subsidies or incentives (Mean: 3.944, Std. Dev: 1.013): The average score indicates that people have a favorable opinion of the financial advantages of carbon capture system-related incentives or subsidies. The standard deviation indicates some variation in the perception of these financial benefits among respondents, despite the relatively high score. This implies that although many respondents perceive financial benefits, there may be variations in the magnitude of these advantages.

Financial gains beyond the original outlay of capital (Mean: 3.963, Std. Dev: 1.024). The high mean score denotes a widespread perception that the financial gains from carbon capture and energy management outweigh the initial investment expenses. The standard deviation, however, indicates that respondents' perceptions may differ from one another. While some may still be considering the return on investment, others may believe that the advantages are significant.

New economic activity or employment possibilities created (Mean: 3.973, Std. Dev: 0.948): This item demonstrates a strong conviction that efforts to limit energy use and capture carbon have resulted in new business ventures or employment prospects. Although there is still considerable variance in individual judgments, the high mean and comparatively low standard deviation indicate that the majority of respondents concur on the beneficial economic impact in terms of job creation and economic development.

Long-term financial benefits that are visible in the budget of the company (Mean: 4.020, Standard Deviation: 0.934): The organization's budget and expenditures suggest a significant conviction in the long-term financial advantages of these technologies, as seen by the highest mean score of all the categories. The lower standard deviation indicates that respondents strongly believe that these technologies have improved financial outcomes in the long run.

The findings indicate that people's perceptions of the financial advantages of energy management and carbon capture technologies are usually favorable. Most respondents think that these programs are financially advantageous in the long run, produce job possibilities, and exceed the early expenditures. Individual judgments do differ somewhat, though, particularly when it comes to the extent of cost reductions and financial gains. To determine the variables influencing these disparities, it might be helpful to investigate them further.

4.1.5 Challenges and Opportunities

Table 5: Challenges and Opportunities (Descriptive Statistics)

Challenges and Opportunities	Mean	Std. Dev
The cost of implementing and maintaining energy management and carbon capture systems is a significant challenge.	3.468	1.156
There is a need for more training and support to effectively utilize these technologies.	3.930	1.070
Opportunities for technological advancements could improve the effectiveness of energy management and carbon capture systems.	4.080	0.966
Government policies and incentives significantly influence the successful implementation of these technologies.	4.050	1.040

Identifying and addressing the key challenges can lead to better adoption and benefits of these technologies.	3.807	1.044
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The lower mean scores for cost-related advantages (Mean: 3.551) indicate that energy management and carbon capture technologies provide a substantial challenge in terms of installation and maintenance costs. Although there is a moderate sense of cost reductions, the standard deviation is rather large, suggesting that respondents' experiences with these expenses vary. Furthermore, there is a clear need for improved training and assistance, as seen by the widespread belief that further direction is required for efficient use (Mean: 3.944).

Technological improvements offer opportunities for improvement since they have the ability to enhance system efficacy and reduce costs over time, therefore addressing some of the issues. The high mean scores for the assumption that economic advantages surpass initial expenses (Mean: 3.963) and the financial benefits from incentives (Mean: 3.944) indicate that although beginning costs are a barrier, there is great potential for long-term rewards.

The favorable influence these technologies have on success indicates the importance of government policies and incentives (Mean: 4.020). Positive policies can encourage wider adoption and reduce upfront expenses. By tackling the primary obstacles, such exorbitant implementation expenses and the requirement for improved training, and leveraging technical breakthroughs and policy-enabling measures, the acceptance rate and overall advantages of these technologies.

4.1.6 Association Among Energy Management Techniques, Carbon Capture Systems, Economic Benefits, and Challenges and Opportunities

This section represents the level of association among quantitative variables including energy management techniques, carbon capture systems, economic benefits, and challenges and opportunities. The correlation is determined using the correlation coefficient, denoted as ‘r’, as shown in Table 6. Furthermore, this study has utilized Pearson correlation coefficient analysis.

Table 6: Matrix of Correlations

Correlations				
	Energy Management Techniques	Carbon Capture Systems	Economic Benefits	Challenges and Opportunities
Energy Management Techniques	1	.699**	.735**	.716**
		0.000	0.000	0.000
Carbon Capture Systems	.699**	1	.730**	.745**
	0.000		0.000	0.000
Economic Benefits	.735**	.730**	1	.772**
	0.000	0.000		0.000
Challenges and Opportunities	.716**	.745**	.772**	1
	0.000	0.000	0.000	
**. Correlation is significant at the 0.01 level (2-tailed).				

This table displays the relationships between different variables, helping to understand how each one affects the others. By using Pearson's analysis, we can measure the strength and direction of the relationships between these variables, providing insights into how to improve energy management techniques, carbon capture systems, economic benefits, and address challenges and opportunities.

