ACHIEVING NET ZERO IN ENERGY-INTENSIVE INDUSTRIES USING AI APPLICATIONS FOR GREENHOUSE GAS REDUCTION: A QUANTITATIVE ANALYSIS

by

ATUL SAGGAR, MCA, B.Com (Hons)

DISSERTATION

Presented to the Swiss School of Business and Management Geneva

In Partial Fulfilment

Of the Requirements

For the Degree

DOCTOR OF BUSINESS ADMINISTRATION

SWISS SCHOOL OF BUSINESS AND MANAGEMENT GENEVA

February, 2024

ACHIEVING NET ZERO IN ENERGY-INTENSIVE INDUSTRIES USING AI APPLICATIONS FOR GREENHOUSE GAS REDUCTION: A QUANTITATIVE ANALYSIS

by

ATUL SAGAR

Supervised by

Dr. Bhawna Nigam

APPROVED BY

____

Dissertation chair

RECEIVED/APPROVED BY:

____

Admissions Director

Dedication

I dedicate this work to my beloved late grandparents, whose unwavering love, wisdom, and guidance have shaped me into the person I am today.

In loving memory of Mrs. Sneh Prabha Saggar and Mr. Ram Prakash Saggar, Whose kindness and compassion illuminated my path, Guiding me through life's challenges with grace and strength. And to Mrs. Usha Vohra and Mr. Ram Gopal Vohra,

Whose boundless love and unwavering support Have been a constant source of inspiration and encouragement.

Their legacy lives on in the values they instilled in me, And their memories will forever be cherished in my heart. With deepest gratitude and love.

Acknowledgements

I would always be thankful to my wife- Komal for her unstinted support throughout this journey.

To my wonderful parents- Mrs. Neena & Mr. Vipan Saggar and my parents in law- Mrs. Veena & Mr. Satish Samtani for their constant encouragement and blessings.

My sincere thanks and gratitude to my dissertation mentor-Dr. Bhawna Nigam, for her constant guidance during the DBA journey and motivation to complete the dissertation in the most efficient manner.

To my seniors- Mr. Durgaprasad for the inspiration instilled with his quote “If its to be Its Upto ME”, Mr. V.P. Ajan for showing the path of continued education and Mr. Ayman for the encouragement to go the extra mile.

To my dear participants in the research for their time and patience for those long interviews, follow-up questionnaires and numerous discussions. Without their sincere support, I could never finish the research work.

Finally, To The Almighty- my whole-hearted thanks and regards, without whose blessings, guidance and support, I would never have progressed this far in my life.

ABSTRACT

ACHIEVING NET ZERO IN ENERGY-INTENSIVE INDUSTRIES USING AI APPLICATIONS FOR GREENHOUSE GAS REDUCTION: A QUANTITATIVE ANALYSIS

ATUL SAGAR

2024

Dissertation Chair: <Chair’s Name>

Co-Chair: <If applicable. Co-Chair’s Name>

Through a detailed study of recent literature, this paper describes key areas where AI technology may be applied to maximize resource use, increase process efficiency, and eventually minimize emissions. Several AI-enabled scenarios are modelled in the quantitative study, considering various industrial contexts' energy consumption, output, and emissions. The study takes advantage of SPSS and Microsoft Excel as the key data analysis tool to evaluate the data provided from 16 different companies. This study evaluates the outcomes of several scenarios to determine the potential greenhouse gas reductions that AI applications could attain.

The study's findings provide significant insight into the viability and outcomes of AI-driven interventions in energy-intensive industries. The study explains the benefits of such interventions from an economic and environmental perspective, in addition to highlighting the need to use AI technology as a critical step toward net-zero emissions. Moreover, this study contributes to the growing corpus of knowledge on sustainable industrial practices by offering policymakers, industry stakeholders, and researchers a rigorous evaluation approach.

Our research highlights the potential of transformative AI applications to address the pressing issue of greenhouse gas emissions in energy-intensive sectors, as we conclude. In order to understand the potential of AI-driven approaches in achieving net-zero objectives, promoting sustainable growth, and ultimately clearing the way for a more environmentally friendly and sustainable industrial landscape, the quantitative study provides a data-driven framework.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

INTRODUCTION

1.1 Overview

Concerns over climate change and the need to slow global warming have made achieving net-zero emissions a primary aim for several businesses. Energy-intensive industries have historically made significant contributions to greenhouse gas emissions, placing them at the forefront of the sustainability issue Chen et al. (2022). The agreement to attain net zero GHG emissions suggests that there is a chance for revolutionary change in the relationship between the objective of lowering greenhouse gas emissions and artificial intelligence (AI) applications. Manufacturing, steel production, and chemical processing are examples of energy-intensive industries that have long been acknowledged as major contributors to global greenhouse gas emissions. These emissions have an impact on the entire planet, and even in 2023, their size will be substantial. Emissions reduction and the transition to a more resilient and sustainable future emphasize how urgently this problem must be resolved (Chen et al. 2022).

Artificial intelligence (AI) applications are becoming essential tools for increasing productivity, optimizing processes, and eventually reducing greenhouse gas emissions in energy-intensive enterprises in the face of this environmental crisis. Modern technology is being utilized to reduce pollutants, speed up industrial processes, and optimize energy consumption. Examples of this technology include machine learning algorithms and data analytics. This section will go into great depth on the case studies and specific examples that demonstrate the current applications of AI in many fields. Growing interest and studies are being done on the potential uses of AI that significantly advance the overarching goal of achieving net-zero emissions in energy-intensive sectors.

This section will look at the quantitative data and models that are now available. We want to evaluate the potential impact and scalability of AI applications on actual progress toward net-zero emissions. Even if artificial intelligence (AI) has enormous promise, there are several obstacles to its effective use in energy-intensive enterprises. The primary obstacles to the widespread adoption of artificial intelligence (AI) technology for cutting greenhouse gas emissions will be looked at in this section. A complete understanding of the challenges that need to be overcome to apply AI to reach net-zero emissions effectively will be offered through a thorough investigation of topics such as high implementation costs, the need for industry-wide collaboration, and data accessibility and quality.

As we start our quantitative study, we must recognize the importance of AI applications in changing the energy-intensive industries' landscape in the direction of sustainability and environmental responsibility. The worldwide responsibility to address climate change has reached a critical turning point due to the urgent need for innovative solutions in every industry. Among the main sources of greenhouse gas (GHG) emissions are energy-intensive industries, which are crucial to the global economy but also pose a significant environmental risk Chen et al. (2022). As the world strives toward its ambitious net-zero targets, there is an increasing need for innovative and sustainable solutions to reduce the environmental impact of these industries.

1.2 Research Problem

Manufacturing, the use of heavy machinery, and chemical production are a few examples of energy-intensive industries with large carbon footprints. The limitations of conventional methods for reducing emissions have led to a paradigm shift in favor of more complex and successful approaches Wang et al. (2018). A multimodal approach combining technological innovation, data-driven decision-making, and the integration of artificial intelligence (AI) technology is needed to handle the complexities of these organizations. This thesis aims to address the pressing need to reduce the harmful environmental consequences of energy-intensive businesses and get them closer to net-zero emissions Wang et al. (2018). The world needs help with the impacts of climate change, and innovative strategies to reduce greenhouse gas emissions are badly required, especially in businesses with high carbon footprints.

This study focuses on the confluence of artificial intelligence (AI) applications with the crucial goal of lowering greenhouse gas emissions in energy-intensive enterprises. The primary goal of the project is to respond to the following query: How can AI technologies be effectively applied to assist energy-intensive enterprises in making the transition to net-zero emissions more rapidly and easily? The complex organizational structure of industrial processes causes several issues, which makes this inquiry crucial Wang et al. (2018). Additionally, a comprehensive, data-driven plan for sustainable practices is desperately needed. The measurable impacts of AI interventions on the reduction of greenhouse gas emissions will be examined in this study using SPSS and Microsoft Excel as quantitative analytic tools.

Variables such as improved energy efficiency, streamlined processes, and the overall environmental impact will be taken into consideration. The study uses statistical models and real-world data to provide empirical evidence of the efficacy of AI applications in producing appreciable reductions in emissions Wang et al. (2018). The ultimate goal of this study's results is to enlighten scholars, business stakeholders, and legislators who are pursuing sustainable development. They draw attention to the crucial role artificial intelligence (AI) may play in assisting sectors of the economy that rely heavily on energy to reach net-zero emissions.

1.3 The Goal of the Study

The primary objective of this thesis is to assess whether AI applications can assist energy-intensive companies in achieving net-zero emissions. Among the target objectives is examining the state of emissions in companies that use a lot of energy. identifying and evaluating artificial intelligence applications that are currently being used to cut greenhouse gas emissions. Establishing a quantitative analytical framework to assess how AI projects help attain net-zero emissions. Explain the possibilities and challenges associated with using AI in specific industries. The need to achieve a sustainable future has increased due to climate change, and this has prompted a critical examination of energy-intensive industries and their consequences for the environment. The thesis subject, "Achieving Net Zero in Energy-Intensive Industries Using AI Applications for Greenhouse Gas Reduction: A Quantitative Analysis," addresses this pressing issue by examining the relationship between artificial intelligence (AI) and environmental sustainability.

Energy-intensive industries, which often contribute heavily to greenhouse gas emissions, are under investigation for their role in hastening climate change. This hypothesis is predicated on the recognition of artificial intelligence (AI) as a revolutionary force that is revolutionizing traditional industrial processes. As industries struggle to meet global climate objectives, integrating AI technology provides a workable solution to lower carbon footprints. Through evaluating the results of AI interventions, the project hopes to provide verifiable evidence of the potential for a green revolution in these sectors. The rationale for AI's application in this case is its capacity to maximize energy utilization, enhance process effectiveness, and identify opportunities for emission reduction.

Machine learning algorithms may be used to evaluate large-scale statistics, identify trends, and optimize operational parameters to lower energy use and boost productivity. Moreover, AI-powered predictive analytics may be used to forecast energy demands, enabling proactive measures to balance supply and demand and reduce unnecessary energy usage. The thesis will look at specific algorithms and uses of artificial intelligence (AI), showing how they are applied in practical situations and calculating how effective they are in reducing greenhouse gas emissions. Examining case studies from various energy-intensive industries, such as the usage of heavy machinery, manufacturing, and chemical production, is a major part of the research. The thesis conducts a comparative examination of AI deployment across many domains to pinpoint sector-specific opportunities and limitations. Understanding the unique characteristics of each company will enable the creation of tailored AI solutions, which will enable a targeted and effective approach to achieving net-zero emissions.

Based on recognized indicators for greenhouse gas emissions, energy consumption, and operational efficiency, a quantitative analysis will be carried out to evaluate the actual impact of AI applications on reducing carbon emissions within industrial contexts. The study will also benefit industry participants, decision-makers, and environmentalists searching for practical ways to slow down global warming. We'll talk about the results in relation to sustainable technologies Rodrigues et al. (2022). The thesis "Achieving Net Zero in Energy-Intensive Industries Using AI Applications for Greenhouse Gas Reduction: A Quantitative Analysis" is a crucial first step in realizing and using AI's promise for the improvement of sustainable industrial practices. By utilizing both a quantitative approach and real-world case studies, the study aims to provide useful information that can guide the integration of AI technologies in energy-intensive sectors, facilitate the transition to net-zero emissions, and support global efforts to combat climate change.

1.4 Importance of the Research

The thesis topic, "Achieving Net Zero in Energy-Intensive Industries Using AI Applications for Greenhouse Gas Reduction: A Quantitative Analysis," is crucial given the urgent need for sustainable practices in the contemporary global environment. Industries with high energy consumption, such as manufacturing, chemical production, and heavy machinery manufacture, are examples of industries that exacerbate climate change by producing large amounts of greenhouse gas emissions Rodrigues et al. (2022). Achieving net-zero greenhouse gas emissions has become imperative as the world grapples with the consequences of environmental degradation. This thesis addresses this requirement by highlighting the use of artificial intelligence (AI) technology to support the transition toward sustainability in energy-intensive businesses. To provide comprehensive and data-driven knowledge of the potential and effectiveness of adopting cutting-edge technology for greenhouse gas reduction, the thesis, "Achieving Net Zero in Energy-Intensive Industries," was written. This paper is not only an academic undertaking; rather, it has real-world ramifications that might shape industrial practices as we advance.

Energy-intensive industries have a big influence on the environment, but they are also essential to the growth of the world economy. The thesis aims to transform the way that companies that have traditionally been associated with large carbon footprints approach environmental sustainability by investigating the use of AI in these sectors. Furthermore, this thesis's quantitative analysis is quite important Le et al. (2011). Quantitative approaches provide a comprehensive assessment of the impact of AI applications on reducing greenhouse gas emissions Rodrigues et al. (2022). The study attempts to quantify the potential benefits of economic efficacy and environmental preservation using data-driven models and statistical studies. This process increases the validity of the recommendations and fortifies the conclusions. For stakeholders attempting to make rational judgments regarding sustainable practices in an environment where data-driven strategies are necessary for industry practices and regulatory decisions, the quantitative research done for this thesis is a valuable resource.

The thesis delves into the potential collaboration between technological innovation and environmental stewardship. By employing AI applications to optimize waste reduction, manufacturing process enhancement, and energy use, industries may provide a complete approach to sustainability Rogelj et al. (2016). By integrating AI, greenhouse gas emissions may be reduced, and these energy-intensive industries can take the lead in adopting innovative solutions to global problems. The study's dual impact underscores its transformative potential and suggests a future where environmental stewardship and economic success will coexist Rogelj et al. (2016). Furthermore, the idea is in line with the more general global objective of achieving net-zero emissions, as expressed in international agreements and climate accords.

The study provides helpful insights into how specific companies may contribute to these overarching goals as nations strive to meet their ambitious goals. The results may have implications for policy frameworks, investment decisions, and collaborative efforts between enterprises, governments, and the scientific community. The thesis, which is fundamentally at the intersection of environmental science, technology, and policy, offers an integrated assessment of the several challenges associated with achieving net-zero emissions in energy-intensive businesses Rogelj et al. (2016). Beyond the realm of scholarly study, the thesis topic, "Achieving Net Zero in Energy-Intensive Industries Using AI Applications for Greenhouse Gas Reduction: A Quantitative Analysis," has a significant bearing. It is an effort to address climate change, one of the most significant issues of our day, in a proactive and useful way. The research offers significant insights through a rigorous examination of AI applications and a robust quantitative analysis that might lead to a paradigm shift in the way energy-intensive sectors operate Rogelj et al. (2016). Doing this paves the way for a day when industries are economically viable while living in harmony with the environment, in keeping with the goals of global sustainability.

1.5 The Purpose of the Study and Research Questions

Examining companies with high energy use and greenhouse gas emissions is crucial now more than ever as the globe struggles to combat climate change. The goal of achieving net-zero emissions has drawn a lot of interest, which has sparked research into creative solutions and technical developments. This project is to investigate the role that artificial intelligence (AI) applications play in assisting energy-intensive firms in making the transition to net-zero emissions, with an emphasis on assessing the effect of these technologies on greenhouse gas reduction. The primary goal is to increase the body of knowledge on sustainable practices in economic sectors that have traditionally caused significant environmental challenges. Several significant study subjects will serve as the investigation's compass. Analyzing the synergistic relationship between renewable energy and artificial intelligence is crucial to creating comprehensive strategies that address energy consumption and the carbon footprint of production processes.

The purpose of this investigation is to provide a broad overview of contemporary technologies and their applications in the manufacturing, chemical production, and mining sectors. Through an analysis of the current level of AI applications, the research aims to identify opportunities and areas in need of future development Ashraf et al. (2022). It's critical to look at barriers like expense, technological complexity, and resistance to change to develop solutions for overcoming these challenges. The measurable effect of AI applications on reducing greenhouse gas emissions is the subject of the third inquiry. This issue seeks to develop a framework for evaluating the concrete advantages of AI interventions to enable a comparative comparison of their effectiveness in various industrial settings Ashraf et al, (2022). Additionally, creating thorough and successful plans requires an awareness of the social, economic, and regulatory variables that might obstruct the application of AI solutions. Understanding the economic viability of AI applications is essential to promoting widespread adoption and ensuring that sustainable practices are compliant with AI.

1. First, what state-of-the-art artificial intelligence systems are now being utilized in energy-intensive enterprises to reduce greenhouse gas emissions?
2. What are the primary barriers preventing energy-intensive enterprises from integrating AI extensively to achieve carbon neutrality?
3. To what extent can the emissions reductions achieved by the present AI technology be quantified in a meaningful and consistent way across various industries?
4. How much can artificial intelligence (AI) enhance the use of renewable energy in energy-intensive industrial processes, and how does this contribute to a general decrease in emissions?
5. What are the advantages and disadvantages of implementing AI technology for businesses, and how do these variables vary based on the industry and region?

CHAPTER II:

REVIEW OF LITERATURE

2.1 Introduction

The release of greenhouse gases, resulting from the overexploitation of fossil fuels and increasing global industrialization, is responsible for global warming and environmental issues. Therefore, achieving net-zero carbon emissions is crucial. Although most nations aspire to achieve carbon neutrality between 2050 and 2070, only a mere 4.5% of them have successfully accomplished this goal. Additionally, cross-national synergies have hindered the advantages of the complementary mitigation and adaptation approaches Yan et al. (2014). We analyze the results and objectives of the 26th United Nations Climate Change Conference of the Parties to design a strategy for attaining a carbon-neutral economy. Efforts to attain carbon neutrality, such as transitioning from fossil fuels to renewable energy, advancing low-carbon technologies, adopting low-carbon agriculture, modifying dietary habits, and enhancing the utilization of food and agricultural waste, are few. Furthermore, it is imperative to implement decentralized energy systems, foster the growth of resilient communities and structures, and promote the electrification of the transportation industry Yan et al. (2014). It is equally important to analyze the life cycle of carbon-neutral systems.

The excessive utilization of finite energy resources and the expanding global industrialization have led to the release of copious amounts of greenhouse gases, therefore elevating the Earth's overall temperature and giving rise to a multitude of environmental degradation issues Yazdani et al. (2020). The global mean atmospheric carbon dioxide (CO2) concentration increased from 285 to 419 parts per million (ppm) between the pre-industrial era, approximately 1850, and the present year, 2022 Sun et al. (2011). The United Kingdom Met Office predicts that the global average surface temperature will rise by around 1.09 °C between 1850 and 2022, with a range of 0.97 to 1.21 °C. Additionally, they predict that 2022 will maintain the pattern of being one of the hottest years globally.

Furthermore, it is projected that global greenhouse gas emissions will rise by 50% by 2050, mostly driven by CO2 emissions resulting from the utilization of non-renewable energy sources. In the absence of effective laws or technical solutions to restrict or control CO2 emissions, both the average atmospheric CO2 concentration and global surface and ocean temperatures will persistently increase. The ecosystem that supports human life has already suffered significant harm because of the rising global temperature due to greenhouse gases Gutowski and T.G. (2007). Instances of this damage encompass the eradication of some species, depletion of biodiversity, aridity, inundations, wildfires, ocean acidification, thawing of polar ice caps, and escalating sea levels.

2.2 Paris Agreement

The Paris Agreement refers to the international treaty that was adopted in 2015 during the United Nations Framework Convention on Climate Change (UNFCCC) conference in Paris UNFCCC (2020). On December 12, 2015, all 197-member parties of the United Nations Framework Convention on Climate Change (UNFCCC) unanimously ratified the Paris Agreement, a comprehensive framework for global efforts to combat climate change after 2020 UNFCCC (2020). This decision was made in response to escalating global temperatures and increasing levels of greenhouse gas emissions. Under the 2015 Paris Agreement, every country pledged to restrict the rise in global temperature to below 2 °C and make efforts to keep it below 1.5 °C. In February 2021, 124 nations worldwide expressed their commitment to achieve net-zero carbon emissions by either 2050 or 2060 and strive for carbon neutrality UNFCCC (2020).

Promoting sustainable development and achieving the objectives set forth in the Paris Agreement is imperative. To achieve net-zero or negative carbon emissions, a comprehensive approach including social, economic, environmental, and technical measures is necessary. This approach involves not just lowering CO2 emissions but also actively removing CO2 from the atmosphere. Utilizing carbon offset or removal initiatives to balance the total amount of greenhouse gas emissions produced by a nation, business, product, activity, or person over a specific timeframe will result in carbon neutrality, which is the state of having no net carbon emissions NBSC (2010). Furthermore, the IPCC emphasized the imperative of diminishing and gradually eliminating the use of fossil fuels, increasing the utilization of renewable energy sources, enhancing energy efficiency, and emphasizing the importance of implementing these actions in urban areas to attain carbon neutrality, as stated in its special report on global warming of 1.5 °C UNFCCC (2020). Furthermore, it is imperative to promote carbon removal or sequestration in both terrestrial and marine ecosystems to achieve a state of net-zero carbon emissions and foster sustainable development NBSC (2010).

Although several governments, regions, and cities have devised strategies to augment carbon storage or removal and achieve future carbon-free plans for transportation, agriculture, food waste, industry, and other sectors UNFCCC (2022). In summary, the study aids governments and citizens across various locations and nations in comprehending the favorable environmental, social, and economic outcomes of attaining carbon neutrality by offering pertinent and current data, strategies, and technology. The 26th United Nations Climate Change Conference of the Parties took place in Glasgow from October 31 to November 12, 2022. This conference was held at a crucial time for the worldwide green recovery. The correlation between human health and decreases in greenhouse gas emissions is widely recognized. Among the countries expected to present plans for reducing greenhouse gas emissions neutrality, attaining net-zero carbon emissions remains challenging.

This literature review addresses the implications of reaching carbon neutrality by 2050 or 2060 for most member countries. It does this by providing a methodical analysis of the implications of the 26th summit of the United Nations Climate Change Conference of the Parties for achieving carbon neutrality NBSC (2010). The evaluation also investigates international activities, mostly related to national policies or programs that are implemented to reach net-zero carbon emissions. Additionally, the assessment maps direct and indirect carbon emissions, thoroughly examines the links and synergies between adaptation and mitigation measures and suggests emissions reduction and atmospheric carbon removal as the two primary paths to carbon neutrality. Reviewing the life cycle analysis of several carbon neutral systems for the technologies or strategies to achieve these objectives, the paper also provides guidelines provided at the 26th United Nations Climate Change Conference.

Only those responsible for 55% and 32% of global emissions have submitted their 2030 targets for enhanced emission reduction, known as nationally determined contributions UNFCCC (2022). The 26th United Nations Conference of the Parties saw a shift in perspective as climate change ceased to be seen as a secondary issue. The 26th United States Climate Change Conference of the Parties in Glasgow has generated significant anticipation for states to establish new commitments to reducing carbon emissions. This event has attracted the attention of world leaders, government officials, companies, and citizens. It is crucial to contemplate a prior United Nations Conference of the Parties on climate change in the meantime. In 2015, a notable occurrence took place for the very first time Wagner et al. (2019). At the 21st United Nations Conference of the Parties, every country pledged to collaborate to mitigate the most severe consequences of climate change by ensuring that global warming remains far below 2 °C, with a target of 1.5 °C UNFCCC (2020). Additionally, each national party pledged to allocate funding to fulfill these objectives simultaneously.

There were four main areas where the 26th United Nations Climate Change Conference of the Parties achieved progress: coal, vehicles, money, and trees Gutowski and T.G. (2007); UNFCCC (2020). A global agreement to quickly phase out coal, the most polluting fossil fuel, is necessary for the first two goals to be achieved. The development of electric cars and the prompt replacement of fuel-based transportation by electric transportation are the second Wagner et al. (2019). With respect to the last two objectives, wealthy nations' 2010 commitment of about $310 per person in the US in yearly financial help to poor nations will need to be fulfilled. In addition, solutions to climate change—which are a component of the biology of global change—should be put into practice and provided.

Global warming must be kept to less than 1.5 °C to prevent the impending issue of global environmental change. Global warming has not yet been kept to 1.5 °C. If targeted changes are not made, global temperatures will increase further, resulting in more extreme weather events, devastating floods, bushfires, and the extinction of species Wagner et al. (2019). By bending the temperature curve to 2 °C, experts have achieved some headway in the fight against global warming. To maintain the temperature curve at 1.5 °C, however, extensive effort must be made, according to scientific data. Leading nations and those with high carbon emissions must take the initiative, and objectives must be swiftly implemented Wagner et al. (2019). The global community must quickly phase out the use of fossil fuels for electricity generation while supporting poorer nations.

2.3 Global environmental issue: GHG emissions

The phenomenon of global warming has already resulted in disastrous weather conditions for individuals worldwide. Humanity must undertake resolute measures to address the grave challenges posed by climate change, since it poses a threat to human security. To assist individuals who are in the greatest need, it is imperative for governments to unite. To mitigate the worst effects of climate change, it is imperative to implement adequate preventive measures. Simultaneously, implementing financial measures for dependable infrastructure and early warning systems is crucial. Habitat conservation and restoration are crucial to alleviate the adverse impacts of climate change and address the challenges related to the management of natural storms and floods.

Reform is necessary for every financial industry practitioner to align with the stated climate aims. Authorities should allocate a designated sum of financial resources to mitigate the adverse impacts of climate change on residential life CCPI (2022). It is imperative for governments to promote the development of environmentally friendly and robust infrastructure while also offering assistance for technological advancements. Developed nations must provide essential assistance to impoverished nations and allocate a substantial amount of public funds towards efforts that promote resilience to climate change Gutowski and T.G. (2007); UNFCCC (2020). Companies must prioritize anticipating and acknowledging the risks posed by climate change to their businesses. National banks and regulators must ensure the resilience of regional financial systems to the adverse impacts of climate change while also assisting firms in transitioning to zero emissions.

The 26th United Nations Climate Change Conference of the Parties reached a consensus that member nations would collectively assume the responsibility of attaining a net-zero economy through individual national efforts. The focal point of debate during the 26th United Nations Climate Change Conference of the Parties is the Paris Rulebook, which encompasses the necessary laws for the full execution of the Paris accord. This will require worldwide cooperation among governments, domestic industries, and financial institutions (CCPI, 2022). Each nation should formulate policies that are tailored to its own circumstances and not only make commitments to the global population but also cooperate in addressing and resolving the global problem of climate change. To ensure that global temperatures remain below 1.5 °C soon, it is imperative for nations to reach a consensus. This section outlines the four main outcomes of the 26th Conference of the Parties to the United Nations on Climate Change UNFCCC (2020). These four objectives will significantly influence the global strategy for tackling carbon emissions and the extent to which nations contribute to achieving net-zero carbon emissions.

The prevailing ecological and environmental challenges that mankind is now facing are global warming and environmental degradation. Unless several governments worldwide execute successful programs, laws, and other steps, the deteriorating natural environment will continue to have an enduring influence on future generations Choi et al. (2017). In 2020, the continuous use of fossil fuels will result in a record-breaking increase in global carbon dioxide emissions, intensifying the issue of global warming. Consequently, the implementation of global climate accords has also profited from the increasing recognition of the necessity to diminish the use of fossil fuels. One example is the 2015 Paris Climate Agreement by the United Nations, which requires all countries to adopt measures to restrict global warming to a level below 1.5 °C. It is necessary for each nation to implement legislation or develop systems to effectively reduce carbon emissions Choi et al. (2017). Different regions, municipalities, and organizations employ diverse programs, methodologies, or strategies to reduce carbon emissions, with the goal of achieving carbon neutrality globally.

The Chinese government has developed a set of guidelines titled "Guidance on Accelerating the Establishment of a Sound Green Low-Carbon Circular Development Economic System" with the goal of progressively attaining net-zero CO2 emissions Pirson et al. (2021). The rules stipulate the objective of attaining the maximum level of carbon emissions by the year 2030 and carbon neutrality by the year 2060 Sun et al. (2011). Additionally, the study by Cheng and colleagues highlighted how some Nordic nations have used Pigouvian tax systems to achieve carbon neutrality by leveraging tax legislation. The analysis conducted by Sen et al. from Victoria University suggests that Australia has the potential to achieve its objective of being carbon neutral in the future Sun et al. (2011). Furthermore, it was proposed that this program and strategy should be explicitly included in university educational institutions. Academics suggested that efforts should be made to generate, broaden, and disseminate knowledge and understanding of carbon neutrality. According to Pirson et al. (2021), For a nation to achieve the goal of carbon neutrality by 2050 or 2060, it is necessary to establish programs, legislation, and policies that focus on reducing greenhouse gas emissions.

Table 1 below shows the level of carbon emissions in some regions before the Paris agreement.

Table 1
GHG emissions in nine EE countries: 2018 data and historical evolution

Country	**Income Category**	**GHG Emissions 2018 (Total, kt of CO_2)**	**% Change (Relative to 2015)**	**% Change (Relative to 1990)**	**% Change (Relative to 1970)**
Austria	High income	74,980	−0.66	−1.68	9.6

Bulgaria	Upper middle	53,330	−6.94	−45.77	−39.42
Croatia	High income	22,550	−0.62	−21.4	−12.4
Czech Republic	High income	122,840	0.45	−32.63	−42.2
Hungary	High income	60,920	4.44	−31.64	−30.56
Poland	High income	389,650	6.39	−11.91	−16.42
Romania	Upper middle	109,010	0.85	−55.54	−38.16
Slovak Republic	High income	39,930	5.72	−40.39	−25.37
Slovenia	High income	17,170	5.27	−3.32	54.52
European Union	Aggregates	3,567,090	−1.50	−21.69	−22.38
World	Aggregates	45,873,850	3.27	53.69	69.54
		Average	1.65	−27.14	−15.60

Energy models have shown sophisticated energy systems since the 1970s. They can be utilized in an investigative manner to examine probable future advancements for the system, such as by applying scenario or game techniques Shin et al. (2017). Furthermore, they may be employed to examine the many elements of the system within a cohesive framework and to understand the operation of the system for a particular duration with meticulousness. They provide a systematic analysis of the implications of significant system reconfigurations and formalize the many elements of the system and their interdependencies Shin et al. (2017). Energy modeling analysis has influenced discussions on energy policy and climate change over the past ten years. This analysis has been used in national energy planning discussions, especially when addressing the reduction of carbon emissions from energy systems.

The 2015 Paris Agreement and the publication of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C have recommended that more aggressive measures need to be taken to limit the temperature increase to 1.5°C. The reduction of CO2 emissions to a net zero level by the year 2050 is imperative UNFCCC (2020). Concurrently, it is necessary to reduce non-CO2 emissions in alignment with the 2°C goals. Several countries, such as the United Kingdom and Sweden, have implemented legislation mandating the achievement of net-zero greenhouse gas emissions Lian et al. (2012). Many researchers are now investigating the consequences of how these aims may be achieved. To achieve this objective, energy modelers must consider how to facilitate this agenda, as it necessitates energy systems to achieve near-zero emissions, if not negative emissions. Currently, national modeling teams are commencing their efforts to tackle the supplementary challenges that arise from heightened ambition Lian et al. (2012). These actions encompass the elimination of residual emissions, sometimes referred to as emissions "headroom," by the target year of achieving net-zero emissions; expediting the pace of mitigation efforts; investigating novel pathways for fuel technology; and devising a framework for climate policy that considers equality.

