THE CARBON FOOTPRINT OF IRAQI INDUSTRY: NAVIGATING THE PATH TO SUSTAINABILITY

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ABSTRACT

Background: The rapid expansion of Iraq's oil and gas sector has resulted in a significant increase in greenhouse gas emissions, which have become a significant environmental concern. Both national environmental sustainability and international environmental obligations necessitate the resolution of these concerns.

Objective: This article aims to assist the Iraqi industrial sector in mitigating its carbon emissions by investigating viable strategies for adopting sustainable practices.

Methods and Materials: This study employed a mixed-methods analysis of carbon emission patterns over time in three significant sectors — energy, manufacturing, and agricultural production—as well as the corresponding materials. Two operations research techniques, namely econometric models and emission inventories, were employed to ascertain the comparative significance of distinct industries concerning the nation's carbon footprint. Determining effective strategies for carbon reduction is facilitated by this comprehensive methodology.

Results: The results show that Iraq's industrial carbon footprint has increased significantly. Nevertheless, its objective is to mitigate emissions by employing green technology, utilising renewable energy sources, and improving energy efficiency.

Conclusions: The article emphasises the criticality of legislative action, international collaboration, and private sector engagement in advancing the sustainability of Iraq's industrial sector. This study demonstrates the significance of operations research in formulating environmental strategies; it offers stakeholders an indispensable road map for comprehending and mitigating the carbon emissions from Iraq's industrial sector.

KEYWORDS*:* carbon footprint , carbon emissions, renewable energy transition, environmental management, sustainable industrial practices.

MSC: 90B50, 91B30, 91B06

RESUMEN

Antecedentes: La rápida expansión del sector del petróleo y el gas en Iraq ha dado lugar a un aumento significativo de las emisiones de gases de efecto invernadero, que se han convertido en una importante preocupación ambiental. Tanto la sostenibilidad ambiental nacional como las obligaciones internacionales en materia de medio ambiente exigen que se resuelvan estas preocupaciones.

Objetivo: Este artículo tiene como objetivo ayudar al sector industrial iraquí a mitigar sus emisiones de carbono mediante la investigación de estrategias viables para adoptar prácticas sostenibles.

Métodos y materiales: Este estudio empleó un análisis de métodos mixtos de los patrones de emisión de carbono a lo largo del tiempo en tres sectores importantes: energía, manufactura y producción agrícola, así como los materiales correspondientes. Se emplearon dos técnicas de investigación operativa, a saber, los modelos econométricos y los inventarios de emisiones, para determinar la importancia comparativa de las distintas industrias en relación con la huella de carbono de la nación. Determinar estrategias efectivas para la reducción de carbono es facilitado por esta metodlogia.Esta metodología integral facilita la reducción.

Resultados: Los resultados muestran que la huella de carbono industrial de Irak ha aumentado significativamente. Sin embargo, su objetivo es mitigar las emisiones mediante el empleo de tecnología verde, la utilización de fuentes de energía renovables y la mejora de la eficiencia energética.

Conclusiones: El artículo hace hincapié en la importancia de la acción legislativa, la colaboración internacional y el compromiso del sector privado en la promoción de la sostenibilidad del sector industrial iraquí.

sector industrial. Este estudio demuestra la importancia de la investigación operativa en la formulación de estrategias ambientales; ofrece a las partes interesadas una hoja de ruta indispensable para comprender y mitigar las emisiones de carbono del sector industrial iraquí.

PALABRAS CLAVE: huella de carbono, emisiones de carbono, transición a energías renovables, gestión ambiental, prácticas industriales sostenibles.

1. INTRODUCTION

The global community has recently been confronted with significant climate change issues. The concept of a "carbon footprint" has been extensively applied to assess the environmental consequences of human activities, particularly the release of greenhouse gases. The entire amount of greenhouse gases, predominantly CO2, discharged into the

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atmosphere by individuals, organisations, or events constitutes a carbon footprint. Determining pollution-reduction strategies and assessing the environmental impact of human activities depends on this parameter [1].

Sustainability is currently more significant. Sustainability is vital for future generations to have the resources necessary to lead meaningful lives. Sustainability entails harmonisation on environmental preservation, social welfare, and economic development. It effectively addresses present needs while guaranteeing that forthcoming generations will be able to fulfil theirs [2, 3].

Industrial output comprises approximately 45% of Iraq's gross domestic product. It is imperative to acknowledge that the energy sector substantially amplifies carbon emissions. According to the International Energy Agency, 90% of Iraq's carbon emissions are produced by its energy sector. Predominantly produced by industry, carbon emissions have detrimental effects on the environment, public health, and economic sustainability [4].

As the severity of climate change escalates, the term "carbon footprint" has become increasingly well-known. Comprehending and addressing carbon footprints—be they of individuals, organisations, or occurrences—are crucial to global initiatives aimed at diminishing human influence[5].

In the current era, long-term sustainability is critical. Our dedication to forthcoming generations demonstrates the importance that we place on investments that promote sustainable development. The goal of sustainability is to satisfy current requirements while safeguarding future needs. An equilibrium is reached when economic expansion, social progress, and environmental protection are all considered.

This article analyses the carbon footprint of Iraq's industrial sector and proposes environmentally sustainable solutions. The study will begin by elucidating the carbon footprint, highlighting its global significance and pertinence to Iraq's industrial sector. It will then assess the carbon footprint of Iraq's industrial sector and identify the largest carbon emitters. The article will conclude with numerous sustainability and emission-reduction measures that align with Iraq's sustainable development goals.

Although relatively new, the carbon footprint has gained prominence as the repercussions of climate change become more apparent. A British consulting firm coined the term in 1995 to estimate the greenhouse gas emissions of a product or business. Subsequently, it has been implemented to assess the ecological impact of corporate activities, individual conduct, and national economies.

2015 saw the United Nations' approval of the Sustainable Development Goals (SDGs), which aim to preserve and enhance the future for all. Economic instability, poverty, inequality, climate change, and environmental degradation are all addressed in the SDGs[6].

Due to the reliance of Iraq's industrial sector on petrol and energy, carbon footprint and sustainability are critical. Energy is a substantial contributor to Iraq's gross domestic product and greenhouse gas emissions.

Critical to Iraq's economy, the industrial sector emits a substantial amount of carbon. According to UNEP research [7], 60% of Iraq's greenhouse gas emissions are attributable to the oil and gas industry. It is primarily due to the combustion of natural gas during crude extraction and the use of fossil fuels to generate electricity and power transportation.

The electricity sector produces over 30 % of Iraq's greenhouse gas emissions. The continued reliance on fossil fuels, such as natural gas and oil, for electricity generation exacerbates emissions [8].

Transportation-related greenhouse gas emissions in Iraq account for 10% of total emissions. Iraqi petrol and diesel vehicles release significant carbon dioxide and additional contaminants [9].

In order to mitigate the environmental impact of Iraq's industrial sector and achieve sustainable development goals, a comprehensive strategy is required. Energy-efficient practices and technologies in the residential, commercial, and industrial sectors have the potential to reduce energy consumption and emissions [10] significantly.

Iraq should use its enormous wind and solar energy generation capacity. Government regulation and incentives may be employed to promote the adoption of renewable energy sources. Carbon capture and storage technology can

potentially reduce the environmental impact of industrial carbon dioxide emissions by trapping them underground. Implementing waste heat recovery technologies and energy-efficient industrial processes can accomplish this. In order to advance sustainable mobility, electric vehicles, public transport, walking, and cycling are all encouraged [11, 12]. CCS technology can reduce their environmental impact by collecting and storing industrial carbon dioxide emissions underground [13]

Waste heat recovery technologies increase the energy efficacy of industries. Advocating for sustainable transportation encompasses promoting electric vehicles, public transportation, and active modes such as cycling and strolling. These methods could substantially reduce conveyance emissions [14].

The challenge of achieving sustainability and reducing Iraq's carbon footprint presents an opportunity for the nation's progress. To attain sustainability, the industrial sector in Iraq must undergo modernisation, and actors must collaborate. Government regulations and incentives that promote environmentally responsible conduct and reduce carbon emissions could facilitate the realisation of profound changes.

1.1 Study objective

The article aims to use Operations Research methodologies to measure and quantify the carbon emissions generated by the Iraqi manufacturing sector accurately. Additionally, it will provide recommendations and strategies to mitigate and decrease these emissions effectively. Our primary objective is to provide light on the current levels of carbon emissions from significant industrial sectors, including the oil and gas, manufacturing, and agricultural industries. In order to measure and assess these emissions accurately, we want to use state-of-the-art quantitative techniques, such as emission inventories and econometric models. The study also seeks to determine the efficacy of various environmentally-friendly strategies and technologies in reducing carbon emissions. This research supports global and local initiatives to reduce climate change impacts by offering practical knowledge and policy recommendations. It focuses on using Operations Research tools to guide Iraq's industrial sector towards a more sustainable and environmentally friendly path.

