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RESEARCH ARTICLE

The Role of the Carbon Footprint in Assessing Environmental Performance in Economic Units: A Case Study of the Kufa Cement Plant

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Abstract

This paper aims to assess the environmental performance of the industrial sector, using the Kufa Cement Plant as a case study due to the tangible environmental impacts of this activity in the areas of gaseous and dust emissions, energy consumption, and waste management. It emphasizes the importance of adopting systematic assessment tools that align with sustainability frameworks and local and international regulations. This research employs a descriptive-analytical methodology, based on the theoretical framework for environmental performance assessment and the principles of environmental management, utilizing performance indicators derived from the international standard ISO 14031 to analyze the plant's operational and environmental data.

The results showed a relative improvement in indicators for controlling solid pollutants, but revealed the persistence of significant challenges related to gaseous emissions and energy intensity. The study concluded that adopting integrated environmental management systems is a pivotal factor in improving performance and mitigating environmental impacts. It recommended investing in clean technologies, strengthening monitoring mechanisms, and integrating environmental considerations into management decision-making processes to ensure improved efficiency and support industrial sustainability. This work offers a valuable practical contribution by presenting a practical model based on international standards for assessing environmental performance in heavy industries within a local context.

Keywords: Environmental impact of the cement industry, Environmental performance assessment, Environmental performance indicators, Environmental management systems (ISO 14031), Life cycle analysis (LCA)

1. Introduction

The accelerating phenomenon of climate change is one of the most prominent contemporary environmental challenges, making environmental performance assessment a central focus of the policies and strategies of economic units, particularly in high-emission industrial sectors. In this context, the carbon footprint has emerged as a key quantitative indicator for measuring and analyzing the environmental impact of production activities and determining their contribution to global warming. Environmental measurement and disclosure practices have evolved over the past decades, driven by international agreements and local legislation, to align economic objectives with environmental protection requirements. However, the true environmental costs, especially those related to carbon emissions, often remain hidden in financial reports and traditional costing systems, creating a gap between apparent financial performance and actual environmental impact. This research focuses on evaluating environmental performance through measuring carbon footprint costs, as an analytical tool that contributes to revealing the true environmental impact of a product, specifically in the cement industry. The research problem is posed as follows: Does calculating carbon footprint costs play a role in evaluating the environmental performance of economic units? The limited capacity of traditional costing systems to integrate carbon emission

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costs and directly link them to environmental performance indicators leads to inaccurate environmental assessments of economic units that fail to reflect the true burden their activities place on the climate. This deficiency not only undermines the credibility of environmental reporting but also limits the effectiveness of management decisions aimed at improving efficiency and transitioning to more sustainable operations. This underscores the urgent need for advanced accounting and costing models that fully integrate the environmental dimension into the decision-making process.

This research aims to clarify the mechanism for calculating carbon footprint costs and integrating them into the environmental performance assessment process, reflecting the relationship between product cost and its resulting environmental impact. Furthermore, the research seeks to demonstrate the role of these costs in enhancing the efficiency of environmental measurement tools and supporting management decisions aimed at improving environmental performance and achieving sustainability. This work is based on the main hypotheses: Calculating carbon footprint costs plays a role in evaluating the environmental performance of economic units. This research employs a methodology that combines both theoretical and applied aspects through the analysis of real-world data from 2021–2024. The study seeks to develop an environmental performance assessment model that economic units can use to integrate the requirements of economic efficiency with environmental sustainability.

The overall structure of this research is as follows: It begins with a review of the literature and previous studies related to environmental performance assessment, carbon footprint measurement, and associated costs, placing the research within the context of current knowledge and highlighting the gap it seeks to fill. It then addresses the research methodology, specifying the data sources used (with a focus on a case study in the cement sector), the analytical framework, and the tools employed to measure and analyze carbon footprint costs. Following this, it presents the analytical and applied research findings, discusses their implications, analyzes the data, and demonstrates the potential of the proposed model to provide more accurate insights into environmental performance and the true cost of products. Finally, the research concludes with the main findings, offers practical recommendations for administrative and economic units in the industrial sector, and suggests directions for future research in this field.