2.4 Optimization of Industrial Processes in Reduction of GHG Emissions

When trying to reach net-zero energy use, one of the biggest problems is figuring out how many public preferences, big unknowns, and political factors are considered in energy models. It is essential to recognize that models do not have exclusive authority in decision-making, and their ability to consider several factors is limited Pirson et al. (2021). The expert session focused on the difficulties related to integrating net-zero emission objectives into energy system modeling Neugebauer et al. (2011). The workshop had a substantial influence on the topics discussed in this study, namely the endorsement of government energy and climate policy. University College London (UCL) and the UK Energy Research Centre (UKERC) co-organized the workshop, "Hitting net-zero: the role of energy modeling in national pathway analyses," which took place in London in January 2020, Pirson et al. (2021). The workshop comprised model practitioners, government consumers of model outputs, advisory and consulting firms, and academic institutions. The emphasis was placed on energy systems models that offer a comprehensive view of both the energy-consuming and energy-supplying sectors.

The ideas discussed at the workshop were classified into three broad categories: (1) practice, (2) function, and (3) scope. According to Milfont et al. (2010), Due to the growing strictness of the net-zero objective, scope (1) concentrates on the possible enlargement of models to incorporate a broader range of options for mitigation. The second function relates to the models' capacity to accurately depict net-zero energy systems Neugebauer et al. (2011). The determination of this is contingent upon the composition of the model, encompassing its paradigm, underlying equations, and associations with other models that are better suited for describing facets of the system Ashraf et al. (2022). The effective application of models for doing net-zero analysis is discussed in Practice (3). This involves increasing involvement and cooperation with colleagues and stakeholders from other disciplines throughout the modeling process, while also considering the elements of unpredictability and scenario formulation.

The three topics are tightly interconnected and of paramount significance. To better understand changes in how people use energy, we need to use stronger multidisciplinary methods that include more information about sociotechnical transitions and make connections between models stronger. Furthermore, it is crucial to improve the portrayal of these interactions within the model Neugebauer et al. (2011). The need to modify the model function may come either from the need to broaden its scope or from the recognition that, to reach net-zero objectives, particular existing options, such as storage in a system with increasing quantities of renewable electricity, must be represented more precisely Milfont et al. (2010). This is a crucial phase for the country-led system of Nationally Determined Contributions (NDCs) created under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement Milfont et al. (2010). The support provided to national efforts in developing low-emission development plans that strengthen NDC commitments will influence longer-term goals, such as achieving net-zero emissions.

The energy modeling procedure raises inquiries while endeavoring to forecast a net-zero future. Here are four recommendations for enhancing the current methodology: To achieve congruence with overarching policy goals, there ought to be: (i) a more thorough and extensive redesign of the future energy system that considers a broader spectrum of uncertainties; (ii) deeper contemplation on the choice of objectives and their execution; and (iv) enhanced involvement and cooperation within the research community Milfont et al. (2010). Primarily, modeling should aid in developing scenarios that integrate significantly transformed future economic systems. To achieve net-zero goals, it is necessary to thoroughly investigate rapid technological and economic advancements Ashraf et al. (2022). Furthermore, it is crucial to document any related disruptive incidents or potential socio-political changes to analyze their potential repercussions (Turner III et al. 2010).

Several examples include the ongoing COVID-19 pandemic, which may have enduring effects on work and travel patterns as well as economic sectors; potentially disruptive alterations caused by the impacts of climate change; or significant policy shifts driven by the recognition that climate change necessitates drastic actions Yang et al. (2022). These circumstances may be seen as unlikely or unconventional within the existing political context, but they align with the substantial movement towards achieving net-zero requirements, thus being logical. Subsequently, essential discussions on the practicality and viability of political mechanisms may commence.

Modelers will face a significant challenge in replicating such a dramatic shift. Expanding the scope of disciplines will be essential to facilitate the understanding of these concepts, whether they are loosely connected to other fields of study or internally simulated. One possible approach to doing this is to engage in collaboration with researchers from many fields who are studying alternate futures, such as automation, digitalization, or other changes to work processes. As a result, there will be more focus on uncertainty analysis Li et al. (2013). The energy modeling community may considerably benefit from the experience of other disciplines, notwithstanding the progress gained in utilizing formal uncertainty analysis approaches.

The writings on strong decision-making and post-normal scientific thinking are remarkable. The study on decision-making under high ambiguity is a significant contribution that introduces innovative ideas in this field Turner III et al. (2010). These approaches offer insights into the most vulnerable aspects of the model solutions when dealing with different types of uncertainty, as well as strategies for effectively addressing uncertainty on a large scale Li et al. (2013). In addition, models are well-equipped to examine a range of climatic goals and the impacts of attaining them at various timeframes and using diverse approaches.

While the establishment of national goals is a political concern, models may be employed to demonstrate the impacts of various allocation systems for future global carbon emission budgets, as well as the repercussions of achieving net-zero emissions at different timeframes on domestic actions Leo Kumar and S.P. (2019). It is crucial to consider the implementation of targets, and models can provide more insight into the distinctions between setting cumulative carbon budgets and a singular net-zero target year at a certain point in time Turner III et al. (2010). The report investigated both scenarios for the UK and showed how adopting a cumulative budget approach and addressing equity issues need significantly more action compared to the government's existing climate plan Leo Kumar and S.P. (2019). The main contention is that the adoption of a net-zero aim does not fully address the issues of policy ambition or the speed of implementation.

The third challenge is aligning net-zero studies with other governmental objectives. To assist policymakers in attaining net zero emissions and fostering a more sustainable economy that has the potential to reduce inequality and advance the United Nations' Sustainable Development Goals (SDGs), modelers must ensure that their efforts are not just focused on meeting an emissions target Omer and A.M. (2008). An increasing number of national discussions will focus on strategies for combining these objectives and achieving their mutually beneficial advantages. Examples encompass investigating strategies to reduce income inequality and unemployment in South Africa while concurrently transitioning the economy to a low-carbon state Omer and A.M. (2008). This approach also acknowledges the benefits of sustainable land and forestry management as a component of a broader objective to enhance environmental quality in China and India Ashraf et al. (2022). Notably, the reduction of air pollution in these countries has been associated with the process of decarbonization.

The issues of involvement regarding models, including their accessibility, openness, communication, input assumptions, and outputs, have not yet been answered. Both international and domestic experiences can be utilized for learning purposes Kholopov et al. (2019). An enhanced interdisciplinary strategy is required to advance towards novel solution domains that surpass conventional technical reasoning and tackle socio-political issues Turner III et al. (2010). This involves engaging with the authorities and other stakeholders at an early stage in any future policy cycle. Furthermore, modeling must provide the capability to evaluate the sociopolitical feasibility of different decarbonization techniques within certain political and economic frameworks Kholopov et al. (2019). For the modeling community to be recognized as a member of a broader research community and engage in collaborative efforts to get access to a more diverse range of academic expertise, it is imperative to enhance participation.

Expanding one's peer group involves being open and receptive to criticism in several aspects, such as sharing the model source and providing clear and transparent documentation of findings. Additionally, it includes utilizing interactive approaches like conducting well-structured workshops Kholopov et al. (2019). Enhancing transparency in modeling assumptions would enable more profound and systematic criticism. The digital business services (DBS) industry has experienced significant growth in recent years and has played a crucial role in facilitating the adoption of digital technologies Chen et al. (2022). The utilization of this technology in state-of-the-art products has completely transformed business processes across several sectors of the economy.

If DBS firms are genuinely committed to reducing their adverse environmental impacts, they should have the capability to enhance their clients' performance to a greater extent Chen et al. (2022). For instance, they should have the capability to promote the digitization of corporate operations in ways that reduce greenhouse gas emissions and minimize energy waste Kholopov et al. (2019). What are DBS's business procedures regarding greenhouse gas emissions and other related issues? This research examines the ESG disclosures of leading companies that provide information technology, marketing, and consulting services Chen et al. (2022). Analyzing the goals, aims, and activities of DBS businesses with above-average ESG ratings using the Refinitiv dataset as a benchmark.

Based on the data, all these firms have clearly defined objectives to achieve net zero, and almost all of them have set explicit timelines. Energy efficiency-promoting services are among the several relevant efforts being implemented. These firms may gain knowledge from one another, and those with lower ESG ratings can adopt models from others, benefiting from the diverse range of initiatives. Most governments worldwide have recognized that tackling climate change is crucial as a fundamental aspect of sustainable development Omer and A.M. (2008). The World Economic Forum report highlights the significant peril of insufficient action in mitigating climate change over the next decade.

Two of the over 40 carbon-pricing mechanisms now in use are emission trading systems and carbon taxes. These mechanisms collectively address 50% of each nation's greenhouse gas (GHG) emissions and contribute to 13% of global emissions Yazdani et al. (2020). The introduction of the EU carbon border tax marks the inaugural implementation of a carbon tax as a direct reaction to allegations of affluent nations engaging in the practice of relocating their emissions overseas Yazdani et al. (2020). The Carbon Border Adjustment Mechanism The suggested reduction in global carbon emissions through the implementation of CBAM is anticipated to be somewhat lower than the significant effort required for its implementation, rendering it a controversial policy (Ashraf et al. 2022).

One of the Sustainable Development Goals (SDGs) of the United Nations (UN) is to promptly address climate change to diminish poverty, enhance well-being, foster peace, and ensure the long-term sustainability of the planet Chen et al. (2022). The incorporation of SDGs into company policy and decision-making processes is imperative, given that the private sector, which is recognized as a key contributor to global warming, has already been acknowledged Yazdani et al. (2020). In 2019, PwC conducted a survey including 1141 organizations from 31 countries across 7 industries. According to Ashraf et al. (2022), these industries include consumer markets (20% representation), financial services (20% representation), technology, media, and telecoms (20% representation), health (2% representation), industrial manufacturing and automotive (21% representation), and energy, utilities, and mining (23% representation).

Based on this research, 25% of firms integrated the Sustainable Development Goals (SDGs) into their public plans, whereas 72% of enterprises included them in their integrated, annual, or sustainability reporting Chen et al. (2022). In addition, 41% of mining and metals companies aspire to attain carbon neutrality between 2030 and 2040, with 77% of these enterprises having already established a target for carbon neutrality Kucukvar et al. (2016). The objective of the 2021 Glasgow Climate Change Conference (COP26) was to set the worldwide climate agenda for the next decade UNFCCC (2020). Nations have pledged to decrease coal production and methane discharges by 2030. 500 global financial institutions have pledged to match their portfolios with the goals of the Paris Agreement and avoid financing environmentally harmful energy enterprises (Bäckstrand et al. 2017).

The phrase "environmental, social, and governance" (ESG) encompasses the concept of integrating sustainability factors into a company's strategy and operations Bäckstrand et al. (2017). Goldman Sachs used these three factors in their Environmental Policy Report, which was originally developed by the United Nations Principles for Responsible Investment in 2006 Yan et al. (2014). The initial component encompasses the management of resources, preservation of the environment, and, notably, the reduction of greenhouse gas (GHG) emissions to improve environmental performance in production and operation Chen et al. (2022). The government dimension focuses on implementing policies to enhance social and environmental laws, as well as improving corporate systems Yan et al. (2014). On the other hand, the social dimension involves initiatives that engage customers, employees, and human rights. Despite the absence of established standards for ESG disclosure, investors largely depend on it as a prominent indicator of non-financial performance in the present day.

International regulatory frameworks assist investors in assessing climate change issues. Companies' ability to meet investor expectations and adhere to responsible investing principles now plays a crucial role in their long-term profitability and access to finance Yan et al. (2014). This depends on their ability to establish clear ESG objectives and restructure their operations accordingly Bäckstrand et al. (2017). Businesses must not only quantify emissions but also model the climate-related risks and opportunities that might affect their financial outcomes and goals Kucukvar et al. (2016). The UK will become the first among the G20 nations to mandate financial institutions and big private enterprises to disclose climate-related financial information in accordance with the criteria established by the Task Force on Climate-Related Financial Disclosures.

The Prudential Regulation Authority and the Bank of England both hold the view that banks may need to hold extra capital to counterbalance the risks linked to climate change. Consequently, this might lead to increased expenses for lending to fossil fuel businesses and projects with a significant carbon footprint. Diminishing investments in assets and enterprises that are considered to have a lower level of environmental sustainability may jeopardize the commercial partnerships that financial institutions maintain with their clients Le et al. (2011). Nevertheless, investing in eco-friendly assets may entail some risks, including fluctuations in asset prices and the emergence and collapse of "bubbles" driven by mistaken perceptions of the supply and demand dynamics in the eco-friendly manufacturing sector Diaz et al. (2011). Consumer demand for ecologically sustainable products with reduced carbon footprints is increasing.

The need for standardization of the ESG disclosure framework has arisen because of investors' growing emphasis on ESG performance. The Global Reporting Initiative (GRI) standards have emerged as one of the solutions. These standards offer comprehensive and reliable data on the economy, environment, society, and global transparency. The 2014/95/EU Directive on non-financial and diversity reporting has had an impact on Europe. Starting in 2017, it is required for large companies to report non-financial information Van der Ven et al. (2017). In 2019, the European Council passed the Sustainable Finance Disclosure Regulation (SFDR) with the aim of integrating ESG-related disclosure information into the investment decisions of the financial industry. In 2021, this became functional.

According to a survey conducted in 2019, a significant majority of investment firms, namely 82%, reported incorporating the environmental, social, and governance (ESG) agenda into their decision-making processes. This strategic approach was deemed crucial for attracting investments from potential investors Van der Ven et al. (2017). ESG rules consider the indirect impacts of a covered company's utilization of suppliers and contractors, in addition to its direct activities. Businesses are required to consider emissions from the whole value chain according to the Scope 3 Standard. This means that B2B services may have substantial emissions associated with their own suppliers. Financial service providers should give special consideration to these factors Van der Ven et al. (2017). The immediate consequences of their actions suggest that they are unlikely to make many disclosures.

Nevertheless, the broader range of loan and investment options pursued by financial institutions can significantly contribute to increased emissions. In fact, certain reports suggest that these choices might result in emissions that are more than 700 percent higher. Creating innovative, environmentally friendly products to meet growing client demand is a substantial opportunity for enhancement. An example of such a product is funds that are aligned with net zero goals Diaz et al. (2011). Companies offering digital business services are increasingly recognizing the importance of improving their ecological performance and addressing the impact of climate change Yang et al. (2022). The Science-Based Targets Initiative (SBTi) provides the most effective strategies for reducing emissions in sectors such as financial institutions and information and communications technology (ICT) (Diaz et al. 2011).

Companies rely on explicit guidance to adhere to net-zero goals that are grounded in scientific criteria. The process of transitioning to alternative sources of energy is a vital component in achieving sustainability objectives, such as mitigating the effects of climate change. Companies employ many strategies to achieve carbon neutrality objectives. In response to climate change, companies invested about 87.5 billion USD in "climate tech" in 2020–2021, as reported by the Measuring Eco-Innovation (MEI) project Diaz et al. (2011). The initiative categorized the investments into different categories Turner 2010). Environmental technology practices encompass the utilization of equipment specifically designed for waste management, water treatment, pollution control, and energy conservation.

The COVID-19 epidemic has profoundly affected the supply and demand of energy. Organizational practices encompass several examples, such as voluntary certification (EMS/ISO 14000, LEED), "green" HRM, independent environmental indicator audits, sustainability-related management activities, and "sustainable green logistics" (green supply chain management) Yang et al. (2022). Businesses can offer environmentally friendly services, such as a mortgage service that specifically tackles climate change Dietmair et al. (2009). They may also reduce pollution, minimize resource usage through platforms that enable the sharing of cars and equipment, or contribute to the overall improvement of the environment through eco-design. Some potential applications of their services include environmental consulting, testing, engineering, and analytics.

2.5 Relationship between Business Policies and Reduction of GHG Emissions

This array of methodologies prompts inquiry about how different types of businesses approach environmental problems, choose policies and objectives, and execute steps to mitigate greenhouse gas emissions. During their literature investigations, they noticed a lack of comprehensive research that offers a detailed picture of the business practices performed by firms Turner III et al. (2010). These assessments analyze the understanding of corporate social responsibility among academics and experts Dietmair et al. (2009). A comprehensive analysis of this nature might assist in addressing the difficulties associated with climate change and offer significant direction for businesses aiming to achieve sustainable development objectives through the adoption of a net-zero approach and efficient risk management. We shall conduct a comprehensive study of the company's present actions to fill this gap Dietmair et al. (2009).. This will offer useful information for firms contemplating the financing of renewable energy products and supply chain improvements that foster net-zero emissions and future operational resilience. This analysis will aid in expediting their energy transformation.

We examine the factors that influence a company's strategy development by drawing a link between its declared strategic objectives and particular industry and supply chain locations, their governance and market position, and other comparable attributes. We do this through our case-based research methodology. This study explores the significant potential of the fast-expanding digital business services (DBS) sector in achieving carbon neutrality objectives. It especially examines the environmental practices of the DBS industry Rodrigues et al. (2022). The study examines the adoption of DBS strategies with the goal of improving energy efficiency, minimizing resource usage, lowering greenhouse gas emissions, and creating ecologically sustainable supply chains by enforcing certain rules. Lastly, what digital solutions do these organizations create for their clients to expedite their shift towards environmental sustainability? Examples of these solutions include software for remote working, services based on cloud computing, tools for calculating emissions and resource usage, and models for assessing climate risks.

This research aims to enhance our understanding of corporate social responsibility by examining eco-innovations to address climate change and efficiently handle the data gathered in Refinitiv. Is it financially advantageous to adopt environmentally sustainable practices? This is a critical inquiry for investors. According to Dietmair et al. (2009), most of the evidence indicates that environmental measures contribute to the improvement of firm value and corporate financial performance. Studies often utilize many indicators, such as Tobin's Q, current ratio, profit margin, debt ratio, market-to-book ratio, return on invested capital, return on sales, and return on assets, to assess the performance of a firm (Marshall & Jonker 2010); Rodrigues et al. (2022). Specific studies incorporate indicators of market expansion, market share, competitive advantage, and customer willingness to pay a higher price for goods.

According to Rodrigues et al. (2022). meta-review of 2000 empirical investigations, extensive research over many years consistently demonstrates a significant positive relationship between corporate success and ESG factors. Hang et al. (2019) conducted a meta-analysis of 142 research articles and found that corporate environmental performance has a positive impact on long-term financial success; however, its short-term benefits may not be substantial. Research conducted in certain countries and industries, such as China, Germany, and Italy, demonstrates that adopting environmentally sustainable measures enhances a company's performance Chan et al. (2018). However, comparative research across different countries indicates that the relationship between environmental practices and commercial success varies regionally. The firms that were sampled and the variables that were measured, including metrics, exhibit significant differences from each other (Hang et al., 2019). The extensive range of evaluated variables (including ESG performance indicators) and sampled enterprises can partially account for the observed discrepancies in results Chan et al. (2018). There is a scarcity of studies on the service industry, with a predominant emphasis on financial services.

Since the 1980s, there has been an increasing use of advanced ICT systems in practically every area of the economy, following the rise in debates about "the microelectronics revolution" Rodrigues et al. (2022). Various user devices, such as tablets and smartphones, are currently being utilized. These devices incorporate interfaces like augmented reality and speech recognition, as well as tools like advanced data analytics and artificial intelligence Ashraf et al. (2022). These technologies are being employed to offer decision support and potentially automate tasks in new and unique situations Rodrigues et al. (2022). Various service activities provide support for fundamental digital technologies.

Specialized digital service corporations have emerged to aid businesses in the initiation or execution of innovations aimed at enhancing their efficiency, effectiveness, market penetration, and client loyalty. These enterprises predominantly offer digital business services (DBS) and are categorized into three sectors: digital advertising, ICT services, and digital business consultancy services Rodrigues et al. (2022). The latter may originate from established corporations in the fields of ICT hardware, telecommunications, advertising and marketing, and consulting services. At times, they may also be relatively young players in the industry.

Consulting services can specialize in the ICT-related elements of business and innovation cultures. They can also offer comprehensive insights on benchmarking and best practices, managing organizational change linked to technology transformation, and building and implementing digital plans. Deep brain stimulation (DBS) exists in three discrete types. An examination of the compromises between technology and market potential, together with the accompanying risks of a fast digital transition, can provide direction for reorganizing value chains and reconfiguring business structures Rodrigues et al. (2022). This is anticipated to improve the operational adaptability, durability, and dependability of the value chains. The market research group "Facts and Factors" predicts that the digital transformation consulting sector will see a compound annual growth rate of 7.5%.. This growth is expected to result in the industry's value increasing from USD 5 billion in 2020 to USD 11 billion by 2026. The digital transformation market had a value of USD 336 billion in 2020 and is projected to increase at a compound annual growth rate of 23.6% from 2021 to 2028.

Over the past few years, digital advertising, including social media and search advertising, has predominantly supplanted traditional forms of advertising. The market is projected to expand from Statista's estimated value of USD 465.6 billion in 2021 to USD 643.7 billion by 2025. Utilizing their expertise in digital media, digital advertising firms employ various strategies to promote messages, mostly aimed at stimulating consumer purchases of specific products but also disseminating messages that encompass a wider range of topics. It is established that digital advertising will account for the largest share of advertising income in the United States in 2021 . While conventional media dominated worldwide advertising spending in 2019, there has been a consistent decrease in traditional media expenditures in previous years. Meanwhile, marketers consistently choose digital media.

To provide ICT services, it is necessary for them to operate and manage data centers that house processing, storage, and network infrastructure . These data centers enable the availability of information and remote computing services, often known as cloud services. They have supported cloud computing, software as a service (SaaS), online security services, and other customer uses . Predictions indicate that the market for software applications pertaining to business intelligence and analytics, which play a vital role in digital business consulting, will grow from USD 15.9 billion in 2021 to USD 17.6 billion in 2024. ICT services generated more than USD 0.9 trillion in total revenue in 2020 Bäckstrand et al. (2017). Out of this, 35% was attributed to ICT outsourcing, while ICT consulting and implementation accounted for 6% . Consultancy services provide educated and recommended guidance to clients on their decisions about the employment of cloud services, knowledge management methods and tools, and artificial intelligence applications.

In addition to transportation, most of the research focuses on the energy and industrial sectors, whereas the service industries are often considered relatively unimportant in terms of mitigating greenhouse gas emissions Bäckstrand et al., (2017). However, transport is not the only industry that consumes a significant amount of energy. The environmental effect of the information and communications technology industry is significant, particularly considering the ongoing shift towards digitalization in manufacturing. According to the World Sustainability Initiative, the ICT industry was formerly projected to decrease its carbon footprint to 1.97% of world emissions by 2030 Le et al. (2011). Based on a recent update, the estimated global greenhouse gas emissions associated with ICT-related services vary from 2.1 to 3.9%. IT services rely on electrical energy, the environmental impact of which varies depending on the emissions associated with the power generation methods employed (Marshall & Jonker 2010).

The energy requirements of large-scale data analytics and artificial intelligence can be substantial, mostly because of the computational demands during the learning phase of complex algorithms and the significant electrical usage of cloud computing data centers. Future reductions in greenhouse gas (GHG) emissions, however, are achievable. The International Telecommunication Union (ITU) established a new standard in 2020, providing the ICT sector industry with a framework to achieve the goals of the Paris Agreement. This standard aims to reduce greenhouse gas emissions by 45 percent from 2020 to 2030. Switching to renewable energy sources in the ICT business has the potential to reduce emissions by almost 85%, according to certain estimations. Several dominant internet and software companies have made a pledge to decrease their carbon emissions. For instance, Microsoft aims to achieve carbon neutrality by 2040 and reach a state of net zero emissions by 2030. Netflix, Google, and Apple currently exclusively rely on renewable sources for their power generation.

ICT firms may make a big contribution to reducing global greenhouse gas emissions by providing expertise in energy conservation, inventory management, and the conversion of analog items to digital format. This can lead to assertions concerning environmentally friendly software, services, platforms, consultancy, and even the "green internet of things," encompassing energy-efficient applications like smart grids, linked automobiles, and other technologies that facilitate smart cities Choi et al. (2017). Following the implementation of the European Energy Efficiency Directive, there has been a notable effect, particularly in Germany, where the DBS industry, encompassing ICT enterprises, digital advertising, and consulting services, has experienced tremendous growth within the energy services sector.

The industry encompasses a range of firms that offer services directly associated with sustainable development, such as energy audits, energy management and contracting, software development, building management, and monitoring and measuring. Simultaneously, there is a growing emergence of ESG professional service firms Choi et al. (2017). These firms provide expertise in data platforms, certification, training, and reporting that are relevant for assessing ESG performance Ashraf et al. (2022). In 2021, there were more than 40 professional services businesses specializing in environmental, social, and governance (ESG) operating in Europe.

2.6 Ethical considerations associated with reduction of GHG emissions

Societal demands for ethical business practices have accompanied the emergence of new digital technologies. There is a rising demand for growth strategies that are socially conscious in their investment choices Choi et al. (2017). Corporate social responsibility (CSR) encompasses the strategies and actions employed by corporations to advocate for the concerns of various stakeholders and the public, with a particular emphasis on environmental matters. CSR ideas are universally recognized as the benchmark by which firms are evaluated for their capacity to engage in socially responsible business operations Dincer et al. (2012). This concept inspires firms to seek methods of integrating profit maximization with broader societal goals.

Although academicians had previously debated similar ideas seven decades ago, it was not until the beginning of the 21st century that corporate social responsibility (CSR) was acknowledged as a valid business strategy and received attention from investors Dincer et al. (2012). Chandler and Werther were pioneers in asserting that corporate social responsibility (CSR) confers organizations with a durable competitive advantage. Porter and Kramer (2006) concurred. Husted and Allen (2007) established a connection between CSR activities and the establishment of a competitive advantage that enhances shareholder value. They argued that this value creation is a response to the needs of society. Heslin and Ochoa (2008) advocated for the implementation of green supply chains and the intentional reduction of environmental footprints. They introduced the notion of minimizing environmental externalities as a strategic objective.

Businesses will engage in collaboration with stakeholders to build a set of business ethics and operational processes that are both feasible and aligned with corporate sustainability strategies. To align the economy with sustainable development paths, recent extensive literature studies have proposed that it is crucial to examine corporate social responsibility (CSR) within the core business activities of companies Dincer et al. (2012). Our study aims to address this gap by examining how organizations may generate shared value and reduce their environmental footprint using measures such as supply chain management, renewable energy generation, and carbon offset purchases Sun et al. (2011). Decommissioning is the ultimate phase of the Oil and Gas Industry (OGI), which explores and extracts hydrocarbons in various global locales, including offshore and onshore areas Dincer et al. (2012). To facilitate the extraction, production, and processing of hydrocarbons, a range of structures are required, including steel jackets, drilling rigs, topsides, and pipelines.

Certain buildings are essential for the entire operational lifespan of the field, with some continuing to be utilized for several decades Sun et al. (2011). Decommissioning constitutes 10% of the overall expenditure in the oil and gas sector, with the United Kingdom alone allocating over £1.5 billion per year for decommissioning operations. Decommissioning involves the dismantling of structures and the proper handling of the materials that are taken out. The Oil and Gas Industry (OGI) engages in the extraction and exploration of hydrocarbons, with decommissioning serving as the final step in the process Sun et al. (2011). In 2019, the UK government declared a climate emergency in acknowledgment of the observed effects of climate change and the increasingly certain scientific evidence that human safety is in jeopardy unless significant measures are taken to decrease greenhouse gas (GHG) emissions into the atmosphere Dincer et al. (2012). The UK government enacted the Climate Change Act 2008 (2050 Target Amendment) Order 2019 with the objective of achieving net zero greenhouse gas emissions by 2050 (Secretary of State, 2019). This necessitates that all parties implicated must undertake measures to reduce emissions stemming from all operations and abstain from relocating greenhouse gas emissions to other regions.

This is also applicable in the decommissioning sector. The Institute of Petroleum's (IOP) "Calculating energy use and gaseous emissions" guidelines (IOP, 2000; BIR, 2019) are presently considered the most effective method for measuring greenhouse gas (GHG) emissions from decommissioning activities in the Northeast Atlantic Region Dincer et al. (2012). The Offshore Petroleum Regulator for Environment and Decommissioning (OPRED), a division of the Department for Business, Energy, and Industrial Strategy (BEIS) in the UK, serves as the governing body responsible for overseeing decommissioning activities. These guidelines provide owners with data and methods to be utilized in their decommissioning reports and plans, which encompass the environmental assessment.

The IOP guidelines were intended to undergo periodic revisions; however, this has not been the case. Factual evidence, such as vessel fuel use, reveals that they are 20 years old according to data from the mid-1990s Dincer et al. (2012). The guidelines attempt to utilize a life cycle assessment (LCA) approach but do so in a limited manner and with numerous crucial assumptions, disregarding substantial quantities of greenhouse gas emissions in the process. An area that requires prompt attention is the accounting method for things that are left in situ. The rules demonstrate prejudices, presumptions, and incongruities. For example, they utilize identical estimates of greenhouse gas emissions for steel that is recycled and reused without considering whether it is melted down, reprocessed, or used again in its original state.

As per the suggestions, materials that are not reused or recycled are effectively excluded from the "materials loop," and the creation of new primary materials will need to compensate for the "lost" material by generating additional greenhouse gas emissions Dincer et al. (2012). Greenhouse gas (GHG) emissions associated with materials that are currently not recyclable are excluded from consideration. Only materials that have the potential to be recycled are considered. Given that substantial quantities of steel, such as steel jackets and topsides, are employed in the extraction, production, and processing of hydrocarbons, the researchers have chosen to use standard steel as the benchmark material for this study Neugebauer et al. (2011). This decision allows them to demonstrate the implications of not adopting a comprehensive life cycle assessment (LCA) methodology Dincer et al. (2012). Due to its high recyclability and widespread collection, around 97% of steel trash may ultimately be recycled.

The IOP proposals fail to consider the geographical placement of recycling and waste management facilities, as well as the associated greenhouse gas emissions generated during the transportation of materials to these recycling sites. Due to the limited number of industrial recycling centers in the UK and the absence of steel recycling facilities, the majority of recyclable materials are sent abroad for reprocessing Neugebauer et al. (2011). No studies have been conducted on this area, and the IOP criteria do not include the costs of greenhouse gas emissions connected to transportation Dincer et al. (2012). To address these issues, this study examines the assumptions inherent in the IOP standards and proposes an alternative to the current accounting methods used in manufacturing and recycling.

The choice of steel as the focus of this study is due to its widespread use and significance in the decommissioning process. While the primary focus of this research is on the UK and North Sea, the methodologies employed may be applied in other regions globally and might potentially provide advantages in several sectors of the economy Neugebauer et al. (2011). The Institute of Petroleum guidelines (IOP, 2000) make significant assumptions on the comparison of greenhouse gas emissions between recycled materials (secondary materials) and primary materials (materials created from fresh According to Broadbent, steel plays a crucial role in the circular economy due to its ability to be recycled indefinitely and its little resource loss throughout the transition process.

