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CARBON FOOTPRINT OF IRAQ'S ENERGY SECTOR: ANALYSIS AND RECOMMENDATIONS FOR A LOW-CARBON FUTURE

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Abstract

Global climate change mitigation efforts focus on reducing anthropogenic emissions, with the energy sector accounting for 77.9% of global greenhouse gas emissions. Iraq faces unique challenges in this context, as it relies heavily on oil and gas for energy production, making the transition to low-carbon resources, carbon capture technologies, and the implementation of renewable energy critical. This study analyzes the carbon footprint of Iraqi power plants and diverse energy sources and proposes practical pathways for adopting solar and wind energy in the Iraqi context. The results reveal that conventional power plants have the highest carbon footprint (450-1000 g CO2/kWh). The study provides practical recommendations for reducing Iraq's carbon footprint, taking into account the country's specific economic and environmental conditions.

Keywords: Environmental pollution, Greenhouse gases, Air pollution, Renewable energy, Iraq, Carbon footprint.

1. Introduction

Iraq faces increasing challenges in balancing growing energy demand with reducing carbon emissions. Despite its vast oil and gas reserves, its overreliance on these resources (more than 90% of energy production) exposes its economy to market volatility and exacerbates climate risks [1].

The importance of this study lies in its comprehensive analysis of the carbon footprint of the Iraqi energy sector across two main scopes: Scope 1 (direct emissions) and Scope 2 (indirect emissions from purchased energy), while providing effective transition strategies tailored to the unique situation of Iraq [2].

1.1. Key Challenges

1.1.1. Fuel Dependency

Oil and gas revenues finance approximately 94% of Iraq's state revenues, causing economic stagnation that hinders renewable energy investments, This vicious cycle of dependence on fossil fuels makes it difficult to allocate the resources needed to transition to more sustainable energy sources [1].

1.1.2. Infrastructure Deficits

Iraq's electricity grids suffer from ageing and limited transmission networks, hindering the integration of renewable energy sources such as solar and wind power, Renewable energy requires advanced infrastructure capable of handling the intermittent nature of these sources, something Iraq currently lacks [3].

1.1.3. Economic and Market Barriers

Current economic conditions and market structures limit foreign investment in clean energy, while fossil fuel subsidies distort market incentives for clean energy adoption, These subsidies consume vast budgets that could be directed toward developing renewable energy sources and creating more sustainable economic frameworks [4].

1.1.4. Methane Leaks

Gas flaring and leakage from oil fields release methane, a greenhouse gas 25 to 80 times more potent than carbon dioxide over short periods, Iraq ranks among the top five countries in the world for gas flaring, contributing significantly to greenhouse gas emissions [5].

2. Methodology

This study adopts a multi-method approach to analysing carbon dioxide emissions from the Iraqi power sector, combining quantitative data analysis, qualitative policy assessment, and scenario modeling, The methodology is specifically designed to address the unique context of Iraq and the particular challenges facing its power sector [6].

2.1. Data Collection

2.1.1. Primary Sources

Government Reports: Data collected from Iraqi Ministries of Oil and Electricity, including annual energy production, fuel consumption, and gas flaring volumes, Field Surveys: Limited field data from power plants in Basra and Mosul, collected in collaboration with local universities [7].

2.1.2. Secondary Sources

International Databases: Data from the International Energy Agency, the World Bank, and the International Renewable Energy Agency on Iraq's energy mix, emission factors, and regional benchmarks, Academic References: Peer-reviewed studies on energy transitions in the Middle East and the impacts of methane flaring [4].

2.2. Emissions Accounting Framework

2.2.1. Scope 1 (Direct) Emissions

We calculated direct emissions according to the methodology established in the Greenhouse Gas Protocol, with specific focus on

- Combustion CO_2 Emissions: We applied the formula (Emissions = Fuel Consumption × Emission Factor) with the following parameters:

- Oil: 800-1000 g CO_2/kWh (adjusted according to IEA standards for Iraq's aging infrastructure)

- Natural gas: 450-600 g CO_2/kWh (World Bank estimates)

- Methane Flaring: We estimated quantities using satellite data from the World Bank's Global Gas Flaring Tracker [8,9].