2. Literature review and hypothesis development

This section reviews the literature related to Environmental performance assessment, (Olatunji et al., 2019) aimed to assess the environmental and social impacts of cement production in Nigeria using a descriptive survey methodology and interviews. The paper emphasized the need to monitor production processes, adopt environmentally friendly practices, and raise local awareness of environmental impacts. Another study evaluated the environmental performance of 188 countries using ecological footprints, carbon footprints, and biocapacity as a comprehensive indicator (Sarkodie, 2021) s. The study identified the United States, China, India, Russia, and Germany as the main hotspots of environmental degradation. It confirmed the existence of environmental convergence across nations, meaning that differences in environmental performance between high-income and low-income countries tend to diminish over the long run. The findings also validated the scale effect hypothesis, indicating that economic growth remains associated with natural resource exploitation and environmental deterioration. The study emphasized the role of international trade in transferring carbon emissions across borders and called for global cooperation to achieve environmental sustainability. Meanwhile, (Sueyoshi & Ryu, 2021) aimed to evaluate environmental performance and sustainable development in the United States during the period 2009–2018, focusing on carbon emissions and the impact of political and geographical factors. Using Data Envelopment Analysis (DEA), the paper found a gradual improvement in environmental performance, with differences attributable to political shifts and geographical location. It recommended transitioning to clean energy to achieve net-zero emissions (Xue et al., 2022) aimed to assess the environmental performance efficiency of energy-consuming sectors in Pakistan using the Environmental Performance Index (EPI) and Data Envelopment Analysis (DEA), the work concluded that the environmental performance of these sectors did not meet the required efficiency and recommended imposing strict environmental standards and penalizing poorly performing companies. A study conducted by Ji and Wang (2021) concluded that calculating and integrating environmental lifecycle assessment indicators (such as global warming potential and acidification potential) alongside economic costs has a crucial impact on evaluating the performance and sustainability of hydrogen production methods (Ji & Wang, 2021). The results showed that less expensive conventional methods (such as steam reforming of methane) are typically the most environmentally damaging, while cleaner methods (such as renewable energy electrolysis) require higher investments but lead to better long-term sustainable environmental performance. Wang & Shittu study underscores the importance of moving beyond traditional metrics when designing environmental policies and incentives. It employed a multidimensional integrated model (GCAM-USA) to assess the effectiveness of emissions reduction policies in the United States. The paper (Wang & Shittu, 2023) offered a practical contribution by designing and analyzing various policy scenarios that combined fiscal incentives (such as tax breaks for electric vehicles) with environmental and social dimensions (such as emissions reduction and improved public health). The results demonstrated that an integrated approach combining fiscal policies with environmental objectives yields meaningful and equitable (Kumari et al., 2024) conducted a life cycle assessment (LCA) of cement production in India, covering raw material extraction, manufacturing, transportation, concrete production, and end-of-life demolition. Using a cradle-to-grave approach, the study quantified CO_2 emissions at each stage and found that the carbon emission factor for the entire cement life cycle is 0.4373 t per ton of cement. The study highlighted that carbonation during concrete's service life absorbs CO_2, partially offsetting emissions, and recommended LCA) as a critical tool for identifying hotspots and improving environmental performance in the cement industry. Augoye et al. (2024) examined the effectiveness of carbon accounting as a strategic tool for reducing corporate carbon footprints through a mixed-methods approach (Augoye et al., 2024). The findings indicate that carbon accounting significantly improves emissions of transparency and, particularly for Scope 1 and 2 emissions, when integrated with robust environmental management systems. However, challenges remain in accurately measuring Scope 3 emissions and achieving industry-wide standardization. The study concludes that carbon accounting is most effective when combined with science-based targets, internal carbon pricing, and emerging digital technologies like blockchain. Carbon pricing mechanisms and life cycle assessment (LCA) to accurately measure emissions and integrate carbon costs into environmental and financial performance assessments. With this objective, the current study fills a significant gap in accounting and environmental literature by presenting an integrated accounting model that measures environmental impact through direct costs and supports sustainable economic decision-makings have discussed environmental performance assessment in economic units, most have focused on evaluating performance through general environmental indicators and using tools such as the Sustainable Balanced Scorecard or quantitative data analysis, analyzing environmental and social impacts separately from accounting costs. The current study is distinguished by its focus on integrating carbon footprint costs into traditional product costs, rather than treating them as period costs. Furthermore, its practical application to the Iraqi General Cement Company lends the research an applied dimension. The paper utilizes carbon pricing mechanisms and life cycle assessment (LCA) to accurately measure emissions and integrate carbon costs into environmental and financial performance assessments. The paper focused on analyzing the sources of carbon dioxide emissions across different production stages, using standard computational methodologies (such as IPCC and WBCSD/CSI). It also conducted a comprehensive review of the latest mitigation technologies, including raw material substitution, clean fuels, carbon capture and storage (CCS), and the development of new high-performance cements. The results highlighted the technical and economic challenges facing the transition to low-carbon cement production, such as high costs. The paper (Liu, 2025) concluded that achieving deep emissions reductions requires a multidimensional approach that combines improving energy efficiency, fuel substitution, reducing clinker content, and supporting CCS technologies. It also recommended a pivotal role for supportive policies and market mechanisms, such as emissions trading systems, to incentivize the green transformation of this emissions-intensive industry. The paper (Bouchouit & Elhamma, 2025) economic units to improve environmental performance and maintain economic efficiency. The paper highlighted two main challenges: first, measuring indirect emissions (Category III), and second, the lack of standardized methodologies for measurement and disclosure. The paper by (Darmayanti et al., 2025) showed that Carbon emission disclosure significantly affects unit economic value, Environmental performance significantly affects economic value, and Profitability significantly affects economic value. The paper also confirmed that media coverage enhances the relationship between carbon disclosure and unit value. However, it did not demonstrate that rage moderates the relationship between environmental performance and unit value. Nor did it demonstrate that media coverage moderates the relationship between profitability and unit value (Göös, 2025). The total carbon footprint was 4,492 tCO_2eq, with 99.9% of emissions falling under Scope 3. Travel to domestic competitions was the largest contributor at 94.5% of total emissions. The study provides a practical model for evaluating organizational environmental performance through carbon footprint analysis and offers benchmark KPIs. A key limitation was the reliance on estimations for travel distances and modal shares in life cycle assessment (LCA) to accurately measure emissions and integrate carbon costs into environmental and financial performance assessments. The current study is distinguished by its focus on integrating carbon footprint costs into traditional product costs, rather than treating them as period costs. Furthermore, its practical application to the Iraqi General Cement Company lends the research an applied dimension. The paper utilizes carbon pricing mechanisms and life cycle assessment (LCA) to accurately measure emissions and integrate carbon costs into environmental and financial performance assessments.