As per the IOP, initial steel production will exclusively occur in a blast furnace (BF) or basic oxygen furnace (BOF), whereas secondary steel, which is recycled, would undergo treatment in an electric arc furnace (EAF) Dincer et al. (2012). Furthermore, it greatly streamlines the issue by asserting that EAFs, which commonly utilize coal as a fuel, consistently rely on energy derived from renewable sources. The World Steel Association claims that, apart from the worldwide shortage of scrap steel, a significant quantity of secondary steel is utilized as an input in the production of primary steel by BF and BOF Dincer et al. (2012). The amount of steel scrap utilized varies globally and lacks uniformity since it is contingent upon the specific steel needed and the availability of scrap. A blast furnace (BF), basic oxygen furnace (BOF), or electric arc furnace (EAF) can be loaded with a maximum of 30% steel scrap. The BF/BOF process is responsible for 90% of steel production in China.

According to the Bureau of International Recycling (BIR, 2019), globally, 70% of steel is produced using the BOF method, while the remaining 30% is generated using the EAF method. Data from the World Steel Association. The production of crude steel rose from 1808 million metric tons in 2018 to 1869 million metric tons in 2019. Apart from 2009, when the global economic recession impacted steel consumption and therefore production, these values have been steadily increasing during the current year Bäckstrand et al. (2017). In 2018, the quantity of steel scrap, which refers to the steel recovered for recycling, amounted to 105 million metric tons Le et al. (2011). This is in comparison to the production of 1808 million metric tons of crude steel, as reported by the BIR (2019). The mismatch between the demand for steel in new items and the supply of steel available for recycling, totaling 1703 million metric tons, highlights a significant imbalance. If the steel sector is experiencing growth, this trend is likely to persist Bäckstrand et al. (2017). In 2019, China's steel production reached a staggering 996 million metric tons, surpassing its 2018 production of 920 million metric tons.

This makes China the leading global maker of steel by a significant margin Le at al. 2011). India ranks second with around 10%. The quantity of steel collected for recycling is also impacted by its resilience. Steel exhibits exceptional stability and, depending on the intended use and form of the item, often remains unobtainable for recycling or scrap for extended periods of time Bäckstrand et al. (2017). During the operational phase of the oil and gas industry, it is widely known that structures such as platforms and jackets are designed to be utilized in marine settings for an extended period. The extent of steel loss due to corrosion and erosion in marine conditions is currently unknown Bäckstrand et al. (2017). However, according to the IOP standards, it is assumed that no steel is lost, and that the quantity of materials used remains constant during the operating lifespan.

Despite recent research questioning this claim, there is currently no published data available to support or contradict it. For the purposes of this report, we will assume that the initial quantity of material is equal to the quantity that has been eliminated Pirson et al. (2021). To maintain the strength and stability of the structure, it is necessary to assume that a cathodic protection system, whether passive or active, is installed and operational while the structure is being used Bäckstrand et al. (2017). Acquiring comprehensive data on decommissioning procedures has proven to be exceedingly challenging, as the data obtained by the authors lacks specific information regarding emissions Pirson et al. (2021). Consequently, it is impracticable to differentiate emissions associated with processes, materials, and transportation, save for a few papers that have provided these details in a restricted manner.

The authors have access to the IOP guidelines, which serve as the recommended practices for operators in the Northeast Atlantic Region, including the UK, when developing decommissioning plans and calculating GHG emissions Bäckstrand et al, (2017). It is reasonable to assume that these guidelines were utilized in conjunction with recommended data points, such as a vessel's fuel consumption rate, to estimate the GHG emissions presented in the Environmental Assessment. This assessment is a legal requirement for every decommissioning project Pirson et al. (2021). The modeling technique employs a life-cycle assessment (LCA) approach to comprehensively quantify both direct and indirect greenhouse gas (GHG) emissions associated with the production and manufacturing of steel, taking into consideration the whole life cycle.

The decommissioning requirement requires the inclusion of greenhouse gas emissions that occur when materials used over the life cycle of the OGI reach the end of their useful life. This is even though decommissioning is the final stage of the OGI's life cycle and so falls within it (IOP, 2000) Bäckstrand et al. (2017). This research employs a top-down approach to evaluate greenhouse gas (GHG) emissions from direct emissions, indirect emissions, and transport emissions in both the main and secondary steel pathways Pirson et al. (2021). Climate change and global warming pose a significant threat to food security and the global supply chain. The task of preserving quality and minimizing losses during the transportation of bulk commodity grains between warm and cold seas has become essential due to the constant growth in trade volume Dincer et al. (2012). To achieve a society that emits no net carbon, it is necessary to develop a plan that is founded on data and has measurable effects. This study utilized the GTAP-E-Power model to examine the economic and welfare impacts of adopting ecologically sustainable cooling systems in marine transportation in Japan, Australia, and New Zealand.

2.7 Case Study: Shipping

The study employed simulations of Japan's technological shift, utilizing SPIAS-e data, in conjunction with subsidies for capital consumption in the electronics, solar power, and sea transportation industries. The results indicated a marginal 0.09% growth in Japan's GDP and a somewhat higher 0.11% growth in the GDP of Australia and New Zealand. Furthermore, a reduction in greenhouse gas emissions from Japan's maritime transportation sector to 8.4 million tons, representing a mere 0.9% of the overall emissions, has the potential to result in a USD 4,219 million boost in the country's welfare Duflou et al. (2012). Cargo sweat is a common problem that arises when bulk cargo is loaded in a chilly environment and then transported to a warmer one. This phenomenon happens when there is contact between warm and humid air and cold objects.

Condensation may cause the cargo to degrade, leading to a reduction in both its worth and quality. The effectiveness of a ship's cargo preservation depends on the proper functioning of its cooling and ventilation systems. To ensure the proper functioning of the cooling and ventilation system, it is imperative to keep it active until the cargo is completely unloaded, even throughout the ship's docking period Duflou et al. (2012). To avoid claims related to cargo damage, it is imperative to keep precise records of the ventilation system's functioning, documenting the time periods when ventilation is operational and when it is unavailable or inaccessible. The cooling and ventilation system aims to decrease the humidity in the cargo hold by substituting the moist air with drier air.

As a result, the cargo may receive up to 15% to 20% protection from harm. Ship condensation and cargo arrangement are also avoided. Hence, to minimize cargo moisture and ensure the cargo remains in optimal condition throughout transportation, it is imperative to run and maintain the cooling and ventilation system effectively Duflou et al. (2012). Accurate documentation is crucial for ensuring the smooth functioning of the system and promptly addressing any issues to prevent cargo damage and claims. In 2017, the expenditure on energy accounted for a range of 20 to 60% of the total operating expenditures. During this period, internal combustion engines were responsible for propelling more than 85% of cargo ships and accounted for 64% of the total cargo volume.

The objective is to reduce the release of greenhouse gases and promote ecologically responsible shipping. Shipbuilding businesses have been improving the efficiency of power supply and propulsion systems by using hybrid energy inputs from renewable sources, such as solar photovoltaic applications Dincer et al. (2012). This hybrid-powered vessel is currently in the experimental phase, but it has the capacity to reduce fuel expenses by 28% and carbon dioxide emissions by 77% through enhanced solar energy efficiency Shin et al. (2017). The International Energy Agency (IEA) projects that the cost of photovoltaic (PV) power is expected to decrease from 25% in 2020 to 65% by 2050 Dincer et al. (2012). Increased use of renewable energy in conjunction with electric vehicles could improve the nation's overall well-being. Food supply networks globally necessitate transportation over great distances, which sometimes expose the products to significant fluctuations in temperature.

Bulk carriers prefer reduced fuel use for ventilation and cooling systems due to the fuel's cost-effectiveness compared to the value of the product Dincer et al. (2012). To address the pressing challenges of climate change and reduce food poverty and greenhouse gas emissions, it is crucial to take prompt and innovative measures to enhance the quality of grain shipments. Chen et al. (2012). The objective is to assess the influence of investments in enhancing cooling systems on the maritime transportation industry, as well as their effects on worldwide commerce and carbon dioxide emissions. The simulation findings should provide crucial economic indicators such as sectoral production, adjustments in the global supply chain, GHG emissions, and welfare analysis.

Simulation findings indicate that Japan's imports into various countries had strong growth in several industries, including food, manufacturing, and transportation equipment, with increases ranging from 1.3% to 1.7% Dincer et al. (2012). The nation's great productivity and competitiveness have led to the production of superior goods, therefore causing this growth. While the electronics sector had a greater influence, other Asian areas nonetheless saw some effects Chen et al. (2012). However, while comparing, it can be observed that the rise of exports was higher in Australia and New Zealand compared to other areas. Given that their products are likely to be complementary to those manufactured in Japan, this tendency might be attributed to the increasing demand for them.

The execution of policy interventions has led to a decrease of 8.4 million tons of greenhouse gas emissions, which account for 0.9% of the overall emissions from Japan's marine transportation industry. The decrease is attributed to technical innovations that have enhanced production and efficiency in relevant industries Chen et al. (2012). These findings show that the implementation of capital-use subsidies and regulatory measures may significantly facilitate the promotion of sustainable practices and reduction of greenhouse gas (GHG) emissions in the maritime transportation sector Dincer et al. (2012). Furthermore, the research revealed that East Asia had a reduction in greenhouse gas (GHG) emissions exceeding 3.0 million tons. This suggests that the impact of these policy actions may extend beyond national boundaries.

This might bolster efforts at the national, international, and regional levels to alleviate the impacts of climate change. The relatively lower utilization of marine transportation in Australia and New Zealand compared to other nations may have played a role in the diminished impact observed in these regions Diaz et al. (2011). The study primarily focuses on the impact of research and development (R&D), utilizing the SPIAS-e indicators to envision a future of technological advancement for Japan Dincer et al. (2012). The simulation results highlight the importance of having a data-gathering infrastructure in place for evidence-based policymaking Yoro et al. (2020). This infrastructure enables policymakers and stakeholders to have a quantitative measure of the overall impact of industrial competitiveness between nations Diaz et al. (2011). According to Mohajan and H.K. (2017), the provision of subsidies for capital investment in industries such as solar energy, electronics, and marine transportation has been found to result in significant policy shocks that have an instantaneous effect on the analysis of welfare, visualization of GDP, and visualization of sectoral output.

The simulation's conclusions are also examined in connection with the economic cooperation agreements that Australia, New Zealand, and Japan have established with Japan Dincer et al. (2012). These agreements have emphasized the need to work together to promote environmentally conscious and sustainable practices, especially in the shipping industry, as well as focusing on investment and the exchange of technology Diaz et al. (2011); Mohajan and H.K. (2017). The global shipping industry has been identified as a primary contributor to greenhouse gas emissions and climate change Yoro et al. (2020). Energy-efficient design, optimized logistics, and the utilization of low-carbon fuels exemplify environmentally friendly shipping methods that effectively reduce the carbon footprint of the business and contribute to global endeavors in achieving net-zero emissions.

2.8 Zero GHG Emissions

Above all, the impact assessment should promote collaboration towards achieving a society with no net carbon emissions. This is particularly relevant due to the study's focus on agricultural commerce, which plays a crucial role in the global food supply chain and is vital for sustainable development Kriegler et al. (2014). To ensure a sustainable future, it is crucial to ensure the resilience of the global food supply chain, given the challenges posed by climate change, increasing food consumption, and the need for more efficient and environmentally friendly production methods Kriegler et al. (2014). Hence, the study's hypothetical situations and suggestions for action can be extended to other domains linked to the worldwide food distribution network, emphasizing the need for collaboration in the endeavor to adopt ecologically conscious and enduring corporate strategies Mohajan and H.K. (2017). It is imperative to achieve net-zero greenhouse gas emissions between 2050 and 2070 to limit global warming to 2 °C. Each greenhouse gas (GHG) has varying heat-trapping capabilities and remains in the atmosphere for varied durations. It is vital to assess the global warming potential of different gases in order to compare them. Table 1 presents the global warming potential and atmospheric lifespan, measured in years, of six greenhouse gases (GHGs).

Table 2
The global warming potential of six greenhouse gases

Gas	**Global warming potential**	**Atmospheric life (Years)**
C02	1	5 to 200
CH4	21	12
N2O	310	114
HFC	140 to 11,700	1.4 to 260
PFC	6,500 to 9,200	10,000 to 50,000+
SF6	23,900	3200

Complete de-carbonization of global industry is essential for achieving climatic stability. This paper presents an examination of technology and policy initiatives from both the supply and demand perspectives Kriegler et al. (2014). This signifies a set of measures that, when combined, can achieve a state of net zero industrial emissions within the required timeframe. Electricity production, carbon capture, energy efficiency (especially at the system level), and zero-carbon hydrogen as a chemical feedstock and heat source are crucial technologies for the supply side Shin et al. (2017). Promising technology also exists for the three industries that are the largest emitters: cement, iron and steel, and chemicals and plastics Mohajan and H.K. (2017). These encompass novel chemical catalysts and separation processes, cement additives, and alternative chemical compositions, as well as various technological approaches for manufacturing carbon-neutral steel.

According to Kriegler et al. (2014), the key demand-side measures are minimizing material waste through efficient design, substituting high-carbon materials with low-carbon alternatives, and adopting actions that promote a circular economy. Strategically designed policies may stimulate the uptake of technology and accelerate the pace of innovation Mohajan and H.K. (2017). Examples of high-value policies include robust government support for research and development as well as its execution, rules promoting energy efficiency or emissions reduction, and the deployment of carbon pricing mechanisms with border adjustments or other price signals Li et al. (2013). To promote these core principles, it is advisable to employ labeling, government procurement of low-carbon goods, data collection and transparency requirements, as well as recycling incentives Shin et al. (2017). It is imperative to guarantee a just transition for workers who are displaced and communities that are affected while implementing these regulations.

Similarly, it is imperative to aid with decarbonization efforts in low- and middle-income countries to promote both economic and human development. The objective of the 2015 Paris Agreement is to limit the rise in the global average temperature to less than 2 °C. Achieving this goal requires the simultaneous decarbonization of all industries globally Li et al. (2013). From 1990 to 2014, there was a significant 65% rise in direct industrial emissions, encompassing emissions from both energy and non-energy activities Lian et al. (2012). This phenomenon may be attributed in part to the industrialization of the developing world, and it is expected that further economic growth will lead to an improvement in living conditions in those regions Li et al. (2013). Industrial decarbonization will be propelled by the declining expenses of eco-friendly technologies, the implementation of environmental laws, and voluntary efforts to combat climate change.

Quantitative assessment may be used to identify significant knowledge gaps and research and development (R&D) opportunities in the field of decarbonization. There are four ways to keep global warming to below 2 °C: the Shell Sky Scenario, the 2-Degree Scenario (2DS), the Beyond 2-Degree Scenario (B2DS), and the route outlined in the Energy Transitions Commission's (ETC) "Mission Possible" report Li et al. (2013). These scenarios include detailed data on carbon dioxide (CO2) emissions in several industry sectors worldwide, hydrogen consumption, and the exploitation of carbon capture and storage (CCS) Lian et al. (2012). The Sky Scenario presents projections from a World Energy Model (WEM) framework extending until the year 2100 Lian et al. (2012). The IEA provides projections until 2060 using a technologically sophisticated "back casting" approach that starts from the desired future and works backwards to determine the necessary steps to achieve it. The projections are generated by ETC based on modeling conducted by the business SYSTEMIQ, which will be included in subsequent technical appendices according to ETC.

While the ETC currently lacks complete time-series data that can be easily accessed, it does provide numbers for the net-zero emissions system. Industrialized nations are targeting to achieve this system by 2050, whereas underdeveloped countries are aiming for 2060. The projected ETC consequences in 2060, taking into consideration that the findings are global and that rising nations contribute the most to global industrial activity Lian et al. (2012). Only carbon dioxide (CO2) emissions from burning and processing are included in all four scenarios; no other greenhouse gases (GHGs) are included Lian et al. (2012). The utilization of hydrogen produced from renewable energy sources, namely through the process of electrolysis, is increasingly gaining momentum as a viable means of directly powering industrial processes and serving as a raw material for chemical production in efforts to reduce carbon emissions Lian et al. (2012). The ongoing decrease in the cost of renewable electricity is what is driving this trend. Global industrial de-carbonization scenarios, despite differences in their technological and subsector scopes, have yielded mostly similar outcomes when zero-carbon hydrogen has been explicitly considered.

Renewable hydrogen has the potential to greatly decrease CO2 emissions in several industrial sectors, including both light and heavy industries. Still, if there aren't any good policies in place, it might be hard for renewable hydrogen to become widely used on the market Ashraf et al. (2022). This is because electrolyzers and transporting hydrogen are expensive, natural gas is cheaper, new process heating equipment is needed, and some new solutions aren't fully developed technologically yet Lian et al. (2012). Two strategies that can accelerate the adoption of renewable hydrogen in industry through intelligent policy include mandating emissions reductions from sectors where hydrogen is the most effective solution for decreasing emissions and making the required research and development (R&D) and infrastructure investments more cost-effective (Yoro et al. 2020).

The projections from the IEA, Shell, and ETC about the use of hydrogen are conflicting. IEA models project that the transportation industry will have little utilization of hydrogen by 2060 Shin et al. (2017). In addition, both the manufacturing and transportation sectors will entirely refrain from utilizing hydrogen. Due to advancements in efficiency and the decrease in industrial energy consumption, the industrial usage of hydrogen hits its peak in the early 2080s. The employment of chemical and mineral admixtures is a crucial method for lowering CO2 emissions Diaz et al. (2011). The characteristics of mineral admixtures may display variances. Both cementitious and pozzolanic supplementary materials are viable options. The addition of cementitious ingredients facilitates the development of crystalline structures in concrete, hence enhancing its characteristics Shin et al. (2017). Mineral admixtures include non-reactive fillers that improve compaction and decrease the need for cement. Inert fillers typically have a cement replacement level that falls between 5% and 15%, whereas additional cementitious materials can achieve a higher replacement level of up to 50%.

However, the amounts of mineral admixtures in concrete mixes might vary greatly depending on the desired properties and specific local needs. The utilization of chemical admixtures has the potential to mitigate the consumption of cement Shin et al. (2017). Chemical admixtures are frequently utilized in relatively reduced proportions in the context of cement application Ashraf et al. (2022). These additives have the potential to enhance workability, air entrainment, and several other favorable characteristics. Chemical admixtures are employed in the construction industry to exert meticulous control over the properties of concrete, facilitating the manipulation of water or cement content as desired Shin et al. (2017). The use of cement at lower elevations is undoubtedly a feasible approach. The implementation of clever concrete management strategies can improve the use of chemical and mineral admixtures in the context of carbon dioxide (CO2) mitigation Shin et al. (2017). Chemical admixtures play a crucial role in enabling the integration of mineral admixtures into concrete compositions (Ashraf et al. 2022).

The practice of incorporating admixtures into concrete has historically been employed as a conventional method to achieve certain properties, such as reducing the heat generated during the hydration process. However, contemporary studies have shifted their attention towards utilizing these additives to mitigate the release of greenhouse gases Shin et al. (2017). There exists a disparity among the hydrogen use projections put forward by reputable entities such as the International Energy Agency (IEA), Shell, and the Energy Transitions Commission (ETC) (Chinnathai & Alkan 2023).   Based on the scenarios presented by the International Energy Agency (IEA), it is projected that the utilization of hydrogen in the transportation sector will be limited by the year 2060 Shin et al. (2017). Moreover, it is anticipated that both the industrial sector and transportation businesses will refrain entirely from utilizing hydrogen as an energy source.

The Shell Sky Scenario outlines a progressive and continuous increase in hydrogen use, commencing from a baseline of zero in the year 2020 and culminating at a rate of 69 exajoules annually by the year 2100 Shin et al. (2017). The industrial usage of hydrogen hits its peak in the early 2080s due to advancements in efficiency and a decrease in industrial energy demand Shin et al. (2017). The employment of chemical and mineral admixtures is a crucial technique for mitigating CO2 emissions.   Variations in the characteristics of mineral admixtures may be observed (Chinnathai & Alkan 2023). Additional materials can be employed, either in the form of cementitious or pozzolanic substances McCollum et al. (2018); Yoro et al. (2020). The use of cementitious elements facilitates the development of crystalline structures within concrete, hence enhancing its inherent characteristics Shin et al. (2017). Mineral admixtures encompass inert fillers that serve the dual purpose of improving compaction and diminishing the need for cement (Chinnathai & Alkan 2023). In general, inert fillers often demonstrate a cement replacement level that falls within the range of 5% to 15%. On the other hand, supplementary cementitious materials have the potential to achieve a higher replacement level of up to 50%.

However, the proportions of mineral admixtures in concrete mixtures may vary considerably depending on the desired properties and specific local needs McCollum et al. (2018). The utilization of chemical admixtures has the potential to decrease the consumption of cement Rodrigues et al. (2022). Chemical admixtures are frequently utilized in relatively smaller proportions in cement applications. These additives have the potential to enhance workability, air entrainment, and several other desired characteristics. Chemical admixtures are employed to exert meticulous regulation over the properties of concrete, enabling modifications to the water or cement content. The use of cement at lower elevations is undoubtedly a feasible option Rodrigues et al. (2022). When aiming to mitigate CO2 emissions, the utilization of chemical and mineral admixtures may be more effectively implemented in conjunction with intelligent concrete management practices McCollum et al. (2018). Chemical admixtures play a crucial role in enabling the integration of mineral admixtures into concrete compositions.

The practice of incorporating admixtures into concrete has traditionally been employed to achieve certain properties, such as reducing the heat generated during hydration McCollum et al. (2018). However, contemporary studies have shifted their attention towards utilizing these additives to mitigate the release of greenhouse gases Rodrigues et al. (2022). Achieving customized qualities from concrete with reduced carbon dioxide emissions may depend significantly on the substitution of alternative inorganic cements for standard Portland cements, even if admixtures are not used McCollum et al. (2018). These alternative cements fall into two groups: non-clinkered alternative cements, which are made without pyro processing, and clinkered alternative cements, which are made with methods akin to those of traditional Portland cements

Rogelj et al. (2016). Different raw materials or less energy needed for kilning are the sources of CO2 reductions from clinkered alternative cements.

If modifications are made to the cement phase composition, the energy demand in kilns may be reduced since different clinker phases have varying enthalpies of formation. Reducing energy use may reduce other environmental aspects, depending on the fuel resources used Mohajan and H.K. (2017). Certain alternate clinkered cement systems, though, could not be as widely available as conventional cements in terms of raw material supplies Rogelj et al. (2016). The large demand for cement worldwide means that in some areas, certain options may be limited by the availability of resources or by competition with other industries for those resources. Although a variety of non-clinkered alternative cements can be made, alkali-activated materials are the ones that receive the most attention in this category of cements. Alkali-activated materials should produce fewer greenhouse gas emissions than regular Portland cement, depending on the choice of solid precursor, alkali-activator, and energy needed for curing. Such considerations should be considered when using alternate cement systems, since they may result in changes in performance Rogelj et al. (2016).

Some types of binders, like those that contain Portland cement, can solidify through a chemical reaction with carbon dioxide (CO2) instead of the usual reaction with water. Often, a significant quantity of carbon dioxide (CO2) is necessary to enable the CO2-involved process to proceed at an acceptable rate. The investigation of binders based on magnesium oxide (MgO) has been a prominent focus of scholarly inquiry. Nevertheless, the utilization of carbonatable calcium silicate-based binders has begun during the initial phases of commercialization. The availability of raw materials necessary for the manufacturing of these cements, like other alternative cements, might possibly provide limitations on their usage Wang et al. (2018). Additionally, it is important to note that some of the raw materials used to make these cements can cause a net increase in carbon dioxide (CO2) emissions over the course of their lifetime compared to Portland cement, even if carbon is stored during the curing process. The cement solutions are not suitable for applications requiring typical steel reinforcement in concrete due to their limited compatibility.

The key strategies for minimizing energy-related emissions in the cement sector are improving the thermal efficiency of cement production gear, transitioning to alternative fuels, electrifying cement kilns, and using carbon capture and sequestration (CCS) technology McCollum et al. (2018). The improvement of a system's energy efficiency can be attained by reducing the moisture content of the input materials, since the energy required for water evaporation is reduced. The enhancement of achieving this objective may be facilitated with the utilization of a dry-process kiln equipped with a multi-stage preheater and proclaimer Wang et al. (2018). The possible utilization of recycled thermal energy for the pre-drying of input materials is a subject of interest. In the context of heat recovery, it is apparent that a grate clinker cooler has superior performance when compared to planetary or rotary-style coolers Wang et al. (2018). The extent to which energy consumption may be reduced because of these modifications is contingent upon the efficiency and age of the current equipment.

The notable regions that have recently increased their cement production capacities demonstrate how common the incorporation of this processing stage is in modern kilns McCollum et al. (2018). Specific mineral compositions have the potential to facilitate the chemical conversion of raw materials into clinker, resulting in a reduction in the required temperature. Consequently, a decrease in temperature leads to a proportional decrease in fuel consumption Yang et al. (2022). Testing and approving different cement chemistries is likely to have a big effect since some of these alternatives can change how well cement works. One viable approach to mitigating heat loss in exhaust emissions is the utilization of oxygen-enriched air as a reactant in conjunction with the fuel Yi et al. (2015). An additional benefit of oxygen combustion is its capacity to reduce the presence of non-CO2 gases in the emission stream, thereby facilitating the carbon capture process Yang et al. (2022). Currently, coal makes up 70% of the total supply and is the most widely used thermal fuel in the cement industry worldwide. The remaining 24% of the overall energy supply is derived from sources of natural gas and oil. The remaining 6% of the composition consists of waste fuels and biomass (Yi et al. 2015).

The key strategies for minimizing energy-related emissions in the cement sector are improving the thermal efficiency of cement production gear, transitioning to alternative fuels, electrifying cement kilns, and using carbon capture and sequestration (CCS) technology Yi et al. (2015). Reducing the moisture content of the input materials can increase a system's energy efficiency because the evaporation of water uses less energy Yang et al. (2022). The enhancement of achieving this objective may be facilitated with the utilization of a dry-process kiln equipped with a multi-stage preheater and proclaimer. The possible utilization of recycled thermal energy for pre-drying input materials is being considered. In the domain of heat recovery, it is apparent that a grate clinker cooler has superior performance when compared to planetary or rotary-style coolers Yi et al. (2015). The extent to which energy consumption may be reduced because of these changes is contingent upon the efficiency and age of the preexisting equipment Diaz et al. (2011). The notable regions that have recently increased their cement production capacities demonstrate how common the incorporation of this processing phase is in modern kilns.

Specific mineral compositions have the potential to facilitate the chemical conversion of raw materials into clinker, resulting in a reduction in the required temperature. Consequently, a decrease in temperature leads to a proportional decrease in fuel consumption Chen et al. (2022). The testing and certification of alternative cement chemistries are expected to have a substantial influence; as certain alternatives possess the capacity to modify the performance characteristics of cement. One viable approach to mitigating heat dissipation in exhaust emissions is the utilization of oxygen-enriched air as a reactant in conjunction with the fuel Chen et al. (2022). An additional benefit of oxygen combustion is its capacity to reduce the presence of non-CO2 gases in the exhaust stream, thereby facilitating the carbon capture process Yi et al. (2015). At present, coal constitutes 70% of the overall energy supply and serves as the preferred thermal fuel for the worldwide cement sector. The remaining 24% of the overall energy supply is derived from sources of natural gas and oil. The remaining 6% consists of waste fuels and biomass materials.

What is the best cost-effective method to decrease greenhouse gas emissions? The principles of economics provide a clear response: decrease emissions until the additional benefits gained from the reduction are equal to the additional expenses incurred (Gillingham & Stock, 2018). A possible solution to this issue is the implementation of a Pigouvian tax, such as a carbon tax. In this case, the tax rate would be determined by the marginal benefit of reducing emissions or, in other words, the monetary value of the damages caused by emitting an additional ton of carbon dioxide (CO2) (Gillingham & Stock, 2018). By internalizing the carbon externality, the market will efficiently identify and implement cost-effective strategies to decrease emissions in alignment with the carbon tax. Nevertheless, the majority of countries, including the United States, do not implement a comprehensive carbon tax that applies to the entire economy.

Instead, they rely on a variety of greenhouse gas mitigation policies that offer financial incentives or impose limitations, usually targeting certain technologies or sectors (Gillingham & Stock, 2018). Climate policies encompass a variety of measures, including regulations on vehicle fuel efficiency, levies on gasoline, requirements for a certain percentage of state electricity to come from renewable sources, financial support for solar and wind power generation, mandates for blending biofuels into transportation fuel, and limitations on the extraction of fossil fuels (Gillingham & Stock, 2018). In the context of a Pigouvian tax, markets efficiently determine the most economically viable methods to decrease emissions. The study by Gillingham and Stock (2018) addresses many problems associated with the costs of carbon emission reduction.

One difficulty is that many politically popular initiatives, like backing biodiesel or providing subsidies for energy efficiency programs, might be expensive due to technological limitations or changes in behavior (Gillingham & Stock, 2018). These programs may seem inexpensive, but their true costs are typically hidden and only become evident when examined by economists. Another difficulty arises when initiatives that are easily noticed are mistakenly seen as expensive, although not actually being so. An illustrative instance is the Clean Power Plan, which would have led to substantial reductions in emissions at a significantly lower cost compared to numerous existing initiatives as shown on table 3 below;

Table 3
New Source Generation Costs when Compared to Existing Coal Generation

Technology	**Cost estimate ($2017/ton CO2)**
Onshore wind	24
Natural gas combined cycle	28

Natural gas with carbon capture and storage	42
Coal retrofit with carbon capture and storage	84
New coal with carbon capture and storage	95
Offshore wind	105
Solar thermal	132

One additional obstacle is that the fixed expenses only offer a limited understanding of the actual expenses associated with a specific action, which should also take into account the changing outcomes (Gillingham & Stock, 2018).

The manifestation of those dynamic repercussions typically relies on the nature of the intervention. If the intervention involves substituting coal electricity generation with natural gas, the initial low costs may result in greater long-term costs if it leads to the establishment of long-lasting natural gas infrastructure that is difficult and expensive to dismantle when the cost of renewable energy decreases. On the other hand, if the intervention involves offering subsidies for buying electric vehicles, the positive impacts of increased demand due to learning by doing and economies of scale can significantly reduce the long-term costs, which may not be apparent when only considering short-term calculations.

Due to the long-term nature of climate change and the extensive changes required to cut emissions, the dynamic costs outweigh the static costs in terms of importance (Gillingham & Stock, 2018). Another issue arises for the economic research community as a result of the aforementioned observation. Our study indicates that the majority of empirical studies conducted by economists mostly examine static costs. These studies often analyze the static costs of initiatives that are already implemented. This phenomenon is inherent due to the availability of data on these initiatives (Gillingham & Stock, 2018). Analyzing the expenses of past programs serves as a valuable reference for constructing forthcoming programs. However, there is a specific need for increased focus on the factors that determine the changing costs in the field of climate change research (Gillingham & Stock, 2018). This field of research combines environmental and energy economics with the existing literature on productivity, dissemination, and learning-by-doing. We have identified two specific sectors, solar photovoltaics and electric cars, where demand-driven strategies have successfully led to cost reductions.

However, it is important to note that this outcome is not guaranteed and the extent of cost reductions might vary significantly between different cases. Climate change is a persistent issue that requires legislative measures aimed at long-term solutions. In order to achieve significant advancements in climate objectives, such as an 80 percent reduction in carbon emissions by 2050 in the United States, it will be necessary to use new technologies, such as is AI, on a large and widespread level. Although each technical advancement is incremental, such as the reduction in cost of electric vehicle batteries, the integration of the grid to utilize wind energy in the Midwest, the decrease in offshore wind expenses, and the creation and adoption of low-carbon fuels for air transportation, the collective impact will be transformative.