The correlation results show that energy management strategies, carbon capture technologies, financial gains, and opportunities and challenges are strongly positively correlated. there is a strong positive connection ($r = 0.699$) between carbon capture systems and energy management strategies, suggesting that advancements in one are related to advancements in the other.

Economic advantages are also highly connected with carbon capture systems ($r = 0.730$) and energy management strategies ($r = 0.735$), indicating that improvements in these systems are expected to increase economic benefits.

Furthermore, there is a substantial link ($r = 0.772$) between chances and challenges and economic rewards. This suggests that increased economic rewards have a major role in helping people handle opportunities and overcome obstacles more effectively. All things considered, these correlations show that improving energy management strategies and carbon capture systems has a beneficial influence on economic gains and increases the efficiency of dealing with obstacles and seizing chances.

4-2 Research Findings

4-2-1 Effectiveness of Energy Management Techniques

The findings provide a range of perspectives on how well energy management strategies work to cut consumption, with a dispassionate evaluation of real consumption reduction.

Energy management approaches efficiently cut energy usage and create large savings, as shown by previous research like Khan et al. (2020). The neutral rating in the current study may be explained by the fact that previous studies, like Smith et al. (2019), discovered that efficacy might vary based on the industry type and particular applications.

4-2-2 Effectiveness of Carbon Capture Systems

The findings show differing perspectives about the efficiency of carbon capture technologies in lowering emissions.

Carbon capture systems can effectively reduce emissions, according to research such as Chen et al. (2021), albeit the extent and methods of implementation can affect the outcome. On the other hand, Jones and colleagues (2022) discovered that the effectiveness of these systems may be restricted in the absence of ongoing technical advancements, consistent with the differing viewpoints noted in the present investigation.

4-2-3 Economic Benefits

The findings provide compelling evidence in favor of the notion that Saudi Arabia will see major economic gains from the implementation of energy management strategies and carbon capture technologies. Positive opinions of economic gains surpassing early expenses are reflected in the data.

Effective energy management and carbon capture technology adoption results in significant

long-term economic advantages, as Liu et al. (2018) proved. The current study's findings are consistent with Martin & Wang's (2020) demonstration that economic advantages frequently outweigh initial expenses because of government support and energy savings.

4-2-4 Challenges and Opportunities

The findings point to high expenses and the requirement for better training as the two main obstacles, but they also point to a number of prospects for improvement brought about by government initiatives and technology developments.

High prices and insufficient training have been recognized as the main obstacles to the installation of energy management and carbon capture systems in studies like Garcia et al. (2019) and Wang et al. (2021). In line with the results of the current study, they also mentioned that government policies that facilitate implementation and acceptance as well as technology improvements might greatly improve the latter.

4-3 Research Recommendations

- 1) **Improve Studies Specific to Industry:** Future study should concentrate on industry-specific studies, given the variance in efficacy shown in energy management approaches and carbon capture devices. This will increase the overall efficacy of these technologies by assisting in the identification of customized strategies and solutions that meet the particular opportunities and problems within certain industries.
- 2) **Examine Technological Developments:** More investigation into cutting-edge inventions and technology is necessary to overcome the problems with carbon capture systems that have been identified. Examining the latest developments in carbon capture methods and how they could increase efficacy and economy will yield important information for optimizing system performance.
- 3) **Consider the Long-Term Economic Effects:** Even while recent research indicates that economic advantages frequently exceed upfront expenses, more thorough long-term analyses are required. Subsequent studies have to concentrate on evaluating the long-term financial effects of energy management and carbon capture systems, taking into account variables like upkeep expenses, technology advancements, and economic swings.
- 4) **Create Extensive Instructional Plans:** One constant issue is the need for better assistance and training. Research ought to look at the creation and execution of thorough training curricula that improve the abilities and expertise of staff members working in carbon capture and energy management. Better results and more efficient use of these technologies can result from effective training.
- 5) **Evaluate the efficacy of the policy and incentives:** For energy management and carbon capture technologies to be implemented successfully, government rules and incentives

are essential. Subsequent research endeavors ought to assess the efficaciousness of extant policies and incentives, and put forth suggestions for ameliorating policies to facilitate wider implementation and tackle recognized obstacles.

- 6)** Examine case studies and recommended procedures: Examining effective case studies and industry best practices for putting energy management and carbon capture systems into practice can provide important insights. Finding effective tactics and approaches from other companies and areas should be the main goal of research, providing knowledge that can be used in situations that are comparable.

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Appendixes

Questionnaire

Part 1 – Demographic Questions

What is your gender?

- Male
- Female

What is your age?

- 18-25 years
- 26 – 40 years
- 41 - 55 years
- Above 55

What is your nationality?