2.1. Similarities and differences between the current study and previous studies

Despite the diversity of previous studies addressing environmental performance evaluation in the industrial sector, most have been characterized by a descriptive, narrative methodology that focuses on presenting results without in-depth critical analysis of their points of agreement and disagreement. In this context, the current study stands out with several distinctive characteristics, while also sharing essential commonalities.

2.2. Similarities between the current study and previous studies

The current study aligns with previous research on several key points, which can be summarized as follows:

First, the current study shares with Olatunji et al. (2019) and Kumari et al. (2024) a focus on the cement industry as one of the most carbon-intensive sectors, reflecting shared research understanding of the sector's importance in addressing climate change challenges. Second, the current study agrees with Ji and Wang (2021), Kumari et al. (2024), and Liu (2025) in adopting lifecycle analysis (LCA) as a primary tool for identifying the most polluting production stages, particularly clinker burning. This reinforces the importance of LCA as a standard tool for assessing carbon footprints. Third, the results of the current study are consistent with those of Darmayanti et al. (2025), which found a significant relationship between environmental performance and the economic value of an economic unit, thus supporting the idea of integrating environmental and financial dimensions in evaluation processes. Fourth, the current study aligns with Bouchouit and Elhamma (2025) and Augoye et al. (2024) in identifying common challenges related to measuring indirect emissions (Scope 3), as well as the lack of standardized methodologies for measuring and accounting for carbon.

3. Methodology

This paper adopted a descriptive-analytical approach, combining theoretical foundations with applied data analysis to assess environmental performance by incorporating carbon footprint costs. The research design is detailed in the following sections.

3.1. Research problem

The research problem lies in the inability of traditional costing systems in Iraqi economic units to measure and integrate carbon footprint costs within product costs, thus limiting the accuracy of environmental performance assessment. This study asks: Can these costs be measured and integrated, and what role do they play in environmental performance evaluation?

3.2. Importance of the research

Its importance lies in the following:

- Supporting sustainable development strategies in Iraq.
- Reducing environmental fees and operating costs.
- Improving operational efficiency and identifying sources of waste.
- Moving towards smart and sustainable production systems.

3.3. Research objectives

- To measure carbon footprint costs as part of product cost, rather than period costs.
- To implement a system for measuring these costs to achieve future economic benefits.
- To study the role of these costs in evaluating environmental performance.

3.4. Research hypothesis

Including carbon footprint costs within the product cost improves environmental performance assessment.

3.5. Data collection

This research employed a descriptive-analytical approach and a case study methodology, utilizing the accounting records of the Kufa Cement Plant for the years 2021–2024. These records included detailed

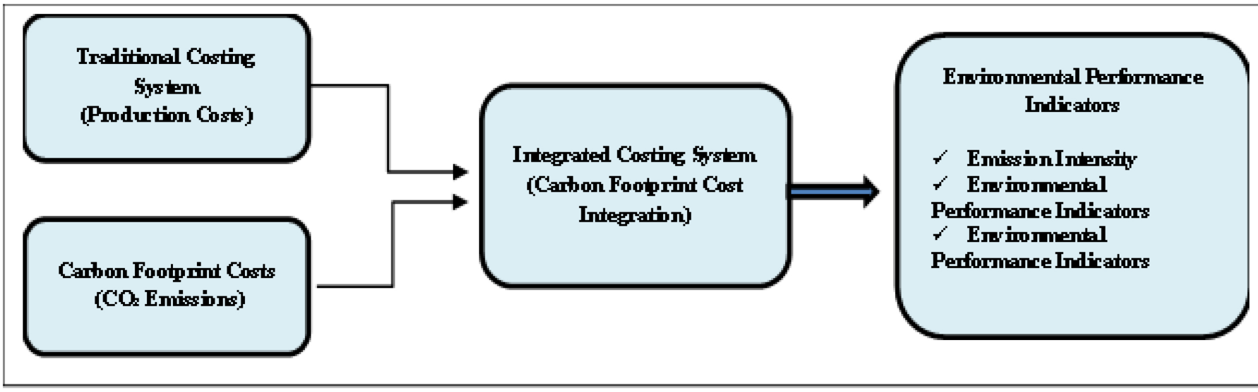

Fig. 1. Figure of the study model of integrating carbon footprint costs into environmental performance assessment.