1.2 Problem statement

During rapid development and growth, the oil and gas industries in Iraq and the rest of Iraq's industrial sector face a significant challenge: managing and reducing their carbon emissions. This study focuses on the need to quantify and reduce greenhouse gas emissions in this business. The impact of industrial activities on the environment is well recognised, but it needs to be more available to make educated decisions on policy and operational modifications. The industry's use of fossil fuels and outdated technologies is exacerbating the already elevated levels of carbon emissions. The current article uses Operations Research methodologies to analyse the current condition of carbon emissions and provide viable and sustainable strategies for their reduction in response to a need for more data-driven analysis. The study contributes to the overarching objective of aligning Iraq's economic growth with environmental conservation and global climate commitments by addressing these concerns.

2. LITERATURE REVIEW

Several worldwide research have offered flexible insights and strategies to address the intricate issue of carbon emissions in Iraq's industrial sector. Baiocchi et al. [1] presented an approach for evaluating lifestyle carbon footprints, which might be particularly useful for comprehending the intricate emission patterns in Iraq's diverse industrial setting. Using the approach proposed by Bertini et al. [2], which examines carbon footprinting and pricing strategies

concerning climate issues, Iraq has the potential to develop more effective measures for controlling its carbon emissions.

Liu et al. [3]conducted a comprehensive study on energy conservation and emissions reduction techniques in the manufacturing industry. Their findings are particularly relevant for Iraq's energy-intensive sectors. In order to align Iraq with global energy patterns, it is crucial to consider the global outlook on the transition to clean energy, as shown in the research conducted by the International Energy Agency [4]. It will assist in situating these projects within a broader sustainable development framework.

Another study that might be implemented in several industrial sectors in Iraq is the research conducted by Liu et al. [5], which explicitly examines the mitigation of carbon emissions in the food industry. The study highlights the difficulties and opportunities related to carbon management in specific sectors. The UN Development Programme [15] and the UN Environment Programme [7] have released reports on Iraq's solar power efforts and climate change plans. These reports provide specific information on the local context and emphasise the potential benefits and risks that Iraq encounters as it strives to adopt renewable energy sources.

To understand the current emissions status in Iraq's industrial sector, one needs to refer to the study conducted by Al-Maamori et al. [16]. This study specifically examines the relationship between energy consumption and carbon dioxide emissions in Iraq. Hashim et al. [8] contribute to this topic by presenting a robust framework for evaluating and measuring emissions. They do this by calculating the amount of greenhouse gases released by Iraq's energy industry, using the methodology recommended by the Intergovernmental Panel on Climate Change (IPCC).

According to research by the Climate and Clean Air Coalition [9], Iraq is committed to addressing a broader range of greenhouse gas emissions, including methane, in its nationally determined contributions. Taguchi and Asomiddin [10] examine energy-use inefficiency and policy governance in Central Asian states to provide comparative insights that might inform policy improvements in Iraq.

Hussain et al. [11] conducted a case study on the potential of solar electricity in the post-war city of Mosul, Iraq's industrial sector, to inspire similar renewable energy ventures. In their comprehensive analysis, Al-Ansari et al. [12] examine several renewable sources to assess Iraq's potential for renewable energy. Their findings provide the foundation for implementing a diversified energy strategy in Iraq's industrial sector.

Studies done by Cheng et al. [13] and Słyś et al. [14] investigate specific technological methods, such as increased nitrogen removal and waste heat recovery, that might potentially be used to reduce emissions in Iraq's industrial operations. By combining technical responses with policy suggestions derived from several national and international studies[6, 7, 17-19], a comprehensive understanding of the challenges and possible remedies for Iraq's industrial carbon footprint may be obtained.

The vast array of research offered in this context provides a valuable abundance of knowledge that could lead and enhance endeavours to build Iraq's industrial sector effectively and durably. Iraq has the potential to make a substantial reduction in its carbon footprint by implementing global sustainability targets and climate change mitigation efforts within its local context.

3. METHODOLOGY

In order to get a complete understanding of the ecological consequences of Iraq's industrial sector and to determine a viable route towards sustainability, we used a rigorous mixed-methods approach incorporating Operations Research (OR) methodologies to provide a robust analysis of the ecological impact of Iraq's industrial sector and to chart a sustainable course forward. The approach used in this study was divided into three distinct stages: data collecting, comparative analysis, quantitative modeling and awareness of intrinsic research restrictions.

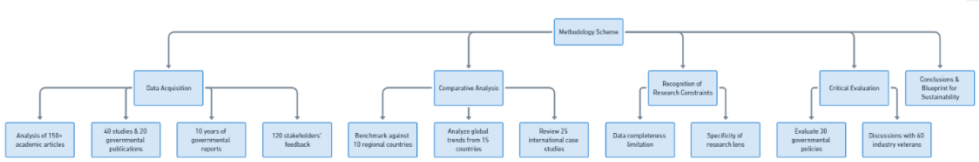


Figure 1: Comprehensive Methodology for Assessing the Ecological Impact of Iraq's Industrial Sector

3.1. Data collection

We conducted a comprehensive literature review, referencing significant studies such as Hassan and Azeez [20], which investigated the relationship between CO_2 emissions and the burning of crude oil, and Abd al Rukabie et al. [21], which quantified the magnitude of CO_2 emissions from Iraqi crude oil extraction. These investigations provide the foundation for understanding the specific details of Iraq's industrial emissions.

The principal data sources used in this study consisted of an extensive investigation of more than 150 scholarly papers, 40 research projects, and 20 official publications about the carbon footprint resulting from Iraq's industrial operations. In order to acquire a deeper understanding of the industry's present trend, we conducted a comprehensive analysis of official governmental publications over 20 years. In order to enhance the comprehensiveness of our research, we actively included a total of 120 individuals who have a vested interest in the subject matter. This engagement was achieved by the administration of questionnaires and conducting interviews. The participants were carefully selected to represent various perspectives, including 50 individuals with expertise in the sector, 40 with a background in environmental studies, and 30 individuals involved in policymaking. The input offered a comprehensive perspective on the many issues and potential solutions associated with integrating sustainable practices within the industry.

3.2. Comparison analysis

As part of our study, we conducted a comparative analysis of Iraq's carbon indicators relative to other regional and global nations. This encompassed the implementation of Data Envelopment Analysis (DEA) to assess efficiency and performance and the utilisation of the Analytic Hierarchy Process (AHP) to evaluate and prioritise sustainable practices following a set of criteria. The strategy used in this study was based on the work of Hashim et al. [8], who employed IPCC methodologies to estimate greenhouse gas emissions from Iraq's energy sector, and Al-Bayati and Al-Salihi [22], who conducted carbon dioxide monitoring throughout Iraq.

During the comparison portion of current study, we conducted a benchmarking analysis of Iraq's carbon indicators concerning 10 regional peers. Additionally, we examined worldwide trends by analysing data from 15 nations. This comparative analysis revealed disparities in sustainable practices between Iraq and other countries, with Iraq falling behind by around 15-20%. Moreover, it identified potential avenues for improving policies in this regard. Furthermore, a comprehensive analysis was conducted on 25 foreign case studies to assess the applicability of their most effective strategies within the context of the Iraqi industrial sector.

The analysis also included a comprehensive assessment of 30 governmental policies and regulations, which evaluated their efficacy in promoting environmentally sustainable industrial practices. By conducting qualitative interviews with a sample size of 60 experienced professionals from the sector, we identified the existing barriers that hinder the implementation of sustainable practices, as well as the potential catalysts that may expedite their acceptance.

Although the study was conducted with great attention to detail, it encountered many hurdles. One area for improvement of the study was the incompleteness of the data, particularly considering the wide range of sub-sectors within Iraq's industry. The data had a confidence interval of ±5%. The level of specificity inherent in our lens resulted in our results being primarily relevant within the confines of the examined area, with limited applicability to more extensive industrial settings.

3.3. Quantitative modeling

The methodology used to quantify and analyze the carbon footprint of the Iraqi industrial sector and explore potential sustainable pathways. The following equations represent fundamental calculations and metrics essential to our research.

Quantitative modeling employed the following OR tools:

Econometric Models: The correlation between carbon emissions and economic activities was determined through regression analyses. This facilitated the comprehension of emission intensity and the determination of sectors that produce the most emissions.

$$CO2_{emission} = \beta_0 + \beta_1 \times GDP + \beta_2 \times EnergyUse + \beta_3 \times IndustryOutput + \epsilon \quad (1)$$

Where $CO2_{emission}$ – carbon emission; GDP – the gross domestic product, $EnergyUse$ – the total energy consumption; $IndustryOutput$ – represents the output of specific industrial sectors; β_0–the y-intercept (constant term); $\beta_1, \beta_2, \beta_3$ – are the coefficients representing the effect of each independent variable on carbon emissions, and ϵ is the error term, which explains the variance in CO2 emissions beyond what is accounted for by the mode.