Despite potential drawbacks, such as increased particulate matter emissions, biomass and waste fuels often exhibit lower carbon dioxide (CO2) intensities compared to coal Yi et al. (2015). The complete decarbonization of heat generation in cement production may require the implementation of cement kiln electrification, also referred to as CCS. The ideal course of action for each cement mill may vary depending on factors such as the cost and availability of carbon-free power, as well as the feasibility of implementing carbon capture and storage within the facility (Chinnathai & Alkan 2023). Since hydrated cement could carbonate and sequester carbon dioxide, initiatives have been initiated to quantify the potential carbon capture and storage capacity through the utilization of crushed concrete and fines as materials at the end of their life cycle Chen et al. (2022). Using curved fabric molds instead of traditional geometries with sharp angles and corners and pre-stressing concrete with tensioned steel cables are two design and engineering methods that can cut down on the amount of concrete needed to reach a certain strength.

Various strategies have been proposed to mitigate greenhouse gas emissions, such as the optimization of concrete mixtures, extending the lifespan of functional obsolescence, and enhancing the design of members or structures through the utilization of high-performance concrete or a more precise selection of a mixture with steel reinforcement Omer and A.M. (2008). Several of these strategies have the potential to reduce overall material consumption, resulting in a corresponding decrease in emissions connected with the manufacturing process (Chinnathai & Alkan 2023). Certain patterns of human habitation may necessitate a reduced need for building materials. Governments are actively facilitating the dissemination of industrial decarbonization data through regulatory mechanisms such as mandatory disclosure, minimum performance standards, procurement policies, and labeling schemes, even though participation in these initiatives is optional.

There are two noteworthy examples of the growing attention from policymakers towards the implementation of data collection and disclosure practices for industrial decarbonization (Chinnathai & Alkan 2023). One instance is China's directive, which mandates that all publicly listed companies must report their emissions data by the year 2020. Another example is Article 173 of France's Energy Transition Law Omer and A.M.

(2008). Considering the transnational nature of supply networks, governments possess the ability to exercise influence over foreign suppliers by implementing regulations that require prominent corporate purchasers to declare the emissions stemming from their respective supply chains. Governments could make it easier for companies to share information about reducing carbon emissions by giving them the tools they need to make and share inventories of greenhouse gas (GHG) emissions, set science-based goals, and look at the best ways to reach those goals.

2.9. Challenges and Solutions

Expanding the market for low-carbon goods and materials is an essential measure in the process of decarbonizing the economy. Carbon labeling schemes serve as a mechanism to enhance the market demand and value of low-carbon products by informing prospective consumers about the environmental implications associated with carbon emissions and subsequently increasing their willingness to pay for such items. The labeling of finished items can be oriented towards customers, like the existing practice of labeling energy-efficient windows, doors, appliances, and lights, among other examples. Utilizing low-carbon products like steel and cement, which end users do not frequently buy directly, may significantly reduce greenhouse gas emissions. In such circumstances, the term "labels" would pertain to entities such as enterprises or governments that engage in large-scale procurement of those items.

Organizations with a focus on attaining environmental, social, and governance (ESG) goals, as well as public procurement initiatives that endorse environmentally friendly items, may find these designations advantageous. An example of this is Apple's deliberate transition to use aluminum as a material with no carbon emissions. Furthermore, the utilization of low-carbon labeling may serve as a promotional tool, stimulating industry innovation and incentivizing the attainment of the label for a greater range of products, all while maintaining a reduced price. The Green Building Rating (GBR) system is well recognized as a prominent illustration of low-carbon labeling. A comprehensive analysis of the many environmental impacts associated with buildings is presented through the implementation of a GBR (Green Building Rating) system. Notably, these schemes are progressively incorporating an evaluation of the embodied carbon present in building materials Le et al. (2011). This variation is contingent upon several aspects, including the building type, climatic zone, operational energy efficiency, and other pertinent considerations.

Carbon labeling is hard to put into place because there isn't enough information to fully evaluate a product's greenhouse gas (GHG) effects, and different accounting methods make it hard to be consistent. The establishment of a clear and rigorously validated methodology is crucial for the accurate determination of carbon emissions associated with materials Kucukvar et al. (2016). The International Organization for Standardization (ISO) has established the preferred methodology, known as life cycle assessment (LCA), as a standardized technique. Multiple carbon labeling initiatives conform to ISO standards, including the environmental product declaration (EPD). The failings of past labeling schemes have been ascribed to inadequate adoption of labels and difficulties in ascertaining values for life cycle assessment (LCA). One potential approach to mitigating these issues is implementing labeling practices at the manufacturer level as opposed to the shop or reseller level.

Numerous technical solutions and advancements in industrial processes have the potential to mitigate emissions. In general, newly developed technologies tend to exhibit higher initial costs compared to established technologies, mostly due to the latter's advantage of having undergone extensive development over a prolonged period and benefiting from economies of scale. Moreover, it is common for incumbents to evade the financial responsibility associated with the adverse external effects that their emissions impose on the environment and human well-being. As a result of this circumstance, it might be arduous for inventive, low-carbon products to provide competitive pricing in comparison to their conventional counterparts.

The provision of governmental assistance plays a pivotal role in facilitating the progress and commercialization of pioneering technologies, particularly those that yield societal benefits through the mitigation of pollutants. The successful commercialization of low-carbon alternatives to traditional products necessitates the transition from laboratory prototypes to viable and lucrative market offerings. The lack of demand will impede manufacturers from making investments in low-carbon technologies and hinder the potential for economies of scale in relation to these emerging technologies. Governments acquire a substantial quantity of industrial products, with an average share of 12% of GDP in OECD countries and a potentially higher proportion of up to 30% in several developing nations. Consequently, the implementation of a government policy that promotes the procurement of low-carbon goods can lead to the development of a substantial market for these items. Consequently, the implementation of a government policy that promotes the procurement of low-carbon goods can lead to the development of a substantial market for these items. The use of this method has the potential to eliminate a substantial barrier that hinders the progress and cost reduction of emerging technologies.

There are several instances of government procurement initiatives aimed at acquiring low-carbon commodities. These include the Buy Clean California Act, Japan's Act on Promoting Green Purchasing, and India's Ujala program, which focuses on efficient lighting. In the year 2001, the nation of Japan implemented a program that led to a yearly decrease of 210,000 metric tons of carbon dioxide (CO2) emissions by the year 2013. The notable decrease in emissions was attained as a result of the effective adherence of 95% of government procurements in the specified sectors to environmentally conscious procurement policies. Based on the data acquired in 2019, it is evident that the Ujala project in India has notable success in attaining an annual power conservation of 46 terawatt-hours (TWh). Simultaneously, the project efficiently diminishes peak demand by 9 gigawatts (GW) and mitigates emissions by 3.7 GW.

The choice of whether to recycle or dispose of things composed of recyclable materials at the end of their lifespan is contingent upon the evaluation of the respective costs linked to each alternative. The intrinsic worth of certain materials, such as steel and aluminum, may be sufficiently substantial to render the recycling of waste material economically and laboriously advantageous. However, the practice of recycling often proves to be ineffective for these materials. In the United States, the recycling rates for steel and aluminum in municipal solid waste (MSW) are at 33% and 19% respectively. There exist several barriers impeding the attainment of higher recycling rates. Certain goods incur higher recycling costs due to the inherent challenges associated with the separation of their constituent parts. If recyclable things are contaminated with inappropriate materials, it may be imperative to dispatch the complete lot for disposal Waste Management, the largest waste management company in the country, collects a sizable portion of recycling material with a contamination level of about 25%, necessitating its disposal in landfills. ills.

There are also economic challenges that arise. Market demand has a big impact on the price of scrap metal. For example, the demand for scrap copper tends to rise during periods of heightened house building, as home builders are significant consumers of this metal. Conversely, during periods of reduced housing demand, the rates offered for scrap copper tend to decline. Recyclable commodities are commonly exported from economically advanced countries to less economically developed nations, where workers engage in manual sorting of metallic waste materials. The financial instability might be a consequence of the 2018 rules implemented by China, which imposed stricter limitations on acceptable contamination levels and restricted the types of materials that would be accepted. The fluctuation of economic conditions might provide challenges for waste management enterprises and urban municipalities in reaching consensus on the stipulations of long-term agreements, so giving rise to possible conflicts.

Construction and demolition (C&D) debris is identified as the primary contributor to solid waste, despite municipal solid waste (MSW) being more visibly noticeable Li et al. (2013). In 2013, it was observed that C&D generated a quantity of debris in the United States that was twice as large as the amount of Municipal Solid Waste (MSW) created, with a total of 548 metric tons. Policies designed to mitigate construction and demolition (C&D) waste can have a substantial impact on the quantity of materials that undergo recycling processes. States have the authority to impose requirements on property owners or contractors to ensure that construction and demolition waste is obligated to be diverted towards recycling or reuse Li et al. (2013). The Construction and Demolition Waste Ordinance implemented by the city of San Francisco mandates the recycling or use of all waste products categorized as construction and demolition (C&D) rubbish.

There are two strategies that towns may employ to promote recycling activities: decreasing recycling prices and increasing landfill fees. Adelaide, Australia, implements periodic increases in its waste disposal levy to encourage recycling practices. Several European countries are increasing private sector participation through the adoption of expanded producer responsibility schemes Li et al. (2013). Under an Extended Producer Responsibility (EPR) system, the producer assumes the financial responsibility for covering the expenditures associated with material recycling. Manufacturers have the option to establish a mechanism wherein end-of-life items are returned to the municipality, or alternatively, they may directly compensate the municipality for the purpose of recycling. Extended Producer Responsibility (EPR) systems contribute to the diversion of waste from landfills, reduction in government expenditures, and providing incentives to manufacturers to increase the production of recyclable products.

EPR payments have the potential to support outreach programs aimed at waste prevention, as well as research and development efforts, in addition to mitigating recycling costs. Several municipalities and countries have set ambitious objectives to significantly reduce trash. In Wales, the objective is to achieve a state of zero waste by the year 2050, whereas in Scotland, the aim is to recycle seventy percent of trash by the year 2025 Lian et al. (2012). The European Commission has established comparable objectives for the purposes of reuse and recycling, with a target of 65% by 2035, up from the previous target of 50% by 2020. A waste management plan often aligns regulations, methods, and incentives in conjunction with specific objectives. In 2014, Scotland implemented a prohibition on the disposal of metal, plastic, glass, paper, cardboard, and separately collected food waste in landfills or through incineration Lian et al. (2012). To facilitate this transition, the Scottish government provided a range of support packages to businesses, local authorities, and the waste management sector. San Francisco was among the pioneering towns to adopt a zero-waste aim in 2003.

The implementation of waste separation regulations, encompassing recycling, composting, and landfilling, was mandated in 2009 as a result of legislative action. By the year 2012, the recycling rate of the city, encompassing both recycling and composting, had achieved a notable level of 80%. This significantly surpassed the national average of 34% and stood as the most elevated percentage among all cities in the

United States Lian et al. (2012). Nevertheless, addressing the remaining 20% poses challenges because of the inherent complexities associated with recycling some items, hence impeding the achievement of complete adherence to recycling requirements. Items that pose challenges in terms of recyclability may be subjected to a tax associated with trash, wherein the generated funds are allocated towards the support of an investment fund and initiatives aimed at promoting recycling education.

In cases when viable alternatives exist, there is a possibility of implementing legislation to prohibit the usage of products that pose challenges in terms of recyclability. To provide an example, San Francisco implemented a ban on single-use plastic straws in 2019, prohibited the use of plastic bags in pharmacies and supermarkets in 2007, and enacted a prohibition on the utilization of polystyrene foam in food service establishments since 2006 Shin et al. (2017). Community outreach and financial incentives are utilized to promote recycling and trash reduction as well. San Francisco households are provided with a comprehensive invoice for waste management expenses in order to enhance their comprehension of their trash disposal practices and the corresponding financial ramifications.

Community outreach and financial incentives are utilized to promote recycling and trash reduction as well. San Francisco households are provided with a comprehensive invoice for waste management expenses to enhance their comprehension of their trash disposal practices and the corresponding financial implications. Households that engage in the practice of transferring their garbage from mixed waste containers to distinct bins designated for composting or recycling purposes will experience a reduction in their monthly expenses Shin et al. (2017). If individuals want to transition to a smaller receptacle for waste disposal, they will furthermore experience financial savings. The municipality has implemented a compliance program to conduct regular audits of waste that fail these inspections first receive warnings, then face financial penalties.

The global landscape is witnessing an acceleration of socioeconomic upheaval due to several reasons, including globalization, technological advancements, and climate change. The surge in partisanship, nationalism, and populist movements can be attributed to growing apprehensions over the accessibility of economic opportunities. The availability of high-quality employment opportunities is a prominent subject of discourse in the context of societal reform. To address the societal divisions caused by political and cultural factors, it is imperative to examine the incorporation of human needs while implementing technical and legislative strategies aimed at decarbonizing the industrial sector Yazdani et al. (2020). The extraction and use of fossil fuels are resulting in employment displacement, notwithstanding the persistent and escalating pollution levels associated with fossil fuel consumption on a worldwide scale. As an illustration, the mining and natural resources industry in the United States provides employment to around about half the population of Hawaii, equivalent to almost half the population of Hawaii. This sector includes activities related to coal, oil, and gas, and contributes to 0.5% of the overall nonfarm employment

2.9.1. The implications of the subject matter are significant and warrant further examination

The integration of artificial intelligence (AI) applications with businesses that consume high amounts of energy carries substantial ramifications for the promotion of environmental sustainability. The analysis demonstrates a measurable decrease in greenhouse gas (GHG) emissions, making a valuable contribution towards the overarching objective of attaining net zero emissions Ashraf et al. (2022). Industries that use AI-driven solutions experience a reduction in carbon emissions and enhancements in their overall commitment to environmental stewardship.

2.9.2. The economic ramifications

In addition to environmental factors, it is important to acknowledge the significant economic implications associated with the integration of artificial intelligence (AI) into energy-intensive operations. The results of the study suggest that the use of AI applications is associated with enhanced efficiency, less waste, and reduced operating expenses Ashraf et al. (2022). The economic advantages outlined provide a strong rationale for enterprises to allocate resources towards the adoption of AI technology to effectively align with environmental targets and financial aims.

This study highlights the significance of technical breakthroughs propelled by artificial intelligence in promoting innovation within industries that consume high amounts of energy. The use of intelligent, data-driven technologies not only improves operational efficiency but also places industries at the forefront of sustainable practices Ashraf et al. (2022). The phenomenon holds significant significance for the worldwide shift towards more sustainable energy sources and the development of robust industrial ecosystems.

2.9.3. Suggestions for Future Research

Interdisciplinary studies refer to the academic field that integrates knowledge and methodologies from other disciplines in order to address complex issues and problems. Further investigation is required to examine multidisciplinary methodologies that amalgamate proficiencies from the fields of environmental science, engineering, and artificial intelligence. Bringing together collaborative efforts can help us understand how artificial intelligence (AI) applications affect the environment in a more complete way, which can speed up the process of finding the best solutions.

2.9.4. Assessment of Long-Term Impacts

The long-term consequences of AI applications in achieving net-zero greenhouse gas (GHG) emissions are significant and complex. Artificial intelligence has the potential to significantly transform key areas that are crucial for attaining sustainability objectives Meinshausen et al. (2009). AI-driven optimization algorithms can improve the efficiency of renewable energy sources in energy production by accurately forecasting and regulating changes in power generation. AI-powered smart grids enhance demand management, minimizing inefficiency and promoting a more stable and adaptable energy infrastructure. Furthermore, AI plays a substantial role in advancing the creation of sophisticated materials and technologies, enhancing the efficiency of resource utilization and reducing the environmental impact of manufacturing procedures Meinshausen et al. (2009). AI-driven advancements in transportation, such as driverless vehicles and traffic management algorithms, have the potential to decrease fuel usage and emissions.

Moreover, AI facilitates the development and execution of extensive climate change policies through the examination of extensive datasets and the simulation of intricate situations, assisting policymakers in devising efficient tactics Meinshausen et al. (2009). To achieve a fair transition and avoid unforeseen consequences, it is essential to carefully analyze the ethical and socio-economic ramifications, despite the apparent advantages. In summary, the use of artificial intelligence (AI) in the effort to achieve net-zero greenhouse gas (GHG) emissions presents a revolutionary and enduring approach, promoting a stronger and ecologically conscious global community.

It is imperative for academics to prioritize the undertaking of comprehensive and protracted monitoring and assessment investigations to assess the enduring implications of AI applications for attaining net zero. This analysis aims to offer valuable insights into the long-term efficacy of artificial intelligence (AI) technologies in mitigating greenhouse gas (GHG) emissions and their capacity to adapt to dynamic industrial environments Meinshausen et al. (2009). Further research should be focused on investigating the legislative and regulatory frameworks that can facilitate the extensive implementation of artificial intelligence (AI) in energy-intensive sectors. The identification of impediments, the formulation of incentives, and the proposal of regulatory guidelines will play a pivotal role in establishing a conducive climate for the adoption and implementation of sustainable practices.

2.10 Conclusion

In summary, our quantitative research underscores the revolutionary capacity of artificial intelligence (AI) applications in energy-intensive sectors with regards to attaining net zero emissions. The integration of artificial intelligence (AI) into industrial processes has far-reaching repercussions across environmental, economic, and technical aspects, hence highlighting its numerous advantages. In the future, the utilization of collaborative multidisciplinary research and the prioritization of long-term impact assessment will play a crucial role in enhancing and expanding these creative solutions. This will eventually contribute to the development of a more sustainable and resilient industrial environment.

To enhance the depth of insights provided to decision-makers, it becomes imperative to address a fresh array of challenges, since the pursuit of the net-zero aim brings about significant changes in the modeling framework. It is evident that certain concerns have been previously identified; nevertheless, considering the crucial significance of modeling in facilitating the development of national energy and climate policies presently, it is essential to promptly resolve these challenges. In terms of scope, breadth encompasses adopting a bold approach to explore potential solutions, including those that are now deemed politically unacceptable or less prominent. Additionally, it involves dedicating thoughtful consideration to concepts such as carbon dioxide removal (CDR), which can significantly impact the resilience of future strategies. To ascertain the continued relevance of modeling approaches in net-zero evaluations, it is necessary to do a comprehensive evaluation of their functional aspects. Instead of only emphasizing the potential actions that may be implemented, the emphasis is shifted towards the effective execution of these measures.

In addition, it is important to guarantee that the models possess the capacity to effectively depict future iterations of system configurations. Ultimately, the practical implementation of this will require a collaborative approach that acknowledges the diverse skills required from various research groups, along with the meaningful engagement of several specialists and stakeholders in the project. In addition to demonstrating a comprehensive comprehension of uncertainty and a willingness to participate in non-traditional scenario analysis, it is crucial for modelers to recognize the diverse array of priorities that decision-makers must consider.

The significance of the decision-making process pertaining to the decarbonization of energy systems has grown in importance. In this context, the energy modeling community possesses the potential to provide a considerable body of knowledge that may support the development of net-zero legislation. Nevertheless, some modifications to the extent, objective, and approach of modeling are required. The purpose of this model is to systematically integrate the interrelationships between the biosphere, atmosphere, economics, and society under a unified analytical framework. The subsequent statement functions as a disclosure. The author(s) failed to disclose possible conflicts of interest.

The researchers have undertaken an examination of the status of digitalization in energy-intensive industries (EIIs) and have put up a conceptual framework aimed at facilitating the implementation of environmentally sustainable smart manufacturing techniques within these sectors. A complete framework comprising five layers has been designed with the aim of augmenting the intelligence of energy-intensive industries (EIIs) and therefore improving energy and material efficiency. The layers encompassed in this framework consist of data collection, process management, simulation and modeling, artificial intelligence, and data visualization. The use of process mining and simulation modeling methodologies, with the intention of supporting the notion of sustainability, enabled the advancements described in the discussion that follows. A test case from the machining sector serves as an illustration of the framework's ability to support sustainable smart manufacturing and enable a thorough digital transition across several phases.

The principal scientific contribution is to the application of process mining, simulation, and modeling methodologies to acquire a full comprehension of the existing state ("Asis") process. To make it easier to build a parametric discrete-event simulation model, process data analysis was used to find deviations from the set norm, share important information, and test operational protocols. The simulation model's output was utilized to predict energy usage, which is later shown on dashboards to pinpoint areas for improvement Duflou et al. (2012). By looking at what we know now, there doesn't seem to be a lot of academic research that investigates how to better understand EIIs by using process mining, modeling, and simulation methods. The writers wish to emphasize this issue. Moreover, the research demonstrated the significance of data quality and truthfulness.

The study further elucidated the significance of ensuring the accuracy of the data and the proper execution of the modeling technique. Furthermore, challenges pertaining to compatibility and interoperability between hardware and software were discovered. To address the limitations related to data quality issues, interoperability, and compatibility with legacy systems, several approaches can be taken in future work. These include the identification and integration of data quality checks and data governance policies at the gateway of each of the five layers. Additionally, it is important to identify historical datasets that are relevant to current processes and assess their suitability for training the models used in the AI layer. Furthermore, the identification of open-source software and APIs that can help overcome issues with real-time data transfer and compatibility problems is also crucial. There are also plans to make this study better by adding ontologies and mapping to the process management layer, self-adapting automation and manufacturing systems, cloud and edge computing, and full knowledge representation.

CHAPTER III:
METHODOLOGY

3.1 Introduction

Considering growing global climate concerns, the need to transition to a sustainable and carbon-free future is more important than ever. Energy-intensive sectors are a significant source of greenhouse gas emissions. Thus, there is an urgent need for creative solutions that will enable them to transition to net-zero carbons emissions. This study proposal will investigate the untapped potential of using Artificial Intelligence (AI) applications to promote significant reductions in greenhouse gas emissions within energy-intensive businesses. This study aims to present a thorough quantitative analysis that highlights the potential of AI-driven solutions and underscores their viability, challenges, and concrete contributions to the global net-zero agenda. It does this by fusing the capabilities of AI with the need to reduce emissions.

The idea of reaching net-zero emissions has moved to the forefront of governmental and industry discourse as the globe struggles with the collision of economic expansion and environmental preservation. Due to their intrinsically carbon-intensive processes, sectors that rely substantially on energy consumption, such as manufacturing, steel production, and chemical processing, frequently face challenging obstacles in their quest for sustainability Diaz et al. (2011). This study investigates how AI technologies, such as process optimization, predictive analytics, and machine learning algorithms, may be used to engineer significant changes in energy-intensive industries. This study highlights the potential of AI-driven interventions in reducing greenhouse gas emissions while providing insights into the complex interactions between technology advancement, industrial practices, and environmental concerns through careful quantitative analysis.

3.2 Overview of the Research Problem

The dissertation focuses on a critical challenge of reducing greenhouse gas (GHG) emissions in energy-intensive industries, which are crucial to the global economy but also contribute significantly to environmental degradation. Despite the growing awareness and efforts to combat climate change, these industries face substantial hurdles in achieving sustainable operational efficiencies, and meeting global emission reduction targets. This dissertation investigates the potential of artificial intelligence (AI) technologies to address this dilemma.

The research problem is multifaceted and explores AI's transformative power to enhance energy efficiency, optimize industrial processes, and significantly reduce GHG emissions. It aims to determine the correlation between AI adoption and emission reductions, investigating whether the integration of AI not only promises theoretical benefits but also delivers quantifiable environmental improvements in practice. The problem extends to examine specific AI applications, such as optimization algorithms that fine-tune energy use and predictive maintenance that prevents wasteful practices, assessing their direct impact on emission levels.

Furthermore, the research problem delves into the broader ecosystem surrounding AI implementation, including the role of corporate sustainability efforts and the influence of regulatory frameworks. It aims to identify how businesses' commitment to sustainability, coupled with supportive policies and incentives, can foster the effective deployment of AI technologies for environmental benefits.

At its heart, this dissertation seeks to bridge the gap between technological innovation and environmental sustainability, offering insights into how AI can be leveraged to not only advance industrial efficiency but also contribute to the global imperative of achieving net-zero emissions. This investigation is crucial for developing actionable strategies that industries can adopt to align with environmental goals, thereby addressing a pressing issue at the intersection of technology, industry, and sustainability.

3.3 Research Purpose and Objectives

It is imperative to examine companies with high energy use and greenhouse gas emissions to combat climate change effectively. The goal of achieving net-zero emissions has sparked research into creative solutions and technical developments, and AI applications play a crucial role in assisting energy-intensive firms in making the transition. This investigation aims to identify opportunities and areas in need of development, overcome barriers, and measure the effectiveness of AI applications in reducing greenhouse gas emissions. By developing a framework for evaluating AI interventions, we can ensure that sustainable practices are compliant with AI and effectively implemented in various industrial settings.

This dissertation explores several key areas where artificial intelligence (AI) intersects with efforts to reduce greenhouse gas (GHG) emissions in energy-intensive industries. Firstly, it examines the relationship between the adoption of AI technologies and the reduction of GHG emissions, seeking to identify whether a positive correlation exists. The investigation extends to AI-based optimization algorithms and their role in improving energy efficiency within industrial settings. By employing these advanced technologies, industries aim to achieve not just short-term gains but also sustainable long-term improvements in energy use, which in turn reduces environmental impact.

Furthermore, the study delves into the impact of predictive maintenance, facilitated by AI, on emission reduction. Predictive maintenance utilizes AI to anticipate equipment failures before they occur, thus ensuring that industrial operations run more smoothly and efficiently, with less energy waste and lower emissions. Another critical area of focus is the interplay between sustainability initiatives and the implementation of

AI technologies. This involves assessing whether businesses that prioritize environmental sustainability and adopt AI solutions witness a tangible decrease in GHG emissions.

The taken objective for the study are given below.

1. Examine the Correlation Between AI Adoption and GHG Emission Reduction.
2. Investigate AI-based Optimization for Energy Efficiency.
3. Analyze the Impact of Predictive Maintenance on Emission Reduction
4. Assess the Interconnection Between Sustainability Efforts and AI Implementation
5. Explore the Influence of Regulatory Frameworks on the Effectiveness of AI Applications

3.4 Research Design

This research design aims to conduct a quantitative analysis of AI applications' impact on the attainment of net zero energy consumption in highly energy-intensive sectors. By utilizing quantitative research methodology, this research endeavors to provide significant contributions that shape sustainable policies and practices in these vital sectors. With an awareness of the constraints, the results will be a fundamental basis for subsequent investigations and pragmatic implementations to achieve environmental sustainability. This study approach seeks to employ quantitative analysis to examine the role of AI applications in attaining net zero emissions in energy-intensive businesses.

The research design aims to examine the role of artificial intelligence (AI) applications in reducing energy consumption and reaching net-zero emissions in energy-intensive businesses. Through a systematic methodology, this study aims to provide significant knowledge that can be used to shape sustainable practices and policy in these crucial industries. The conclusion emphasizes the research design approach. Utilizing a systematic approach implies a well-organized and structured technique. At the same time, the focus on generating important insights says that the study intends to offer practical and usable information. The emphasis on disseminating sustainable practices and policies signifies a broader objective of exerting influence on practical implementations in the actual world.

Recognizing the constraints of the investigation is crucial. This exemplifies honesty and a pragmatic comprehension of the research’s extent and possible limitations. Limitations may arise from data constraints, methodological limitations, or other problems potentially impacting the study's conclusions. The findings will provide a foundation for future research and practical applications in pursuing environmental sustainability. The expected impact of the study is stated below. The results are anticipated to provide the foundation for future research attempts, indicating that the investigation is an independent effort contributing to a continuing discourse in the area. Moreover, including actual applications strengthens the notion that the study is not purely theoretical but instead seeks to have tangible effects in the real world, specifically concerning environmental sustainability.

3.4.1 Correlation Between AI Adoption and GHG Emission Reduction

To implement the first objective of examining the correlation between AI adoption and greenhouse gas (GHG) emission reduction in energy-intensive industries, a detailed methodology is outlined below, focusing on the steps to collect, analyze, and interpret data to understand the relationship between these variables.

Determine if there is a statistically significant correlation between the rate of adoption of artificial intelligence (AI) technologies and the reduction of GHG emissions in energy-intensive industries.

Step 1: Defining Variables

Independent Variable (IV): Rate of adoption of AI technologies. This can be measured through various indicators such as the percentage of processes automated, investment in AI technologies, or the number of AI projects implemented within the organization.

Dependent Variable (DV): Reduction in GHG emissions. This will be quantified based on the change in emissions levels before and after AI technology implementation, measured in equivalent units of carbon dioxide (CO2e).

Step 2: Data Collection

Survey Development: Create a structured questionnaire targeting professionals in energy-intensive industries. The questionnaire will include sections on organizational AI adoption levels, specific AI technologies implemented, and quantifiable impacts on GHG emissions. Employ a stratified random sampling technique to ensure representation across various sectors within energy-intensive industries (e.g., manufacturing, energy production, agriculture). Aim to collect a diverse range of responses from different organizational sizes, geographical locations, and levels of AI maturity.Supplement survey data with case studies, industry reports, and academic research that document instances of AI adoption and associated emissions outcomes.

Step 3: Data Analysis

Descriptive Analysis: Begin with a descriptive statistical analysis to understand the distribution of AI adoption rates and GHG emission reductions across the sample.

Correlation Analysis: Use Pearson correlation coefficient analysis to assess the linear relationship between the rate of AI adoption and the reduction in GHG emissions. The Pearson correlation coefficient (r) will indicate the strength and direction of the relationship, where:

- $r = 1$ indicates a perfect positive linear relationship.
- $r = -1$ indicates a perfect negative linear relationship.
- $r = 0$ indicates no linear relationship.

Conduct a simple linear regression analysis if the correlation is significant, to further explore the relationship and quantify the impact of AI adoption rate on GHG emission reductions.

Step 4: Validation and Reliability Checks

Where available, compare findings with external datasets or studies that have examined similar relationships to validate results. Sensitivity Analysis, Perform sensitivity analysis to understand how changes in AI adoption metrics affect GHG emission outcomes, ensuring the robustness of the findings.

Step 5: Ethical Considerations

Ensure that all data collected, especially from surveys, maintain the confidentiality and anonymity of respondents. Informed Consent, Obtain informed consent from all survey participants, clearly stating the purpose of the research and how the data will be used.

Step 6: Reporting Results

Present the findings, highlighting the strength and significance of the correlation between AI adoption and GHG emission reductions. Discuss potential factors influencing this relationship and implications for industry practices. Acknowledge any limitations in the study, such as response bias in surveys or limitations in accurately measuring AI adoption rates. Based on the findings, offer recommendations for how energy-intensive industries can leverage AI technologies to achieve greater GHG emission reductions.

This methodology aims to provide a comprehensive approach to understanding the correlation between AI adoption and GHG emission reduction, contributing valuable insights to the field and guiding future AI implementation strategies within energy-intensive industries.

3.4.2 AI-based Optimization for Energy Efficiency

To address the second objective, "Investigate AI-based Optimization for Energy Efficiency," in the context of reducing greenhouse gas (GHG) emissions in energy-intensive industries through the use of artificial intelligence (AI) applications, a detailed methodology is outlined below. This approach involves collecting, analyzing, and interpreting data to understand how AI-based optimization impacts energy efficiency and contributes to environmental sustainability.