Source: Prepared by the researchers.

quantitative data on raw material consumption (limestone, clay, gypsum, etc.), fuel usage (heavy fuel oil and natural gas), electricity consumption, and corresponding production. This data was obtained from the plant's official reports, internal accounting documents, and environmental monitoring records. The period 2021–2022 represents the baseline period using heavy fuel oil, while the period 2023–2024 reflects the operational phase following the partial switch to natural gas, thus enabling a comparative analysis of environmental performance.

3.6. Measurement of variables

The key variables were measured quantitatively to ensure an objective assessment. Environmental performance was determined by indicators based on the carbon footprint. The carbon footprint cost was calculated by determining the total CO_2 emissions during the cement production cycle (raw material extraction, grinding, clinker burning, and final grinding) using standardized emission factors and activity data. This total was then converted into a monetary value by applying a hypothetical carbon price per ton of CO_2 (US$46 for 2021–22 and US$65 for 2023–24, based on global carbon market trends). Key performance indicators included:

- Emission intensity: Total CO_2 emissions (tones)/Total cement production (tons).
- Carbon cost per unit: Total carbon cost (US$)/Total cement production (tons).
- Energy efficiency: Energy consumed (kWh or liters of fuel)/Total cement production (tons).

3.7. Scope of the research

Spatial Scope: Iraqi General Company for Cement Industry/Kufa Cement Plant.

Temporal Scope: Data for the years 2022, 2023, and 2024.

Corona footprint cost analysis of sulfate-resistant cement (Al-Asad brand).

3.8. Research model

Fig. 1 summarizes the analytical framework of the paper, illustrating the integration of carbon footprint costs into a comprehensive performance evaluation system.

This model represents the relationship between traditional costing systems and carbon footprint costs as key inputs, integrating them into a comprehensive costing system that incorporates the cost of carbon emissions into the product cost. This integration contributes to improved environmental performance indicators, particularly emissions intensity, carbon cost per unit produced, and energy efficiency, thereby supporting more accurate environmental assessments and sustainable management decisions.

3.9. The concept of environmental performance assessment

Performance evaluation "A broad and multi-functional process that combines key performance indicators to help assess business performance, ensuring continuity of management processes, value creation, adaptability and rapid response, and helping the company improve and grow" (Narkunienė & Ulbinaitė, 2018).

Methods for evaluating the performance of an economic unit are classified into two main types:

First: Traditional: Relies on historical financial indicators (profitability, liquidity) and is criticized for its backward-looking nature and unsuitability for the dynamic environment.

Second: Modern: Combines financial and non-financial indicators (customer satisfaction, operational efficiency, innovation) to achieve a holistic view. Among the most prominent modern models are:

- Economic Value Added (EVA): Focuses on creating value for shareholders.
- Balanced Scorecard (BSC): Links strategy to four pillars (finance, customers, internal processes, and learning and growth).
- Performance Prism: Integrates the role of stakeholders.
- Six Sigma: Focuses on improving quality and reducing defects.
- Multi-Criteria Management (MCDM): Combines several indicators into a single composite indicator and is characterized by its flexibility.

Based on the above, the researcher believes that there is no single ideal system. Instead, the choice depends on the nature of the activity and the evaluation of objectives. The researcher recommends using modern, integrated systems to obtain more accurate results.

Environmental performance is defined as a measure of environmental impact, resource consumption, and related financial elements, along with efforts to reduce this impact and implement preventive measures. It is a multi-dimensional concept that reflects the integration of operational and administrative performance in environmental management. It is defined as a systematic and continuous management process to provide reliable and verifiable information that enables the economic unit to measure, analyze, and monitor its environmental performance against predefined criteria, using a set of quantitative and qualitative indicators, with the aim of supporting decision-making, achieving continuous improvement, and participating in achieving sustainability goals (Arezina, 2024). It is a vital tool for measuring the sustainability of economic activities, reflecting their environmental impact, and providing insights into a country's capacity to absorb the environmental consequences of business activities. Consequently, it highlights the environmental constraints that must be respected and serves as a benchmark guiding the relationship between commercial competitiveness and sustainable energy practices (Noman et al., 2024). Environmental performance assessment is defined as a systematic process aimed at measuring and evaluating the environmental performance of organizations or activities through a set of indicators that reflect the efficiency of resource use, emission and pollution levels, and adherence to environmental requirements, thereby supporting environmental decision-making and improving sustainability(Asadnabizadeh & Moe, 2024). The definition of Arezina (2024) was adopted because of the following:

- aligns with the unit of analysis (the plant).
- Aligns with my methodology (LCA + carbon costs).
- supports my objectives (decision support, continuous improvement, and sustainability).
- provides a comprehensive theoretical framework that allows me to link the accounting and environmental dimensions.