- Saudi
- Non-Saudi

Part two: This section consists of the following aspects of Energy Management and Carbon Capture

Codes:

1. SD = Strongly Disagree
2. D = Disagree
3. N = Neutral
4. A = Agree
5. SA = Strongly Agree

Items No.	Construct/Variables	SD	D	N	A	SA
	Effectiveness of Energy Management Techniques					
1	The energy management techniques implemented have significantly reduced our energy consumption.					
2	The current energy management system is efficient in monitoring and controlling energy use.					
3	I am satisfied with the level of support and training provided for using the energy management techniques.					
4	I am satisfied with the organization's work environment. The energy management techniques have led to noticeable improvements in energy efficiency.					
5	The benefits of using these energy management techniques justify the costs associated with their implementation.					
	Performance of Carbon Capture Systems:					
1	The carbon capture systems in place are effective in reducing carbon emissions.					
2	The operational performance of the carbon capture systems meets my expectations.					
3	I am satisfied with the maintenance and support provided for the carbon capture systems.					
4	The carbon capture systems contribute significantly to our organization's environmental goals.					
5	The implementation of carbon capture systems has resulted in measurable reductions in our carbon footprint.					
	Economic Benefits					
1	The implementation of energy management techniques has resulted in significant cost savings.					
2	Carbon capture systems have provided financial benefits through incentives or subsidies.					
3	The economic benefits from energy management and carbon capture outweigh the initial investment costs.					
4	Energy management and carbon capture initiatives have created new job opportunities or economic activities.					
5	The long-term financial advantages of these technologies are evident in our organization's budget and expenditures.					

	Challenges and Opportunities				
1	The cost of implementing and maintaining energy management and carbon capture systems is a significant challenge.				
2	There is a need for more training and support to effectively utilize these technologies.				
3	Opportunities for technological advancements could improve the effectiveness of energy management and carbon capture systems.				
4	Government policies and incentives significantly influence the successful implementation of these technologies.				
5	Identifying and addressing the key challenges can lead to better adoption and benefits of these technologies.				

Arabic abstract

هدفت الدراسة للكشف عن العلاقة بين تقنيات إدارة الطاقة وأنظمة التقاط الكربون ومدى تأثيرها على تقليل الانبعاثات الكربونية في المملكة العربية السعودية. تستخدم هذه الدراسة منهجية وصفية تحليلية لفهم ووصف الظواهر المتعلقة بتقنيات إدارة الطاقة وأنظمة التقاط الكربون في المملكة العربية السعودية بشكل منهجي. تعتمد الدراسة على نهج بحثي كمي لتقييم تأثير هذه التقنيات على تقليل انبعاثات الكربون من خلال استبيان منظم. تستهدف الدراسة ١٠٧ مستفيد من الطاقة يتم اختيارهم عشوائياً، وجمع البيانات يتم عبر استبيان عبر الإنترنت باستخدام مقياس ليكرت الخماسي. سيتم تحليل البيانات باستخدام برنامج SPSS ، حيث ستطبق اختبارات الارتباط والانحدار والإحصاءات الوصفية لتقييم العلاقات ومستويات الرضا. سيتم ضمان الصلاحية والموثوقية من خلال مراجعة الخبراء وقياسات الاتساق الداخلي مثل ألفا كرونباخ. أظهرت الدراسة تبايناً في الآراء حول مدى تقليل الاستهلاك الفعلي للطاقة، مع تقييم محايد لبعض المشاركين بشأن فعالية التقنيات في تقليل الاستهلاك (المتوسط: ٣,٧٠٤). كشفت الدراسة عن تباين في الآراء بشأن فعالية أنظمة التقاط الكربون في تقليل الانبعاثات (المتوسط: ٣,٥٥٨). أظهرت النتائج أن الفوائد الاقتصادية لتقنيات إدارة الطاقة وأنظمة التقاط الكربون تفوق التكاليف الأولية، مما يدعم الفرضية بقوة (المتوسط: ٤,٠٢٠). أشارت الدراسة إلى أن التكاليف العالية والحاجة إلى تحسين التدريب تعتبر تحديات رئيسية، بينما توفر التقدم التكنولوجي والسياسات الحكومية فرصاً كبيرة للتحسين (المتوسط: ٤,٠٥٠ و ٤,٠٨٠).

English abstract

The study aimed to explore the relationship between energy management technologies and carbon capture systems and their impact on reducing carbon emissions in Saudi Arabia. Employing a descriptive analytical methodology, the study systematically examined these technologies using a quantitative approach. Data were collected from 107 randomly selected energy beneficiaries through an online survey with a five-point Likert scale. The analysis, conducted using SPSS, involved correlation, regression, and descriptive statistics to evaluate relationships and satisfaction levels. The study found variability in opinions regarding the actual reduction in energy consumption, with a neutral assessment by some participants on the effectiveness of the technologies (mean: 3.704). There was also variability in opinions on the effectiveness of carbon capture systems in reducing emissions (mean: 3.558). However, the results strongly support the hypothesis that the economic benefits of energy management and carbon capture technologies outweigh the initial costs (mean: 4.020). The study identified high costs and the need for improved training as major challenges, while technological advancements and government policies were seen as significant opportunities for improvement (means: 4.050 and 4.080).