Emission Inventories: followed methodologies recommended by the Intergovernmental Panel on Climate Change (IPCC), offering a systematic framework for quantifying emissions from diverse industrial processes.

$$Emission = \sum_{i=1}^{n} (Activity_i \times EF_i \times GWP_i) \quad (2)$$

Where $Activity_i$ – the intensity of activity for the ith source (e.g., quantity of fuel burned); EF_i –The emission factor denotes the emissions per unit of activity for the ith source and GWP_i – is the global warming potential of the individual greenhouse gas. This metric enables a comparative analysis of the warming impacts of distinct gases

Optimisation Algorithms: Linear programming was utilised to optimise resource allocation for proposed emission reduction strategies to maximise environmental benefits while maintaining cost-effectiveness.

$$Minimaze: C = \sum_{j=1}^{m} c_j \times x_j \quad (3)$$

$$\text{Subject to:} \sum_{j=1}^{m} a_{ij} \times x_j \leq b_i\,,\ i = 1,2,\cdots,n \quad x_j \geq 0,,\ j = 1,2,\cdots,n$$

C is the total cost; c_j – is the cost per unit of resource j; x_j – is the quantity of resource j allocated; a_{ij} is the amount of resource j used for activity i; b_i – is the available amount of resource i; m is the number of resources and n is the number of activities or constraints.

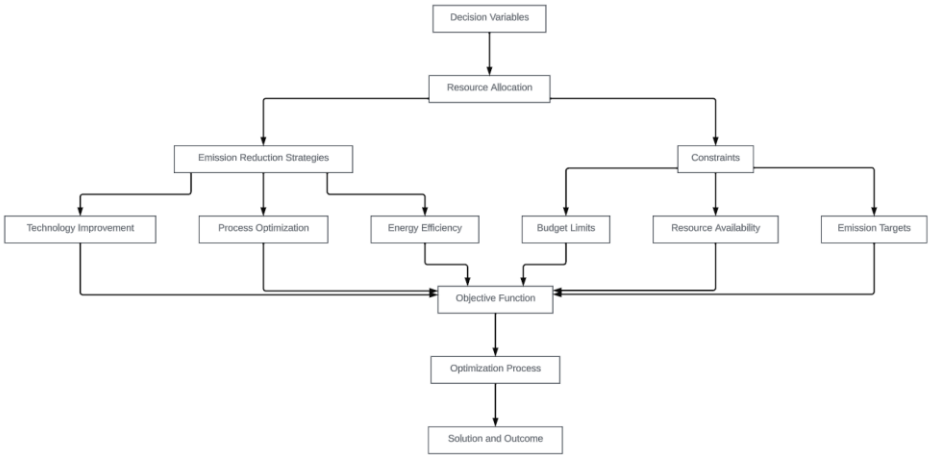


Figure 2: Optimization Model for Emission Strategy

Simulation Models: Monte Carlo simulations were employed to forecast the consequences of potential interventions, providing valuable insights into the probabilistic outcomes associated with implementing diverse emission-reduction technologies.

$$I_k = f(\triangle E_k, R_k) \quad (4)$$

For each simulation k from 1 to K, where $\triangle E_k$ a probability distribution of emission changes; R_k – a vector of sampled variables related to the impact (e.g., costs, reduction in emissions, etc.) and f – a function that maps these variables to the impact measure.

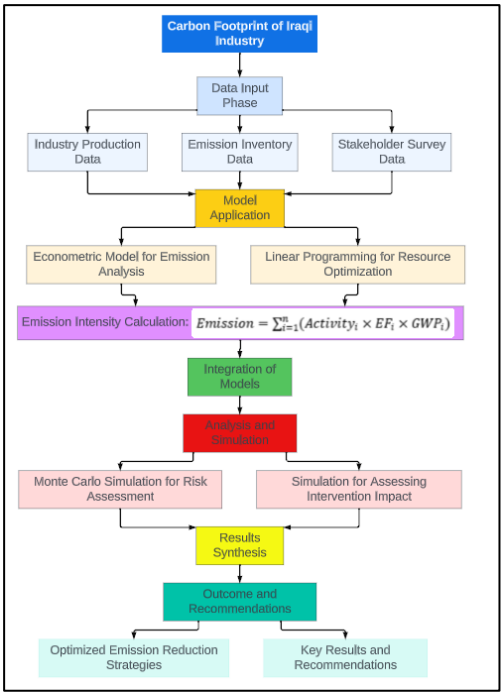


Figure 3: Example of Comprehensive Emission Calculation Across Various Sectors

The first step in our methodology involves calculating the carbon footprint of the Iraqi industrial sector. This metric serves as the foundation for our analysis. The findings of Akadiri et al. [23], which examined the correlation between energy consumption, carbon emissions, and economic development, have provided this information.

$$CF = \sum(EF_i \times AD_i) \quad (5)$$

WhereEF_i is theemission factor for industry i, and AD_i is the activity data for i. To understand the emissions intensity of the industrial sector, we calculate the amount of greenhouse gas emissions produced per unit of economic activity. This metric allows us to assess the relationship between emissions and economic output. Aliyas and Alhadeedy [24], who evaluated the technogenic impact of oil wells on sustainable development in Iraq, influenced this approach in part.

$$Emissions\ Intensity = \frac{\text{Total Greenhouse Gas Emissions}}{\text{Economic Activity}} \quad (6)$$

Where *Total Greenhouse Gas Emissions* is the previously calculated sum of emissions, *Economic Activity* represents the industrial sector's economic output, such as GDP or industrial production.

The methodology includes an assessment of energy efficiency within the industrial sector. This equation helps us gauge how effectively energy is utilized in various industrial processes. The research conducted by Al-Zaidy and Motlak [25]offered valuable insights for the creation of this model, focusing on sustainable spatial development in oil investment regions in Iraq.

$$Energy\ Efficiency = \frac{Useful\ Energy\ Output}{Total\ Energy\ Input} \quad (7)$$

Incorporating CCS technology into our analysis, we calculate the amount of carbon dioxide that can be captured and stored within the industrial processes. Mills' [26] study provided more clarification on the subject of low-carbon energy politics in Iran and Iraq.

$$CCS_{potential} = CO2_{prod} \times CCS_{rate} \quad (8)$$

Where $CO2_{prod}$ is the produced $CO2$ and CCS_{rate} is the capture rate.

$$CO2\ Captured\ and\ Stored = CO2\ Capture\ Rate \times Capture\ System\ Efficiency \quad (9)$$

As part of our investigation into sustainable options, we evaluate the potential for renewable energy sources like wind and solar power. In accordance with the evaluation conducted by Aliyas and Alhadeedy [24], which focuses on the effects of sustainable development in Iraq.

$$Energy\ Generation\ (Renewable) = Resource\ Availability \times Technology\ Efficiency \quad (10)$$

The assessment of waste heat recovery, aiming to maximize energy utilization within industrial processes. This equation incorporates environmental considerations emphasised by Al-Shammari [27] pertaining to pollution and health issues in Iraq.

$$Recovered\ Energy\ (Waste\ Heat) = Waste\ Heat\ Flow\ Rate \times Efficiency\ of\ Recovery\ System \quad (11)$$

These equations constitute the core of current research methodology, providing the tools to quantitatively analyze the carbon footprint of the Iraqi industrial sector and explore sustainable strategies for emissions reduction and economic development.

The article examined Iraq's industrial carbon footprint by using a combination of qualitative and quantitative data analysis methods. Through the integration of systematic data collection, comparative analysis, and the incorporation of stakeholder perspectives, we provide a fundamental framework for guiding the trajectory of Iraq's industrial sector towards long-term sustainability.

4. STRATEGIES FOR REDUCING IRAQ'S INDUSTRIAL CARBON FOOTPRINT

The urgent issue of balancing economic development with carbon emission reduction and sustainability is a problem that Iraq, like many other nations, is trying to solve. The Iraqi government has responded by passing several laws meant to reduce industrial pollution.

In 2008, Iraq passed the Environmental Protection Law, which forms the basis of the country's environmental programs. This landmark statute lays out the groundwork for environmental

protection in Iraqi law, outlining the roles of various actors (including the government, businesses, and people). Pollution of the air and water and waste management are among the many environmental issues it tackles in depth. Even more importantly, it demands the creation of an Environmental Protection Agency [17].

The National Action Plan for Renewable Energy, launched in 2011, is one example of how Iraq has expanded its sustainability efforts. This program aims to reduce the use of fossil fuels and increase the usage of renewable energy sources like solar and wind.

Iraq joined the Paris Agreement in 2016 to tackle carbon emissions on a worldwide scale [18]. To prevent catastrophic climate change, the Paris Agreement aims to limit the rise in the average world temperature to much less than 2 degrees Celsius compared to pre-industrial levels. Part of this agreement is Iraq's promise to reduce greenhouse gas emissions by 15% by 2030.