2.2.2. Scope 2 (Indirect) Emissions

Emissions from purchased electricity in industrial sectors were estimated using grid density data (750 g CO_2/kWh) [10].

2.3. Renewable Energy Potential Assessment

2.3.1. Solar Energy

High-Potential Areas Identification: Areas such as Anbar and Basra were identified using NASA solar radiation data (over 3,000 kWh/m²/year), Levelized Cost of Energy Analysis: Comparing the levelized cost of electricity for solar energy projects with fossil fuels [11].

2.3.2. Wind Energy

Wind Speed Data: National Oceanic and Atmospheric Administration datasets were analyzed to assess the feasibility of wind energy projects in western Iraq (average 5-7 meters/second) [12].

3. Previous Studies on Iraq's Energy Sector and Carbon Emissions

3.1. International Reports

3.1.1. World Bank (2022)

Title: Roadmap for Reducing Methane Flaring in Iraq

Key Findings:

Iraq ranks among the top five countries globally in gas flaring, emitting between 15 and 20 billion cubic meters of methane annually, Gas flaring contributes approximately 50 million tons of carbon dioxide equivalent annually, with hotspots in southern oil fields (Rumaila and West Qurna), Capturing flared gas for power generation could reduce emissions by 30% and generate between 8 and 10 gigawatts of electricity[13].

3.1.2. International Energy Agency (2023)

Title: Iraq Energy Outlook

Key Findings:

Fossil fuels (oil and gas) account for 93% of Iraq's electricity mix, with average emissions ranging from 800 to 1,000 grams of carbon dioxide per kilowatt-hour, Solar power could meet 30-40% of Iraq's daytime electricity demand by 2030 with targeted investments[14].

3.1.3. United Nations Development Programmed (2021)

Title: Renewable Energy Potential in Iraq

Key Findings:

Solar irradiance levels in southern Iraq (Basra and Anbar) range between 2,500 and 3,000 kWh/m²/year, comparable to solar power plants in Saudi Arabia, Wind speeds in western Iraq (5-7 meters per second) are suitable for decentralized wind farms[15].

3.2. Local Studies

3.2.1. Al-Maliki et al. (2020)

Title: The Carbon Footprint of the Iraqi Oil and Gas Sector

Key Findings:

Oil extraction and refining contribute 70-80% of total carbon dioxide emissions in Iraq As in Figure (1). Inefficient gas turbines and outdated infrastructure increase emissions by 20-25% compared to modern plants[6].

