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Carbon Footprint Evaluation of a Ready-Mixed Concrete Plant

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ABSTRACT

Rapid population growth and the vital needs of people are increasing day by day. One of these needs is nutrition, clothing, and shelter. As the housing needs of people increase, the construction and building sector is progressing in parallel with technological developments. Innovations related to the production of ready-mixed concrete and cement, which are indispensable building elements of the construction sector, make human life easier. These sectors should be evaluated in terms of greenhouse gas emissions and sustainable environment. Identifying, calculating, and reporting data in these sectors for carbon footprint calculation contribute to environmental issues and development for consumers and organizations. In this study, the carbon footprint of a ready-mixed concrete plant is calculated, and its environmental impacts and suggestions for reducing carbon emissions are given. It was found that the total carbon emission caused by consumption amounts was 1 038 396 tons of carbon dioxide equivalent. According to the results obtained in the carbon footprint in the greenhouse gas calculation, 98.383% of the total emission (1 021 604 tons of carbon dioxide equivalent) is carbon dioxide emission, 0.149% (1551 tons of carbon dioxide equivalent) is methane emission, and 1.468% (15 242 tons of carbon dioxide equivalent) is diazot monoxide emission.

Keywords: Cement, ready-mixed concrete plant, carbon footprint, life cycle

INTRODUCTION

With the advancement of age, climate changes and population growth are increasing day by day and bringing along many environmental problems. In this sense, the most important environmental problems are resource scarcity, increasing amounts of greenhouse gases (GHGs), rising temperature, climate changes, natural disasters, and disruption of ecological balance.[1,2] The consumption of fossil fuels with the industrial revolution has led to a rapid increase in GHG emissions in the atmosphere, with carbon dioxide (CO_2) levels reaching dangerous levels.[1,3,4] Global warming and environmental pollution are caused by production, manufacturing, all kinds of industrial activities, agriculture, transportation, construction, the construction sector, mining, energy production and use, and human activities.[1,4] Today, the construction sector ranks first among the sectors monitored to meet the needs of the growing population and the needs it brings with it in order to achieve a sustainable beneficial economy, and at the same time, it ranks second after transportation in terms of the total GHG emissions it generates.[5,6] When carbon emissions and resource use in the construction sector are evaluated together, energy consumption, especially during the production of building materials, accounts for 20% of the amount consumed during the production of buildings and construction structures. This is very significant in terms of GHGs.[7-9] Such emissions are also caused by the carbon content of additives, auxiliaries, and building materials used in the construction industry, and it has been emphasized that recycling and switching to environmentally friendly additives will reduce these emissions.[9,10] Concrete, ready-mixed concrete, and cement, which have a large share in the construction sector, are materials with a high global carbon footprint due to their high carbon content and are the most widely used building materials in this field.[10,11] As environmental awareness increases, the materials used in the construction sector play an important role in the choice of environmentally sensitive materials, and while these materials are diversified in parallel with the development of technology due to energy and material costs, recycling methods are applied (6%) and the use of alternative additives is becoming widespread.[12,13] Properties such as durability, applicability, and versatility play an important role in the selection of materials used in the construction industry. On the other hand, low CO_2 emissions is a new parameter that plays a role in the selection of materials used, and new methods to reduce them have been investigated in recent years.[14]

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READY-MIXED CONCRETE AND CEMENT INDUSTRY

As a requirement of rapid population growth, industrialization and urban life, modern urban structures, buildings, roads, bridges, infrastructure systems, water and wastewater systems are made of concrete, ready mixed concrete and cement-based concrete.[12,15] Cement and concrete are preferred as construction and building materials due to their durability, ease, and wide range of availability. According to the 2019 data, the amount of carbon emissions from power, energy, and fossil fuels used in these production processes and in the transfer transportation phase is considerable and accounts for approximately 10% of global emissions. It is environmentally important to take measures to reduce these impacts. These measures include turning to alternative building materials and auxiliary elements, producing environmentally friendly materials, developing technologies to minimize environmental risks, promoting recycling, and developing building materials for a sustainable environment.[12]

The production of concrete, which is widely used in the construction sector with global growth and population increase, is over 3.8 tons per person per year in the world; concrete has an important value in carbon footprint assessment due to its high CO_2 emissions during the manufacturing and supply process. For this reason, its environmental impacts are taken into account and controlled in developed countries, especially in European countries.[16,17] In 2021, the number of companies in the sector increased by 11% and the number of facilities increased by 7% in Türkiye compared to the previous year. While the number of ready-mixed concrete companies in Türkiye was 25 and the number of facilities was 30 in 1988, these values increased to 450 and 900 in 2019. And with an increase, the number of ready-mixed concrete companies reached 600 and the number of facilities reached 1106 in 2022.[18] Table 1 shows the amount of ready-mixed concrete production in the world and Türkiye. Policies and action plans should be developed on a global scale to reduce the production of concrete, ready-mixed concrete, and cement to meet the needs of the age.