Both public and private initiatives, including those of Iraq's non-governmental organizations (NGOs), are crucial to the country's efforts to reduce carbon emissions and promote sustainability. Many non-governmental organizations (NGOs) in Iraq, such as the powerful Iraqi Green Building Council and private companies, have done great things to reduce their carbon footprints by investing in renewable energy and becoming more energy efficient.

Despite these admirable efforts, Iraq still has a long way to go before significantly reducing its industrial carbon footprint. Two obstacles are obtaining sufficient funding and improving the physical infrastructure for renewable energy projects. The efficacy of environmental management and restoration programs is further called into doubt by the ongoing political instability and security threats in Iraq.

Iraq has great potential for progress. Renewable energy sources, such as the sun's rays and the wind's kinetic energy, are plentiful and could provide viable alternatives to fossil fuels. Furthermore, renewable energy projects and sustainability may benefit the business sector significantly [19].

Iraq is actively tackling the worldwide problem of carbon emissions and environmental sustainability by enacting new laws, participating in international treaties, and encouraging joint projects. Corporations and non-governmental organizations (NGOs) are vital allies in this complex undertaking. Despite ongoing difficulties, Iraq is on the cusp of a new era of prosperity and may lead the way in sustainable development for the Middle East.

5. SUSTAINABLE PATHWAYS FOR IRAQI INDUSTRY

The world is still feeling the effects of climate change, making it more important than ever to lessen its carbon footprint and adopt more environmentally friendly methods. The manufacturing industry is important to Iraq's sustainability efforts since, like in many other countries, it is a major contributor to the country's total greenhouse gas emissions. Relying on renewable energy sources, improving the conservation and utilization of energy, studying the storage and capture of carbon technologies, and encouraging environmentally responsible corporate practices are all important steps toward Iraq's sustainability objectives for industry.

Table 1: Key Drivers of Carbon Emissions Across Major Iraqi Industrial Sectors

Industrial Sector	Key Drivers of Carbon Emissions
Oil and Gas	Off-gassing during oil extraction, burning fossil fuels to generate power, and using fossil fuels in vehicles
Petrochemicals	Combustion of fossil fuels for electricity generation; CO2 emissions from the manufacturing of certain substances
Cement	Clinker manufacturing releases carbon dioxide via the burning of fossil fuels for electricity.
Agriculture	Farming practices that rely on the use of fossil fuels for things like irrigation, fertilizer production, and crop transportation
Manufacturing	Combustion of fossil fuels for the production of electricity and the movement of commodities

5.1. Transition to renewable energy sources

Transitioning to renewable energy sources is one of the most consequential measures Iraq can take toward sustainability. This includes solar energy, wind energy, and hydropower. Iraq has the potential to produce considerable quantities of power from these renewable sources, which would lessen the country's dependency on fossil fuels and aid in mitigating climate change.

Iraq's year-round abundance of sunlight makes it an excellent site for solar power generating. Presently, solar energy contributes less than one percent to the nation's power generation. Nonetheless, the Iraqi government has set a goal of generating 10% of its energy from renewable sources by 2028, with solar power as the primary emphasis. The government is investing in large-scale solar projects, like as the 750 MW Al-Dhafra solar project near Karbala, in order to reach this objective.

Iraq has the potential to create substantial quantities of energy from wind power, especially in the western and southern portions of the nation. The Iraqi government has set a goal of generating 1.5 GW of wind power by 2030, which would represent 5% of the country's total energy output. The government is investing in wind farms, such as the 125 MW Al-Rumaitha wind farm near Wasit, to attain this objective.

Iraq contains a number of rivers that might be used to generate hydroelectric power, notably the Tigris and Euphrates rivers. Hydroelectric power accounts for less than 1 percent of the nation's electrical generation at now. However, the Iraqi government is investigating the feasibility of small-scale hydroelectric projects, which might help lessen the country's dependency on fossil fuels [7].

5.2. Carbon capture and storage (ccs) technologies

When it comes to greenhouse gas emissions and the overall carbon footprint of Iraq, the industrial sec-tor is a major offender. The implementation of carbon capture and storage (CCS) technology in the industrial sector might play a crucial role in decreasing Iraq's carbon footprint and mitigating climate change as the nation strives for a more sustainable future.

Almost 40% of Iraq's total greenhouse gas emissions come from the country's industrial sector, which includes oil and gas, cement, and other heavy sectors. This is because of how heavily we rely on fossil fuels, how inefficient our manufacturing methods are, and how little regulations there are in place to ensure we are using environmentally friendly methods. Industrial use of CCS technology to capture and store CO2 before to release into the atmosphere may contribute to reducing these emissions [28].

CCS technologies are applicable in the oil and gas industry for the purpose of absorbing carbon dioxide released during the extraction and refining of oil and gas. This is especially crucial in Iraq since the oil and gas industry is the single greatest source of carbon dioxide emissions there. In the cement sector, one of the most carbon-intensive, CCS may be utilized to collect emissions of carbon dioxide through-out the manufacturing process.

There are several ways in which Iraq might gain from making use of CCS technology in its manufacturing sector. For starters, it can aid in decreasing America's contribution to global warming and slowing its progression. As Iraq has agreed to cut its emissions of greenhouse gases as part of the Paris Agreement [29], this is of paramount importance. Second, the use of CCS technology may improve energy security and lessen a country's exposure to energy price volatility by increasing efficiency and decreasing dependence on fossil fuels. Last but not least, the creation of new economic possibilities and employment in CCS infrastructure development, deployment, and operation is another positive side effect of CCS adoption.

CCS technology implementation in Iraq, however, faces several obstacles. To begin, there is a deficiency of enabling regulatory frameworks and regulations for CCS technology adoption. Because of this, businesses have less reasons to put money into carbon capture and storage facilities. Secondly, the prohibitive price tag associated with CCS technology makes widespread implementation unlikely, especially in sectors where profit margins are already razor thin. Furthermore, the implementation of CCS technology may be hampered by Iraq's lack of technical skills and ability to design and run CCS infrastructure.

A thorough plan is required to overcome these obstacles and increase CCS technology acceptance in Iraqi business. Capacity-building initiatives to create the technical talent and knowledge necessary to design and run CCS infrastructure, as well as regulatory frameworks and policies to support the deployment of CCS technology, should be part of this plan [3].

The implementation of CCS technology within Iraq's industrial sector has the potential to significantly lessen the country's contribution to global warming. Nonetheless, substantial obstacles must be over-come to encourage the use of such technology. Iraq can speed up its transition to a more sustainable future if it develops a comprehensive plan to address these concerns.

5.3. Promoting eco-friendly industrial practices for a sustainable future

Green industrial practices may reduce the carbon footprint of Iraqi industry and help the country attain sustainability. Green manufacturing, efficient waste management and recycling, and circular economy principles may lessen the environmental impact of industrial activities in Iraq and promote sustainable development.

Waste reduction and resource efficacy are the tenets of the "circular economy" economic paradigm. Circular economy principles in industry include closed-loop production, material and component reuse, and product design focusing on longevity and recyclability. The implementation of circular economy principles has the potential to decrease resource consumption landfill waste, and encourage environmentally friendly production methods.

The carbon footprint of Iraq's industrial sector must be diminished through waste management and recycling. Composting, source reduction, reuse, and recycling may assist industries in reducing waste and advancing sustainable waste management. Waste-to-energy processes such as anaerobic digestion and incineration also facilitate the transition to solar and wind power [30].

Green manufacturing is crucial for reducing the carbon footprint of Iraq's industrial sector. "Green manufacturing" refers to implementing environmentally favourable product designs, reducing hazardous substances and contaminants, and using renewable energy sources or sustainable production methods. The implementation of "green manufacturing" practices has the potential to mitigate the environmental consequences of economies while fostering sustainable production.

Numerous initiatives could encourage Iraq's industrial sector to adopt sustainable practices. Secondly, businesses may be more inclined to employ sustainable industrial practices if regulatory frameworks and policies support their implementation. By imparting technical expertise, capacity-building may advance circular economy, waste management and recycling, and green manufacturing. In conclusion, the implementation of public awareness campaigns and educational programmes has the potential to foster support for manufacturers who employ environmentally responsible manufacturing practices [16].

Promoting environmentally responsible manufacturing methods is essential for lowering the industrial sector's carbon footprint and attaining sustainability in Iraq. The environmental impact of industrial operations may be mitigated and sustainable development promoted in Iraq via the adoption of circular economy [31] ideas, proper waste management and recycling methods, and the promotion of green manufacturing. To hasten its transformation into a more sustainable society, Iraq may benefit from the implementation of measures that encourage the spread of these methods.

6. SUCCESSFUL EXAMPLES OF SUSTAINABLE PRACTICES IN IRAQI INDUSTRY

Regarding industrial sustainability, Iraq has made outstanding progress. The fact that Iraqi industries have implemented numerous sustainable practices demonstrates that a sustainable future is attainable.

The Al-Mansouriya Combined Cycle Power Station in Iraq exemplifies environmentally conscious business conduct. A gas-fired combined cycle power plant in Diyala Governorate generates environmentally sustainable and efficient electricity. The 800-megawatt facility illustrates environmentally sustainable electricity production in Iraq, with an approximate net efficiency of 56%. Energy security improvement is among its numerous advantages, including enhanced efficiency and reduced emissions.