Here Objective is to Evaluate the impact of AI-based optimization algorithms on improving energy efficiency within energy-intensive industries, and assess the subsequent effect on GHG emission reductions.

Step 1: Defining Variables

Independent Variable (IV): Implementation of AI-based optimization algorithms. This involves quantifying the extent of AI optimization use in industrial processes, categorized by type, scale, and scope of application.

Dependent Variable (DV): Improvement in energy efficiency, measured through metrics such as energy consumption per unit of output, energy cost savings, or other industry-specific efficiency indicators. The secondary dependent variable will be the quantifiable reduction in GHG emissions resulting from enhanced energy efficiency.

Step 2: Data Collection

Survey Development: Design a detailed questionnaire aimed at decision-makers and technical staff in energy-intensive sectors. Include questions about the specifics of AI optimization technologies adopted (e.g., machine learning models for process optimization, AI for predictive maintenance), the scale of implementation, and perceived impacts on energy efficiency and GHG emissions. Utilize purposive sampling to target organizations known for their AI technology adoption in various energy-intensive sectors. Ensure the sample includes a broad range of industries, organization sizes, and geographic locations to capture diverse experiences with AI optimization.

Complement survey data with case studies, academic literature, and industry reports documenting instances of AI optimization in energy-intensive industries and their impacts on energy efficiency and emissions.

Step 3: Data Analysis

Analyze the collected data to summarize the types, scales, and scopes of AI optimization technologies implemented across the sample. Perform multiple regression analysis to assess the relationship between AI-based optimization (IV) and improvements in energy efficiency (DV), controlling for relevant covariates such as industry type, organization size, and baseline energy efficiency levels. Additionally, model the indirect effect on GHG emission reductions as a result of improved energy efficiency.

Calculate effect sizes to quantify the magnitude of AI optimization's impact on energy efficiency and GHG emission reductions, providing insight into the practical significance of these relationships.

Step 4: Validation and Reliability Checks

Where possible, validate findings against external benchmarks or datasets from similar studies to ensure the reliability and generalizability of the results. Conduct sensitivity analyses to test the robustness of the findings against variations in AI optimization implementation metrics and energy efficiency measurement methodologies.

Step 5: Ethical Considerations

Adhere to strict data privacy guidelines, ensuring the confidentiality of organizational data collected through surveys and interviews. Obtain explicit informed consent from all participants, clearly explaining the research purpose, how the data will be used, and participants' rights.

Step 6: Reporting and Interpretation

Detail the statistical relationships found between AI optimization implementation and energy efficiency improvements, including any significant variations by industry or technology type. Discuss the implications of these findings for GHG emission reduction efforts. Acknowledge the limitations inherent to the study, such as potential biases in self-reported data or the challenges of isolating the impact of AI from other efficiency-enhancing interventions. Offer strategic recommendations for energy-intensive industries on leveraging AI optimization for energy efficiency, considering both technical and organizational factors that influence success.

This outcome is to rigorously assess the contribution of AI-based optimization to energy efficiency in energy-intensive industries, providing a foundation for understanding how AI technologies can be effectively deployed to achieve environmental sustainability goals.

3.4.3 Predictive Maintenance and Emission Reduction

To pursue the third objective, "Analyze the Impact of Predictive Maintenance on Emission Reduction," within the broader context of utilizing artificial intelligence (AI) applications to achieve net-zero emissions in energy-intensive industries, a detailed methodology is outlined below. This methodology focuses on understanding how AI-supported predictive maintenance can lead to reductions in greenhouse gas (GHG) emissions by enhancing equipment efficiency and minimizing downtime.

Determine the extent to which AI-supported predictive maintenance programs contribute to reducing GHG emissions in energy-intensive industries through improved equipment efficiency and reduced operational downtime.

Step 1: Defining Variables

Independent Variable (IV): Adoption and intensity of AI-supported predictive maintenance programs. This variable will be measured through indicators such as the number of systems under predictive maintenance, the sophistication level of the AI technologies used, and the scope of implementation across the organization's operations.

Dependent Variable (DV): Reduction in GHG emissions, measured by changes in emission levels before and after the implementation of predictive maintenance programs. Secondary measures include improvements in equipment efficiency and reductions in operational downtime, as these are direct contributors to emission reductions.

Step 2: Data Collection

Create a comprehensive survey aimed at maintenance managers, operational heads, and sustainability officers within energy-intensive sectors. Questions should cover details of predictive maintenance programs, including technology adoption, coverage of machinery/equipment, perceived impacts on equipment efficiency, downtime, and emissions.

Use stratified sampling to ensure representation from a variety of sectors within energy-intensive industries, including but not limited to manufacturing, energy, and heavy industry, to capture a wide range of predictive maintenance applications. Supplement primary survey data with case studies, industry reports, and peer-reviewed research that document specific examples of predictive maintenance leading to energy and emissions reductions.

Step 3: Data Analysis

Summarize the adoption levels and characteristics of AI-supported predictive maintenance programs across the sample. Conduct regression analysis to explore the relationship between the implementation of predictive maintenance (IV) and reductions in GHG emissions (DV). Include control variables such as industry type, company size, and baseline emissions levels to isolate the effect of predictive maintenance.

Implement path analysis to model the indirect effects of predictive maintenance on GHG emissions through intermediate variables like equipment efficiency and downtime reduction, providing a clearer picture of the causal mechanisms at play.

Step 4: Validation and Reliability

Where possible, cross-validate the findings with external data or similar studies to ensure the reliability of the results. Perform sensitivity analysis to assess how changes in the measurement of predictive maintenance adoption or emissions reductions impact the study's findings, ensuring the robustness of conclusions drawn.

Step 5: Ethical Considerations

Guarantee the confidentiality of data collected from participants, ensuring that no sensitive company information is disclosed. Clearly communicate the purpose of the research to participants and obtain informed consent, ensuring that participation is voluntary and that participants understand their rights.

Step 6: Reporting and Interpretation

Report on the statistical relationships identified between predictive maintenance programs and GHG emission reductions, including the mediating effects of equipment efficiency and reduced downtime. Analyze the implications of these findings for energy-intensive industries, particularly in terms of operational practices and sustainability strategies.

Limitations and Recommendations: Acknowledge any study limitations, such as potential response biases or limitations in tracking emissions accurately. Provide recommendations for industries on optimizing predictive maintenance programs for better environmental outcomes.

This comprehensive methodology aims to rigorously evaluate the impact of AI-supported predictive maintenance on GHG emission reductions, offering valuable insights into how such technologies can be effectively leveraged within energy-intensive industries to support sustainability goals.

3.4.4 Sustainability and AI in Business Practices

To address the fourth objective, "Assess the Interconnection Between Sustainability Efforts and AI Implementation," in the context of achieving net-zero emissions in energy-intensive industries, a detailed methodology is developed. This approach is designed to explore how businesses' sustainability efforts correlate with the implementation of artificial intelligence (AI) technologies and the resultant impact on greenhouse gas (GHG) emissions.

Investigate the relationship between corporate sustainability initiatives and the implementation of AI technologies, focusing on how these efforts collectively contribute to the reduction of GHG emissions in energy-intensive industries.

Step 1: Defining Variables

Independent Variable (IV): Level of sustainability efforts. This will be measured through various indicators such as sustainability goals, investment in sustainable practices, and the extent of sustainability programs within the organization.

Dependent Variable (DV): Degree of AI implementation in sustainability-related processes, quantified by the number of AI projects aimed at sustainability, the scope of AI applications in environmental management, and the integration of AI in achieving sustainability targets.

Step 2: Data Collection

Develop a survey targeting executives, sustainability officers, and technology managers within energy-intensive industries. The survey will include questions about the organization's sustainability goals, the role of AI in their sustainability strategy, specific AI applications for environmental management, and perceived impacts on GHG emissions. Implement a purposive sampling method to select companies known for their sustainability efforts and AI adoption across different sectors within energy-intensive industries. Ensure diversity in terms of company size, geography, and industry to capture a broad perspective.

Complement survey data with case studies, industry analyses, and academic literature that document the integration of AI in sustainability efforts and its impact on environmental outcomes.

Step 3: Data Analysis

Provide an overview of the sustainability efforts and AI implementation levels across the sampled organizations. Use Pearson correlation analysis to examine the relationship between the level of sustainability efforts (IV) and the degree of AI implementation (DV), assessing the strength and direction of this relationship.

If a significant correlation is found, conduct multiple regression analysis to further explore the relationship, controlling for potential confounding variables such as industry type, company size, and baseline emissions levels.

Step 4: Validation and Reliability

Validate findings through comparison with external benchmarks or datasets from similar studies, enhancing the credibility of the results. Conduct sensitivity analyses to test how variations in the measurement of sustainability efforts or AI implementation affect the study’s conclusions.

Step 5: Ethical Considerations

Ensure that all collected data, especially sensitive organizational information, is kept confidential and secure. Obtain informed consent from all survey participants, clearly explaining the research’s purpose and how their data will be used, ensuring transparency and ethical integrity.

Step 6: Reporting and Interpretation

Detail the findings from the correlation and regression analyses, highlighting the nature of the relationship between sustainability efforts and AI implementation. Discuss the implications of these findings for businesses in energy-intensive industries, emphasizing how AI can be leveraged in sustainability strategies to achieve environmental goals.

This methodology aims to systematically explore the interconnection between sustainability efforts and AI implementation in energy-intensive industries, providing insights into how these two areas can be synergistically harnessed to drive down GHG emissions and promote environmental sustainability.

3.4.5 Influence of Regulatory Frameworks on AI Efficacy

To address the fifth objective, "Explore the Influence of Regulatory Frameworks on the Effectiveness of AI Applications," in the context of achieving net-zero emissions in energy-intensive industries, a detailed methodology is crafted. This approach aims to understand how different regulatory environments impact the adoption and efficacy of artificial intelligence (AI) technologies for reducing greenhouse gas (GHG) emissions.

Examine how favorable regulatory frameworks and governmental incentives influence the adoption of AI technologies in energy-intensive industries and their effectiveness in contributing to GHG emission reductions.

Step 1: Defining Variables

Independent Variable (IV): Regulatory frameworks and governmental incentives. This includes the presence of policies supporting AI innovation, environmental regulations encouraging emission reductions, and financial incentives for sustainable practices.

Dependent Variable (DV): Effectiveness of AI applications in reducing GHG emissions, measured through the adoption rate of AI technologies, quantifiable improvements in emissions, and the scalability of AI solutions for environmental management.

Step 2: Data Collection

Develop a structured questionnaire for industry professionals, policymakers, and experts in environmental regulation. Include questions on the nature of existing regulatory frameworks, specific governmental incentives for AI and sustainability, the impact of these policies on AI adoption, and the perceived effectiveness of AI in reducing emissions. Use a combination approach of purposive and snowball sampling to target respondents across various jurisdictions with differing regulatory environments. Ensure the sample includes a mix of sectors within energy-intensive industries to capture diverse regulatory impacts.

Gather data from legal databases, industry reports, and academic papers on regulatory policies related to AI and sustainability, focusing on comparative analyses of regulatory impacts on AI adoption and effectiveness in emission reductions.

Step 3: Data Analysis

Compare AI adoption rates and emission reduction outcomes across different regulatory environments to identify patterns or correlations with regulatory frameworks and incentives. Conduct regression analysis to quantitatively assess the relationship between regulatory frameworks (IV) and the effectiveness of AI applications in emission reductions (DV), controlling for industry-specific factors and baseline emissions levels.

Perform thematic analysis on open-ended survey responses and case studies to understand the nuanced effects of regulatory frameworks on AI implementation strategies and challenges.

Step 4: Validation and Reliability

Employ data triangulation by comparing findings from surveys, secondary data, and case studies to ensure consistency and reliability of results. Test the sensitivity of the findings to different definitions of regulatory support and measures of AI effectiveness, ensuring robust conclusions.

Step 5: Ethical Considerations

Protect the identity of survey participants and the confidentiality of sensitive information provided, particularly regarding regulatory critiques or company-specific practices. Clearly inform participants about the study's goals, how their data will be used, and obtain their consent, adhering to ethical research standards.

Step 6: Reporting and Interpretation

Report the analysis results, highlighting how regulatory frameworks and incentives correlate with or influence the effectiveness of AI in reducing GHG emissions.

Discuss the policy implications of the findings, suggesting how regulatory adjustments could enhance the role of AI in achieving sustainability goals within energy-intensive industries.

Limitations and Future Research, Acknowledge the study's limitations, including potential biases or the evolving nature of regulatory frameworks, and propose directions for future research to build on the findings.

This detailed methodology is designed to provide comprehensive insights into the influence of regulatory frameworks on the effectiveness of AI applications for GHG emission reductions, offering valuable information for policymakers, industry stakeholders, and researchers interested in leveraging AI for environmental sustainability.

3.5 Population and Sample

The idea of reaching net-zero emissions has moved to the forefront of governmental and industry discourse as the globe struggles with the collision of economic expansion and environmental preservation. Due to their intrinsically carbon-intensive processes, sectors that rely substantially on energy consumption, such as manufacturing, steel production, and chemical processing, frequently face challenging obstacles in their quest for sustainability Diaz et al. (2011). This study investigates how AI technologies, such as process optimization, predictive analytics, and machine learning algorithms, may be used to engineer significant changes in energy-intensive industries. This study highlights the potential of AI-driven interventions in reducing greenhouse gas emissions while providing insights into the complex interactions between technology advancement, industrial practices, and environmental concerns through careful quantitative analysis.

In the study on achieving net zero in energy-intensive industries using AI applications for greenhouse gas reduction, the population refers to all eligible companies operating in energy-intensive sectors that could potentially participate in the study. The aim of random sampling was to ensure that this population was adequately represented in the study sample to increase the external validity of the research findings.

3.6 Participant Selection

The selection of participants is a crucial aspect of any research study, and it requires careful consideration to ensure that the results are valid, reliable, and representative of the broader population. To achieve this, a random sampling technique is often employed to select participants in a way that reduces systematic biases and ensures that all eligible companies operating in energy-intensive industries have an equal opportunity to participate.

Random sampling has several advantages in research studies, including enhancing the study's external validity by ensuring that the sample is representative of companies operating in energy-intensive sectors. This approach reduces the potential for selection bias, which can occur when certain traits consistently deviate from the population, by selecting individuals at random.

Additionally, random sampling aids in guaranteeing the ethical conduct of the research by mitigating prejudice and bias and ensuring that every qualified firm is afforded an equal opportunity to participate in the study. Obtaining a sample representative of the energy-intensive industries is crucial for the study results to be generalizable, and random sampling is implemented to grant each organization an equitable chance of being included in the study.

Finally, random sampling is crucial to ensure the statistical rigor of quantitative analyses. Statistical rigor enables the execution of various statistical tests and analyses predicated on the assumption of randomness to derive significant conclusions regarding the relationships and patterns present in the data. Therefore, the use of random sampling in selecting participants for the study on achieving net zero in energy-intensive industries using AI applications for greenhouse gas reduction was done to ensure the results would be fair, reduce bias, improve external validity, and be helpful for a wide range of companies in the target industries.

3.7 Instrumentation

The following text pertains to the design and implementation of a survey instrument for collecting data on the use of artificial intelligence (AI) applications in reducing greenhouse gas emissions and advancing net-zero objectives in energy-intensive sectors. The survey will be structured to gather comprehensive information about the various AI applications being used, the specific strategies employed by companies to achieve net-zero emissions, and the progress made towards attaining sustainability goals. To ensure the survey's validity and reliability, it will be carefully designed and structured, incorporating both closed-ended and open-ended questions in an approachable format. The Likert scale and multiple-choice formats will be used to collect quantitative data while oen-ended questions will provide qualitative insights.

Prior to the survey's release, a pilot test will be conducted to detect and resolve any uncertainties, misinterpretations, or concerns regarding the clarity of the questions. The survey will be distributed digitally through safe and reliable means, and participants will receive a guarantee of anonymity to encourage honest feedback.

The survey's duration will be communicated to participants to optimize response rates, and ethical considerations will be taken into account, such as obtaining informed consent and addressing any potential hazards related to study participation.

The data collected from this survey will be used for a comprehensive quantitative analysis of the impact of AI applications on achieving net-zero emissions in energy-intensive industries.

3.8 Data Collection Procedures

The following are the procedures that will be implemented in collecting data for the research study. Firstly, the survey will be distributed electronically to the selected representatives of the companies that have been chosen to participate in the study. This will enable the speedy collection of data, as responses can be gathered promptly. The survey will contain clear and concise instructions on how to fill it out, as well as contact information for a named person who can help address any questions or concerns.

The representatives who will be receiving the survey will be selected randomly from each qualified company. These representatives could be individuals who are knowledgeable about and involved in the implementation of AI and sustainable projects, or those whose organizations are responsible for environmental strategies. A precise data collection period will be set, and participants will be informed of this timeline to allow them ample time to consider their responses.

To encourage a higher response rate, reminders will be sent out during the data collection period at strategic times. These reminders may stress the importance of the subjects being studied and how their efforts will contribute to the research. Additionally, incentives may be offered to further motivate respondents to complete the survey. Such incentives could include providing participants with a summary of the study results or entering them into a raffle for an industry-appropriate reward.

The survey will be administered through a secure and user-friendly online platform that is optimized for accessibility and compatibility with a variety of devices. Before sending out the survey, its usability will be checked to ensure that it works on all browsers and devices. Data encryption and security measures will also be taken to protect the privacy of the collected data.

During the data collection period, the research team will be closely monitoring survey responses to promptly detect and resolve any irregularities or concerns. This quality control procedure is intended to ensure the accuracy and integrity of the gathered data. To cater to the diverse communication preferences of participants, multiple channels of communication, such as email, direct messaging, and phone calls, will be utilized to guarantee that invitations and reminders for surveys are received and acknowledged by respondents.

3.9 Data Analysis

The data analysis approach used to investigate the impact of regulatory frameworks on the efficacy of AI applications in mitigating greenhouse gas (GHG) emissions in energy-intensive industries is a comprehensive strategy that combines multiple methods. This approach employs both quantitative and qualitative techniques to evaluate how regulatory environments affect AI adoption and its success in reducing emissions. The key components of the data analysis approach comprise comparative analysis, regression analysis, qualitative analysis, triangulation, and sensitivity analysis.

Comparative analysis is used to identify patterns or correlations between different regulatory frameworks and the outcomes related to AI adoption rates and GHG emission reductions across various jurisdictions. Data from surveys and secondary sources are categorized based on regulatory environments, and the effectiveness of AI applications under these categories is compared to identify trends.

Regression analysis is used to quantitatively assess the relationship between the independent variable (regulatory frameworks and governmental incentives) and the dependent variable (effectiveness of AI applications in GHG emission reductions). Statistical models are developed to control for potential confounding factors, such as industry type and baseline emissions levels, allowing for the isolation of the effect of regulatory frameworks on AI effectiveness. The analysis includes calculating regression coefficients to determine the strength and direction of the relationship.

Qualitative analysis is used to gain insights into the nuanced impacts of regulatory frameworks on the adoption and effectiveness of AI technologies for environmental management beyond what can be captured through quantitative measures alone. Thematic analysis is conducted on qualitative data collected through open-ended survey questions, interviews, and case studies. This analysis identifies common themes, challenges, and opportunities related to regulatory influences on AI implementation and sustainability outcomes.

Triangulation is used to enhance the reliability and validity of the analysis by cross-verifying findings from different data sources and methods. The study cross-references outcomes from comparative and regression analyses with insights derived from qualitative analysis. This process ensures that conclusions drawn are consistent across multiple data sources and analytical approaches.

Sensitivity analysis is used to test the robustness of the findings against variations in the operationalization of regulatory support and measures of AI effectiveness. The analysis examines how changes in definitions or measurements of key variables affect the study’s conclusions. This involves adjusting the parameters of the regression models and reassessing the thematic analysis based on alternative interpretations of qualitative data.

This integrated data analysis approach enables a comprehensive exploration of how regulatory frameworks and governmental incentives influence the adoption and effectiveness of AI technologies in reducing GHG emissions. It combines the strengths of quantitative methods, which provide measurable evidence of relationships and effects, with qualitative insights, which offer depth and context to understand the mechanisms behind these relationships.

3.10 Research Design Limitations

Quantitative research relies heavily on numerical data and statistical analysis, which may result in overlooking the complexities and depths inherent in qualitative components. Qualitative aspects encompass particulars contingent upon the context, subjective experiences, and opinions that often prove challenging to quantify. While quantitative research provides numerical insights, it may fail to capture subtleties and contextual information amenable to qualitative methods such as open-ended surveys and research inquiries. Analyze the ramifications of the results in the context of attaining net zero energy consumption in energy-intensive industries through the implementation overviews. Researchers must recognize the limitations of quantitative data in this context and consider integrating qualitative methods to gain a more comprehensive understanding of the phenomenon under investigation.

Generalizability pertains to the degree of applicability of a study’s results to a more extensive demographic. Limiting the generalizability of the results, the industries or businesses included in the study may not always be representative of the entire population. The findings may not be relevant to various circumstances if the research sample is slight, such as focusing exclusively on specific sectors or firms. It is imperative for researchers to precisely delineate the boundaries and restrictions of their investigation to prevent the formulation of overly generalized conclusions. A greater emphasis should be placed on the diversity and representativeness of the sample to bolster the Study’s external validity.

3.11 Conclusion

This research aims to study the role of artificial intelligence (AI) in reducing energy consumption and achieving zero emissions in energy-intensive industries. The study will use a systematic approach to obtain practical information that can be used to shape sustainable practices and policies in these sectors. The research will also recognize the limitations and constraints of the study, such as data and methodological limitations, to provide a foundation for future research and practical applications towards environmental sustainability. The study expects to have tangible effects in the real world by contributing to a continuing discourse on environmental sustainability.

CHAPTER IV:

RESULTS

4.1 Introduction

In study Exploring Influence of Regulatory Frameworks on the Effectiveness of AI Applications aims to reduce greenhouse gas emissions in energy-intensive industries. To achieve this, the study uses Exploratory Data Analysis (EDA) to understand the characteristics of the data and gain insights into how regulatory frameworks impact the effectiveness of AI technologies.

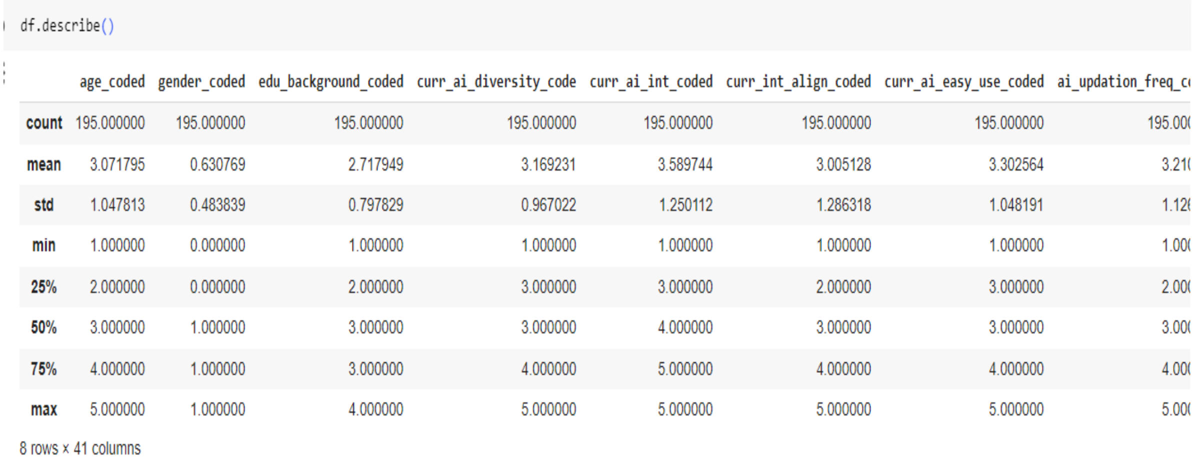
EDA involves analyzing and visualizing data to identify patterns, anomalies, and relationships between variables related to regulatory environments, AI adoption, and GHG emission reductions. This study uses Descriptive Statistics to summarize the data and Distribution Analysis to identify typical ranges of AI effectiveness. Correlation Analysis is used to assess potential relationships between the regulatory environment and the effectiveness of AI applications in emissions reduction.

Visualization Techniques such as scatter plots, bubble charts, box plots, and heat maps are used to explore potential relationships between variables. Anomaly Detection is used to identify outliers in the dataset. Finally, Cross-tabulation and Pivot Tables are used to compare GHG emission reductions by industry type within different regulatory frameworks.

The significance of EDA is that it helps identify significant variables, refine research questions, and ensure that subsequent analyses are grounded in a solid understanding of the dataset's characteristics and the relationships between key variables.

4.2 Exploratory Data Analysis

Below is the snapshot of descriptive statistics of the dataset. This gives us an idea of the distribution of the dataset.



```
df.describe()
```

	age_coded	gender_coded	edu_background_coded	curr_ai_diversity_code	curr_ai_int_coded	curr_int_align_coded	curr_ai_easy_use_coded	ai_updation_freq_c
count	195.000000	195.000000	195.000000	195.000000	195.000000	195.000000	195.000000	195.00
mean	3.071795	0.630769	2.717949	3.169231	3.589744	3.005128	3.302564	3.21
std	1.047813	0.483839	0.797829	0.967022	1.250112	1.286318	1.048191	1.12
min	1.000000	0.000000	1.000000	1.000000	1.000000	1.000000	1.000000	1.00
25%	2.000000	0.000000	2.000000	3.000000	3.000000	2.000000	3.000000	2.00
50%	3.000000	1.000000	3.000000	3.000000	4.000000	3.000000	3.000000	3.00
75%	4.000000	1.000000	3.000000	4.000000	5.000000	4.000000	4.000000	4.00
max	5.000000	1.000000	4.000000	5.000000	5.000000	5.000000	5.000000	5.00

8 rows × 41 columns

Figure 1 Exploratory Data Analysis Snapshot

Then we create a histogram of the educational background of the sample data.

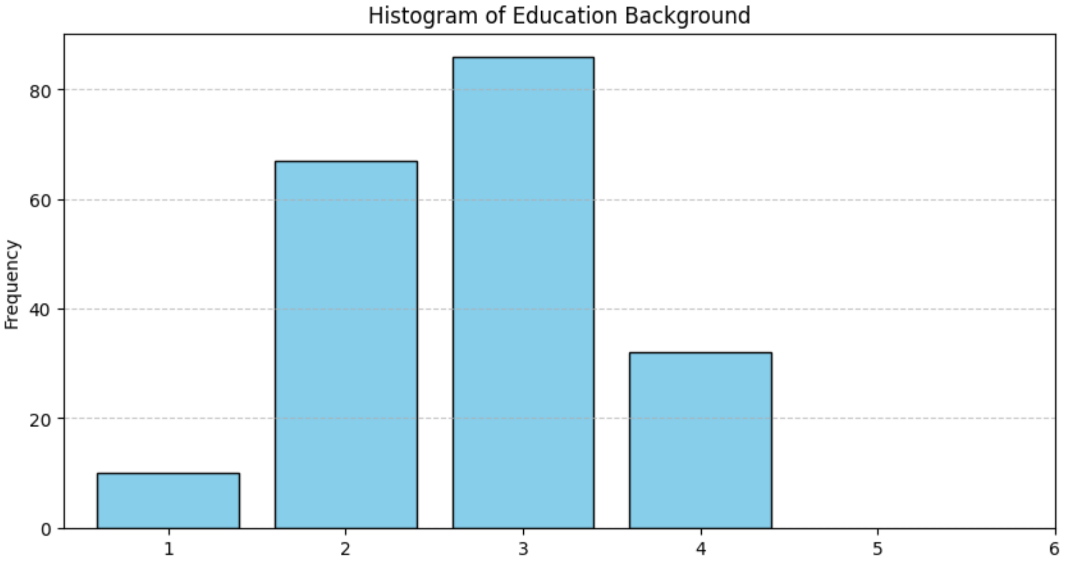


Figure 2 Histogram of Education Background

There were 5 options given to the respondents for capturing their educational background. They were coded as follows:

- High School = 1
- Bachelor's Degree = 2

- Master's Degree = 3
- PhD or equivalent = 4
- Other (please specify) = 5

The histogram shows that the maximum respondents, i.e, 86 in number, at least have a Master's Degree. 67 respondents possess at least a Bachelor's Degree, thus also making them credible sources too. On the other hand, 32 respondents out of 195 have a PhD's or equivalent degrees, thus making them specialised in the field. They are likely to possess specialised knowledge and expertise in their field of study. Respondents with advanced degrees are more likely to provide thoughtful and well-articulated responses to questionnaire items, leading to richer and more informative data. Their participation can contribute to the methodological rigour of the study, ensuring that data collection and analysis methods are sound and appropriate.

We also visualise the proportions of various industry types we have within the sample data to get a look of the diversity within the same:

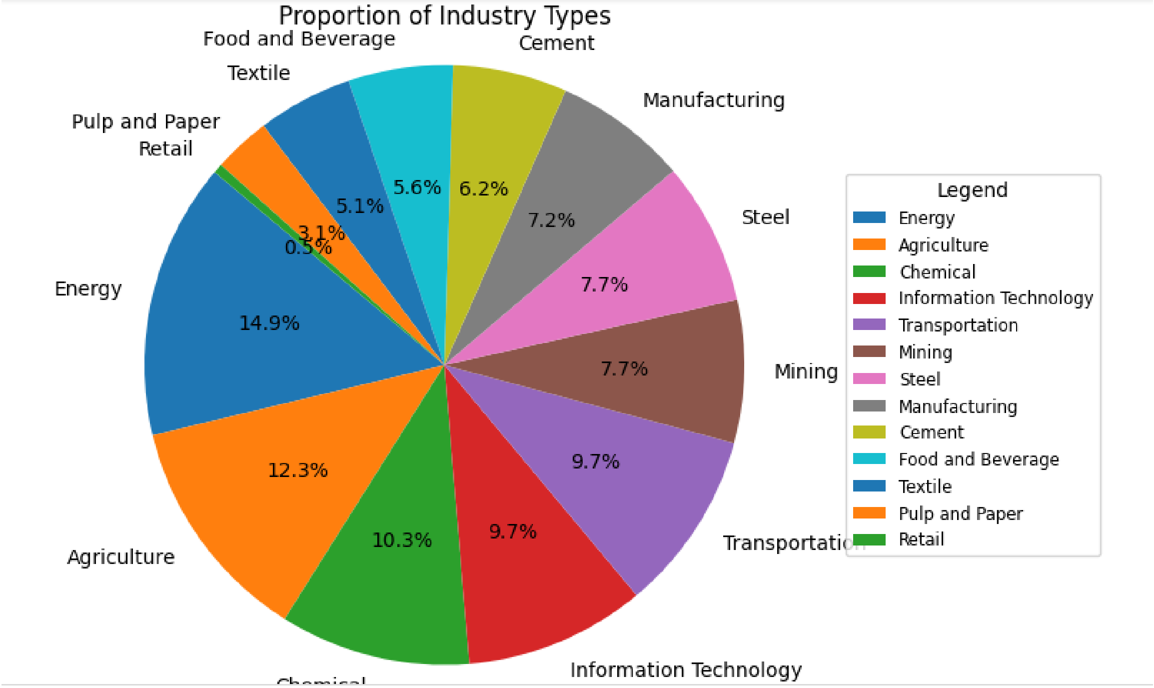


Figure 3 Industries Types

The above graph shows various proportions of the sample that belong to different industry types.