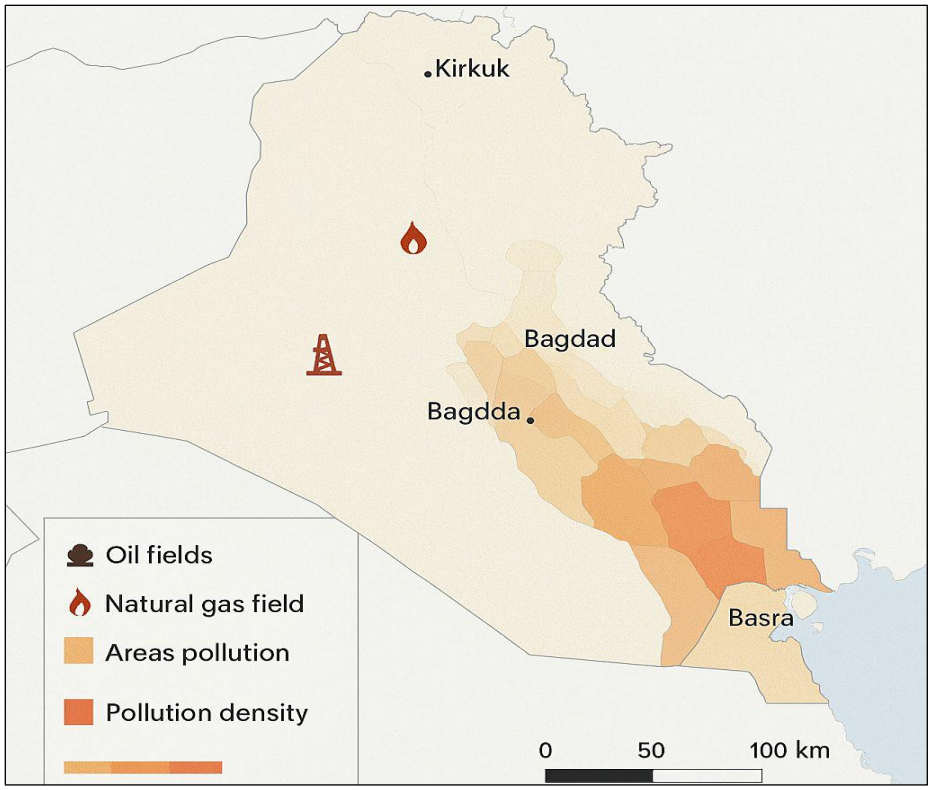

Figure 1: Distribution map of the areas with the highest fuel production and associated pollution sources in Iraq.

3.3. Regional Comparisons

3.3.1. International Renewable Energy Agency (2022)

Title: Renewable Energy Prospects in the Middle East

Key Findings:

Iraq lags behind its regional peers (such as the United Arab Emirates and Saudi Arabia) in renewable energy adoption, with solar/wind power accounting for only 3% of its energy, Regional cooperation (such as GCC grid integration) could reduce renewable energy costs in Iraq by 20-30%[14,16].

3.4. Policy Analysis

3.4.1. Iraqi Ministry of Electricity (2023)

Title: Draft Renewable Energy Strategy

Key Objectives:

Target 12 GW of solar energy by 2030 (20% of total production), Reduce gas flaring by 50% through World Bank-funded projects[17].

3.4.2. Chatham House (2021)

Title: Iraq's Energy Sector: Reform or Collapse?

Key Findings:

Fossil fuel subsidies ($8-10 billion annually) drain public funds and hinder clean energy investments, Proposed reforms include phasing out subsidies and implementing carbon pricing[18].

4. Renewable Energy Potential in Iraq

4.1. Solar Energy

Iraq possesses enormous solar energy potential, receiving approximately 3,000 hours of sunshine annually, making it among the most suitable regions for harnessing this renewable source. However, progress in this field has been slow due to lack of investment, technical challenges, and political obstacles [11].

The carbon footprint of solar energy is approximately 48 grams of CO_2/kWh, significantly lower than conventional energy sources. Nevertheless, solar energy

technologies face challenges in recycling solar panels after their lifespan, requiring sustainable disposal strategies [12].

4.2. Wind Energy

Western regions of Iraq show suitable wind speeds (5-7 meters/second) for establishing small and medium-sized wind farms. However, current generation capacity is extremely limited, indicating a significant untapped opportunity, Wind energy has a low carbon footprint of approximately (11) grams of CO_2/kWh, making it nearly carbon-neutral compared to conventional power plants[12].

5. Results and Discussion

5.1. Scenario Modeling

5.1.1. Business as Usual (BAU)

Emissions growth was projected (2023-2030) assuming continued fossil fuel dominance, Under this scenario, carbon dioxide emissions are expected to increase by 35% by 2030 (from 150 million tons annually in 2023 to 200 million tons) [1].

5.1.2. Renewable Energy Transition Scenario

This scenario assumes 30% renewable energy integration by 2030, According to modeling, this could reduce annual emissions by 25-30% (45-60 million tons of carbon dioxide), Solar-based power grids could also save between $1.2 billion and $1.8 billion annually in fuel subsidies[3].