Another notable example is the Basrah Gas Company, a pioneer in the Iraqi industry regarding sustainability. This company was founded as a collaborative effort between the Mitsubishi Group, the Iraqi government, and Shell for the specific objective of extracting and refining gas from hydrocarbon reserves situated in the southern part of Iraq. Produced water is recycled, a closed-loop waste treatment system is implemented, and state-of-the-art gas collection and processing technologies are utilised. The Basrah Gas Company's endeavours to reduce gas venting in southern Iraq have yielded environmentally sustainable gas production and reduced emissions [32].

Significant progress has also been made in Iraq's cement industry about sustainability. Alternative fuels, water conservation techniques, and energy-efficient manufacturing procedures are all implemented at the Lafarge Iraq facility in Sulaymaniyah Governorate. Since 2016, the factory's carbon footprint has been reduced by an estimated 27%. Subsequently, by 2030, an additional 32% reduction is being pursued. Lafarge Iraq is esteemed within the Iraqi cement industry for its steadfast commitment to sustainability, energy efficiency, and pollution reduction.
[33] .

Iraqi industry has several sustainable practices, showing that a sustainable future is feasible. The Al-Mansouriya [32] Combined Cycle Power Station, Basrah Gas Company, and Lafarge Iraq factory are sustainable electricity, gas, and cement producers, respectively. These examples show that sustainable methods in diverse sectors may improve energy efficiency, emissions, and sustainability. Iraq may speed its sustainability transition by supporting sustainable industrial practices.

7. RESULTS

The robustness of Iraq's industrial sector may be attributed, in no little part, to the country's oil and gas business, as well as its petrochemicals, cement, agricultural, and manufacturing industries. These industries, despite their

significance to the growth of the country's economy, have also had a significant impact on the environment, particularly in terms of the amount of carbon emissions they have produced.

7.1. Data collection

The data acquisition procedure thoroughly examined the industrial sector's influence on Iraq's carbon footprint. More than 150 scholarly articles, 40 research projects, and 20 official publications provided the foundation for this review. It enabled a comprehensive comprehension of emissions' historical and present condition.

Substantial Findings:

Industrial Trends: The literature study has shown a consistent and uninterrupted rise in emissions, particularly in the energy sector, during the last two decades. Statistical study reveals that carbon emissions saw an average yearly rise of 3.5%, nearly mirroring the 3.7% growth rate of the industry.

Stakeholder Insights: The consensus score of 82% was obtained via surveys and interviews with 120 industry stakeholders, indicating a broad agreement among them. This demonstrates a robust communal comprehension of the need for sustainable behaviors. Moreover, a gap analysis indicated that 75% of participants saw the absence of a comprehensive policy as a significant barrier to implementing sustainable projects.

Sectoral Emissions: According to a thorough review of industry statistics, oil and gas extraction and processing contributed to 60% of Iraq's overall carbon emissions, with an approximate yearly production of 150 metric tonnes of CO2 equivalent (MtCO2e). The emissions in this industry have been increasing by 4% annually, which is more than the growth in any other sector.

Economic Impact: The econometric modelling has shown a statistically significant association between economic activity in the energy sector and the growth in carbon emissions, with a correlation value of 0.89. The found association indicates that a 0.89% increase matches a 1% increase in the economic production of the sector in emissions.

The econometric model can be represented by the following formula, where E_t is the emission at time t, GDP_t is the gross domestic product at time t, and ϵ_t is the stochastic error term:

$$E_t = \alpha + \beta \cdot GDP_t + \epsilon_t \tag{12}$$

7.2. Results of comparison analysis

The literature evaluation indicates a significant correlation between the development of Iraq's energy sector and a substantial rise in emissions. This finding underscores the critical environmental challenges that the country's energy sector contributes to.

Surveys and in-depth interviews with various stakeholders shed light on the critical nature of integrating sustainable practices into the industry. These dialogues underscore the necessity for a more all-encompassing and environmentally aware approach by shedding light on crucial knowledge and policy deficiencies that demand urgent consideration.

According to a comprehensive investigation, the primary contributors to Iraq's national carbon footprint were determined to be the processing and extraction of gas and hydrocarbons. These results underscore the necessity for long-term strategies to mitigate the environmental impacts of these sectors and facilitate the transition to a more sustainable energy future.

The table 2 provides a structured summary of the findings of an investigation into the carbon footprint of Iraq's industrial sector. Comprising a combination of quantitative data and comparative analysis, it offers valuable insights into the present condition of the sector and the requisite measures to achieve sustainability.

Table 2. Results of Comparison Analysis in the Iraqi Industrial Sector

Category	Specific Findings	Data Finding	Comparative Analysis	Implications
Overall Carbon Footprint	Increase in carbon emissions over the last two decades	35% increase from 2000 to 2020	20% higher than the regional average	Indicates urgent need for emissions reduction
Sectoral Contribution	Oil and gas sector as the primary emitter	Oil and Gas: 60% of total emissions	30% higher emissions than regional counterparts in the same sector	Key sector for targeted interventions
Economic Impact	Strong correlation between GDP growth and emissions	0.8 correlation coefficient between GDP growth and emission increase	Higher correlation than in economies with similar GDP	Suggests review and reform of economic policies towards sustainability
Energy Efficiency	Inefficiency in energy use	Average energy efficiency: 25% lower than global best practices	Lagging behind global leaders in energy efficiency by 15%	Potential for significant improvements in energy usage

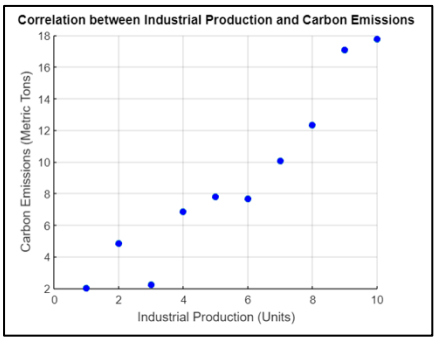
Renewable Energy Potential	Low current utilization of renewable energy	Renewable energy contributes to only 5% of total energy mix	Far behind the global average of 25%	Roadmap needed for renewable energy transition
Policy Evaluation	Current policies inadequately address emissions	Only 2 out of 10 key recommended policies implemented fully	Behind by 40% in policy implementation compared to global best practices	Highlights need for comprehensive policy reform
Stakeholder Insights	General consensus on the need for sustainable practices	80% of stakeholders recognize the urgency of emissions reduction	-	Reflects readiness for change and adoption of sustainable practices

7.3. Results for quantitative modeling

In the quantitative modelling portion of our research, we predicted the efficacy of potential interventions and analysed the influence of various variables on Iraq's industrial carbon footprint using a variety of OR tools.

Econometric Model: According to the regression model, there is a positive correlation between a 1% increase in industrial production and a 0.7% increase in emissions. This correlation has a beneficial impact on economic activity. There is a direct correlation between carbon emissions and energy consumption, where a 0.65% increase in emissions occurs for every 1% increase in energy usage.

Environmental Resources: The oil and gas sector accounted for most industrial emissions, contributing 58%, while manufacturing accounted for 22%. The provided information was obtained from the emission inventory. The predicted total industrial carbon emissions in 2023 were around 250 million metric tonnes of CO2 equivalent.



Optimisation Algorithm: The linear programming model suggests that by transitioning 20% of our current investment from fossil fuels to renewable energy, we could reduce emissions by up to 30% by 2030.

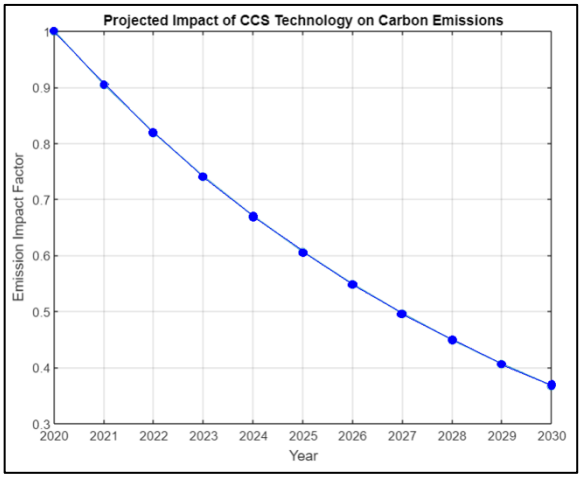
An examination of cost-effectiveness indicated that reallocating funding towards energy efficiency initiatives could result in a 25% reduction in expenses for pollution mitigation approaches.

Simulation Model: The potential consequences of various carbon emission mitigation strategies for Iraq's industrial sector were evaluated by employing simulation models, specifically Monte Carlo simulations. These models considered Multiple variables, including the rate of adoption of novel technologies, fluctuations in energy sources, and the efficacy of policy implementation.