However, I will utilize the definition of Asadnabizadeh and Moe (2024) in the section related to identifying quantitative indicators (emission intensity, energy efficiency, and cost per unit). I will only use the concept of "carrying capacity" from the definition of Noman et al. (2024) when discussing the research's national environmental impacts in the conclusion and recommendations section.

3.10. Objectives of environmental performance assessment

Sustainable environmental performance assessment is a key strategic tool for enhancing the effectiveness of economic units and achieving their objectives. Therefore, performance assessment has important aspects, including (Anis, 2020):

- Improving operational efficiency: measuring the extent to which environmental objectives are achieved and taking the necessary corrective actions.
- Enhancing sustainable competitiveness: by focusing on continuous improvement and achieving a competitive advantage based on environmental performance.
- Achieving comprehensive sustainability: by integrating and improving environmental and social performance with financial performance.
- Supporting monitoring and control processes: as a fundamental pillar of administrative and environmental control systems.
- Diagnosing problems and identifying strengths and weaknesses, which contribute to improving performance and correcting courses.
- Providing the necessary information for strategic decision-making: whether related to development, investment, or the introduction of fundamental changes.
- Providing essential data for planning: at the operational and strategic levels.

Table 1. Quantity of (raw materials, fuel, electrical energy) used in 2021, 2022.

	Quantity (Tons)		Fuel Consumed (Liters)		Electricity Consumed (kWh)	
Item Name	2021	2022	2021	2022	2021	2022
Limestone	884,096	885,227	_	_	_	_
Clay Soil	162,668	175,639	_	_	_	_
Iron Ore	31,177	35,949	_	_	_	_
Screened Sand	65,216	71,670	_	_	_	_
Gypsum	20,122	26,878	_	_	_	_
Total	1,163,279	1,197,363	102,688,126	9,742,697	6,372,081	6,947,000

Source: Prepared by the researchers.

- Supporting the formulation of public policies: at the level of the economic unit or at the national level, which promotes a focus on sustainability.

4. Results

4.1. Calculating the carbon footprint of the cement production life cycle at the kufa cement plant

The researchers adopted the principle of Life Cycle Analysis (LCA), where carbon emissions are measured for each stage separately to identify the most emitting stages in the production chain. These stages include the extraction and transportation of raw materials, processing and mixing operations, kiln burning (the largest source of emissions), grinding, and final packaging. The calculation will be performed as follows:

4.1.1. Calculating the carbon emissions for 2021 and 2022

Table 1 provides an analysis of the material and energy inputs required for the production process at the Kufa Cement Plant for the years 2021 and 2022.

The researchers note that the significant difference between the amount of fuel used in 2021 and 2022 is due to the gradual shift from liquid oil to gas.

4.1.1.1. Phase One: Extraction and Transportation of Raw Materials

Table 2 shows the estimated carbon dioxide (CO_2) emissions in tons for the Kufa Cement Plant during the years 2021 and 2022.

A significant decrease in total emissions is observed in 2022, the main reason for which is the sharp decline in auxiliary equipment fuel emissions, indicating a shift in energy source or a significant improvement in efficiency.

Table 2. Carbon emissions for the extraction and transportation of raw materials for 2021 and 2022.

	Emissions (CO_2) (tons)	
Item	2021	2022
Transportation Emissions (22 km)	92	95
Equipment Electricity	574	625
Auxiliary Equipment Fuel	6,528	619
Total	7,194	1,339

Source: Prepared by the researchers.

4.1.1.2. Phase Two: Crushing and grinding raw materials

Table 3 shows the estimated carbon emissions in tons during the crushing and grinding stage of raw materials, which is the second stage in the production process, during the years 2021 and 2022.

The overall results show a significant decrease in the carbon footprint of this stage in 2022 compared to the previous year, due to the sharp decrease in the value of emissions from the drying process.

4.1.1.3. Phase Three: Burning and clinker formation (main stage)

Table 4 provides an analysis of carbon dioxide emissions during the third and most crucial stages of the production process: combustion and clinker formation. This stage is the largest contributor to the plant's overall carbon footprint.

Table 4 shows a significant environmental improvement during the burning and clinker formation stage, with carbon emissions decreasing from 768,938 tons in 2021 to 549,969 tons in 2022, a reduction of 28.5%.

This decrease is primarily attributed to a substantial reduction in emissions from the main kiln fuel, which fell by 90.5%, indicating a fundamental shift in the energy system (such as fuel replacement or efficiency improvements).

It is noteworthy that this improvement occurred despite continued or even increased production activity, as evidenced by the slight increases in calcination (2.9%) and electricity (9%) emissions. This confirms that the reduction stems from a genuine improvement in efficiency, not a decrease in production.