1. The highest proportion of samples comes from the energy industry which is approximately 15%, followed by Agriculture which is 12.3%.
2. The third highest proportion comes from the Chemical industry which stands at 10.3%.
3. Rest industries hold small proportions of the data.

This pie chart tells us that the sample has been diverse, and collecting data from a diverse sample:

- reflects the broader population more accurately, ensuring that findings and conclusions drawn from the data are more generalizable and applicable to a wider range of contexts.
- Diversity in the sample helps mitigate biases that may arise from homogeneity, ensuring that the data collected is more objective and reflective of the true variability within the population.
- By capturing a wide range of perspectives, experiences, and characteristics, data from a diverse sample enhances the validity of the research findings, as they are less likely to be influenced by confounding variables or omitted factors.
- Ensuring diversity in the sample promotes fairness, equity, and inclusivity in research practices, aligning with ethical principles of respecting the dignity and rights of all individuals.

Thereafter, we visualised the proportions of age categories that were present in the sample data through a pie chart:

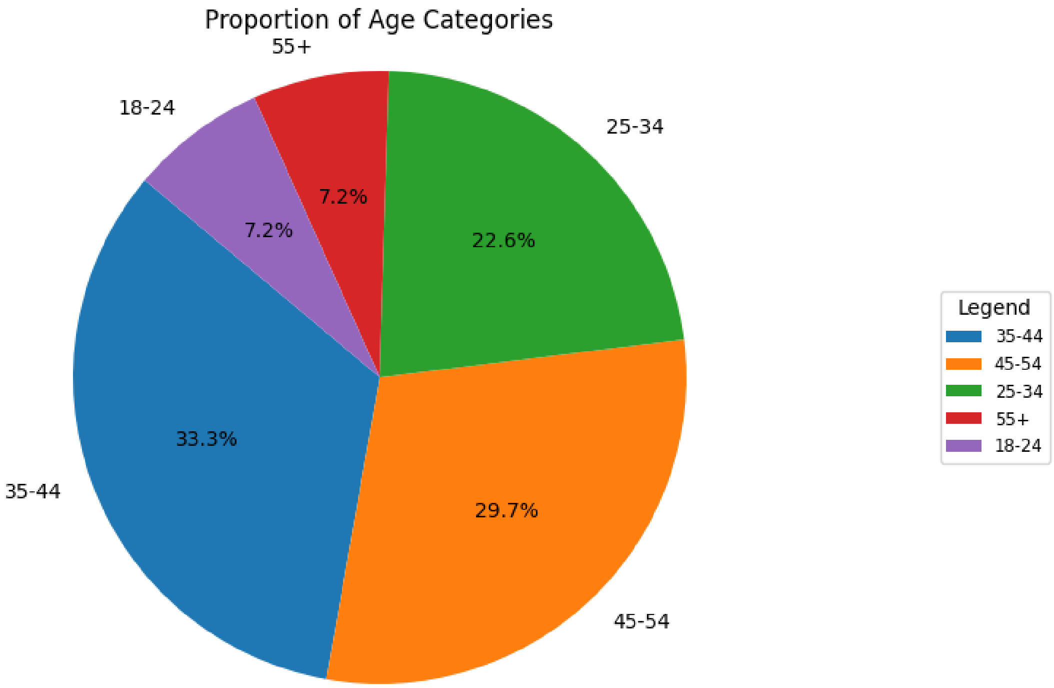


Figure 4 Age categories

The above graph shows various proportions of the sample that belong to different age categories.

4. The highest proportion of samples comes from the category 35-44 years which holds 33.3% sample proportion, followed by 45-54 which is 29.7%.
5. The third highest proportion comes from the 25-34% which stands at 22.6%.
6. Rest age categories hold smaller amounts of proportions.

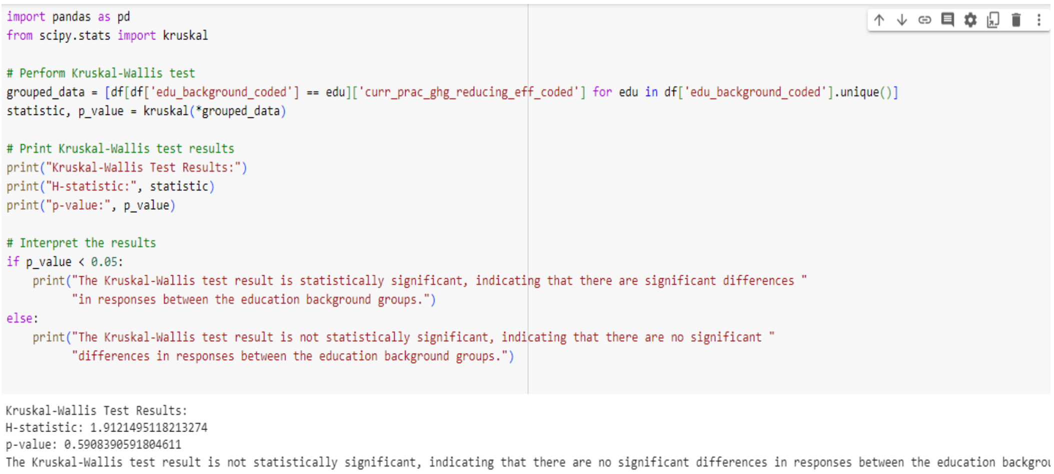
This tells us that the sample belongs to the diverse age groups. Different age groups bring unique perspectives, experiences, and insights to the survey, enriching the data and providing a more comprehensive understanding of the issues being studied.

Surveying individuals across various age groups allows us to explore generational differences in attitudes, behaviours, and preferences within industries.

4.3 Current Practices Are In Reducing Energy-Related Emissions

4.3.1 Kruskal's Wallis Tests

As a part of exploratory data analysis, we also perform Kruskal's Wallis test to see if there's a varied response that we get for the question "How effective do you believe your organisation's current practices are in reducing energy-related emissions?" across various educational backgrounds.



```
import pandas as pd
from scipy.stats import kruskal

# Perform Kruskal-Wallis test
grouped_data = [df[df['edu_background_coded'] == edu]['curr_prac_ghg_reducing_eff_coded'] for edu in df['edu_background_coded'].unique()]
statistic, p_value = kruskal(*grouped_data)

# Print Kruskal-Wallis test results
print("Kruskal-Wallis Test Results:")
print("H-statistic:", statistic)
print("p-value:", p_value)

# Interpret the results
if p_value < 0.05:
    print("The Kruskal-Wallis test result is statistically significant, indicating that there are significant differences "
          "in responses between the education background groups.")
else:
    print("The Kruskal-Wallis test result is not statistically significant, indicating that there are no significant "
          "differences in responses between the education background groups.")
```

```
Kruskal-Wallis Test Results:
H-statistic: 1.9121495118213274
p-value: 0.5908390591804611
The Kruskal-Wallis test result is not statistically significant, indicating that there are no significant differences in responses between the education backgrou
```

Figure 5 Kruskal's Wallis Tests

The output from the Kruskal-Wallis test includes the test statistic (H-statistic) and the associated p-value. Here's an explanation of each component**:**

4.3.2 H-statistic (Test Statistic)

In the provided output, the H-statistic is approximately 1.912. This statistic is calculated based on the ranks of the data and represents the test statistic for the Kruskal-Wallis test. It measures the degree of difference between the groups' median ranks.

p-value:

The p-value associated with the Kruskal-Wallis test is approximately 0.591. This p-value represents the probability of observing the data if the null hypothesis (i.e., the assumption that there are no differences between the groups) is true.

In this case, the p-value is greater than the typical significance level of 0.05, suggesting that there is insufficient evidence to reject the null hypothesis.

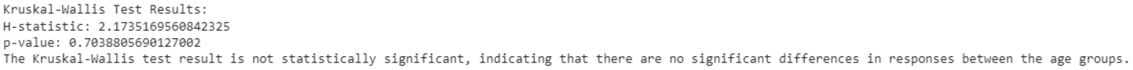
4.3.3 Interpretation

The Kruskal-Wallis test was conducted to analyze the ordinal data and investigate the differences in responses related to education background groups. The test results show that there is no statistically significant difference in the responses among the education background groups. The p-value calculated from the test is greater than the significance level of 0.05, which means that the null hypothesis cannot be rejected. Therefore, it can be concluded that education background does not have a significant impact on the effectiveness of current practices in reducing energy-related emissions.

To examine the relationship between age and the effectiveness of current practices in reducing energy-related emissions, Kruskal’s Wallis test was conducted. The test aims to determine if there are any significant variations in responses to this question among different age groups. The detailed analysis of the results from this test will help us understand the impact of age on the effectiveness of current practices in reducing energy-related emissions.

In summary, the Kruskal-Wallis test did not find any significant evidence to conclude that there are differences in responses between the education background groups. Similarly, Kruskal’s Wallis test is being conducted to determine the effect of age on the effectiveness of current practices in reducing energy-related emissions. The results will provide a detailed understanding of the factors that impact the effectiveness of current practices in reducing energy-related emissions.

We also performed Kruskal’s Wallis test to see if there's a varied response that we get for the question "How effective do you believe your organization’s current practices are in reducing energy-related emissions?" across various age groups.



```
Kruskal-Wallis Test Results:
H-statistic: 2.1735169560842325
p-value: 0.7038805690127002
The Kruskal-Wallis test result is not statistically significant, indicating that there are no significant differences in responses between the age groups.
```

Figure 6 Kruskal’s Wallis test to see varied response

4.3.4 Interpretation of p-value

The p-value represents the probability of observing the data, or more extreme data, under the assumption that the null hypothesis is true.

In this case, the null hypothesis is that there are no significant differences in responses between the age groups.

A p-value greater than the chosen significance level (commonly 0.05) indicates that there is insufficient evidence to reject the null hypothesis.

The obtained p-value of approximately 0.7039 is much larger than 0.05, suggesting that there is no statistically significant evidence to reject the null hypothesis.

Based on the obtained results, we fail to reject the null hypothesis.

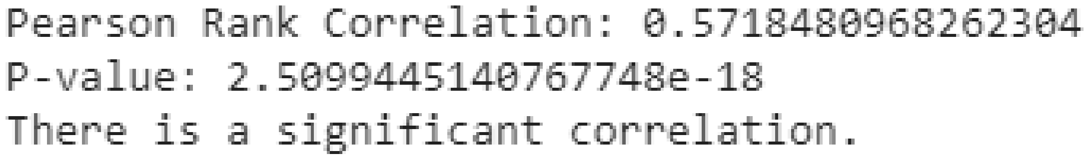
Therefore, we conclude that there are no significant differences in responses between the age groups, as indicated by the Kruskal-Wallis test.

In summary, the Kruskal-Wallis test results suggest that there is no statistically significant evidence to conclude that responses differ significantly between the age groups being compared.

4.4 Examine the Correlation between AI Adoption and GHG Emission Reduction

The objective here is adoption and integration of AI technologies and the reduction of greenhouse gas emissions in energy-intensive industries are positively correlated.

Method used is pearson correlation between reduction of greenhouse gas emissions and rate of adoption of AI technologies.



```
Pearson Rank Correlation: 0.5718480968262304
P-value: 2.509944514076748e-18
There is a significant correlation.
```

Figure 7 Results Pearson Correlation

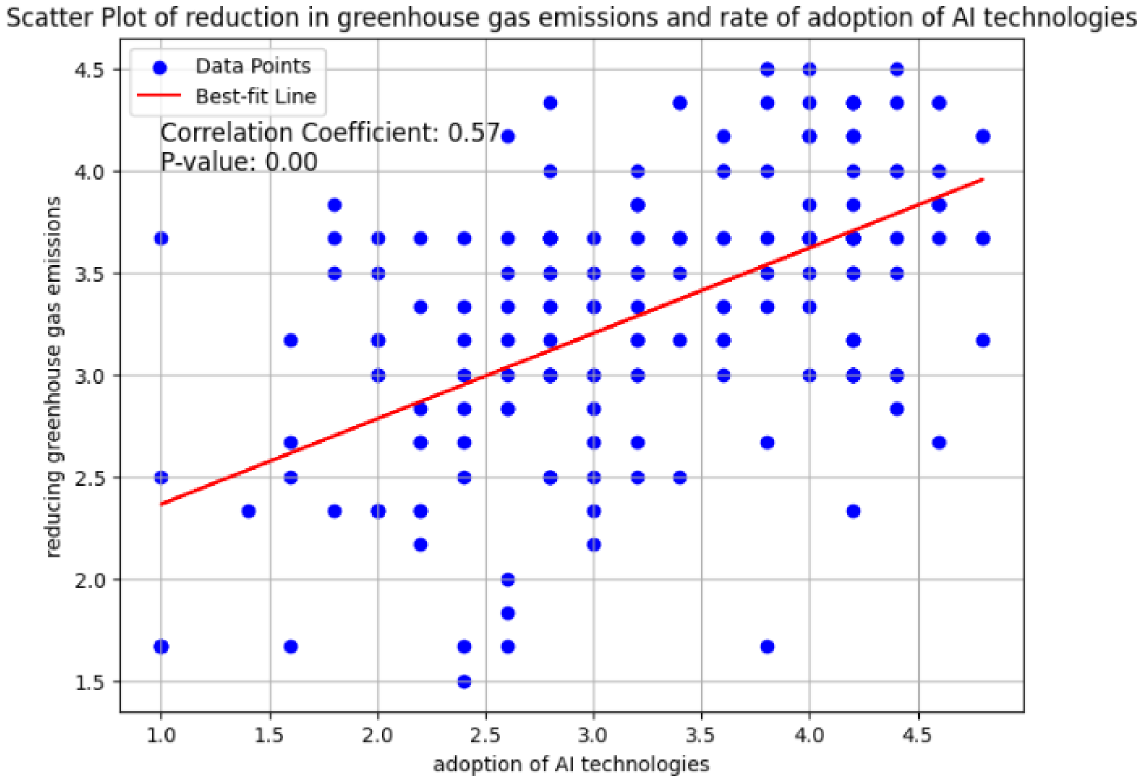


Figure 8 Plot between greenhouse gas emissions and adoption of AI

The scatter plot you've provided appears to illustrate the relationship between the rate of adoption of AI technologies and greenhouse gas emissions. The plotted points indicate individual data entries for different entities, such as companies or industrial facilities, representing their respective levels of AI technology adoption and the associated greenhouse gas emissions.

The red best-fit line suggests a positive linear relationship between these two variables, as indicated by the upward slope. This is further supported by the correlation coefficient (r) of 0.57 displayed on the chart, which denotes a moderate positive correlation between the adoption of AI technologies and greenhouse gas emissions.

Moreover, the p-value is reported as 0.00, which typically denotes a value less than the conventional alpha level of 0.05, suggesting that the observed correlation is statistically significant, and the likelihood of this result occurring by chance is very low.

It's important to note that while the correlation is positive, the interpretation of this relationship in the context of reducing greenhouse gas emissions requires careful consideration. A positive correlation might imply that as AI adoption increases, emissions also increase, which seems counterintuitive if AI technologies are supposed to help reduce emissions. This could be due to a variety of factors, such as an initial increase in emissions due to the energy and resources required to develop and integrate AI systems, or it might reflect a stage where AI technologies are being adopted but not yet fully optimized for emissions reduction.

Further analysis would be needed to understand the nuances of this relationship, including considering other variables that might influence emissions and the specific types of AI technologies being implemented. Additionally, longitudinal data tracking emissions over time post-AI adoption would provide more insights into the long-term effects of AI on emissions.

4.4.1 Pearson Rank Correlation

The Pearson correlation coefficient is a measure of the strength and direction of the linear relationship between two continuous variables. In this case, the Pearson correlation coefficient is approximately 0.572. This value ranges between -1 and 1, where:

- A value of 1 indicates a perfect positive linear relationship (as one variable increases, the other variable also increases).
- A value of -1 indicates a perfect negative linear relationship (as one variable increases, the other variable decreases).
- A value of 0 indicates no linear relationship between the variables.

In your case, a Pearson correlation coefficient of 0.572 suggests a moderate positive linear relationship between the two variables.

4.4.2 P-value

The p-value associated with the correlation coefficient measures the statistical significance of the observed correlation. In your case, the p-value is approximately 2.51e-18, which is a very small value.

- A small p-value (typically less than 0.05) indicates strong evidence against the null hypothesis, suggesting that the observed correlation is statistically significant.
- Conversely, a large p-value suggests weak evidence against the null hypothesis, indicating that the observed correlation may be due to random chance.
- In this case, the extremely small p-value indicates that the observed correlation is statistically significant.

4.4.3 Interpretation

Based on the provided output, we can interpret the results as follows:

- There is a statistically significant moderate positive linear relationship (Pearson correlation coefficient = 0.572) between the two variables.
- The probability of observing such a correlation coefficient (or even stronger) by random chance alone is extremely low (p-value ≈ 2.51e-18).

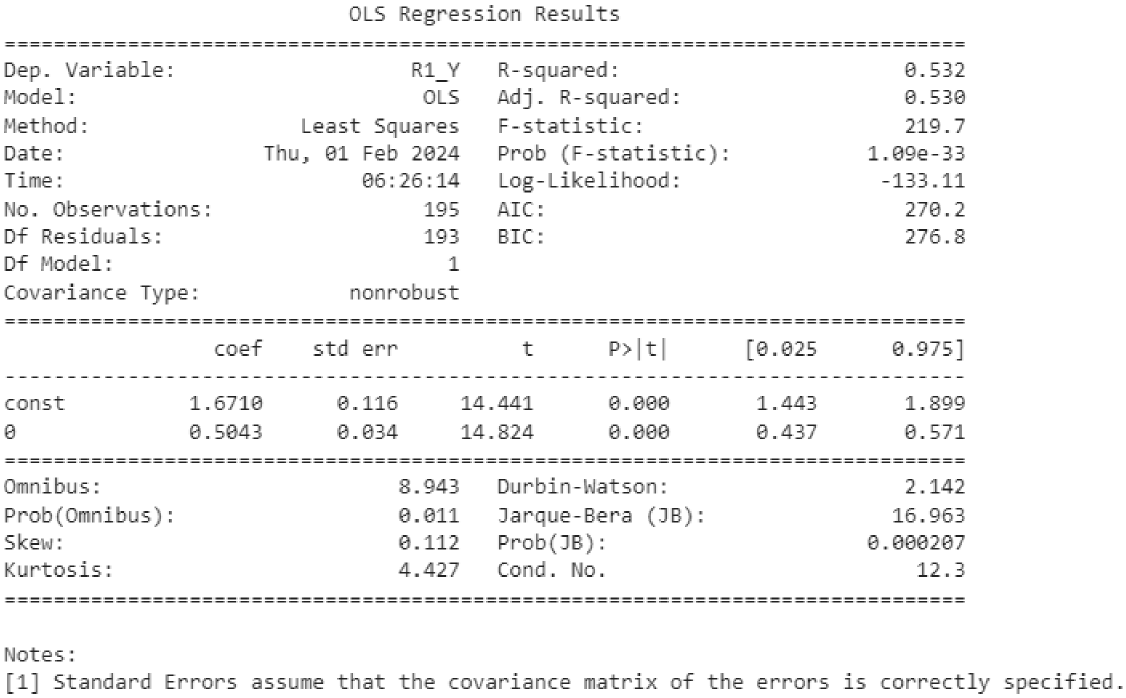
- Therefore, we reject the null hypothesis that there is no correlation between the variables, and conclude that there is a significant correlation between them.

In summary, the output suggests that there is a statistically significant positive linear relationship between the two variables, meaning that as one variable increases, the other tends to increase as well.

4.5 Investigate AI-based Optimization for Energy Efficiency

The second objective which were explored as AI-based optimization algorithms are used in energy-intensive industrial processes with a quantifiable gain in energy efficiency and a corresponding decrease in greenhouse gas emissions in the long and short run.

Method use here is Regression Analysis where dependent variable is a decrease in greenhouse gas emissions and independent variable is the quantifiable gain in energy efficiency due to the use of AI-based optimization algorithms.



```
                            OLS Regression Results
==============================================================================
Dep. Variable:                   R1_Y   R-squared:                       0.532
Model:                            OLS   Adj. R-squared:                  0.530
Method:                 Least Squares   F-statistic:                     219.7
Date:                Thu, 01 Feb 2024   Prob (F-statistic):           1.09e-33
Time:                        06:26:14   Log-Likelihood:                -133.11
No. Observations:                 195   AIC:                             270.2
Df Residuals:                     193   BIC:                             276.8
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          1.6710      0.116     14.441      0.000       1.443       1.899
0              0.5043      0.034     14.824      0.000       0.437       0.571
==============================================================================
Omnibus:                        8.943   Durbin-Watson:                   2.142
Prob(Omnibus):                  0.011   Jarque-Bera (JB):               16.963
Skew:                           0.112   Prob(JB):                     0.000207
Kurtosis:                       4.427   Cond. No.                         12.3
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 9 Regression Results

In the above results, the regression model is highly significant. The coefficient of the independent variable is positive, that is, 0.5043, with a p-value of 0.000 and Prob (F-statistic) as 1.09e-33. This suggests that the decrease in the greenhouse gas emissions is positively correlated with the quantifiable gain in energy efficiency due to the use of AI-based optimization algorithms.

Based on the provided output, here's a breakdown of the key components and their implications:

- Dependent Variable: This is the variable that the model is trying to predict. However, the dependent variable's name (R1_Y) is not fully descriptive, so it's unclear what specific aspect of greenhouse gas emissions or AI adoption this refers to.

- R-squared: At 0.532, this indicates that approximately 53.2% of the variability in the dependent variable can be explained by the model. This is a measure of the model's goodness of fit.
- Adjusted R-squared: At 0.530, it is very close to the R-squared value, which suggests that the number of predictors in the model is appropriate for the number of observations.
- F-statistic: With a value of 219.7 and an associated p-value of approximately 0.00 (shown as 1.09e-33), this indicates that the model is statistically significant. This means that the independent variables, collectively, have a statistically significant effect on the dependent variable.
- The coefficient for the constant (const) is 1.6710, with a very low p-value, indicating that it is statistically significant.
- The coefficient for the independent variable (θ), possibly representing the rate of adoption of AI technologies, is 0.5043. This means that for each unit increase in the adoption of AI technologies, the dependent variable increases by an average of 0.5043 units.
- Standard Error (std err): The standard errors for the coefficients are quite low, which indicates precision in the coefficient estimates.
- T-statistic: Both the constant and the independent variable have large t-statistic values, which, combined with the low p-values, suggest that both coefficients are significantly different from zero.
- P>|t|: The p-values for both the constant and the independent variable are less than 0.05, indicating that both are statistically significant predictors of the dependent variable.

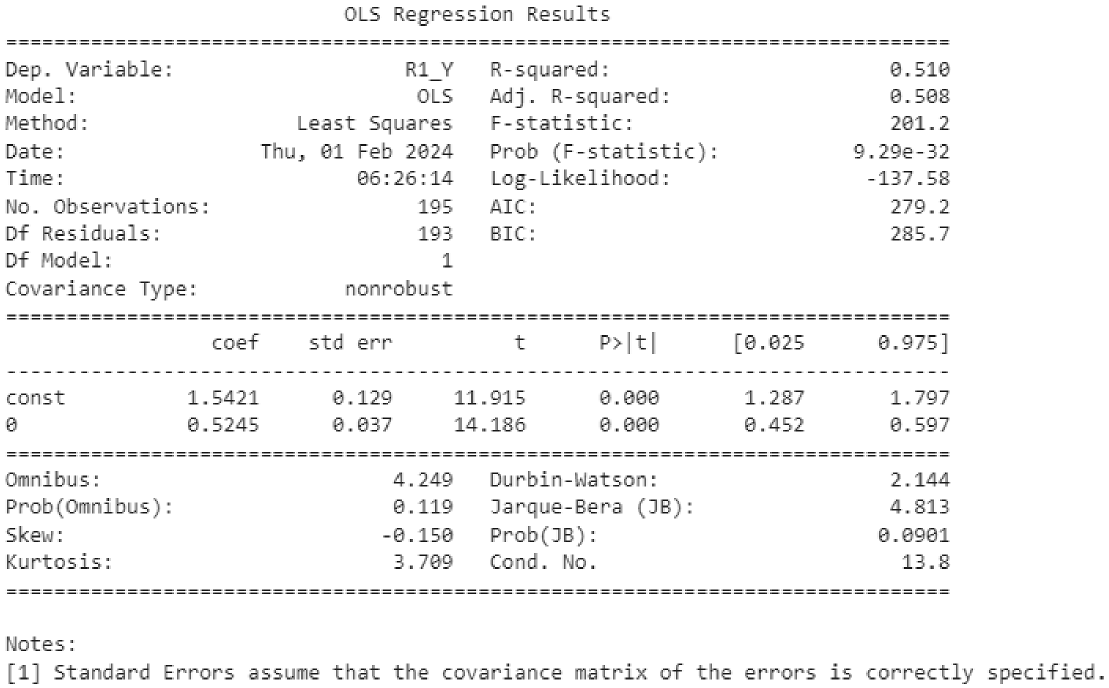
- Confidence Interval: The 95% confidence intervals for the coefficients are not provided, but the standard error can be used to construct them, indicating the range within which we can be confident that the true population parameter lies.
- Omnibus: The Omnibus test has a low p-value, indicating that the residuals are not normally distributed, which could be a concern for the validity of the model.
- Durbin-Watson: The Durbin-Watson statistic is close to 2 (2.142), which suggests that there is no significant autocorrelation in the residuals of the model.
- Jarque-Bera (JB): The JB test has a high test statistic and a low p-value, which further indicates that the residuals are not normally distributed.
- Skew: The skewness is close to zero, suggesting that the residuals distribution is fairly symmetrical.
- Kurtosis: The kurtosis value indicates that the tails of the residuals distribution are heavier than those of a normal distribution, which can be a sign of outliers or anomalies in the data.

The regression output suggests that the model explains a significant portion of the variance in the dependent variable and that the independent variable has a statistically significant and positive impact on it. However, the non-normality of residuals (based on the Omnibus and Jarque-Bera tests) could be a concern and may warrant further investigation, such as checking for outliers, applying transformations, or using robust statistical methods.

4.6 Analyze the Impact of Predictive Maintenance on Emission Reduction

In this the objective through increased equipment efficiency and decreased downtime that follows the adoption of AI-supported predictive maintenance programs in energy-intensive sectors, there is a considerable reduction in energy-related emissions.

Method: Run a regression analysis with independent variables as equipment efficiency and downtime; the dependent variable is the reduction in the greenhouse gas emissions.



```
                            OLS Regression Results
==============================================================================
Dep. Variable:                   R1_Y   R-squared:                       0.510
Model:                            OLS   Adj. R-squared:                  0.508
Method:                 Least Squares   F-statistic:                     201.2
Date:                Thu, 01 Feb 2024   Prob (F-statistic):           9.29e-32
Time:                        06:26:14   Log-Likelihood:                -137.58
No. Observations:                 195   AIC:                             279.2
Df Residuals:                     193   BIC:                             285.7
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          1.5421      0.129     11.915      0.000       1.287       1.797
0              0.5245      0.037     14.186      0.000       0.452       0.597
==============================================================================
Omnibus:                        4.249   Durbin-Watson:                   2.144
Prob(Omnibus):                  0.119   Jarque-Bera (JB):                4.813
Skew:                          -0.150   Prob(JB):                       0.0901
Kurtosis:                       3.709   Cond. No.                         13.8
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 10 Regression Results for Reduction

In the above results, the regression model is highly significant. The coefficient of the independent variable is positive, that is, 0.5245, with a p-value of 0.000 and Prob (F-statistic) as 9.29e-32. This suggests that the decrease in the greenhouse gas emissions is strongly related to an increase in the adoption of AI-supported predictive maintenance programs in energy-intensive sectors.

- Dependent Variable (R1_Y): This variable is being predicted by the model. The exact nature of R1_Y isn't specified in the output, but it's the metric of interest, presumably related to greenhouse gas emissions or another factor linked to the adoption of AI technologies.
- R-squared: The value of 0.510 suggests that the model explains 51% of the variance in the dependent variable, indicating a moderate fit.
- Adjusted R-squared: At 0.508, it's very close to the R-squared, indicating that the number of predictors is adequate and not inflating the variance explained artificially.
- F-statistic: A value of 201.2 with a p-value close to zero (9.29e-32) indicates the model is statistically significant. This means there's a very low probability that the observed results are due to chance.

Coefficients:

- Constant (const): The intercept is 1.5421, and with a p-value of 0.000, it's statistically significant. This value would represent the expected value of R1_Y when the independent variable θ is zero.
- Independent Variable (θ): The coefficient for θ is 0.5245. For each unit increase in θ, there is an average increase of 0.5245 units in the dependent variable R1_Y. The p-value of 0.000 indicates this is a statistically significant predictor.
- Standard Error (std err): This represents the average distance that the observed values fall from the regression line. The lower the standard error, the more precise the estimate.
- T-statistic: The t-values for both the constant and θ are quite high, which further supports their statistical significance.

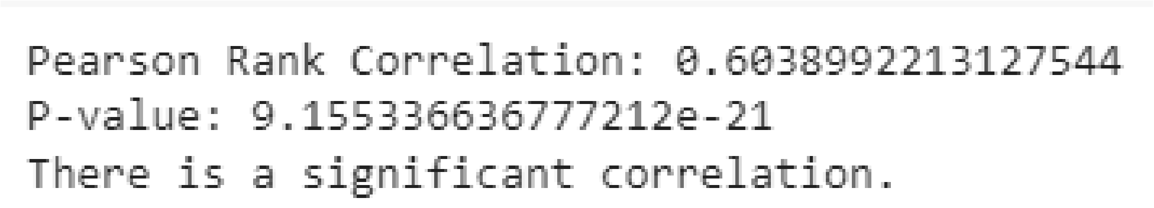
- Omnibus: The Omnibus test assesses the skewness and kurtosis of the residuals. A Prob(Omnibus) of 0.119 suggests that the residuals are fairly normally distributed (no significant skewness and kurtosis), although this p-value is above the common alpha level of 0.05, indicating this result is not statistically significant.
- Durbin-Watson: At 2.144, it indicates there is no serious autocorrelation in the residuals.
- Jarque-Bera (JB): With a JB value of 4.813 and a p-value of 0.0901, the test suggests that the residuals are normally distributed, as the p-value is higher than the typical significance level of 0.05.
- Skew: The slight negative skew (-0.150) indicates the tail on the left side of the distribution is slightly longer or fatter than the right side.
- Kurtosis: A kurtosis of 3.709 suggests that the distribution has heavier tails and a sharper peak than the normal distribution.
- Condition Number: At 13.8, the condition number is well below 30, suggesting that multicollinearity is not a concern for this model.

In summary, the model appears to be a good fit, with the independent variable θ significantly predicting the dependent variable R1_Y. The diagnostics do not indicate any major issues with the model, although the Omnibus test p-value suggests that the normality of residuals could be better, but it's not a concern given the non-significance of the result. The results should be interpreted in the context of the research hypothesis and the nature of the data to draw relevant conclusions.