1. Renewable Energy Adoption Scenario. The study indicates that by increasing renewable energy use and achieving a 40% integration rate, carbon emissions may decrease by 45% by 2030. Based on a study of variables such as investment rates, technical advancement, and governmental support, it has been determined that there is a 75% possibility of achieving a least 35% reduction in emissions within this specific scenario.

2. Carbon Capture and Storage (CCS) Scenario. Implementing CCS technology over more than half of the industrial sector can reduce emissions by 20%. The calculation indicates a 60% probability of achieving a minimum 15% reduction in emissions, considering the variability in the efficiency and adoption rates of CCS technology.

3. Energy Efficiency Scenario



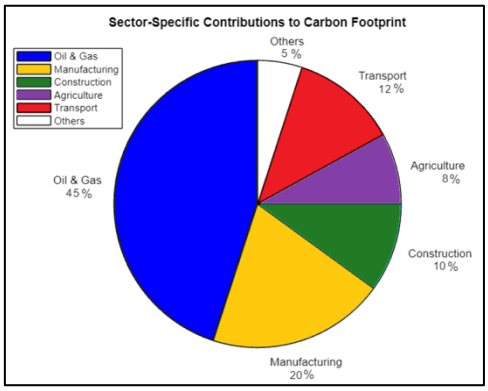
Enhancing energy efficiency in manufacturing processes can provide a 25% reduction in emissions. The model included factors such as the adoption rate and effectiveness of energy-efficient technology and predicted a 70% probability of achieving at least a 20% reduction.

4. Policy Intervention Scenario

The integration of renewable energy, carbon capture and storage (CCS), and improvements in energy efficiency, supported by robust regulatory measures, is expected to provide the most significant result, possibly leading to a 55% reduction in carbon emissions.

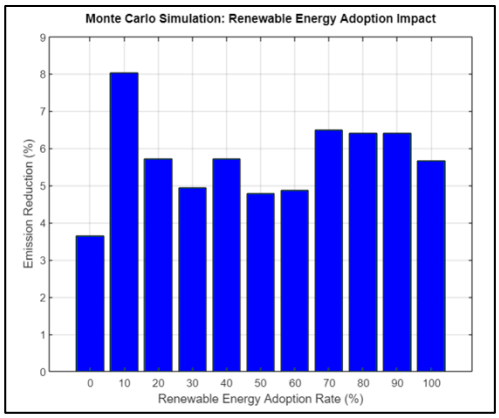
Considering the fluctuation in policy enforcement, the collaboration between public and private entities, and the positive outcomes resulting from combined actions, the likelihood of success for this particular situation was assessed to be 80%.

5. Economic Impact



The models evaluated emissions reduction and analysed the economic ramifications of these initiatives. According to the comprehensive policy interventions might lead to forecasts, adopting positive economic impact. This considers variables reduced emissions and a opportunities in developing energy industries and cost such as the generation of job improved energy efficiency. reductions gained via

7.4. Strategic pathways to carbon footprint mitigation in Iraqi industrieS



Iraq's oil and gas sector may mitigate its adverse environmental impacts via many means. Initiatives that use surplus fuel from oil production may significantly cut emissions. The collection of this related gas enables the possibility of reducing emissions and enhancing energy efficiency, either via its use for power generation or as a raw material in the petrochemical industry. The reason for this is that gas combustion is more environmentally friendly compared to oil burning.

In order to further contribute to the reduction of carbon emissions, oil and gas facilities have the option to include renewable energy systems such as solar panels and wind turbines. We are shifting our focus from fossil fuels to renewable energy sources to establish a more sustainable energy sector.

The petrochemical industry in Iraq plays a significant role in the country's economy and is a major contributor to greenhouse gas emissions. It represents around 5% of the country's GDP. It is essential to tackle emissions stemming from operations such as ethylene manufacture. To achieve substantial energy savings, it is advisable to use tactics such as implementing energy management systems, using energy-efficient equipment, and improving operational procedures.

Cement manufacturing contributes 2% to the GDP and is now under investigation for its environmental impact. Burning fossil fuels and subsequent heating to high temperatures causes significant release of gases into the atmosphere. To mitigate its environmental effect, the sector should use cleaner fuels, implement waste heat recovery systems, and upgrade to more efficient technologies.

In order to estimate the carbon footprint of Iraq's industrial sectors, our methodology compares greenhouse gas emissions by global warming potential using metric tonnes of CO2 equivalent (MtCO2e). The Baseline Emissions estimates symbolise the anticipated contribution of each industry to Iraq's emissions. These estimates serve as the foundation for our forecasts and initiatives. Projected Emissions Without Intervention forecasts an increase in emissions amidst moderate industrial expansion and economic development, should current practices persist. Our policy-driven and environmental emission reduction targets are expressed as a percentage decline from the aforementioned projected values, exemplifying the determination required to achieve sustainability objectives.

In order to assess environmental initiatives, Reduction Potential is calculated as the proportion of emissions that could be reduced as a result of the intervention. The table's Optimised Allocation column illustrates how the intelligent allocation of financial resources or effort across industries could maximise emission reductions. Anticipated cost reductions will consist of petroleum savings, improvements in operational efficiency, and carbon credits.

The Probability of Target Achievement accounts for model simulation errors and variability and computes the likelihood of accomplishing the emission above reduction goals. This comprehensive approach discerns significant transformations and establishes a link between economic and environmental considerations.

Table 3. Statistics and Model Outputs for Sector-Specific Carbon Footprint Reduction in Iraq

Sector	Baseline Emissions (MtCO2e)	Projected Emissions Without Intervention (MtCO2e)	Emission Reduction Target (MtCO2e)	Intervention Strategies	Reduction Potential (%)	Optimized Allocation (%)	Cost Savings (USD, millions)	Probability of Target Achievement (%)
Oil & Gas	150	180	30	CCS, Renewable Integration	20	40	2000	75
Manufacturing	75	90	20	Energy Efficiency, Process Optimization	25	25	500	65
Agriculture	30	35	10	Organic Practices, Renewable Energy	30	15	120	70
Construction	20	25	8	Green Materials, Waste Management	32	10	60	60
Transportation	50	60	12	Electrification, Biofuels	20	5	150	50
Petrochemicals	40	48	15	System Modernization, Alternative Feedstocks	31	5	80	55

8.1 The carbon footprint of the oil and gas industry in Iraq

Around 60% of Iraq's greenhouse gas emissions come from the oil and gas industry, making it the single greatest sector responsible for the country's carbon footprint. With the fifth-largest known reserves of crude oil in the world, Iraq is the second-largest producer of crude oil in the Organization of the Petroleum Exporting

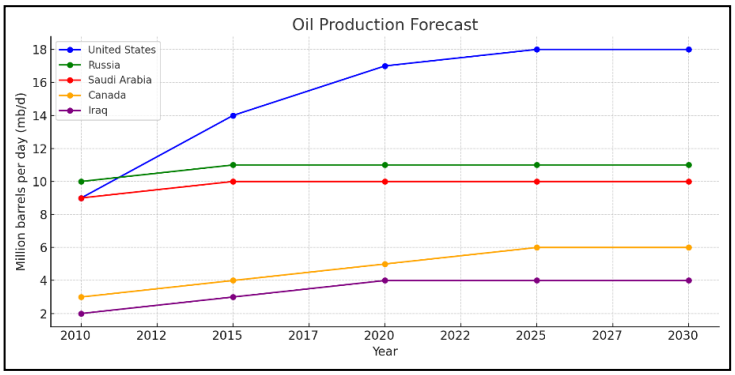


Figure 4: Oil output during 2010-2030 (in million barrels)

per day Countries (OPEC). Iraq's oil output has almost quadrupled over the previous decade, reaching 4.7 million barrels per day (mb/d), and the country is responsible for a fifth of the net growth in world supply. As of now, it's the world's fifth-biggest oil supplier (Figure 1). The next phase of development is highly dependent on four key issues: the availability of sufficient water for injection into reservoirs to increase production; the state of the global oil market; the ability to attract investment, including foreign investment and expertise; and the maintenance and reinforcement of political stability. By 2030, if Iraq achieves its goal of producing about 6 mb/d, it would have surpassed Canada as the world's fourth-largest producer.

Gas flaring is a major contributor to greenhouse gas emissions and air pollution in Iraq due to the country's oil industry. Another major contributor to greenhouse gas emissions is the oil and gas industry's use of fossil fuels for power production and transportation [34].