In the modern era, CO_2 emissions from the production and shipment of cement, the most widely used building material and a critical component of both concrete and mortar, account for approximately 2.4% of global emissions. In the process of clinker production in limestone quarries or other raw carbonate mineral sources, which are the main building blocks of cement production, calcium carbonate ($CaCO_3$) is calcined into quicklime (CaO), the main component of cement, during which the largest carbon emission occurs as a result of the combustion of fossil fuels.[15,19] More than 4 billion tons of Portland cement are produced in the world annually, depending on the demand.[20-24] In developing countries like Türkiye, this need is increasing day by day, leading to an increase in the accumulation of GHGs.

Table 1. Ready-Mixed Concrete Production in the World and in Türkiye

	2020	2021	2021	2021	2021
Austria	11.5	12.8	255	50.2	1.4
Belgium	12.4	14.0	235	59.6	1.2
Denmark	2.8	3.1	96	32.3	0.5
Finland	2.9	2.9	193	15	0.5
France	37.0	40.6	1856	21.9	0.6
Germany	55.3	54.2	1900	28.5	0.7
Ireland	4.7	4.7	220	21.4	0.9
Italy	28.7	35.8	1800	19.9	0.6
Netherlands	7.4	7.2	188	38.3	0.4
Poland	25.7	26.6	1096	24.3	0.7
Portugal	5.7	6.2	231	26.8	0.6
Slovakia	3.0	2.9	280	10.4	0.5
Spain	22.8	25.8	1601	16.1	0.5
England	20.7	23.6	1062	22.2	0.4
Israel	20.8	21.1	226	93.4	2.4
Norway	3.7	3.6	208	17.3	0.7
Türkiye	95.0	105.0	1106	94.9	1.3

Carbon Footprint

Carbon dioxide constitutes a large proportion of GHGs released into the atmosphere. Since it has the largest proportion among GHGs, it is accepted and used as the main component in the "carbon footprint" calculation. The concept of carbon footprint was first introduced in the 1990s by William E. Rees and Mathis Wackernagel, sustainable environmental advocates, as part of the ecological footprint concept.[25] Carbon footprint calculation is the calculation of CO_2, methane (CH_4), nitrous oxide, and fluorinated gases released into the atmosphere as a result of vital activities under the name of GHGs (in equivalent amounts). The carbon footprint value of that individual or community is defined for the carbon dioxide (CO_2) emissions thrown into the nature as a result of the vital activities of individuals or societies.[26] Greenhouse gas sources, which come to the fore with the transition to modern life and population growth, are emissions from energy production, vehicle use and public transportation, industrial and agricultural uses, and other similar activities. The carbon footprint basically consists of 2 main parts. These are called primary and secondary carbon footprints. The main component of the primary carbon footprint is CO_2 emissions resulting directly from the use of fossil fuels for domestic and industrial heating and lighting, energy consumption for power, and transportation. Secondary carbon footprint is expressed as indirect CO_2 emissions resulting from the production, use and degradation of all products in nature. According to the Intergovernmental Panel on Climate Change (IPCC), 3 main approaches are used to calculate the carbon footprint with this data. These approaches, called tiers, consist of 3 different categories. These are the 1st tier, 2nd tier and 3rd tier approaches.

In the tier 1 approach, the calculation is made using data from national energy statistics and the amount of fuel and emission factors according to the type of fuel used. In the tier 2 approach, in addition to tier 1, specific emission factors and combustion technologies for the country or specific regions are used. In the tier 3 approach, fuel statistics and technology-dependent emission factors determined according to the combustion technology and the thermal power of the combustion plants and statistical information are used.[27] Figure 1 shows the GHG sources and their boundaries. Since the amount of CO_2 is high in this model, general calculations are made in terms of equivalent CO_2 (Equation 1), while the total amount of carbon is calculated from Equation 2.[21,28]

$$CO_2eq[kg] = CO_2[kg] + 25 \times CH_4 + 298 \times N_2O \tag{1}$$

$$Total\ Carbon\,(GgC) = ET\ (TJ) \times CEF\left(\frac{tC}{TJ}\right)10^{-3} \tag{2}$$

where ET represents energy consumption (TJ) and CEF represents carbon emission factor (tons of carbon/TJ).[28]