4.1.1.4. Phase Four: Clinker grinding and cement production

Table 5 shows the carbon emissions during the final stage of the production process, namely the clinker grinding and cement production stage. In this stage, the clinker is ground with the required additives to produce the final cement product, which is then

Table 3. Carbon emissions for the crushing and grinding stage of materials for 2021, 2022.

	Emissions (CO_2) (tons)	
Item	2021	2022
Electricity from crushers and mills	2,868	3,126
Drying process emissions (9% of furnace fuel emissions)	25,544	2,423
Total	28,412	5,549

Source: Prepared by the researchers.

Table 4. Carbon emissions for the furnace stage for 2021, 2022.

	Emissions (CO_2) (tons)	
Item	2021	2022
Emissions from the calcination process of raw materials	508,934	523,596
Emissions from the main furnace fuel	258,283	24,497
Electricity from the furnace and fans (30% of total electricity)	1,721	1,876
Total	768,938	549,969

Source: Prepared by the researchers.

Table 5. Carbon emissions for the cement grinding and production stage for 2021 and 2022.

	Emissions (CO_2) (tons)	
Item	2021	2022
Electricity in cement mills	574	625
Emissions during filling and loading of the final product	1,254	8,034
Total	1,828	8,659

Source: Prepared by the researchers.

Table 6. Total carbon emissions for cement manufacturing production stages in 2021 and 2022 at the Kufa Cement Plant.

	2021		2022	
Stage	CO_2 emission quantity (tons)	Ratio	CO_2 emission quantity (tons)	ratio
Extraction and Transportation	7,194	0.89%	1,339	0.2%
Crushing and Grinding (Raw Materials)	28,412	3.52%	5,549	1%
Burning and Clinker Formation (Kilns)	768,938	95.36%	551,776	97.3%
Final Grinding and Packaging	1,828	0.23%	8,659	1.5%
Total	806,372	00%1	567,323	00%1

Source: Prepared by the researchers.

packaged and loaded for distribution. The table reflects the environmental impact of two main activities: first, electricity consumption in the cement mills, and second, the packaging and shipping of the final product.

Environmental degradation in the final stage (final grinding and packaging) negates part of the significant gains achieved in previous production stages (especially the kiln stage), confirming that genuine environmental improvement requires a comprehensive approach that includes all production processes, including logistical processes, and not just industrial processes.

Table 6 provides an analysis of the main sources of emissions during the cement production process, and the relative share of each source in the total carbon footprint, highlighting the areas that have the most impact on the environment, and working to address them in the future.

Total carbon emissions for the years (2021–2022) 806,372 + 567,323 = 1,373,695 tons of CO_2

To calculate the carbon footprint per ton of sulfate-resistant cement produced in 2021 and 2022 at the Kufa Cement Plant, we apply the following equation:

CF per ton of sulfate-resistant cement = Total CO_2 emissions ÷ Quantity of cement produced

$$= 1,373,695\ tons \div 1,389,360.1\ tons$$

$$= 0.99\ tons\ of\ CO_2$$

$$Carbon\ price = Total\ emissions \times Price\ per\ ton\ of\ CO_2$$

$$= 1,373,695 * 46\$$$

$$= 63,189,970$$

A carbon price of $65 was adopted according to the EU Carbon Permits prices reported by Trading Economics (2026).

Table 7. Quantity of (raw materials, fuel, electrical energy) used in 2023, 2024.

	Quantity (Tons)		Fuel Consumed (Liters)		Electricity Consumed (kWh)	
Item Name	2023	2024	2023	2024	2023	2024
Limestone	993,629	948,033	_	_	_	_
Clay Soil	223,561	208,047	_	_	_	_
Iron Ore	39,2145	38,239	_	_	_	_
Screened Sand	44,419	34,574	_	_	_	_
Gypsum	44,753	37,993	_	_	_	_
Total	1,345,577	1,266,886	1,684,784	1,684,784	5,014,791	2,894,854

Source: Prepared by the researchers.

4.1.2. Calculating carbon emissions for 2023 and 2024

Table 7 provides the basic data needed to calculate the carbon footprint for 2023 and 2024, showing the quantities of the main inputs consumed in the production process.

Data indicates a significant improvement in operational efficiency in 2024, particularly in electricity conservation, while maintaining fuel efficiency. This could positively impact the intensity of carbon emissions (emissions per ton of production) when calculating the final carbon footprint**.**

4.1.2.1. Phase One: Extraction and Transportation of Raw Materials

Table 8 presents an analysis of carbon emissions in the first stage of the cement production cycle, namely the extraction and transportation of raw materials. The figures show a comparison between 2023 and 2024, focusing on three main sources of emissions: emissions resulting from transporting materials over 22 km, electricity consumption for operating extraction equipment, and fuel consumption for auxiliary equipment.

In 2023, total emissions from the extraction and transportation phase amounted to 665 tons. However, in 2024, we witnessed a significant improvement, with emissions dropping to just 468 tons. This improvement resulted from clear progress across all areas: a slight decrease in transportation emissions, a substantial 42% improvement in electricity efficiency, and an exceptional 83% reduction in equipment fuel consumption.