4.7 Assess the Interconnection Between Sustainability Efforts and AI Implementation

The results for the objective businesses prioritising sustainability by implementing and reaping the rewards of artificial intelligence (AI) solutions, and having reduced greenhouse gas emissions go hand-in-hand, that is, they are positively correlated.

Method: Pearson correlation between reduction in greenhouse gas emissions and businesses that prioritise sustainability.



```
Pearson Rank Correlation: 0.6038992213127544
P-value: 9.155336636777212e-21
There is a significant correlation.
```

Figure 11 Correlation results values

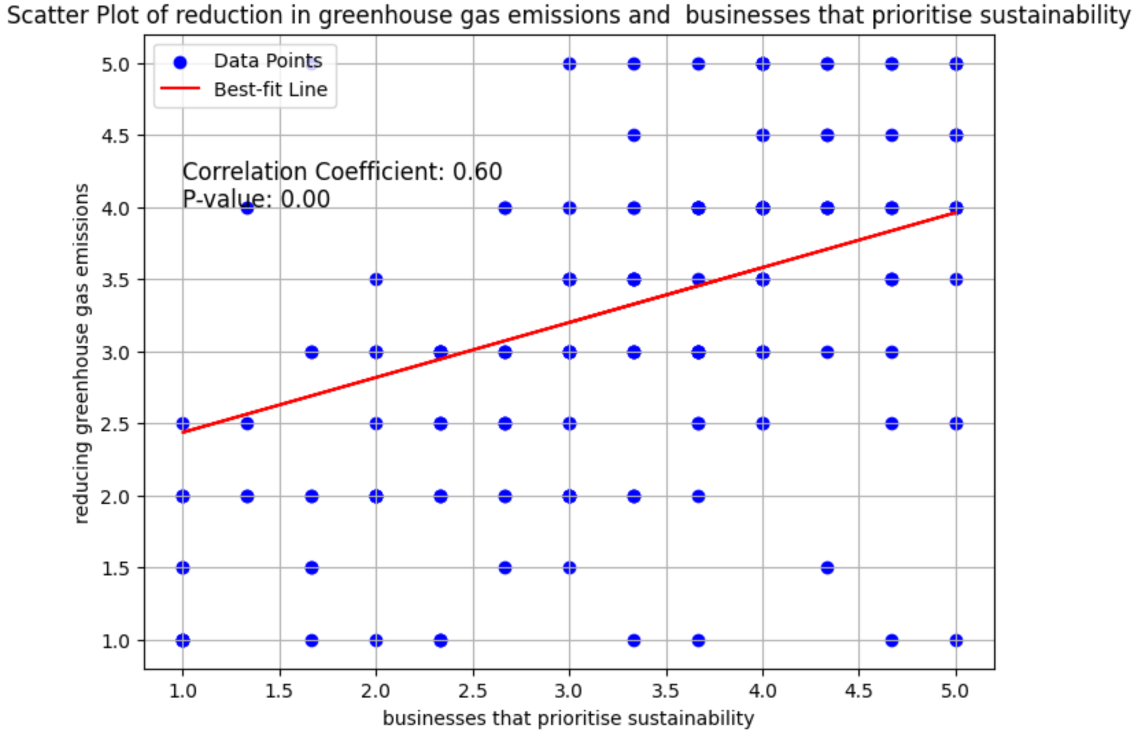


Figure 12 Plot for reducing GHG and business Preferring Sustainability

4.7.1 Pearson Rank Correlation Coefficient

The value of 0.6038992213127544 represents the Pearson correlation coefficient between the two variables. This coefficient measures the strength and direction of the linear relationship between the variables. A value of 1 indicates a perfect positive linear relationship, -1 indicates a perfect negative linear relationship, and 0 indicates no linear relationship.

In this case, the value of 0.6039 suggests a moderate positive linear relationship between the variables. This means that as one variable increases, the other variable tends to increase as well, and vice versa, but not perfectly so.

P-value: The p-value of 9.155336636777212e-21 represents the probability of observing a correlation coefficient as extreme as or more extreme than the observed value (0.6039) under the null hypothesis that there is no correlation between the variables.

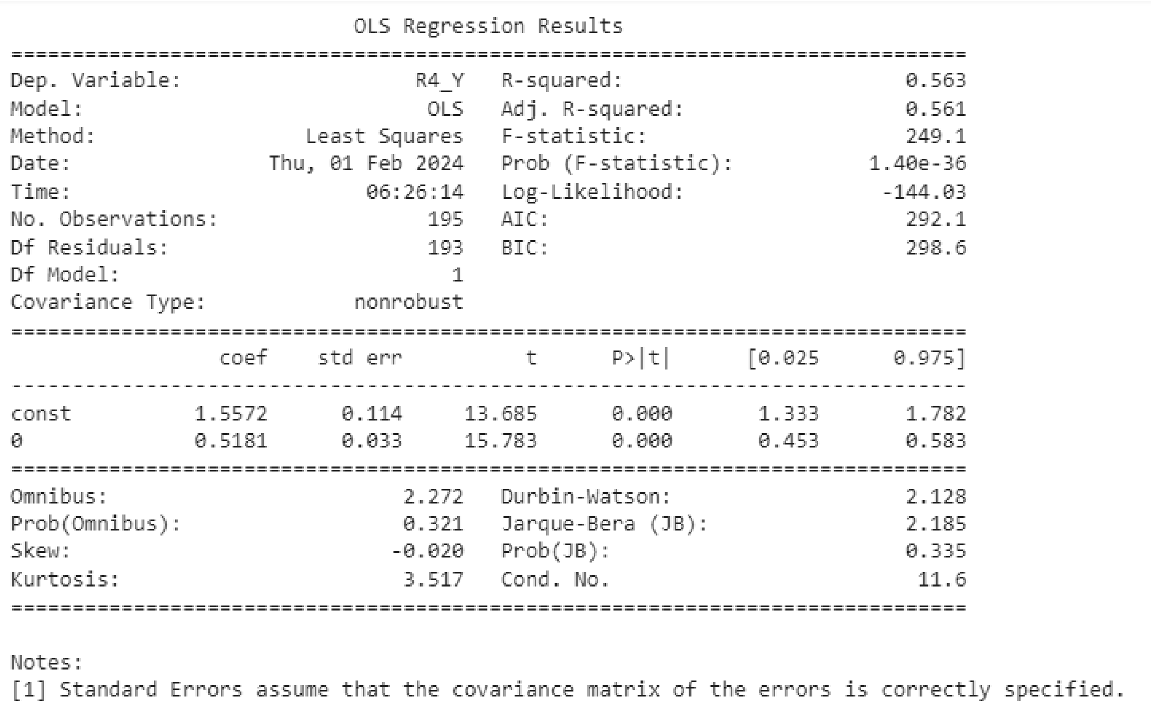
In this case, the p-value is extremely small, close to zero. This indicates strong evidence against the null hypothesis. Typically, if the p-value is less than a chosen significance level (e.g., 0.05), we reject the null hypothesis and conclude that there is a statistically significant correlation between the variables.

The statement "There is a significant correlation" indicates that the observed correlation between the variables is unlikely to be due to random chance alone. Therefore, we can infer that there is a statistically significant linear relationship between the two variables.

4.8 Explore the Influence of Regulatory Frameworks on the Effectiveness of AI Applications

The final objective is the efficacy of AI applications for lowering greenhouse gas emissions in energy-intensive industries are favourably influenced by the existence of favourable regulatory frameworks and governmental incentives.