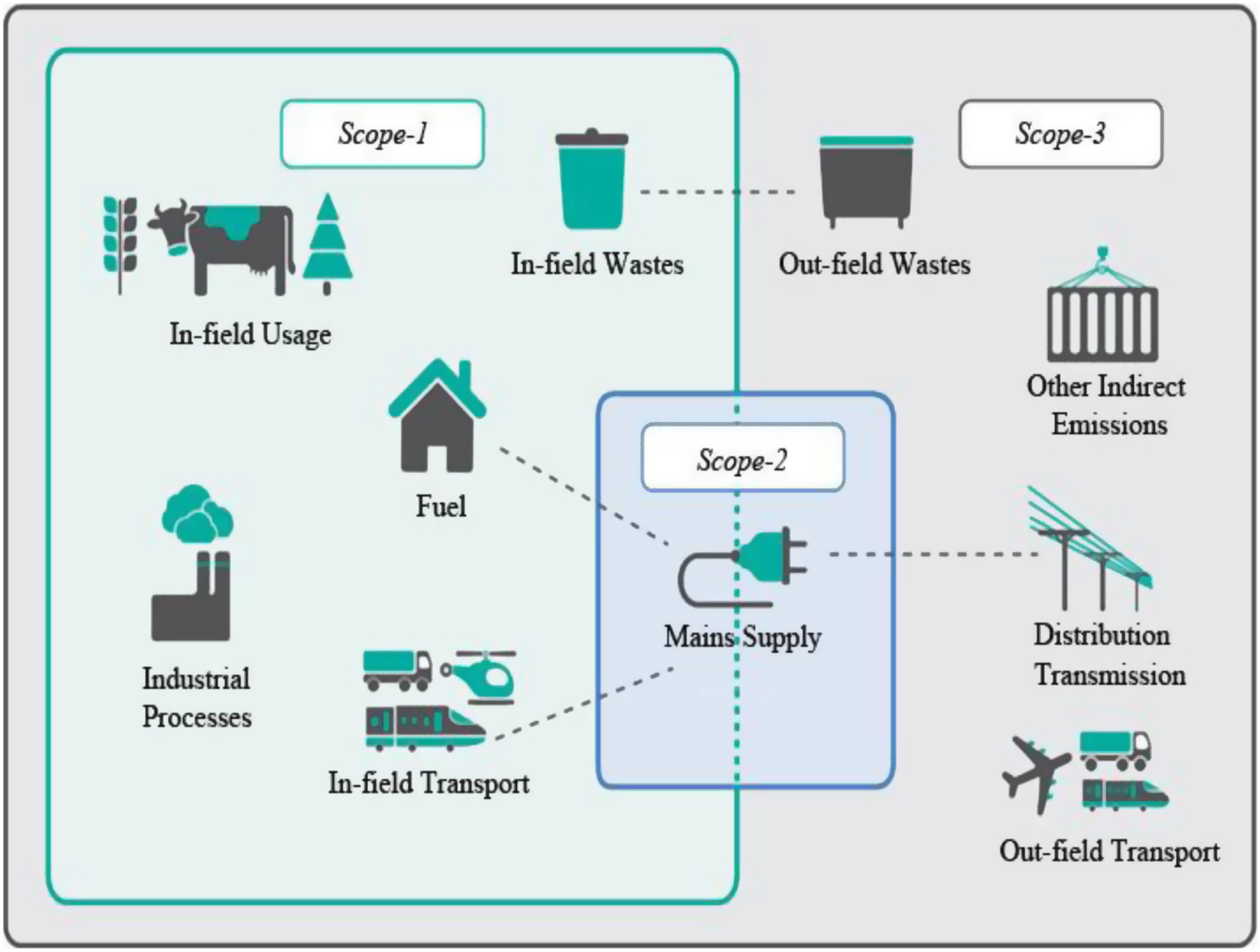

Figure 1. Greenhouse gas sources and their limits.[27]

According to the IPCC, the concept of global warming potential (GWP) has been developed to compare the impact of anthropogenic GHGs on the atmosphere. Specifically, GWP is a measure of how much energy it would take to emit 1 ton of a gas over a given period of time compared to the emission of 1 ton of CO_2. According to the GWP magnitude, the potential to increase the atmospheric temperature is calculated.[29] Carbon dioxide equivalent is used to assess and quantify different gas emissions based on GWP values. It is obtained by multiplying the kgCO_2 equivalent in kilograms by the corresponding GWP. That is, kgCO_{2e} = (the weight of the gas in kg) × (the GWP value of the gas.[30]

In 2020, a 10% reduction in GHG emissions in the USA was observed (according to United States Environmental Protection Agency data) with the regulations made since 2019, especially with the use of 11% less fossil fuels, the transition to less carbon-intensive natural gas and renewable resources, and the use of electrical energy.[31] The data on the distribution of carbon emissions by sectors in the USA are given as 27% for transportation, 25% for electricity generation, 24% for industry, 11% for livestock, 7% for trade, and 6% for households. The resulting GHGs are 3% fluorogases, 7% nitrogen oxides, 11% CH_4, and 79% CO_2.[31]

Cement Industry Greenhouse Gas Emissions

The energy used during cement production accounts for 12%-15% of the total energy used in industries.[32] Dry cement production steps consist of raw material production, kiln preparation, baking clinker calcination, and cement grinding and packaging. Carbon dioxide emissions from cement production are mainly composed of 3 main components:

1. Carbon dioxide emissions from the degradation of limestone containing calcium carbonate ($CaCO_3$) and $MgCO_3$ during clinker production: here, process-related CO_2 emissions are directly caused by the degradation of raw materials.
2. Carbon dioxide emissions related to the fuel used during the process: here, high temperature is required for clinker calcination. Fossil fuels (coal, petroleum coke, and natural gas) and alternative fuels (plastic, rubber, and sludge) can be used in cement production.
3. Electricity-related CO_2 emissions: these emissions are indirectly caused by electricity consumption.[33]

Typical GHG rates from the cement sector are given in Table 2.[34]

Since a significant amount of GHG carbon emissions in the cement sector occurs during clinker production, the tier 3 method is used in production-based calculations. The process is based on input