4.1.2.2. Phase Two: Crushing and grinding raw materials

Table 9 shows the estimated carbon emissions in tons during the crushing and grinding stage of raw materials, which is the second stage in the production process, during the years 2023 and 2024.

Table 8. Carbon emissions for the extraction and transportation of raw materials for 2023 and 2024.

Item	2023	2024
Transportation Emissions (22 km)	107	100.34
Equipment Electricity	451	260.54
Auxiliary Equipment Fuel	619	107.11
Total	665	468.00

Source: Prepared by the researchers.

The crushing and grinding stage showed a marked improvement in operational and environmental efficiency in 2024, primarily reflected in reduced electricity consumption. This trend aligns with the overall improvement in plant-wide electricity efficiency, as reported in the baseline consumption data (Table 7).

4.1.2.3. Phase Three: Burning and clinker formation (main stage)

Table 10 shows the estimated carbon emissions during the most influential stage in the production process, which is the burning of materials and formation of clinker, during the years 2023 and 2024.

The most polluting phase saw marginal improvement in 2024, with the biggest challenge (chemical emissions from calcification) remaining high without radical improvement, and no new progress was recorded on the fuel side after the previous massive improvement.

4.1.2.4. Phase Four: Clinker grinding and cement production

Table 11 shows the carbon emissions in the final stage of the manufacturing cycle, which is clinker grinding and cement production**.**

The table shows near-complete stability in total emissions, with a marginal decrease from 8,485 tons to 8,461 tons in 2024. However, this stability masks a significant internal shift: Electricity emissions decreased by 42%. Packaging and shipping emissions increased by 2% to 8,200 tons, meaning they now account for 97% of total emissions for this phase. Logistics operations remain the biggest environmental challenge, as the increase in their emissions has offset a significant improvement in energy efficiency.

Table 12 provides an analysis of the main sources of emissions during the cement production process, and the relative share of each source, highlighting the areas that have the greatest impact on the environment, and working to address them in the future.

Table 9. Carbon emissions for the crushing and grinding stage of materials for 2023, 2024.

	Emissions (CO_2) (tons)	
Item	2023	2023
Electricity from crushers and mills	2,257	1,303
Drying process emissions (9% of furnace fuel emissions)	419	419
Total	2,676	1,722

Source: Prepared by the researchers.

Table 10. Carbon emissions for the furnace stage for 2023, 2024.

	Emissions (CO_2) (tons)	
Item	2023	2024
Emissions from the calcination process of raw materials	588,690	554,262
Emissions from the main furnace fuel	4,238	4,238
Electricity from the furnace and fans (30% of total electricity)	1,354	782
Total	594,282	559,282

Source: Prepared by the researchers.

Table 11. Carbon emissions for the cement grinding and production stage for 2023 and 2024.

	Emissions (CO_2) (tons)	
Item	2023	2024
Electricity in cement mills	451	261
Emissions during filling and loading of the final product	8,034	8200
Total	8,485	8,461

Source: Prepared by the researchers.

Table 12. Total carbon emissions for cement manufacturing production stages in 2023 and 2024 at the Kufa Cement Plant.

	2023		2024	
Stage	CO_2 emission quantity (tons)	ratio	CO_2 emission quantity (tons)	ratio
Extraction and Transportation	665	0.11%	468	0.08%
Crushing and Grinding (Raw Materials)	2,276	0.38%	1,722	0.30%
Burning and Clinker Formation (Kilns)	594,282	99.51%	559,282	98.13%
Final Grinding and Packaging	8,485	1.42%	8,461	1.48%
Total	605,708	00%1	569,932	00%1

Source: Prepared by the researchers.

$$Total\ carbon\ emissions\ for\ the\ years\ (2023-2024)$$

$$605,708.13 + 569,931.96 = 1,175,640\ tons\ of\ CO_2$$

To calculate the carbon footprint per ton of sulfate-resistant cement produced in the years (2023, 2024) at the Kufa Cement Plant, we apply the following equation:

$$CFP\ per\ ton\ of\ cement = Total\ CO_2\ emissions \div Quantity\ of\ cement\ produced$$

$$= 1,175,640\ tons \div 1,512,209.6\ tons$$

$$= 0.78\ tons\ CO-eq$$

$$Carbon\ price = Total\ emissions \times Price\ per\ ton\ of\ CO_2$$

$$= 1,175,640 \times 65\$$$

$$= 76,416,600\ \$$$

*A carbon price of $65 was adopted according to the EU Carbon Permits prices reported by Trading Economics (2026).

4.2. Carbon cost allocation using the ABC system for the kufa cement plant (2021–2024)

4.2.1. Basic steps for implementing ABC

To enhance the accuracy of environmental performance assessment, carbon costs were allocated to products using the Activity-Based Costing (ABC) system. Four emission-generating activities were identified: calcination (kiln), fuel combustion (kiln), electricity consumption (mills and crushers), and material transportation. Cost drivers were defined as tons of raw materials, liters of fuel, kWh of electricity, and

Table 13. Distribution of Carbon Costs by Main Activities (Using ABC).