5.2. Emission Levels by Energy Source

5.2.1. Fossil Fuel Dominance

Oil-fired power plants contributed approximately 70% of Iraq's electricity, emitting between 800 and 1,000 grams of carbon dioxide per kilowatt-hour (kWh) due to outdated combustion technologies As in Table (1), Natural gas accounted for 25% of electricity generation, with average emissions ranging between 450 and 600 grams of carbon dioxide per kilowatt-hour (kWh) [19].

Table1: Carbon dioxide emissions from the energy sector in Iraq by source [19].

Energy Source	Share of Electricity Production(%)	Emissions (g CO_2/kWh)
Crude Oil	**70%**	**800–1000**
Natural Gas	**25%**	**450–600**
Solar Energy	**3%**	**48**
Wind Energy	**2%**	**11**

5.2.2. Renewable Energy Sources

Solar and wind power contributed less than 5% of total electricity generation but showed significantly lower emissions (11–48 grams of carbon dioxide per kilowatt-hour) [1].

5.3. Methane Flaring Impact

Satellite data revealed that between 15 and 20 billion cubic meters of gas are being flared annually in Iraq as in Figure 1, releasing approximately 50 million tons of carbon dioxide equivalent (mostly methane), Gas flaring is concentrated in southern oil fields (such as Rumaila and West Qurna) [13].

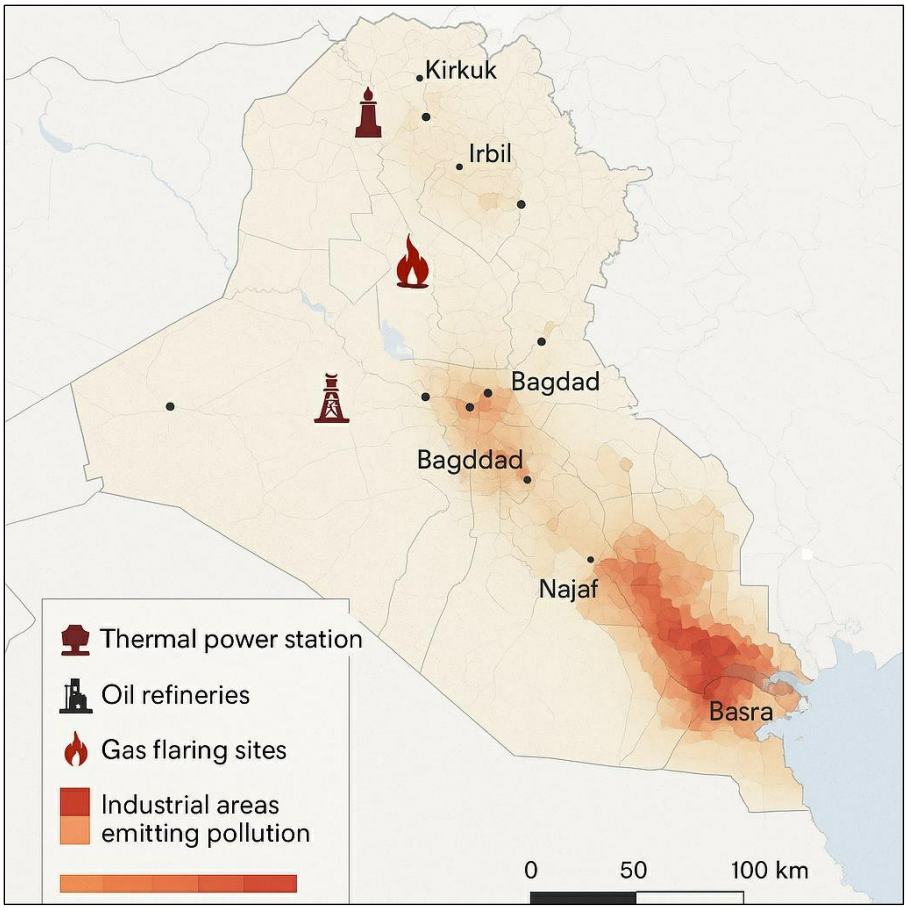

Figure 2: Shows the sources of excessive use of fuel for energy production.