Table 2. Cement Industry Greenhouse Gases

Component	Concentration
CO_2	14%-33% (w/w)
NO_2	5%-10% (w/w)
NO_x	<200-3000 mg/Nm^3
SO_2	<10-3500 mg/Nm^3
O_2	8%-14% (v/v)

methods based on raw materials and the volume and chemical composition of clinker and dust from the kiln system.[33,35] The distribution of carbon emissions by sectors in the USA is given as 27% for transportation, 25% for electricity generation, and 24% for industry, production, raw materials and binders. While natural substances increase the cost of using raw materials, a decrease in emissions has been observed.[13,36] Of the total GHG components, about one-third of CO_2 emissions are reported to come from the industrial sectors, emitting 2370 TJ of CO_2, which is 43% of the total. Depending on the type of fuel used, it is estimated that about 0.9-1.0 tons of CO_2 is emitted per ton of clinker and 0.65-0.92 tons of CO_2 is emitted from 1 ton of cement production.[32,37,38]

Ready-Mixed Concrete Plant Greenhouse Gas Emissions

The elements that affect GHG in ready-mixed concrete production are cement, aggregate, water, chemical, and auxiliary additives, and the component that causes the highest emission is cement. For the production of 1 ton of clinker, approximately 0.9-1 ton of CO_2 emission occurs. Emissions also occur during the transportation of aggregates and binders. As the transportation distance increases, vehicle fuel consumption and exhaust emissions also increase.[39] Greenhouse gases generated in the production of ready-mixed concrete are produced during the preparation and transportation of compositions such as limestone, gravel and sand, aggregate and water for use.[40] Emissions can be reduced by reducing the energy and resource use during the preparation and transportation of the product, which is concrete that has not yet hardened and has not been transported to the construction site using a mixer.[41] Since CO_2 emissions in ready-mixed concrete plants are calculated in terms of energy consumption per unit of material produced, examples of reducing the carbon footprint of concrete and concrete structures depend on the use of raw materials. For example, emissions during the production of Portland cement were found to be higher than the use of ecofriendly other materials.[42] In this sense, ground-granulated blast furnace slag, a by-product of the steel industry, causes minimum carbon emissions when used as fly ash additive. In addition, when environmentally friendly recycled materials are selected for concrete use and when reduction in water use is emphasized with innovative approaches, emission amounts are also reduced.[43,44] The production and use of ready-mixed concrete in the construction industry and the steel and cement used as building materials consume approximately 40% of all energy and 1% of transportation and shipping costs.[2,30] Preventing the pollution of natural resources and new approaches to energy use are important components that reduce the carbon footprint.

Carbon Footprint Management

Framework setting, data collection, collaboration with stakeholders, statistical evaluations, calculations and reporting are essential in carbon footprint management. Calculations are based on the consumption amount according to the sectors and the carbon emission factor according to the relevant IPCC calculation data. Various improvements to reduce the carbon footprint have become mandatory for both a sustainable economy and a sustainable environment. When determining the carbon footprint, enterprises should determine the assessment of risks and measures to be taken in the light of statistical data to determine environmental impacts. Regular controls should be carried out in all business units, processes should be monitored, staff should be trained, all expenses of the enterprises should be audited, and energy reduction measures should be investigated.[45,46] The environmental problems arising from ready-mixed concrete plants were evaluated by classifying them as the amount and types of energy used, solid waste management, air, water, soil pollution emission amounts and types, and fossil fuels used. By evaluating and reducing these impacts, environmental risks will also be reduced.[47] Technological developments play an important role in the calculation and reduction of carbon emissions for a sustainable environment in the production and transportation of concrete and cement. Material quality in cement and concrete production with the zero carbon principle, design and features for architects and engineers, use and post-use disposal and recycling processes are a whole evaluated as.[22] Sanctions and regulations should be managed by governments to control sustainable practices. The use of alternative cement and concrete products should be encouraged by following developments and innovations, and practices such as accelerated carbon capture should be implemented to ensure long-term sustainability. A significant amount of waste is generated in ready-mixed concrete plants every year. In the management of these wastes, crushing and screening the hardened concrete returned to the plant and recycling it for use as aggregates would be a positive environmental approach. In 1 study, it was found that concrete with recycled aggregates in Brazil has economically favorable conditions.[48]

By using recycled concrete, resource reduction and indirect emission reduction can be achieved. The part of concrete waste that can be recycled consists of 70% aggregate. The remaining 30% is non-recyclable paste (a combination of cementitious materials, water, partially hydrated cement, or pozzolanic reacted products). A system can be installed that can recover quality aggregates by washing the cement paste with fresh or gray water generated during washing.