Method: Regression Analysis where independent variable is favourable regulatory frameworks and governmental incentives and dependent variable is the efficacy of AI applications.



```
                            OLS Regression Results
==============================================================================
Dep. Variable:                   R4_Y   R-squared:                       0.563
Model:                            OLS   Adj. R-squared:                  0.561
Method:                 Least Squares   F-statistic:                     249.1
Date:                Thu, 01 Feb 2024   Prob (F-statistic):           1.40e-36
Time:                        06:26:14   Log-Likelihood:                -144.03
No. Observations:                 195   AIC:                             292.1
Df Residuals:                     193   BIC:                             298.6
Df Model:                           1
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          1.5572      0.114     13.685      0.000       1.333       1.782
0              0.5181      0.033     15.783      0.000       0.453       0.583
==============================================================================
Omnibus:                        2.272   Durbin-Watson:                   2.128
Prob(Omnibus):                  0.321   Jarque-Bera (JB):                2.185
Skew:                          -0.020   Prob(JB):                        0.335
Kurtosis:                       3.517   Cond. No.                         11.6
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Figure 13 Regression for AI application reducing GHG

In the above results, the regression model is highly significant. The coefficient of the independent variable is positive, that is, 0.5181, with a p-value of 0.000 and Prob (F-statistic) as 1.40e-36. This suggests that the increase in the effectiveness of AI applications for lowering GHG emissions is strongly related to an increase in prioritising sustainability.

- Dependent Variable: The dependent variable is labeled as R4_Y, but the specific metric it represents is not described in the output.

- R-squared: The R-squared value is 0.563, indicating that approximately 56.3% of the variance in the dependent variable can be explained by the model.
- Adjusted R-squared: At 0.561, it remains close to the R-squared value, which suggests that the model's explanatory power is appropriately adjusted for the number of predictors.
- F-statistic: The F-statistic is 249.1 with an associated p-value that is effectively zero (1.40e-36), strongly indicating that the overall model is statistically significant.

Coefficients:

- Constant (const): The coefficient for the constant term is 1.5572, with a very low p-value, indicating that it is statistically significant.
- Independent Variable (θ): The coefficient for the independent variable θ is 0.5181, which suggests a positive relationship between θ and the dependent variable R4_Y. The p-value of 0.000 indicates that this is a statistically significant predictor.
- Standard Error (std err): The standard errors for the constant and θ are relatively small, suggesting precision in the estimates.
- T-statistic: The t-statistics for both the constant and θ are large and the corresponding p-values are very small, indicating statistical significance.
- Omnibus: The Omnibus test has a p-value of 0.321, suggesting that the residuals' distribution does not significantly deviate from normality.
- Durbin-Watson: The Durbin-Watson statistic of 2.128 is close to 2, suggesting there is no significant autocorrelation in the residuals.

- Jarque-Bera (JB): The JB test statistic is 2.185 with a p-value of 0.335, indicating that the residuals are normally distributed.
- Skew: The negative skew (-0.20) indicates a slight asymmetry in the residuals distribution, with a longer tail to the left.
- Kurtosis: The kurtosis value of 3.517 suggests a slightly "peakier" distribution than a normal distribution, indicating heavier tails.
- Condition Number: The condition number is 11.6, which does not suggest a problem with multicollinearity.

In summary, the regression model appears to be statistically significant and a good fit for the data, explaining a substantial portion of the variance in the dependent variable R4_Y. The positive coefficient for θ indicates a direct relationship with the dependent variable. The diagnostics do not show any major concerns regarding the residuals' normality or autocorrelation. However, the actual implications for the study's hypotheses depend on the specific nature of the dependent variable and the independent variable θ.

CHAPTER V:

DISCUSSION

5.1 Introduction

The objective of this study is to furnish empirical evidence in support of the claim that energy-intensive industries are actively placing a high priority on the adoption of ecologically friendly practices. The primary aim of the survey was to examine the participants' awareness, knowledge, and experiences about net-zero emissions in energy-intensive industries, with a particular emphasis on the integration of artificial intelligence (AI). The demographic overview offered a comprehensive understanding of the matter by encompassing responses from 16 diverse participants from global energy-intensive enterprises who represented a range of age cohorts and educational backgrounds. The surveys offer a complete depiction of diversity, facilitating a full and multifaceted comprehension of the subject matter. Industry representation refers to individuals or organizations from a particular industry serving as representatives or advocates for that industry. The incorporation of feedback from notable energy-intensive corporations, such as Shell and Total Energies, enhances the survey's conclusions in terms of trustworthiness. These corporations have significant positions within the energy industry, and their viewpoints about attaining net zero are expected to exert considerable influence Duflou et al. (2012). Including more energy-intensive industries expands the range and relevance of the findings.

5.2 Discussion of Current Practices Are In Reducing Energy-Related Emissions

The data indicates that many participants fall between 40–49 and 50–59. This observation shows that persons with considerable professional experience, maybe holding management or executive positions, are actively involved in conversations about attaining net zero . The demographic in question frequently possesses a blend of practical knowledge and progressive viewpoints, which has the potential to positively impact the formulation and execution of productive tactics.

5.2.1 Academic Qualifications

The presence of a significant proportion of individuals with master's degrees suggests a notable degree of educational attainment among the participants included in the study. Possessing advanced degrees in relevant fields can favor the quality of replies. People with such educational backgrounds will likely have a more profound comprehension of the intricacies involved in energy-intensive businesses and the effective incorporation of artificial intelligence solutions for sustainable practices.

5.2.2 The Advantages of Diversity

The survey benefits from including participants from various age groups and educational backgrounds, contributing to its robustness. The presence of many perspectives contributes to a comprehensive understanding of the multiple obstacles and possibilities involved in attaining a state of net zero. Diverse experiences and a range of educational degrees can contribute to a more thorough comprehension of the subject matter, potentially generating more nuanced and robust insights.

5.2.3 Implications about the use of artificial intelligence (AI)

The demographic profile of individuals engaged in debates about using artificial intelligence (AI) to reduce greenhouse gas emissions indicates the active participation of decision-makers and seasoned experts. The potential for integrating AI technology in energy-intensive businesses appears promising since individuals occupying leadership roles are more likely to initiate organizational transformations and provide novel solutions. Climate science and environmental studies experts are expected to play a crucial role in these discussions. They offer valuable perspectives on the possible influence of AI solutions in reducing the effects of climate change and may provide direction on how to put them into practice.

Professionals possessing specialized knowledge in artificial intelligence, machine learning, and data science play a crucial role as valuable contributors. Their role involves the development and enhancement of AI solutions specifically designed to tackle environmental concerns. Environmental advocates and groups may actively participate in talks around artificial intelligence (AI) and its potential to mitigate greenhouse gas emissions. They frequently offer insights on ethical considerations, potential hazards, and the overall influence of AI technologies. Experts from many fields such as environmental studies, computer science, and economics can offer their specialized knowledge to discussions regarding the convergence of artificial intelligence and climate change.

Professionals in the technology sector, such as engineers and developers, are engaged in the development of artificial intelligence (AI) solutions for monitoring the environment, optimizing renewable energy, and other applications with the goal of lowering carbon emissions. There is a clear gender gap in the survey findings, with more male respondents than female respondents. Future surveys might use focused outreach techniques to attract participation from underrepresented groups in order to remedy this. Furthermore, using non-binary alternatives and inclusive phrasing might result in a more representative sample. Due to the possibility of gender-related insights being biased in favor of the majority gender, the existing distribution raises questions regarding possible biases in interpreting survey results. To make findings that are inclusive and truthful, it is essential to provide a fairer representation.

Careful modifications to survey design are necessary to address underrepresentation in survey participation. Crucial actions include providing a range of gender choices, using age-specific marketing techniques, and thinking about how accessible the survey is to respondents with different educational levels. Enhancing participation may also be achieved by using inclusive language and making sure the survey platform is user-friendly for all demographics. Researchers may aim for a more representative and inclusive sample in survey design by proactively addressing these factors, which will result in more reliable and equitable study findings.

5.2.4 The implications and recommendations of the study are as follows

The age distribution of the responses may impact the development and implementation of awareness programs. Tailoring information to align with the problems and viewpoints of those aged 50–59 may provide notable effectiveness. The observed favourable attitude towards using artificial intelligence (AI) in mitigating greenhouse gas emissions presents a promising prospect for further advancement in this domain CCPI (2022). Implementing focused educational programs or workshops can effectively augment comprehension and cultivate a more holistic recognition of the significance of artificial intelligence (AI) in attaining net-zero emissions.

It is essential to consider the communication channels utilized by respondents for information dissemination CCPI (2022). For upcoming efforts to raise awareness, it is necessary to fully understand the best ways to explain complicated ideas about net-zero and artificial intelligence (AI) applications. The findings of this study offer a basis for implementing focused interventions aimed at improving awareness and understanding of the utilization of artificial intelligence (AI) applications to achieve net zero emissions in energy-intensive sectors CCPI (2022). The opportunity exists to expedite the adoption of sustainable practices in these industries by customizing methods to align with the demographic features of respondents and by addressing specific knowledge gaps.

Although the present study offers significant insights, it is recommended that future research delve into the viewpoints of younger professionals and people with varied educational backgrounds. This will contribute to comprehensively comprehending the issues and solutions associated with attaining net zero. Moreover, a comprehensive analysis of the distinct responsibilities held by the participants within their respective institutions might provide a more profound understanding of the mechanisms involved in the decision-making procedures. The demographic profile of the survey respondents indicates a well-rounded and knowledgeable viewpoint about attaining net zero emissions in energy-intensive sectors by utilizing artificial intelligence. The critical insights derived from this heterogeneous cohort of participants are expected to be crucial in informing and developing forthcoming policies and activities to promote sustainable and ecologically conscious behaviors within the energy industry.

5.3 Discussion of AI Adoption and GHG Emission Reduction

The poll evaluated participants' understanding of artificial intelligence (AI) applications in mitigating greenhouse gas emissions. The diverse range of reactions implies a degree of inconsistency in comprehending the potential of artificial intelligence in addressing the reduction of greenhouse gas emissions. The prevailing favourable disposition towards recognizing artificial intelligence (AI) applications is a source of encouragement Chan et al. (2018). This statement suggests a willingness to adopt technological interventions to tackle environmental issues. Additional examination might explore specific artificial intelligence (AI) applications that participants know about and those they may lack familiarity with. This can provide a framework for future educational activities addressing knowledge deficiencies in specific domains.

5.3.1 Levels of Awareness

The data reveals that a significant proportion of participants self-assessed their level of awareness about greenhouse gas emissions at level 3 on a 5-point scale, suggesting a satisfactory degree of knowledge on the subject matter Milfont et al. (2010).

Investigating the precise components or facts contributing to this self-assessment is essential. Gaining insight into the origins of awareness can facilitate the customization of forthcoming efforts and educational programs to enhance knowledge in domains that exhibit deficiencies.

5.3.2 Individual Dedication to Sustainability

The observation that 50% of the participant’s assert having prior expertise in mitigating their carbon emissions is indicative of a favourable trend. This statement signifies an individual's dedication to promoting sustainability and acknowledging their obligation to minimize their environmental footprint Milfont et al. (2010). Further investigation into the essence of these experiences, encompassing potential lifestyle modifications, energy conservation practices, and other endeavors, would be a captivating endeavor. The survey's findings provide fascinating new information on the experiences, expertise, and familiarity of the participants with greenhouse gas reduction.

First off, there was a wide variety of answers when asked how acquainted people were with the idea of "net-zero emissions" in energy-intensive businesses. Of those, 31.3% said they were very familiar with it (ranked 5) and 18.8% said they knew nothing about it at all (rated 1). This discrepancy in respondents' awareness begs the issue of what variables are impacting respondents' knowledge of net-zero emissions. These discrepancies might be the result of disparities in professional experience, educational backgrounds, or exposure to environmental public debate. Regarding respondents' understanding of using AI applications to reduce greenhouse gas emissions in industrial settings, it is noteworthy that 43.8% of them assess their level of knowledge as extremely informed (ranked 5). Examining this finding necessitates looking at the relationship between understanding of AI applications and awareness of net-zero emissions. According to the report, there is a chance for education or awareness campaigns to close the knowledge gap and help people understand how artificial intelligence (AI) might help achieve sustainability objectives.

In addition, the study showed that 37.5% of respondents rank their knowledge with greenhouse gas emissions as highly acquainted (rated 5). Investigating the relationship between knowledge of AI applications and familiarity with greenhouse gas emissions may provide important insights into a comprehensive grasp of environmental concerns. A stronger feeling of responsibility and an encouragement of sustainable activities are highlighted by the identification of increased awareness as a possible motivator for more aggressive initiatives. In terms of individual experiences, 43.8% of participants reported actively lowering their carbon footprint. Investigating the motivations behind the decisions made by people with and without expertise might provide insightful data for creating efforts that are specifically targeted.

One way to get people who have never reduced their carbon footprint to think about it is via specialized teaching programs or rewards. 56.3% of respondents felt they have an excellent grasp (ranked 3) of the factors decreasing greenhouse gas emissions, according to their self-assessment of knowledge. Examining whether this self-report is consistent with real knowledge, as suggested by earlier answers, helps direct efforts to improve comprehension among individuals who gave themselves a lower rating. Just 12.5% of respondents said they have received training or instruction in process optimization for reducing greenhouse gas emissions. In addition to highlighting the need for expanded educational programs in this area to provide people the skills they need to contribute to the reduction of greenhouse gas emissions, this finding highlights the potential influence of training on knowledge and actions. Patterns or common themes may be found by investigating important aspects that respondents think contribute to the decrease of greenhouse gas emissions. With the use of this data, policies and interventions may be better suited to the goals and perceptions of the general public, leading to a more knowledgeable and involved community that is actively pursuing sustainable behaviors.

The study's findings indicate that the respondents possess a fundamental level of awareness and dedication. The observation suggests a favorable indication towards the future acceptance and implementation of artificial intelligence (AI) applications designed to mitigate greenhouse gas emissions inside businesses that consume significant amounts of energy Milfont et al. (2010). Gaining insight into the opinions and experiences of individuals is of paramount importance since these individuals possess the potential to act as advocates and influencers within their respective sectors.

5.4 Disscussion of AI-based Optimization for Energy Efficiency

Regarding greenhouse gas emissions and individual commitment to sustainability, the participants showed a praiseworthy comprehension of emissions. Many participants showed a proactive commitment to reducing their carbon footprint, indicating a commendable personal commitment to advancing sustainability Le et al. (2011). At the same time, most participants needed formal education in process optimization for mitigating greenhouse gas emissions. A large percentage showed a good understanding of the various elements that contribute to this matter. Nevertheless, many individuals needed more formal instruction in this domain, underscoring the existence and the edge that educational initiatives may address.

The study's findings indicate that the participants demonstrated an awareness of several factors contributing to reducing greenhouse gas emissions. These aspects encompass incorporating energy-efficient techniques, carpooling and public transit, using renewable energy sources, and the execution of legal mandates Duflou et al. (2012). The acknowledgement demonstrated a thorough understanding of the intricate approach required to decrease emissions effectively. It is widely accepted that optimizing processes is a practical approach to mitigating greenhouse gas emissions from a managerial perspective. The survey's findings provide insightful information on how businesses might combine process efficiency with a decrease in greenhouse gas emissions. First off, a sizable portion of participants (43.8%) said that process optimization had reduced greenhouse gas emissions in their companies. The fact that most people agree that process optimization techniques are effective suggests a favorable trend. It would be fascinating to learn more about the particular process optimization techniques used to get these outcomes and investigate possible best practices for broader implementation.

5.4.1 Energy-efficiency lighting and appliances

Identifying energy-efficient lights and appliances as a crucial component implies acknowledging the significance of migrating towards more sustainable technology in both everyday living and industrial practices Michaelowa et al. (2019). This observation suggests a propensity among participants to allocate resources toward and embrace energy-efficient measures.

5.4.2 The concepts of carpooling and public transit

The acknowledgement of the use of carpooling and public transit underscores a comprehension that individual decisions regarding transportation contribute to collective greenhouse gas emissions Michaelowa et al. (2019). This suggests a potential inclination toward alternative modes of transportation and a shift toward more environmentally friendly commuting behaviors, possibly influenced by initiatives promoting environmental consciousness.

5.4.3 Use of renewable sources

Many renewable energy sources include solar power, wind power, hydropower, geothermal energy, and biomass. Recognizing the significance of renewable energy sources signifies a more comprehensive comprehension of the imperative to shift away from fossil fuels towards more environmentally friendly alternatives Chen et al. (2012). This observation may indicate a recognition of renewable energy's viability and imperative nature in mitigating the carbon emissions linked to sectors with high energy consumption.

5.4.4 Governmental directives

The recognition of governmental directives as a significant factor implies that regulatory frameworks and policies have a vital impact on guiding companies towards adopting sustainable practices. This observation suggests a certain degree of confidence in governmental initiatives and acknowledging the necessity for collective action at a policy level Michaelowa et al. (2019). The acknowledgement of public knowledge as a significant determinant is intriguing, as it implies that disseminating information through awareness campaigns and educational endeavors may influence individuals' attitudes and actions. This highlights the need to promote the dissemination of knowledge on the environmental consequences associated with energy-intensive businesses and emphasize the potential contributions individuals may make in mitigating greenhouse gas emissions.

Furthermore, a significant portion of participants (43.8%) confirmed that their organizations had particular goals and standards for achieving net-zero emissions. This suggests that corporations are becoming more conscious of and dedicated to harmonizing with more general sustainability objectives. For firms looking to establish comparable standards, further research on the nature of these goals, the plans in place to achieve them, and any obstacles that may arise might be very insightful. Three-quarters of the respondents indicated financial advantages, indicating that using process optimization techniques has produced financial gains for their firms. This research implies that businesses have financial and environmental incentives to implement sustainable practices. Examining certain instances where financial gains were made might provide other organizations with inspiration and important insights.

Regarding the use of artificial intelligence (AI) in process optimization, 43.8% of respondents said that AI has been beneficial in reducing greenhouse gas emissions. This demonstrates the increasing significance of cutting-edge technology in sustainability initiatives. Comprehending the particular AI applications that produced favorable outcomes and any obstacles faced would be essential for enterprises thinking about implementing comparable technology integrations. Notably, 43.8% of respondents said that their organizations often monitor and report on the progress made in reducing greenhouse gas emissions. An essential component of sustainability projects is regular monitoring and reporting, which shows responsibility and openness.

For those looking to improve their own monitoring and reporting procedures, investigating the approaches and reporting frameworks used by these firms may provide insightful advice. The survey findings provide a comprehensive understanding of how companies are attempting to reduce greenhouse gas emissions by using process optimization and technical innovations. Expanded investigation and evaluation of the particular approaches, obstacles, and optimal methodologies may foster a more comprehensive comprehension and extensive implementation of sustainable practices across many sectors.

5.5 Discussion of Impact of Predictive Maintenance on Emission Reduction

Numerous organizations have established specific objectives and benchmarks to achieve the goal of net-zero emissions. It is essential to acknowledge that there was a realization of substantial financial benefits arising from the optimization of processes. Nevertheless, a minority of respondents said they have successfully reduced emissions by employing artificial intelligence (AI) technology. The task at hand involves the identification of barriers and opportunities. Although the outcomes present a positive perspective, examining potential obstacles that impede the extensive use of artificial intelligence (AI) solutions is crucial. Possible problems include financial implications, intricacies associated with technology, or insufficiency in regulatory backing Milfont et al. (2010). Similarly, identifying possibilities, such as examining established case studies or utilizing collaborative frameworks, may serve as a valuable tool in informing strategies aimed at surmounting these obstacles.

5.5.1 The customization of communication and training programs

Given the self-reported levels of awareness, it would be advantageous to develop communication and training initiatives tailored to address these findings. These programs can target specific areas where respondents may perceive themselves to have lower confidence or expertise. By identifying and addressing critical areas of knowledge that are lacking, the sector has the potential to improve general awareness and promote a more seamless transition to the implementation of artificial intelligence (AI)-driven solutions aimed at reducing greenhouse gas emissions. Benchmarking and goal setting are commonly employed strategies in several fields and industries. It involves systematically comparing an organization's performance to industry standards or best practices, aiming to identify.

The survey findings can be a foundational reference point for future benchmarking and target establishment endeavors. Establishing industry-wide standards for levels of awareness and commitment can be helpful in monitoring development over a period. Furthermore, the establishment of ambitious yet attainable objectives can incentivize organizations to actively engage in programs aimed at reducing greenhouse gas emissions. The quantitative survey results on achieving net zero emissions in energy-intensive sectors using artificial intelligence (AI) applications for reducing greenhouse gas emissions have given us a lot of helpful information about how much the participants understood process optimization. The observation that a considerable proportion of participants lacked formal expertise or education in the field of process optimization aimed at reducing greenhouse gas emissions is of particular significance.

This observation implies the existence of a possible deficiency in knowledge and abilities within a crucial domain that is essential for the attainment of sustainability objectives. The situation raises questions about how prepared the workforce in energy-intensive sectors is to adopt and implement effective emissions reduction strategies. One encouraging aspect is the considerable proportion of participants demonstrating a sound comprehension of the factors contributing to mitigating greenhouse gas emissions. This finding suggests that the respondents possess a certain degree of consciousness and informal understanding, which could serve as a basis for future educational and training endeavors. It would be intriguing to investigate the origins of this comprehension, whether it is obtained from hands-on experience, independent acquisition of knowledge, or exposure to established standards within the sector.

Nevertheless, the discovery that many participants lack formal training in process optimization to reduce greenhouse gas emissions constitutes a noteworthy outcome. This observation suggests an avenue for enhancing educational programs and training initiatives, encompassing academic institutions and industry-specific training programs. Additionally, this implies the existence of unexplored possibilities for enhancing professional growth and promoting the diffusion of information within the realm of sustainability and policies aimed at reducing emissions. It would be advantageous for relevant stakeholders, such as educational institutions, business groups, and governments, to contemplate implementing measures specifically designed to mitigate the existing knowledge disparity, to effectively respond to these results. One potential approach is creating and implementing specialized educational initiatives, workshops, and training sessions that specifically enhance process optimization strategies to mitigate greenhouse gas emissions.

Furthermore, including sustainability and emissions reduction subjects in pertinent educational programs can improve the readiness of upcoming individuals in energy-intensive sectors. It is advisable for firms operating in these industries to contemplate allocating resources towards implementing ongoing learning and development initiatives for their employees. This may encompass strategies such as advocating for knowledge-sharing platforms, incentivizing active engagement in pertinent conferences and seminars, and cultivating an organizational ethos prioritizing innovation and sustainability. The findings indicate obstacles and prospects for improving the understanding of process optimization to reduce greenhouse gas emissions in energy-intensive sectors. The implementation of focused educational and training efforts has the potential to make a substantial contribution towards attaining net-zero objectives within these areas.

The implications and subsequent discussion of the topic warrant more examination and analysis. The wide range of issues acknowledged suggests that a comprehensive strategy is necessary to achieve net-zero goals. The respondents demonstrate an understanding that a combination of solutions, such as technical developments, individual behavior adjustments, and policy assistance, is essential for achieving successful greenhouse gas (GHG) reduction. The function of artificial intelligence (AI) in accomplishing net-zero goals is a topic of interest that warrants exploration while not being directly addressed in the given material. Artificial intelligence (AI) applications hold significant potential in optimizing energy consumption, enhancing industrial operations, and facilitating data-driven decision-making processes to promote sustainable practices.

It would be beneficial to explore the problems and limitations that respondents see in implementing these initiatives aimed at reducing greenhouse gas emissions. The comprehension of possible barriers might provide valuable insights for formulating focused initiatives and policies aimed at surmounting these issues. A more thorough analysis of these factors may be achieved by a more holistic comprehension of the survey findings and practical recommendations for advancing sustainable practices in energy-intensive sectors.

The results of the poll indicated that there were significant themes of obstacles and opportunities. The study participants identified many barriers that impede the utilization of artificial intelligence (AI) in mitigating greenhouse gas emissions. The issues encompassed in this context consist of budgetary limitations, technological constraints, regulatory hurdles, and a prevailing deficiency in comprehension Bäckstrand et al. (2017). Despite these limitations, it is widely recognized that artificial intelligence (AI) can enhance processes, enable early detection, and reduce process time. The survey findings indicated a notable discrepancy between the perceived effectiveness of artificial intelligence (AI) applications and the extent to which users actively embrace their implementation Bäckstrand et al. (2017). While acknowledging the potential of artificial intelligence (AI), the participants indicated a lack of personal exposure to AI-based approaches to reduce greenhouse gas emissions. This observation suggests that further research and engagement are required in this field.

5.6 Discussion of Sustainability Efforts and AI Implementation

When contemplating the future, the individuals included in the study showed moderate optimism regarding the capacity of artificial intelligence (AI) applications to aid in achieving net-zero emissions. The importance of government assistance and policies in promoting the development of AI applications for this objective was underscored, with a specific focus on the value of a regulatory framework that facilitates support Bäckstrand et al. (2017). The participants' ideas highlighted the importance of promoting collaboration among diverse businesses and nations, incorporating sustainable practices by leveraging artificial intelligence in education, and raising awareness as pivotal approaches in achieving net-zero emissions. These solutions highlight the imperative nature of implementing a comprehensive and cooperative strategy that integrates many stakeholders.

5.6.1 The optimization of processes and their impact on greenhouse gas emissions

A significant proportion of participants believe that optimizing approaches has proven to be an efficient means of reducing greenhouse gas emissions Li et al. (2013). This observation indicates that experts in the sector acknowledge the potential for mitigating environmental effects through the optimization and simplification of internal operations. This study aims to provide clear and measurable objectives and benchmarks for achieving net-zero emissions. Notably, a considerable proportion of participants expressed that their respective organizations had established explicit goals and performance indicators to attain net-zero emissions Li et al., (2013). This displays a dedication to achieving long-term sustainability objectives and implies that firms actively strive towards certain benchmarks.

5.6.2 The financial advantages derived from process optimization

Several participants said that they had financial advantages because of optimizing processes. This assertion is consistent with the widely accepted notion that efficiency enhancements frequently result in cost reductions. This may encompass the mitigation of energy consumption, waste generation, and total operating expenses, making a favourable contribution to the financial performance of the company Chen et al. (2012). The present study aims to elucidate the many challenges associated with implementing artificial intelligence (AI) applications to reduce emissions.

According to the survey findings, a smaller proportion of respondents reported achieving success in reducing emissions through using artificial intelligence (AI) technologies. This observation suggests that although the promise of artificial intelligence (AI) in promoting environmental sustainability is acknowledged, its practical application and instances of successful implementation may be somewhat limited in scope Li et al. (2013). Artificial intelligence (AI) for emission reduction poses inquiries regarding the obstacles and difficulties firms encounter in properly using this technology.

5.7 Summary

CHAPTER VI:

SUMMARY, IMPLICATIONS, AND RECOMMENDATIONS

6.1 Summary

Integrating artificial intelligence (AI) applications has emerged as a viable approach for lowering greenhouse gas (GHG) emissions in energy-intensive businesses to achieve the goal of net zero emissions. This study employs a quantitative approach to examine the influence and efficacy of artificial intelligence (AI) in mitigating carbon emissions across several sectors. This research investigates several methods and technologies and their respective advantages to provide insights into the possibilities for achieving a more sustainable future.

The study explores the integration of Artificial Intelligence (AI) in achieving net-zero emissions within energy-intensive industries, presenting empirical evidence that these sectors prioritize eco-friendly practices. With input from 16 diverse professionals from leading global companies, the study's survey captures a range of perspectives, particularly from individuals likely to influence sustainability strategies due to their experience and advanced educational backgrounds. The discussion spans five main areas, starting with a demographic overview that reveals a participant pool well-versed in sustainability and AI, suggesting a favorable environment for implementing AI-driven emissions reduction strategies.

The research addresses the level of awareness and individual commitment to sustainability, highlighting a satisfactory self-assessed knowledge of emissions and a proactive stance in personal sustainability efforts among participants. However, there appears to be a lack of formal education in process optimization, pointing to potential gaps that could be bridged through targeted educational programs.

The study also sheds light on the financial and operational benefits perceived from process optimization, with a considerable number of participants recognizing the efficacy of such practices in reducing emissions. Despite this, the adoption of AI for emissions reduction is not as widespread, indicating barriers that require further exploration.

Finally, the study underscores the importance of supportive regulatory frameworks and collaborative efforts across industries and nations to foster the adoption of AI for sustainability goals. The findings suggest moderate optimism for the role of AI in achieving net-zero emissions but also the need for educational and policy-driven initiatives to enhance the understanding and application of AI solutions in the quest for environmental sustainability. Overall, the study calls for a multi-faceted approach, combining technology, individual behavior change, and policy support to effectively tackle greenhouse gas emissions in energy-intensive sectors.

6.2 Implications

The study suggests that there is an opportunity to leverage AI to achieve net-zero emissions within energy-intensive industries. While there is already some awareness and interest in sustainability practices, the study reveals that there is still a significant lack of formal training and comprehensive educational programs to equip stakeholders with the necessary understanding and skills to leverage AI effectively.

The study also highlights that the actual application of AI technologies in process optimization for emissions reduction remains limited. This is due to various barriers to adoption, including financial constraints, technological complexities, and a lack of regulatory support. To accelerate the use of AI in reducing emissions, targeted research, policy-making, and collaborative frameworks are necessary to address these barriers.

Furthermore, the findings stress the crucial role of government policies and frameworks in supporting the adoption of AI technologies to meet net-zero targets. A regulatory environment conducive to AI innovation and implementation could significantly enhance the industry's capacity to reduce emissions.

Overall, the study implies that a concerted effort is needed to bridge the gap between current practices and the potential for AI to contribute to emissions reduction. This will require an investment in human capital, technology, and regulatory support, along with industry collaboration and continued research to realize the full potential of AI in addressing the challenges of climate change and sustainability within energy-intensive sectors.

6.3 Recommendations for Future Research

Further investigation is required to examine multidisciplinary methodologies that amalgamate proficiencies from environmental science, engineering, and artificial intelligence Pirson et al. (2021). Collaborative endeavors have the potential to yield a more thorough comprehension of the intricate interplay between artificial intelligence (AI) applications and their environmental consequences.

6.3.1 Evaluation of Long-Term Effects

Academics must prioritize executing comprehensive and protracted monitoring and assessment studies to assess the enduring implications of AI applications in attaining net zero Dincer et al. (2012). This study offers a comprehensive analysis of the long-term efficacy of artificial intelligence (AI) technologies in mitigating greenhouse gas (GHG) emissions and their capacity to adapt to dynamic changes in industrial environments.

6.3.2 Policy and Regulatory Considerations

There is a need to prioritize research endeavors that investigate the policy and regulatory frameworks necessary to facilitate the extensive implementation of artificial intelligence (AI) in energy-intensive sectors Van der Ven et al. (2017). The identification of impediments, the formulation of incentives, and the proposal of regulatory guidelines will play a pivotal role in establishing a conducive climate for the adoption and implementation of sustainable practices.

Our quantitative research underscores the revolutionary capacity of artificial intelligence (AI) applications in energy-intensive sectors to attain net zero emissions. Integrating artificial intelligence (AI) into industrial processes has far-reaching repercussions across several dimensions, including environmental, economic, and technical. This integration highlights the diverse advantages of incorporating AI into industrial operations. Multidisciplinary research emphasizes the evaluation of long-term impacts, so it is crucial to prioritize collaboration Van der Ven et al. (2017). These efforts will enhance and expand creative solutions, eventually promoting a more sustainable and resilient industrial environment.

Addressing a fresh array of challenges is imperative since pursuing the net-zero aim. It significantly changes the modelling environment to enhance the quality of insights provided to decision-makers. It is evident that specific concerns are not novel; yet, considering the crucial role that modelling must assume in facilitating the development of national energy and climate policy presently, these obstacles must be promptly tackled Dincer et al. (2012). In scope, breadth encompasses adopting a radical approach to explore potential solutions, including those now deemed politically unacceptable or less prominent. Additionally, it involves critically considering concepts such as carbon dioxide removal (CDR) and their potential impact on future resilience Le et al. (2011). It is imperative to critically evaluate their functional aspects to ascertain the continued relevance of modelling tools in net-zero evaluations.

Instead of only emphasizing the potential actions that can be implemented, the emphasis is shifted towards effectively executing these measures. Furthermore, ensuring that the models can represent future iterations of system configurations is crucial. In practice, successful collaboration necessitates recognizing the diverse range of disciplinary skills necessary from different research teams and fostering meaningful involvement in the process from several experts and stakeholders. In addition to possessing a robust understanding of uncertainty and a willingness to engage in unconventional scenario analysis, modelers must acknowledge the many priorities that decision-makers must consider.

As decarbonizing energy systems involves critical decision-making, it presents an opportunity for the energy modelling community to provide substantial information to bolster net-zero legislation. However, some scope, purpose, and modelling technique adjustments are necessary. This model aims to comprehensively incorporate the many connections among the biosphere, atmosphere, economy, and society into a cohesive analytical framework. The following statement serves as a disclosure. The author(s) did not disclose the potential conflicts of interest.

The authors have analyzed the existing state of digitalization in energy-intensive industries (EIIs) and proposed a framework to facilitate the adoption of sustainable smart manufacturing in these sectors. A comprehensive framework of five layers has been devised to incorporate intelligence into energy-intensive industries (EIIs) to enhance energy and material efficiency. These layers include data gathering, process management, simulation and modelling, artificial intelligence, and data visualization. The utilization of process mining and simulation modelling to facilitate sustainability has enabled this advancement Wagner et al. (2019). A test case in the machining industry illustrates the framework's capacity to allow sustainable smart manufacturing and drive thorough digital transformation through its various stages.

The primary research contribution lies in using process mining, simulation, and modelling techniques to understand the existing process comprehensively. Data from processes was used to find problems, share information, and look at how things work so that it would be easier to build a parametric discrete-event simulation model. The result of the simulation model was employed to forecast energy consumption, which is subsequently shown on dashboards to identify specific areas for enhancement Chen et al. (2012). More research is needed to investigate the comprehension of EIIs by integrating process mining, modelling, and simulation methodologies to the best of their knowledge. The writers want to highlight this aspect. Furthermore, the study showed the importance of data quality and integrity.

The study also illustrated the significance of ensuring the accuracy of the data and the proper execution of the modelling technique. Furthermore, the challenges to the compatibility and interoperability of hardware and software were recognized by Wagner et al. (2019). One possible approach to mitigating the challenges arising from data quality issues and interoperability concerns involves implementing data quality checks and governance policies at the entry points of each of the five layers. Additionally, exploring historical datasets pertinent to current processes and assessing their suitability for training AI models can be beneficial. Moreover, leveraging open-source software and APIs that facilitate real-time data transfer and address compatibility issues can be advantageous Wagner et al. (2019). This study is associated with other plans to improve by adding ontologies and mapping to the process management layer, setting up self-adapting manufacturing and automation systems, thinking about cloud and edge computing issues, and ensuring all knowledge is provided entirely within the study.

6.4 Conclusion

This study provides a comprehensive analysis of the current state of net-zero emissions efforts within energy-intensive industries, with a particular focus on the role of Artificial Intelligence (AI) in driving these initiatives. The data was collected from seasoned professionals across the globe, reflecting a substantial representation of those at the forefront of integrating and executing eco-friendly practices. The findings reveal a positive inclination towards adopting AI technologies for sustainability, yet they also highlight a significant disparity in the level of formal education and training in process optimization for emissions reduction.

One of the study's most significant implications is the urgent need for enhancing awareness and expertise regarding AI applications through targeted educational programs and professional training. This is critical for harnessing the full potential of AI in the environmental domain. Furthermore, the study underscores the critical role of supportive regulatory frameworks that incentivize the adoption of AI technologies, implying that policy interventions play a vital role in shaping the future of sustainable practices within these sectors.

While participants recognize the financial and operational benefits of process optimization, there is still a significant gap in the implementation of AI solutions for emissions reduction, indicating existing barriers that must be addressed, including technological, financial, and regulatory challenges.

In light of the survey responses, the study calls for industry leaders, policymakers, educators, and technology developers to collaborate in promoting a transition towards more sustainable practices. This requires establishing clear benchmarks for net-zero goals, fostering an environment conducive to AI innovation, and ensuring that the workforce is equipped with the necessary skills to implement such technologies effectively.

The conclusion of this study is not merely a call to action, but an urgent demand for change. It emphasizes the need for ongoing research, active dialogue among stakeholders, and an unwavering commitment to continuous improvement and innovation. By doing so, energy-intensive industries can move closer to their net-zero ambitions, leveraging AI as a powerful ally in the fight against climate change and the pursuit of a sustainable future.

APPENDIX A

SURVEY COVER LETTER

Questionnaire On “Achieving Net Zero In Energy-Intensive Industries Using Ai Applications For Greenhouse Gas Reduction: A Quantitative Analysis”

Section 1: Demographics

1.1 Age:

- 18-24
- 25-34
- 35-44
- 45-54
- 55+

1.2 Gender:

- Male
- Female
- Non-binary
- Prefer not to say
- Other (please specify)

1.3 Educational Background:

- High School
- Bachelor's Degree
- Master's Degree
- PhD or equivalent
- Other (please specify)

1.4.a Industry type:

- Manufacturing

- Energy
- Agriculture
- Mining
- Transportation
- Information Technology
- Chemical
- Pulp and Paper
- Textile
- Cement
- Steel
- Food and Beverage
- Other

1.4.b If you selected other, please specify the industry below

____

Section 2: Types of AI Applications Used

2.1.a What kinds of AI applications are currently being used in your organisation to reduce greenhouse gas emissions? (Select all that apply)

- Energy Management Systems
- Emission Monitoring Systems
- Predictive Maintenance
- Optimization Algorithms
- Other

2.1.b If you selected other, please specify which:

____

2.2 How would you rate the diversity of AI applications used in your organisation for reducing greenhouse gas emissions?

- Very Limited
- Limited
- Moderate
- Extensive
- Very Extensive

2.3 To what extent are these AI applications integrated into your current processes for reducing greenhouse gas emissions?

- Not integrated at all
- Slightly integrated
- Moderately integrated
- Very integrated
- Extremely integrated

Section 2: Integration into Current Processes

2.4 How well do you think the current integration of AI applications into your processes aligns with your organisation's goals for reducing greenhouse gas emissions?

- Not well at all
- Not very well
- Neutral
- Very well
- Extremely well

2.5 To what extent do employees in your organisation find it easy to use AI applications in their daily tasks related to greenhouse gas emissions reduction?

- Not at all easy
- Slightly easy
- Moderately easy
- Very easy
- Extremely easy

2.6 How regularly are AI applications updated and adapted to meet the changing needs of your organisation in reducing greenhouse gas emissions?

- Rarely or Never
- Occasionally
- Sometimes
- Often
- Always

Section 3: Perceived Effectiveness of AI applications in lowering GHG emissions

3.1 In your opinion, how effective are the AI applications currently used in your organisation for lowering greenhouse gas emissions?

- Not effective at all
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective

3.2 To what extent do you think the current AI applications contribute to a measurable reduction in greenhouse gas emissions within your organisation?

- Not at all
- Slightly
- Moderately
- Very
- Extremely

Section 4: Assessing Adoption of AI-Supported Predictive Maintenance Programs, equipment efficiency and downtime

4.1 To what extent do you believe that energy-intensive sectors are adopting AI-supported predictive maintenance programs?

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

4.2 How confident are you in the effectiveness of AI-supported predictive maintenance programs in preventing unplanned downtime in energy-intensive sectors?

- Not at all confident
- Slightly confident
- Moderately confident
- Very confident
- Extremely confident

4.3 In your opinion, to what extent do AI-supported predictive maintenance programs contribute to the overall efficiency of equipment and machinery in energy-intensive sectors?

- Not at all
- Slightly
- Moderately

- Very
- Extremely

4.4 How likely are energy-intensive sectors to increase their investment in AI-supported predictive maintenance programs in the future?

- Very Unlikely
- Unlikely
- Neutral
- Likely
- Very Likely

4.5 How much impact do you think the adoption of AI-supported predictive maintenance programs has on reducing energy-related emissions in energy-intensive sectors?

- No impact at all
- Little impact
- Moderate impact
- High impact
- Very high impact

4.6 How would you rate the overall efficiency of your organisation's equipment in meeting production demands and minimizing resource consumption?

- Very Inefficient
- Inefficient

- Neutral
- Efficient
- Very Efficient

4.7 Considering planned maintenance, unexpected breakdowns, and other factors, how would you rate your organisation's ability to manage and minimize downtime in its operations?

- Very Ineffective
- Ineffective
- Neutral
- Effective
- Very Effective

Section 5: Assessing Amount of Energy-Related Emissions

5.1 How would you rate the current level of energy-related emissions in energy-intensive sectors that you are familiar with?

- Very High Emissions
- High Emissions
- Moderate Emissions
- Low Emissions
- Very Low Emissions

5.2 How effective do you believe your organisation's current practices are in reducing energy-related emissions?

- Not effective at all
- Slightly effective
- Moderately effective
- Very effective
- Extremely effective

5.4 To what extent is your organisation committed to actively reducing energy-related emissions?

- Not committed at all
- Slightly committed
- Moderately committed
- Very committed
- Extremely committed

5.5 How satisfied are you with the current efforts of your organisation in reducing their energy-related emissions?

- Not satisfied at all
- Slightly satisfied
- Moderately satisfied
- Very satisfied
- Extremely satisfied

5.6 On a scale of 1 to 5, where 1 represents "No Gain" and 5 represents "Significant Gain," please rate the extent to which you have observed a quantifiable improvement in energy efficiency in your organisation's operations since implementing AI-based optimization algorithms.

- No Gain
- Slight Gain
- Moderate Gain
- Significant Gain
- Very Significant Gain

5.7 To what degree do you believe the implementation of AI-based optimization algorithms has led to a measurable reduction in greenhouse gas emissions in your organisation?

- No Reduction
- Slight Reduction
- Moderate Reduction
- Significant Reduction
- Very Significant Reduction

Section 6: AI-Based Optimization Algorithms in Energy-Intensive Industrial Processes

6.1 How would you rate the integration of AI-based optimization algorithms into your current energy-intensive industrial processes?

- Not integrated at all.
- Slightly integrated.
- Moderately integrated.
- Very well integrated.
- Fully integrated.

6.2 To what extent do you believe AI-based optimization algorithms have improved the efficiency of your energy-intensive industrial processes?

- Not improved at all.
- Slightly improved.
- Moderately improved.
- Significantly improved.
- Drastically improved.

6.3 How satisfied are you with the performance of AI-based optimization algorithms in achieving energy efficiency within your industrial processes?

- Not satisfied at all.
- Slightly satisfied.
- Moderately satisfied.
- Very satisfied.

- Extremely satisfied.

6.4 Have you observed a quantifiable decrease in greenhouse gas emissions because of implementing AI-based optimization algorithms in your energy-intensive industrial processes?

- No, there has been no decrease.
- Yes, to a very limited extent.
- Yes, to a moderate extent.
- Yes, to a significant extent.
- Yes, there has been a substantial decrease.

6.5 How confident are you that the use of AI-based optimization algorithms will continue to play a crucial role in reducing greenhouse gas emissions in energy-intensive industrial processes in the future?

- Not confident at all.
- Slightly confident.
- Moderately confident.
- Very confident.
- Extremely confident.

Section 7: Sustainability Policy

7.1 To what extent does your business have a formal sustainability policy or strategy in place that guides decision-making and operations?

- No formal sustainability policy
- Minimal, informal consideration of sustainability
- Moderate, with some formalized sustainability practices
- Substantial, with a well-defined sustainability policy
- Comprehensive, with an integrated and widely communicated sustainability strategy

7.2 How much does your business invest in or use renewable energy sources as part of its operations?

- No investment or use of renewable energy
- Limited investment or use of renewable energy
- Moderate investment or use of renewable energy
- Significant investment or use of renewable energy
- Extensive investment or use of renewable energy, aiming for self-sufficiency

7.3 To what degree does your business actively engage in eco-friendly practices, such as waste reduction, recycling, and sustainable sourcing?

- No active engagement in eco-friendly practices
- Minimal, sporadic engagement in eco-friendly practices
- Moderate, with some efforts towards eco-friendly practices
- Substantial, with a consistent commitment to eco-friendly practices

- Comprehensive, with an extensive and integrated approach to eco-friendly practices throughout the business

Section 8: Regulatory Frameworks and Governmental Incentives

8.1 How aware are you of the existence of regulatory frameworks that encourage the use of AI applications in energy-intensive businesses for reducing greenhouse gas emissions?

- Not aware at all
- Slightly aware
- Moderately aware
- Very aware
- Extremely aware

8.2 To what extent do you perceive the current regulatory frameworks as favourable and supportive of the adoption of AI applications for lowering greenhouse gas emissions in energy-intensive industries?

- Not favourable at all
- Slightly favourable
- Moderately favourable
- Very favourable
- Extremely favourable

8.3 How influential do you believe governmental incentives are in promoting the adoption of AI applications for reducing greenhouse gas emissions in energy-intensive businesses?

- Not influential at all
- Slightly influential
- Moderately influential
- Very influential
- Extremely influential

APPENDIX B

INFORMED CONSENT

Dear [Participant's Name],

Re: Request for Participation in Survey on AI Applications for Greenhouse Gas Reduction in Energy-Intensive Industries

I hope this message finds you well. My name is [Your Name], and I am a researcher at [Your Institution/Organization]. I am conducting a study to understand the pivotal role of Artificial Intelligence (AI) applications in achieving net-zero emissions within energy-intensive industries.

Your expertise and insights are invaluable to this research, and I kindly request your participation in a survey designed to gather comprehensive information on current perspectives, challenges, and opportunities regarding the integration of AI for greenhouse gas reduction strategies.

The survey comprises questions covering various facets of AI implementation, challenges faced, potential benefits, and ethical considerations within energy-intensive sectors. Your responses will remain confidential and will be used solely for academic research purposes.

Your contribution will significantly aid in advancing our understanding of the efficacy of AI in achieving sustainable and eco-friendly practices in energy-intensive industries. Your time and input are highly appreciated.

Please find the survey linked below. Your participation is entirely voluntary, and you may withdraw at any stage. Should you have any queries or require further information, please feel free to contact me at [Your Contact Information].

Thank you for considering this request. Your participation will be immensely valuable to the success of this study.

Warm regards,

[Your Name]

[Your Position]

[Your Institution]

REFERENCES

Ashraf, W.M., Uddin, G.M., Ahmad, H.A., Jamil, M.A., Tariq, R., Shahzad, M.W. and Dua, V., 2022. Artificial intelligence enabled efficient power generation and emissions reduction underpinning net-zero goal from the coal-based power plants. Energy Conversion and Management, 268, p.116025.

Bäckstrand, K., Kuyper, J.W., Linnér, B.O. and Lövbrand, E., 2017. Non-state actors in global climate governance: from Copenhagen to Paris and beyond. Environmental Politics, 26(4), pp.561-579.

Chan, S., Falkner, R., Goldberg, M. and Van Asselt, H., (2018). Effective and geographically balanced? An output-based assessment of non-state climate actions. Climate Policy, 18(1), pp.24-35.

Chen, J., Taylor, J.E. and Wei, H.H., 2012. Modeling building occupant network energy consumption decision-making: The interplay between network structure and conservation. Energy and Buildings, 47, pp.515-524.

Chen, L., Msigwa, G., Yang, M., Osman, A.I., Fawzy, S., Rooney, D.W. and Yap, P.S., 2022. Strategies to achieve a carbon neutral society: a review. Environmental Chemistry Letters, 20(4), pp.2277-2310.

Diaz, N., Redelsheimer, E. and Dornfeld, D., 2011. Energy consumption characterization and reduction strategies for milling machine tool use. In Glocalized Solutions for Sustainability in Manufacturing: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd-4th, 2011 (pp. 263-267). Springer Berlin Heidelberg.

Dietmair, A. and Verl, A., 2009. A generic energy consumption model for decision making and energy efficiency optimisation in manufacturing. International Journal of Sustainable Engineering, 2(2), pp.123-133..

Dincer, I. and Rosen, M.A. (2012). Exergy: Energy, Environment and Sustainable Development. Google Books.

Duflou, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M. and Kellens, K., 2012. Towards energy and resource efficient manufacturing: A processes and systems approach. CIRP annals, 61(2), pp.587-609.

Gutowski, T.G., 2007, June. The carbon and energy intensity of manufacturing. In 40th Seminar of CIRP, Keynote Address, Liverpool University, Liverpool, UK.

Kholopov, V.A., Antonov, S.V., Kurnasov, E.V. and Kashirskaya, E.N., 2019. Digital twins in manufacturing. Russian Engineering Research, 39, pp.1014-1020.

Kriegler, E., Weyant, J., Blanford, G.J., Krey, V., Clarke, L.E., Edmonds, J.A., Fawcett, A.A., Luderer, G., Riahi, K., Richels, R.G. and Rose, S., (2014). The Role of Technology for Achieving Climate Policy Objectives: Overview of the EMF 27 Study on Technology Strategies and Climate Policy Scenarios. Climatic Change, 123 (3-4): 353-367, (PNNL-SA-93355).

Kucukvar, M., Cansev, B., Egilmez, G., Onat, N.C. and Samadi, H., 2016. Energy-climate-manufacturing nexus: New insights from the regional and global supply chains of manufacturing industries. Applied energy, 184, pp.889-904.

Leo Kumar, S.P., 2019. Knowledge-based expert system in manufacturing planning: state-of-the-art review. International Journal of Production Research, 57(15-16), pp.4766-4790.

Le, T.P.N. and Lee, T.R., 2013. Model selection with considering the CO 2 emission alone the global supply chain. Journal of Intelligent Manufacturing, 24, pp.653-672.

Li, D.H., Yang, L. and Lam, J.C., 2013. Zero energy buildings and sustainable development implications–A review. Energy, 54, pp.1-10.

Lian, K., Zhang, C., Shao, X. and Gao, L., 2012. Optimization of process planning with various flexibilities using an imperialist competitive algorithm. The International Journal of Advanced Manufacturing Technology, 59, pp.815-828.

McCollum, D.L., Zhou, W., Bertram, C., De Boer, H.S., Bosetti, V., Busch, S., Després, J., Drouet, L., Emmerling, J., Fay, M. and Fricko, O., 2018. Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals. Nature Energy, 3(7), pp.589-599.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C., Frieler, K., Knutti, R., Frame, D.J. and Allen, M.R., 2009. Greenhouse-gas emission targets for limiting global warming to 2 C. Nature, 458(7242), pp.1158-1162.

Michaelowa, K. and Michaelowa, A., 2019. Transnational climate governance initiatives: designed for effective climate change mitigation?. In The Comparative Politics of Transnational Climate Governance (pp. 146-178). Routledge.

Milfont, T.L. and Duckitt, J., 2010. The environmental attitudes inventory: A valid and reliable measure to assess the structure of environmental attitudes. Journal of environmental psychology, 30(1), pp.80-94.

Mohajan, H.K., 2017, March. Greenhouse gas emissions, global warming and climate change. In Proceedings of the 15th Chittagong Conference on Mathematical Physics, Jamal Nazrul Islam Research Centre for Mathematical and Physical Sciences (JNIRCMPS), Chittagong, Bangladesh (Vol. 16).

Neugebauer, R., Wertheim, R. and Harzbecker, C., 2011. Energy and resources efficiency in the metal cutting industry. In Advances in Sustainable Manufacturing: Proceedings of the 8th Global Conference on Sustainable Manufacturing (pp. 249-259). Springer Berlin Heidelberg.

Omer, A.M., 2008. Energy, environment and sustainable development. Renewable and sustainable energy reviews, 12(9), pp.2265-2300.

Pirson, T. and Bol, D., 2021. Assessing the embodied carbon footprint of IoT edge devices with a bottom-up life-cycle approach. Journal of Cleaner Production, 322, p.128966

.Rodrigues, R., Pietzcker, R., Fragkos, P., Price, J., McDowall, W., Siskos, P., Fotiou, T., Luderer, G. and Capros, P., 2022. Narrative-driven alternative roads to achieve mid-century CO2 net neutrality in Europe. Energy, 239, p.121908.

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K. and Meinshausen, M., 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 C. Nature, 534(7609), pp.631-639.

Sun, Q. and ZHANG, W.M., 2011. Carbon Footprint Based Multilevel Hierarchical Production Process Control. China Mechanical Engineering, 22(9), p.1035.

Choi, S., Battulga, L., Nasridinov, A. and Yoo, K.H., 2017. A decision tree approach for identifying defective products in the manufacturing process. International Journal of Contents, 13(2), pp.57-65.

Turner III, D. W., 2010. Qualitative interview design: A practical guide for novice investigators: underpinning net-zero goal from the coal-based power plants. Energy Conversion and United Nations Framework Convention on Climate Change (UNFCCC) (2022) Nationally Determined Contributions (NDCs).

UNFCCC., 2020. Long-term low greenhouse gas emission development strategy of the European union and its member states." Submission to the UNFCCC on behalf of the European union and its member states.

Van der Ven, H., Bernstein, S. and Hoffmann, M., 2017. Valuing the contributions of nonstate and subnational actors to climate governance. Global Environmental Politics, 17(1), pp.1-20.

Wagner, R., Schleich, B., Haefner, B., Kuhnle, A., Wartzack, S. and Lanza, G., 2019. Challenges and potentials of digital twins and industry 4.0 in product design and production for high performance products. Procedia CIRP, 84, pp.88-93.

Wang, N., Phelan, P.E., Harris, C., Langevin, J., Nelson, B. and Sawyer, K., 2018. Past visions, current trends, and future context: A review of building energy, carbon, and sustainability. Renewable and Sustainable Energy Reviews, 82, pp.976-993.

Yan, J., Feng, C. and Li, L., 2014. Sustainability assessment of machining process based on extension theory and entropy weight approach. The International Journal of Advanced Manufacturing Technology, 71, pp.1419-1431.

Yang, M., Chen, L., Msigwa, G., Tang, K.H.D. and Yap, P.S., 2022. Implications of COVID-19 on global environmental pollution and carbon emissions with strategies for sustainability in the COVID-19 era. Science of the Total Environment, 809, p.151657.

Yazdani, M.A., Benyoucef, L., Khezri, A. and Siadat, A., 2020, November. Multi-objective process and production planning integration in reconfigurable manufacturing environment: augmented ε-constraint based approach. In 13ème CONFERENCE INTERNATIONALE DE MODELISATION, OPTIMISATION ET SIMULATION (MOSIM2020), 12-14 Nov 2020, AGADIR, Maroc.

Yi, Q., Li, C., Zhang, X., Liu, F. and Tang, Y., 2015. An optimization model of machining process route for low carbon manufacturing. The International Journal of Advanced Manufacturing Technology, 80, pp.1181-1196.

Yoro, K.O. and Daramola, M.O., 2020. CO2 emission sources, greenhouse gases, and the global warming effect. In Advances in carbon capture (pp. 3-28). Woodhead Publishing.