5.4. Renewable Energy Potential

5.4.1. Solar Energy

Southern regions (Basra and Anbar) demonstrated solar irradiance exceeding 3,000 kWh/m²/year, sufficient to power 5 million homes through 10 GW of solar power, The levelized cost of electricity (LCOE) for solar projects ($0.03-0.05/kWh) was lower than fossil fuels ($0.08-0.12/kWh) [3].

5.4.2. Wind Energy

Western regions of Iraq (Najaf and Anbar) demonstrated average wind speeds of 5-7 m/s, suitable for small and medium-sized turbines[20].

5.5. Policy and Infrastructure Barriers

5.5.1. Subsidies

Fossil fuel subsidies total $8-10 billion annually, distorting market incentives for renewable energy [1].

5.5.2. Grid Constraints

Aging infrastructure causes transmission losses of 20-25%, hindering the integration of renewable energy sources [7].

5.5.3. Stakeholder Feedback

80% of experts cited economic and technical challenges as the primary barriers to clean energy investments[7].

5.6. Validation and Sensitivity Analysis

5.6.1. Peer Review

Results are consistent with regional studies (such as the IEA's Middle East Energy Outlook) [9].

5.6.2. Sensitivity Tests

A 10% increase in solar energy adoption resulted in an 8-12% reduction in emissions across all scenarios, Fluctuating oil prices ($50-100 per barrel) had little impact on the viability of renewable energy due to the low costs of solar energy [21].

5.7. Key Findings

1. Iraq's energy sector emits over 150 million tons of CO_2 annually, driven by inefficient fossil fuel use.

2. Solar energy offers the most viable decarbonization pathway, with 30% emission reductions achievable by 2030.

3. Methane flaring remains a critical, under-addressed issue, contributing approximately 33% of Iraq's total GHG footprint.

4. Political and financial reforms are essential to unlock $5–7 billion in renewable investments by 2030 [22].

6. Conclusions and Recommendations

6.1. Conclusions

Iraq stands at a crossroads: continued reliance on fossil fuels threatens high emissions and economic fragility, while adopting renewable energy offers a path toward energy resilience, job creation, and climate action, Prioritizing solar energy investments, modernizing infrastructure, and adopting supportive policies are urgent steps to align Iraq's energy sector with global decarbonization goals, International partnerships and financing will be pivotal to this transformation, ensuring that Iraq leverages its vast renewable energy potential to build a sustainable future.

6.2. Practical Recommendations

6.2.1. Expanding Solar Energy

Exploit desert areas (such as Anbar, Najaf, and Muthanna) to establish large-scale solar farms. Pilot projects with 50-100 MW capacity could be initiated in high solar irradiance areas, with gradual expansion to 1 GW annually.

6.2.2. Improving Efficiency

Upgrading existing plants with advanced combustion technologies could reduce emissions by 15-20% with moderate investments. Priority should be given to power plants in Basra, Baghdad, and Mosul for upgrades, given their size and impact.

6.2.3. Policy Incentives

Enacting laws to stimulate private investment in renewable energy, such as feed-in tariffs and tax exemptions for clean energy projects. Gradually reducing fossil fuel subsidies by 10% annually could free up resources to support renewable energy projects.

6.2.4. Regional Cooperation

Partnering with neighboring countries to develop smart grids and share knowledge. Joining initiatives such as the GCC Interconnection Initiative could improve grid stability and facilitate renewable energy integration.

6.2.5. Research and Development

Conducting field measurements of methane leaks and flaring volumes, and developing local emission factors for Iraqi oil and gas facilities. A national renewable energy research center could be established in collaboration with local universities and international partners to develop solutions tailored to the Iraqi context.

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