In addition, gray water from aggregate reclamation, dust suppression, or other cleaning processes, such as washing the inner surfaces of mixer drums and mixer truck wheels, can be used for beneficial environmental management. Carbon and water footprints can be reduced through environmental approaches, many of which are based on energy and resource recovery. It is important to take the necessary measures for a sustainable environment. Since energy is the most important parameter in concrete plants, the use of waste heat as an alternative energy source, implementation of innovative CO_2 capture and storage technologies, sequestration of CO_2 by increasing biological absorption capacity in forests and soils, and the use of blended cement by reducing the clinker/cement ratio should be expanded. Other important measures include increasing the use of renewable energy sources or nuclear energy and the use of alternative raw materials including fly ash, slag, gypsum, anhydrite, and fluorite using non-carbonated calcium raw materials.[32,34,49] The production and environmental impacts of ready-mixed concrete used in housing and infrastructure works in urban areas in Latin America and the Caribbean were examined, and it was determined that 7.16 tons of material was used for the production of 2 604 862 m^3 of ready-mixed concrete, of which 99.1% were primary raw materials and 0.9% were secondary raw materials. It was observed that 5.36 tons (~78.6%) of the material used here was aggregate and the emission value was ~19.5% of the total Equivalent CO_2 eq. It was found that by using recycled aggregates instead of Portland cement used in this process, a saving of 20% in the use of raw materials can be achieved to ensure sustainability in building materials.[21]

MATERIALS AND METHODS

The ready-mixed concrete batching plant, whose carbon footprint is calculated, has a total area of 17 855 square meter, 953 square meter closed. There are 33 employees in the facility, and the number of workers may increase seasonally depending on the increase in workload. A total of 116 000 m^3 of ready-mixed concrete was produced at the facility in 2021. For this production, raw materials were transported, electricity and water were consumed, coal was used in the facility for heating purposes, and the concrete produced was delivered to the buyer in transmixers. The activities that cause carbon footprint formation as a result of the ready-mixed concrete production activity can be counted as transportation, electricity consumption, water consumption, and facility heating. All vehicles in the facility use diesel fuel, and coal is used as the fuel for heating purposes. All data used in this study are taken from the company's records. Consumption data for 2021 are given in Table 3, the site plan of the ready-mixed concrete plant is given in Figure 2, and the flowchart is given in Figure 3.

According to the workflow of the plant, ready aggregate is discharged into the bunker with the help of construction machinery, and this material is conveyed to the washing and screening point with the help of conveyor belts and from there to the stockyard. Meanwhile, the washed sand prepared in the plant is also discharged into the bunker with the help of construction machinery. In addition, with the help of moving belts, the material in the bunker is conveyed to the mixing boiler with the help of the water pump in the water tank and the cement augers in the cement silos. All materials coming to the mixing boiler are mixed in the desired proportions in this boiler. The ready-mixed concrete produced is filled into mixer vehicles from the filling point. Mixer vehicles returning to the plant at the end of the working day are washed with water in the inclined area in the first step of the settling pool. The wastewater coming out of this pool is transferred to the second pool with the help of a pipe, and the water waiting here is allowed to settle. The water remaining on the surface is taken to the next pool and sent to the water tank with the help of a pump. All of the wastewater generated as a result of washing the mixers is reused within the system, preventing waste generation.

Table 3. Consumption of Concrete Plant Data

Consumption Data	Quantity (Per Year)
Diesel fuel (L)	329 629
Solid fuel (lignite coal) (kg)	10 000
Water (L)	22 791 200
Electricity (kW)	703 112.92

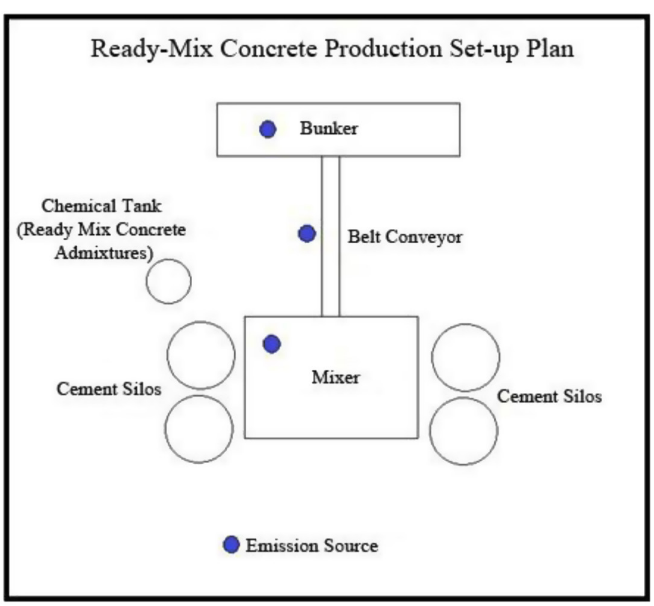

Figure 2. Ready-mixed concrete production site plan.

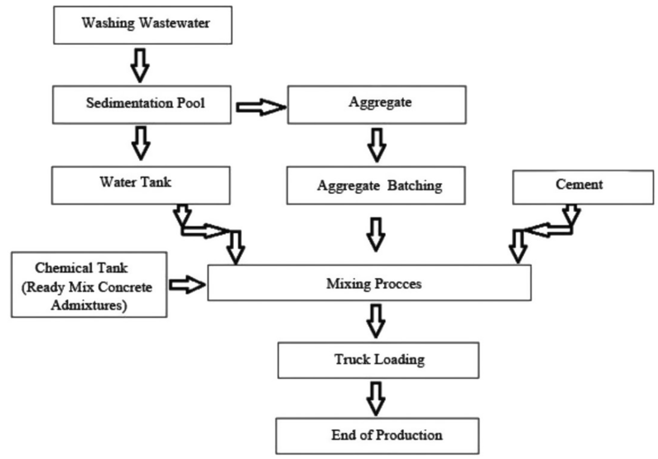

Figure 3. Ready-mixed concrete production work flowchart.