Activity	Cost Driver	Contribution to Total Emissions (%)
Kiln Fuel Combustion	Liters of fuel/Operating hours	∼33%
Calcination Emissions (Chemical Reaction)	Tons of raw materials	∼66%
Mills & Crushers Operation	kWh (Kilowatt-hour)	∼0.5%
Transportation & Auxiliary Equipment	Liters of diesel/km	∼0.5%

Source: Prepared by the researchers.

liters of diesel, respectively. The analysis revealed that calcination and fuel combustion together accounted for approximately 99% of total carbon costs, while electricity and transportation contributed only 1%. This distribution enables more equitable product pricing and identifies priority areas for emission reduction investments.

From Table 13, we observe the following:

- Most impactful activities: Calcination and furnace fuel emissions together account for 99% of total carbon costs, thus prioritizing investment in emissions reduction.
- Higher costs despite lower emissions: In 2023-2024, despite a 14.4% decrease in emissions, carbon costs increased by 7.8% due to a rise in the global carbon price from $63 to $79.5/ton.
- At least costly activities: Mill operation and transportation account for only 1% of total costs, but improving them remains crucial for overall efficiency.
- Applying ABC: This allocation allows each activity to be charged at its actual cost, supporting fair pricing decisions and prioritizing environmental improvement.

5. Discussion

A comparative analysis of the two times revealed a significant decrease in total carbon emissions. Total carbon dioxide emissions amounted to 1,373,695 tons for the period (2021–2022); it decreased to 1,175,640 tons for the period (2023–2024), a decrease of 14.4%. The main reason for these decreases is attributed to the gradual shift from the use of liquid fuel (heavy fuel oil) to gas, which has led to a significant improvement in combustion efficiency and a reduction in emissions. In addition to the improvement in emissions intensity per ton of cement, the carbon footprint was 0.99 tons of CO_2/ton of cement for the period (2021–2022) and decreased to 0.78 tons of CO_2/ton of cement for the period (2023–2024), a decrease of 21.2%. Despite the increase in production, specific emissions decreased thanks to process improvements and the use of cleaner fuels. The distribution of emissions across the production stages was as follows: the kiln stage (combustion and clinker formation) remained the largest contributor to emissions (over 95% in both periods), but it saw a significant decrease in absolute emissions for the other stages (transport, crushing, final grinding) and recorded varying reductions, especially in the transport and grinding periods. Fuel and electricity consumption decreased significantly after the switch to gas, with reductions observed in most phases, reflecting improvements in energy efficiency. Despite the decrease in emissions, the cost increased due to the higher assumed price of carbon, highlighting the importance of continued emissions reductions to mitigate future financial burdens. The carbon cost for the period 2021–2022 was approximately $63.2 million (assuming a price of $46/ton), and for the period 2023–2024 it was approximately $76.4 million (assuming a price of $65/ton). These are positive indicators of environmental transformation and the factory's success in reducing emissions despite increased production. The application of an accounting model that integrates carbon footprint costs into performance evaluation has led to improved operational efficiency and supported operational sustainability.

6. Conclusion

This research provides important evidence on the impact of integrating carbon footprint costs into environmental performance assessments in the cement industry. However, it is important to recognize some limitations of this work, such as its focus on a single cement plant (the research sample) and its reliance on secondary data, which may limit the generalizability of the findings. Addressing these limitations is a priority for future research. Specifically, future studies should explore the applicability of the proposed integrated costing model across different industrial sectors, as this is essential for a broader understanding of the field and will help develop solutions that are more effective. Expanding this work will enable researchers to fill existing gaps and ensure the findings can be more widely applied in practical applications. The Kufa Cement Plant also demonstrated a clear environmental improvement between the two periods, particularly in reducing carbon emissions and improving the environmental efficiency of production. This reflects the effectiveness of the transition to cleaner fuels and process improvements and supports the plant's ability to adapt to local and international environmental requirements and enhance its long-term sustainability.

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Authors' declaration

- Conflict of Interest: None.
- We hereby confirm that all figures and tables in the manuscript are our own.
- Ethical Clearance: The project was approved by the local ethical committee at University of Baghdad.
- There are no animal studies in the manuscript.
- There are no human studies in the manuscript.

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Authors' contribution statement

Muna Mohammed Murad: Conceived and designed the analysis, Collected the data, Contributed data or analysis tools, Performed the analysis, Wrote the paper.

Bahaa Hussein Mohammed: Conceived and designed the analysis, Performed the analysis.

Data availability statement

The datasets analyzed during the current study are not publicly available due to confidentiality agreements with the Kufa Cement Plant. However, they are available from the corresponding author upon reasonable request and with the explicit permission of the plant management.

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