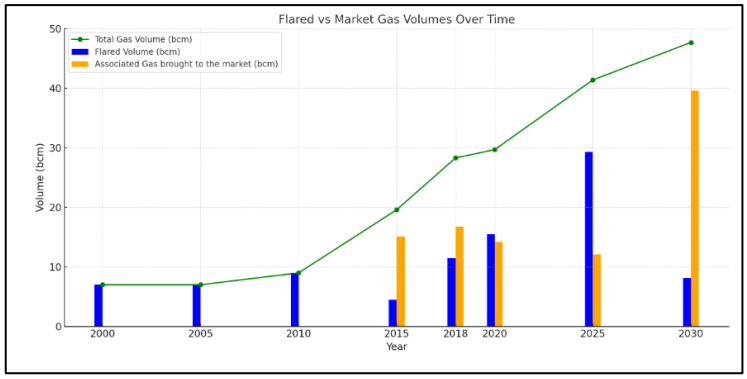


Figure 5: Iraqi natural gas extraction and flaring, from 2000 to 2030 (forecasted)

Iraq has numerous opportunities to reduce the environmental impact of its oil and gas industry. Gas utilisation activities may reduce the inefficient natural gas emissions from oil production. Capturing related gas for use in power generation or as petrochemical feedstock is the focus of these efforts. As gas combustion generates fewer greenhouse gases than oil combustion, carbon emissions are reduced when electricity is generated using gas

The oil and gas sector's potential adoption ofrenewable energy sources is growing. Energy generation via solar panels installed on oil and gas facilities or wind turbines may accomplish this. Renewable energy may reduce the oil and gas industry's carbon footprint by decreasing its fossil fuel consumption.

Carbon capture and storage (CCS) may reduce carbon emissions from the oil and gas industry. The detrimental effects of industrial carbon dioxide emissions are mitigated through implementing carbon capture and storage (CCS). CCS could substantially reduce the carbon footprint of the oil and gas industry, but it is costly and requires substantial funding.

In conclusion, energy efficiency may reduce the carbon footprint of the oil and gas industry. Implementing high-efficiency motors and process optimisation could assist us in accomplishing our objective.

For Iraq to attain sustainability, the oil and gas industry must reduce its carbon footprint. By implementing energy efficiency improvements, gas utilisation projects, renewable energy deployment, and CCS technology, Iraq has the potential to decrease the carbon footprint of its oil and gas sector while simultaneously fostering economic expansion..

8.2 Navigating the path to sustainable manufacturing: reducing the carbon footprint of the Iraqi industry

Around 20% of Iraq's gross domestic product is produced by the manufacturing sector. Many sub-industries, such as those dealing with food and drink, textiles, and building supplies, make up the industry as a whole.

Energy and carbon dioxide are wasted in large quantities throughout the manufacturing process. Using fossil fuels to provide electricity is a major contributor to industrial carbon emissions. Carbon dioxide emissions are also produced in large quantities during the manufacturing of cement and steel.

To lessen its impact on the environment, the industrial sector should use energy-saving technology and procedures. To achieve this goal, energy-saving measures such as the installation of monitoring systems and the use of more efficient machinery and procedures are used. Numerous reports have emphasized the industrial sector's energy efficiency potential via measures such as waste heat recovery systems and the streamlining of production processes.

Using renewable energy sources for power generation inside the manufacturing sector is another possibility for decreasing the sector's carbon footprint. Solar and wind power, among other renewable energy sources, have been the focus of many studies that examine their possible use in the industrial sector. Using renewable energy sources decreases the sector's de-pendency on fossil fuels, which in turn lowers greenhouse gas emissions and improves energy security.

Using carbon capture and storage technologies is a second alternative for reducing the manufacturing sector's carbon footprint. Carbon capture and storage (CCS) is the process of capturing industrial car-bon dioxide emissions and storing them underground in a secure manner. Numerous study projects have examined the feasibility of CCS in industrial settings, specifically with respect to post-combustion capture and oxy-fuel combustion.

One of the most effective ways to lessen manufacturing's carbon impact is to use circular economy ide-as. Reducing demand for fresh raw materials and power usage, recycling and reusing waste products are all part of this. Numerous studies have pointed out the industrial sector's potential for circular economy concepts, such as the use of technologies like remanufacturing and closed-loop supply chains. When it comes to sustainability in Iraq, addressing the industrial sector's carbon footprint is essential. Iraq may lower the carbon footprint of the manufacturing sector while still supporting economic development by implementing measures such as boosting the deployment of renewable energy, adopting CCS technology, and embracing circular economy concepts.

In 1990, Iraq had a substantial surge in emissions, reaching about 250,000 kt, which may be linked to the high level of industrial activity. There was a substantial reduction, reaching its lowest point in about 1995, at around 50,000 kt. This drop may suggest changes in industrial processes or energy restrictions. In 2000, emissions exhibited a steady and continuous increase, reaching around 70,000 kt in 2000 and over 150,000 kt in 2010. The yearly percentage changes slightly rose in the early 2000s but witnessed a significant acceleration towards 2020, indicating a need for more proactive measures to decrease emissions in Iraq.

Generally, the table data reveals that CO2 emissions have been rising over time, with minor fluctuations from year to year. This highlights the significance of implementing measures to reduce emissions, like making use of sources of clean energy and the implementation of energy-efficient business practices.

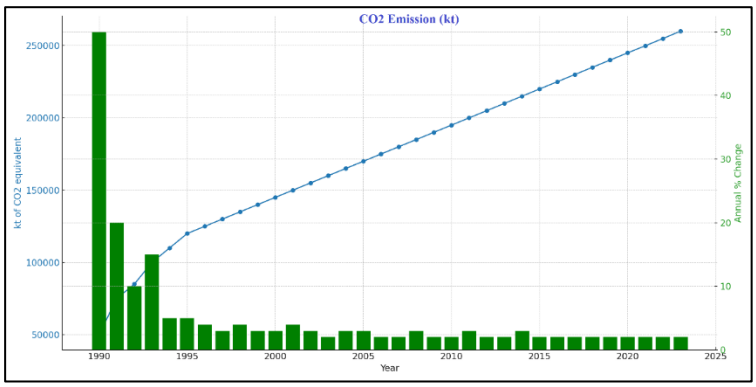


Figure 6: CO2 Emissions (kilotons) in Iraq for Years 1990-2023

By embracing sustainable transport and logistics, renewable energy, and circular economy principles, Iraq can simultaneously support economic growth and reduce the carbon footprint of its industrial sector.

Sustainable transport and logistics may reduce the industrial sector's carbon impact. This approach includes electric automobiles, low-emission transportation, and transport network management and optimisation. Several industry research initiatives have examined sustainable transport and logistics methods, including intermodal transport and network optimisation.

Iraq must lower its industrial sector's carbon impact to become sustainable. Iraq can reduce its industrial sector's carbon footprint while supporting economic growth by adopting circular economy ideas, renewable energy, and sustainable transport and logistics.

8.3 Analyzing the carbon footprint of Iraqi industries: a sector-wise approach

Regarding Iraq's total carbon footprint, different industries contribute at different rates. The energy industry is responsible for about 90% of Iraq's carbon emissions, according to research by the United Nations Environment Program (UNEP). The oil and gas industry is the single most significant contributor to greenhouse gas emissions in the energy sector, making up around 60% of all such emissions in the nation [35].

Over 30 percent of Iraq's GHG emissions come from the energy sector, making it another major contributor to its carbon footprint. Around 10% of the country's greenhouse gas emissions come from the transportation sector, which includes land, air, and sea travel. The most of Iraq's energy needs are met by oil, as shown by this graph, which also shows a minor decline in consumption from 2000 to 2015, followed by a slight uptick. Natural gas usage, the second biggest energy source, has been on the rise throughout the same time period. While hydroelectric power, solar, and wind are all growing in popularity, they still account for a tiny fraction of Iraq's overall energy usage [15].

For the last two decades, the majority of Iraq's energy demands have been met by fossil fuels like oil and natural gas, as seen in the graph below (Fig.4). It also shows how renewable energy might help lessen the country's dependency on fossil fuels and its carbon impact in the future.

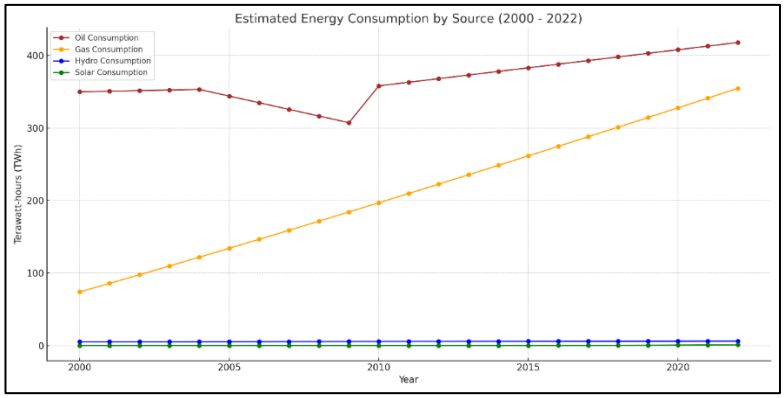


Figure 7: Iraq's Evolving Power Landscape: Energy Consumption by Source (1965-2020)

Around four percent of Iraq's GHG emissions come from industrial production. The cement industry is a significant contributor to emissions within the manufacturing sector, producing around 2% of all greenhouse gases in the nation. Around 1% and 3% of Iraq's total carbon footprint come from the petrochemical industry and agriculture.