RESULTS AND DISCUSSION

Based on the consumption data of the ready-mixed concrete plant, calculations were made using the tier 1 method formulas specified in the IPCC report. While making the calculations, the calorific values of the emission factors given separately for each record in the IPCC report were taken as the basis. Emission factors determined by Department for Food, Environment and Rural Affairs (DEFRA) were used in the carbon footprint calculation for electricity consumption and water consumption. While calculating the carbon footprint for fossil fuels, the GWPs of CH_4 and diazot monoxide (N_2O) emissions resulting from the combustion process are calculated by converting them into CO_2 equivalent, which has the largest proportion among GHGs. The carbon emission amounts obtained as a result of the calculations are given in Table 4.

According to the calculation results, it was found that the total CO_2 equivalent emission caused by consumption amounts was 1 038 396 tons of CO_{2e}. Of this total emission, 98.383% (1 021 604 tons CO_{2e}) is CO_2 emission, 0.149% (1551 tons CO_{2e}) is CH_4 emission, and 1.468% (15 242 tons CO_{2e}) is N_2O emission (Figure 4).

How the total amount of emissions is proportioned to the consumption data is also shown graphically in Figure 5. When the total CO_2 equivalent emission is evaluated according to the

Table 4. Ready-Mixed Concrete Plant Greenhouse Gas Emissions

Emissions	Quantities (tCO_{2e})
CO_2 emission	
Diesel	871.746
Lignite	12.019
Electricity	134.442
Water	3.396
CH_4 emission	
Diesel	0.964
Lignite	0.025
Electricity	0.562
Water	0.000
N_2O emission	
Diesel	14.223
Lignite	0.055
Electricity	0.963
Water	0000
Total	1038.396

consumption sources of the ready-mixed concrete batching plant, it can be seen that diesel fuel consumption (886 933 tons CO_{2e}) has the highest emission rate of 85.414% and water consumption (3396 tons CO_{2e}) has the lowest emission rate of 0.327%.

How the consumption ratios for specific gases are calculated is also shown graphically in Figures 6-8.

When all calculations are analyzed, CO_2 and N_2O were found to be the gases with the highest and lowest emission rates, respectively, while diesel fuels were found to have the highest

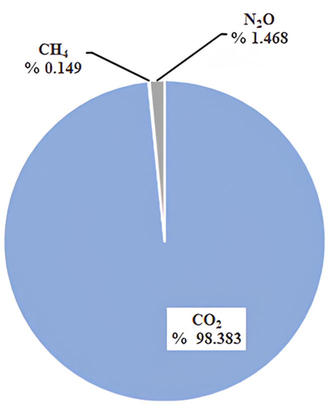

Figure 4. Distribution of total CO_2 equivalent emissions by gases. CH_4, methane; CO_2, carbon dioxide; N_2O, diazot monoxide.

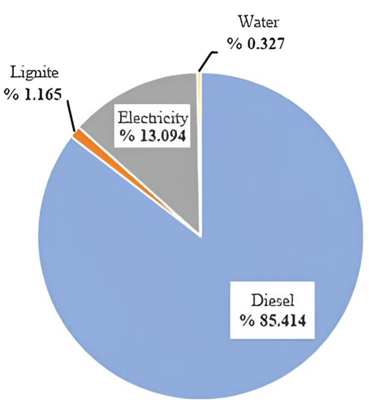

Figure 5. Distribution of total carbon dioxide equivalent emissions by sources consumed.

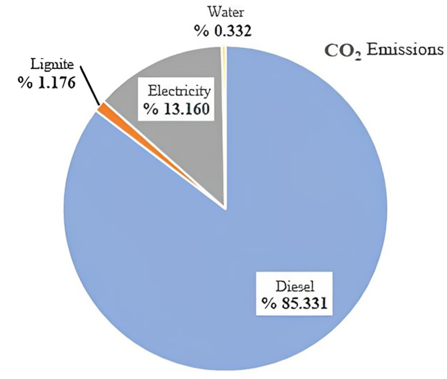

Figure 6. Distribution of carbon dioxide (CO_2) emissions according to the resources consumed.

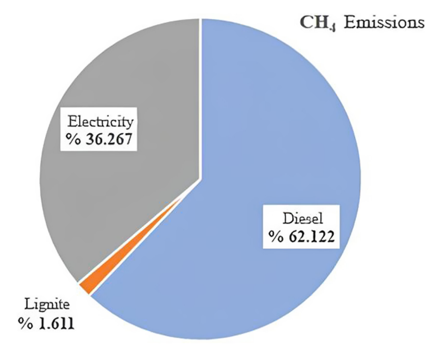

Figure 7. Distribution of methane (CH_4) emissions by sources consumed.

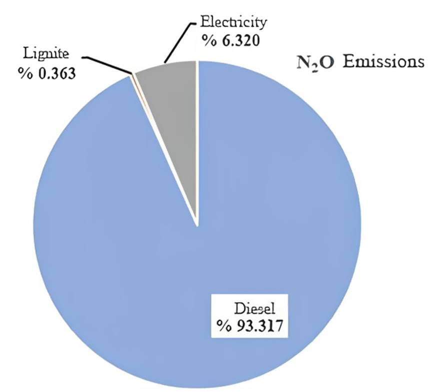

Figure 8. Distribution of diazot monoxide (N_2O) emissions according to the resources consumed.

contribution to carbon emissions when evaluated on the basis of consumed resources.

CONCLUSIONS

The production of concrete, ready-mixed concrete, and cement, which are the main components of housing and infrastructure, roads, water and wastewater systems, and all kinds of buildings and structures, emit a significant proportion of GHGs emitted worldwide. Sustainable construction and sustainable economy should be targeted for carbon reduction through innovative technology and advancements in the ready-mixed concrete sector. In order to reduce the carbon footprint, energy efficiency should be increased, waste heat recovery should be maximized, waste should be utilized, and alternative raw materials should be used by reducing the use of Portland cement. Governments should also introduce new regulations and standards for cement-based materials. Innovative solutions in the use of cement-based concrete and zero carbon understanding should be supported on behalf of humanity.

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REFERENCES

1. Labaran YH, Mathur VS, Muhammad SU, Musa AA. Carbon footprint management: a review of the construction industry. *Clean Eng Technol*. 2022;(9):100531.
2. Tathagat D, Dod RD. Role of green buildings in sustainable construction-need, challenges and scope in the Indian scenario. *IOSR JMCE Ver II*. 2015;12(2):2320-2334. Available at: www.iosrjournals.org.
3. Edeoja JA, Edeoja OA. carbon emission management in the construction industry – case studies of the Nigerian construction industry. *Am J Eng Res*. 2015;4(7):112-122.
4. Jackson DJ. *Addressing the Challenges of Reducing Greenhouse Gas Emissions in the Construction Industry: a Multi-perspective Approach*. Published online 2020. University of Edinburgh.
5. Sebaibi N, Boutouil M. Reducing energy consumption of prefabricated building elements and lowering the environmental impact of concrete. *Eng Struct*. 2020;213:110594. [CrossRef]
6. Luisa FC, Gracia A, Pisello AL. Integration of renewable technologies in historical and heritage buildings. *Energy Build*. 2018;177:96-111.
7. Pacheco-Torgal FP, Faria J, Jalali S. Embodied energy versus operational energy. Showing the shortcomings of the energy performance building directive (EPBD). *Mater Sci Forum*;730-732:587-591. [CrossRef]
8. Fernandez NP. *The Influence of Construction Materials on Life Cycle Energy Use and Carbon Dioxide Emissions of Medium Size Commercial Buildings* (Thèse de Doctorat). Victoria University; Wellington: 2008.
9. Xiao J, Wang C, Ding T, Akbarnezhad AA. A Recycled aggregate concrete high-rise building: structural performance and embodied carbon footprint. *J Cleaner Prod*. 2018;199:199868-199881. [CrossRef]
10. Bastos J, Batterman SA, Freire F. Life-cycle energy and greenhouse gas analysis of three building types in a residential area in Lisbon. *Energy Build*. 2014;69:344-353. [CrossRef]
11. Asif M, Muneer T, Kelley R. Life cycle assessment: a case study of a dwelling home in Scotland. *Build Environ*. 2007;42(3):1391-1394. [CrossRef]
12. Belaïd F. How does concrete and cement industry transformation contribute to mitigating climate change challenges? *Resour Conserv Adv*. 2022;15:200084. [CrossRef]
13. Geng Y, Sarkis J, Bleischwitz R. How to globalize the circular economy. *Nature*. 2019;565(7738):153-155. [CrossRef]
14. Cao Z, Masanet E, Tiwari A, Akolawala S. *Decarbonizing Concrete: Deep Decarbonization Pathways for the Cement and Concrete Cycle in the United States*. India: Industrial Sustainability Analysis Laboratory, Northwestern University; 2021.
15. IEA. *WBCSD, World Business Council on Sustainable Development & CSI, Cement Sustainability Initiative. Technology Roadmap: Low-Carbon Transition in the Cement Industry*. 2018. [CrossRef]
16. Petek Gursel AP, Masanet E, Horvath A, Stadel A. Life-cycle inventory analysis of concrete production: a critical review. *Cem Concr Compos*. 2014;51:38-48. [CrossRef]
17. Xuan D, Poon CS, Zheng W. Management and sustainable utilization of processing wastes from ready-mixed concrete plants in construction: a review. *Resour Conserv Recycl*. 2018;136:238-247. [CrossRef]
18. THBB. *Turkey Ready-Mixed Concrete statistics*. 2021. http://www.thbb.org/sektor/istatistikler/.
19. Andrew RM. Global CO2 emissions from cement production. *Earth Syst Sci*. 2018;10:195-217.
20. Saadé M, Erradhouani B, Pawlak S, Appendino F, Peuportier B, Roux C. Combining circular and LCA indicators for the early design of urban projects. *Int J Life Cycle Assess*. 2022;27(1):1-19. [CrossRef]
21. Cordoba G, Paulo CI, Irassar EF. Towards an eco-efficient ready mix-concrete industry: advances and opportunities. A study of the Metropolitan Region of Buenos Aires. *J Build Eng*. 2023;63:105449. [CrossRef]
22. Miller SA, Habert G, Myers RJ, Harvey JT. Achieving net zero greenhouse gas emissions in the cement industry via value chain mitigation strategies. *One Earth*. 2021;4(10):1398-1411. [CrossRef]
23. Barcelo L, Kline L, Walenta G, G. EG, E. Cement and carbon emissions, Mater. *Struct Constr*. 2014. [CrossRef]
24. Bajželj B, Allwood JM. Designing climate change mitigation plans that add up. *Environ Sci Technol*. 2013;47(14):8062-8069. [CrossRef]
25. Wackernagel M, Galli A. An overview on ecological footprint and sustainable development: A chat with Mathis Wackernagel. *Int J Ecodyn*. 2007;2(1):1-9. [CrossRef]
26. Chen R, Zhang R, Han H. Where has carbon footprint research gone? *Ecol Indic*. 2021;120. [CrossRef]
27. Feng K, Davis SJ, Sun L, Hubacek K. *Correspondence: Reply to Reassessing the Contribution of Natural Gas to US CO2 Emission Reductions Since 2007*. 2017;(7):10693.
28. IPCC. Guidelines for national greenhouse gas inventories. 2006. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.
29. Ziping Wu Z, Duan H, Kaili Li K, Ye L. A comprehensive carbon footprint analysis of different wastewater treatment plant configurations. *Environmental Research*. 2022;214(2):113818. ISSN 0013-9351. [CrossRef]
30. Mathur VS, Farouq MM, Labaran YH. The carbon footprint of the construction industry: a review of direct and indirect emission. *J Sustain Constr Mater Technol*. 2021;6(3):101-115. [CrossRef]
31. EPA. *Overview of greenhouse gases and sources of emissions. Key findings from the 1990-2020 U.S.* 2022. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.
32. Ali MB, Saidur R, Hossain MS. A review on emission analysis in cement industries. *Renew Sustain Energy Rev*. 2011;15(5):2252-2261. [CrossRef]
33. Nie S, Zhou J, Yang F, et al. Analysis of theoretical carbon dioxide emissions from cement production. *Methodol Appl J Clean Prod*. 2022;334:130270.
34. Bosoaga A, Masek O, Oakey JE. CO2 capture technologies for the cement industry. *Energy Procedia*. 2009;1(1):133-140. [CrossRef]
35. CSI. CO2 accounting and reporting standard for the cement industry. version 3.0. 2011. Available at: https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resource.
36. Gao T, Liu Q, Wang J. A comparative study of carbon footprint and assessment standards. *Int J Low Carbon Technol*. 2014;9(3):237-243. [CrossRef]
37. Deja J, Uliasz-Bochenczyk A, Mokrzycki E. CO2 emissions from the Polish cement industry. *Int J Green Gas Control*. 2010;4(4):583-588. [CrossRef]
38. Anand S, Vrat P, Dahiya RP. Application of a system dynamics approach for assessment and mitigation of CO2 emissions from the cement industry. *J Environ Manage*. 2006;79(4):383-398. [CrossRef]
39. THBB. *Turkey Ready-Mixed Concrete Association Ready-Mixed Concrete Life Cycle Guide*. 2021. Available at: https://www.thbb.org/media/523136/hazır-beton-yaşam-döngüsü-rehberi-v4010921.pdf.