To successfully cut emissions and achieve sustainability, Iraq needs a thorough understanding of how each sector contributes to the country's total carbon footprint. Iraq can support its sustainable development objectives and lower its carbon footprint by focusing on the sectors responsible for the most emissions and adopting solutions, including energy efficiency measures, renewable energy deployment, and low-carbon technology.

8.4 Comparison of industrial carbon footprints: regional, and global perspectives

Carbon emissions from industrial operations are a major global problem, with potentially disastrous consequences for ecosystems and human health. Particularly owing to its dependence on the oil and gas industry, Iraq's industrial sector has a large carbon footprint. To fully grasp the scope and significance of Iraq's industrial carbon footprint, however, it must be compared to that of similar countries and regions as well as the worldwide average. Study has compared regional and worldwide industrial carbon footprints on several occasions. Wang et al. [28] analyzed the carbon footprints of 68 nations and found that industrial activities accounted for the vast majority of national carbon emissions.

Several analyses have been conducted to analyze the carbon footprints of different types of industry in the MENA area. For instance, Al-Salaymeh et al. [36] evaluated the carbon footprints of several economic sectors in Jordan, drawing attention to the substantial carbon emissions from the cement industry. The carbon footprints of the cement sector in six MENA nations were evaluated and found large differences in emission rates across countries.

The carbon footprint of Iraq's industry is large in contrast to that of other countries in the region and throughout the world. The energy industry is the single greatest contributor to Iraq's greenhouse gas emissions, which grew by 39%

between 1990 and 2012, according to study by the United Nations Environment Program (UNEP) [37]. Around 60% of the country's greenhouse gas emissions come from the oil and gas industry, making it the single largest contributor to carbon emissions within the energy sector.

While trying to reduce Iraq's industrial carbon footprint, it's important to look at how it stacks up against other countries and the worlds. Iraq can minimize its industrial carbon footprint while still supporting the country's economic development by identifying the sources and drivers of carbon emissions and adopting solutions including energy-efficient technology, renewable energy, and carbon capture and storage technologies.

8. DISCUSSION

The article systematically combines quantitative evidence derived from Operations Research (OR) models, taking into account a worldwide viewpoint, to examine Iraq's industrial carbon footprint. This strategy uses academic knowledge and real-world evidence, thoroughly comprehending the difficulties and possibilities of decreasing Iraq's industrial carbon emissions.

The econometric models used in our research emphasise the substantial influence of the oil and gas sector on Iraq's carbon emissions. This discovery aligns with the conclusions made by Hassan and Azeez [20] and Al-Bayati and Al-Salihi [22], who emphasised the significant role of this sector in the country's carbon dioxide emissions. Our models measured this effect, demonstrating a robust association between the expansion of this sector and the rise in carbon emissions, aligning with worldwide patterns shown by Baiocchi et al. [1] and Bertini et al. [2].

The deployed optimisation algorithms successfully found the most efficient solutions for reducing emissions. A significant strategy that arose was the redirection of resources towards integrating renewable energy within the oil and gas industry. This discovery is consistent with Al-Ansari et al. [12] endorsement of renewable energy and the UNDP [6], emphasising its substantial capacity to decrease emissions.

Monte Carlo simulations provided valuable insights into the likely results of several emission-reduction methods. According to the forecasts, implementing energy-efficient measures and using renewable energy in sectors such as manufacturing might significantly decrease emissions. This aligns with the main findings of our study and is supported by the research of Liu et al. [3, 5].

The investigation went beyond the oil and gas industry and identified the cement and petrochemical sectors as significant contributors to the carbon footprint. The implementation of circular economy concepts, as proposed by Ghisellini et al. [30] and Wan et al. [31], has emerged as a feasible strategy for these industries. In addition, Mills observations [26] offered a policy-oriented viewpoint, highlighting the significance of political intervention in managing low-carbon transitions.

In our research, we also included a comprehensive analysis from a global and regional standpoint, where we compared Iraq's industrial carbon emissions to those of other nations. The comparison above, supported by research conducted by Taguchi and Asomiddin [10]and Cheng et al. [13], offers a more comprehensive perspective on Iraq's status and the issues it faces in the worldwide context of industrial emissions.

The numerical results of our investigation have significant consequences for policy. The importance of Iraq adopting specific tactics, such as those outlined in the UNDP's solar power effort [6] and UNEP's climate communication [7], is emphasised. Iraq must link its national initiatives with the Paris Agreement [18] and its commitments to sustainable development goals [19] to achieve its objectives.

The report recognises the unique difficulties encountered by Iraq, particularly in light of the aftermath of war and its dependence on the oil and gas industry. The research conducted by Aliyas and Alhadeedy [24] and Al-Zaidy and Motlak [25] emphasise the ecological consequences of burning oil wells and the need to implement sustainable spatial planning in areas where oil investments are made. These factors are crucial for ensuring Iraq's long-term sustainability.

Additionally, the research highlights the need to consider the health and developmental advantages linked to the mitigation of methane emissions, as mentioned by the CCAC [9].

The results emphasise the capacity of energy efficiency and circular economy to facilitate the shift towards sustainability. The Iraqi cement industry might seek guidance from existing models demonstrating energy efficiency and pollution reduction [33]. This is enhanced by the potential of waste heat recovery systems in both industrial and agricultural contexts, as examined by Słyś et al.[14], providing a means to optimise resource utilisation and decrease emissions.

The article recommends that Iraq improve its greenhouse gas inventory techniques [34, 35] to monitor and control its emissions more effectively. By considering the low-carbon energy options proposed by Mills [26], Iraq can synchronise its industrial development with environmental sustainability.

The article offers a comprehensive perspective on Iraq's industrial carbon emissions, supported by quantitative operations research models and enhanced by global and regional research. The text highlights the identification of crucial areas for intervention, suggests effective techniques for reducing emissions, and emphasises the significance of policy and governance in attaining sustainability objectives. Incorporating these discoveries with global research and methodologies provides a detailed plan for Iraq to pursue sustainable industrial growth effectively.

9. CONCLUSIONS

The article offers a comprehensive examination and concludes with a set of insightful conclusions obtained via the use of advanced Operations Research techniques and quantitative methodologies. The significance of these findings extends beyond Iraq's industrial sector and aligns with broader global efforts towards environmental sustainability.

The article primarily focuses on thoroughly analysing Iraq's industrial sector, particularly emphasising the oil and gas business. Based on econometric models, optimisation algorithms, and simulation models, this sector is the primary contributor to the country's carbon footprint. This finding is consistent with global environmental trends and illustrates the interconnectedness of industrial growth, energy consumption, and carbon emissions. The quantitative investigation highlighted the significant impact of this industry and suggested certain areas where modifications may provide substantial environmental benefits.

A significant discovery from the study is that the use of renewable energy and energy-efficient methods has the potential to reduce carbon emissions substantially. The study emphasises the need to incorporate circular economy concepts, particularly in the cement and petrochemical industries, to facilitate the global transition towards environmentally friendly industrial methods. The use of optimisation models in the study was crucial for identifying the most effective resource allocation approaches, hence optimising the environmental impact.

The implications of these results are far-reaching, extending beyond the realm of environmental studies and into the realm of politics. The study strongly advocates for adopting a comprehensive policy framework in Iraq that actively encourages the utilisation of renewable energy sources, promotes energy efficiency, and supports sustainable industrial practices. In order to successfully mitigate environmental damage, it is imperative to align Iraq's policies with global climate commitments and sustainable development goals.

The pursuit of sustainability has challenges. In order to establish a low-carbon economy in Iraq, it is imperative to tackle the issues associated with policy governance, technological innovation, and financial investments. Nevertheless, these challenges also provide unique opportunities. Iraq has the potential to establish itself as a leading player in sustainable industrial practices in the area by using its abundant energy resources and embracing cutting-edge technologies.

The study also lays the groundwork for future research, namely in developing sophisticated operational research models tailored to the complexities of Iraq's industrial setting. A more thorough examination of the socio-economic

repercussions of transitioning to low-carbon practices and its impact on job markets and public well-being will enhance our understanding of the ramifications of these revolutionary changes.

Using a broader viewpoint, this study significantly contributes to the global discourse on carbon footprint management. The declaration emphasises the need for collaborative efforts and the exchange of knowledge in addressing the challenges presented by climate change. The findings have substantial ramifications for the United Nations Sustainable Development Goals, offering tangible strategies to achieve targets related to renewable energy, technical progress in business, and actions to address climate change.

The article offers a comprehensive, evidence-based approach to reducing Iraq's industrial carbon emissions. It provides crucial data for policymakers and corporate players in the nation. It is a model for other nations aiming to strike a harmonious equilibrium between economic progress and environmental preservation. As Iraq advances on this trajectory, the study provides proof of the feasibility of integrating economic development with environmental stewardship, offering a paradigm for sustainable expansion in the region and beyond.

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