40. Gijlswijk V, Pascale RN, Vos SE, Urbano G. Carbon footprint of concrete based on secondary materials. *Heron*. 2015;60:113-139.
41. Kim B, Jeong J. Real-time low-carbon prediction in ready-mixed concrete production process for smart manufacturing. *Procedia Comput Sci*. 2022;203:205-212. [CrossRef]
42. McGarry H, Martin B, Winslow P. Delivering low carbon concrete for network rail on the Routemap to net zero. *Case Stud Constr Mater*. 2022;17:1343. [CrossRef]
43. Şanal İ. Significance of concrete carbon dioxide in terms of carbon dioxide emissions: social and Environmental Impacts. *J Polytech*. 2018;0900:369-378.
44. Zhan B, Poon C, Shi C. CO2 curing for improving the properties of concrete blocks containing recycled aggregates. *Cem Concr Compos*. 2013;42:1-8. [CrossRef]
45. Kızıltan B, Doğan DU. A framework proposal for reporting carbon footprints in the cement sector çağ. *Univ J Soc Sci*. 2021;18(1):40-58.
46. Coşgun N, Esin N. A study regarding the environmental management system of ready mixed concrete production in Turkey. Building and Environment 2006;41(8):1099-1105.
47. Ciftci B. *Environmental Assessment of Ready-Mixed Concrete Plants*. 2019.
48. de Brito Prado Vieira L, Domingues de Figueiredo A, John VM. Evaluation of the use of crushed returned concrete as recycled aggregate in ready-mix concrete plant. *J Build Eng*. 2020;31(3):101408. [CrossRef]
49. Caruso H. *Reduction of Carbon Dioxide Emissions from Cement Plants. Published Online 2007.*