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The Environmental Impact of Reusing Post-Earthquake Demolition Waste: İskenderun Case Study

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Highlights

• This paper focuses on the environmental impact of recycled aggregate concrete.
• The life cycle assessment methodology was used in the study.
• The environmental impact of recycled aggregate concrete was compared assessed.

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Abstract

Producing recycled aggregate from construction and demolition waste generated by earthquakes and using it as raw material in concrete production would be effective for urgent waste management after disasters and to reduce the environmental impact of concrete production by decreasing resource use. In this study, the life cycle assessment (LCA) method was used to examine the environmental implications of concrete produced using recycled aggregates (RA) derived from construction and demolition waste (CDW) of buildings demolished after the earthquake that struck Iskenderun and was centered in Kahramanmaraş. In addition, the environmental consequences of an equal volume of concrete produced in the same location utilizing natural aggregates (NA) were assessed. For the LCA of these two types of concrete, openLCA software and the ReCiPe midpoint database were used. LCA was conducted considering terrestrial ecotoxicity, climate change, terrestrial acidification, photochemical oxidant formation, marine ecotoxicity, human toxicity, freshwater ecotoxicity, ozone depletion, particulate matter formation, marine eutrophication, and ionizing radiation impact factors. The results show that cement has the highest impact on the environment by far.

1. INTRODUCTION

Construction and demolition waste (CDW) is defined as a mixture of different waste streams, including inert waste, nonhazardous waste, and hazardous waste generated from the construction, renovation, and demolition activities of buildings, roads, bridges, and other structures. A typical CDW consists of 71.4% concrete and ceramic, 10.2% metal, 10.2% wood, 2% plastic, 2% paper, 1% glass, and 3.1% other materials on average. While the type of structures that exist influences the substance and amount of waste materials, according to the United States Environmental Protection Agency [1], concrete, asphalt, wood, metal, roofing, rock, and wood are the main types of construction and demolition waste debris. Concrete and rock are inert materials that constitute a significant proportion of CDW. Lauritzen, (1994) [2], in their study, where they gave the amount of material in the demolition of a house with a living area of 100–50 m^2, calculated that a concrete waste of 56 tons, which is 40% of the weight of the house, could be formed. This is the largest ratio by weight compared to the other materials. Oikonomou, 2005 [3], indicated that the amount of concrete that can be obtained from a demolition would be around 40% in his work about recycled aggregate concrete (RAC). Lopes et al., (2019) [4], investigated the compositions of different CDW and found that the average concrete and rock proportions were about 22% and 28% by weight, respectively. Huang et al., 2002 [5], determined that approximately 50% of construction and demolition waste in Hong Kong is composed of concrete waste.

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Due to the high amount of concrete in CDW, it has great potential for recycled aggregate (RA) production. Using concrete in CDW to produce RA conserves resources, requires less landfill space, may lower waste management costs, and may lead to job opportunities. Recycling is frequently the preferred alternative [6]. Considering the huge amount of aggregate in concrete (about 70–80 by volume), producing concrete using RA makes considerable contributions to eliminating the environmental issues led by aggregate production and landfilling of CDW.

Earthquakes may lead to the generation of up to 15 times more CDW than the average annual CDW production in an earthquake-affected region [7]. In the case of Türkiye, 11 provinces were devastatingly affected by the 7.7-magnitude Kahramanmaraş-centered earthquake that occurred on February 6, 2023. This earthquake caused approximately 280 000 buildings to collapse or be severely damaged. As a result, 615 976 000 m^3 of CDW were generated [8]. It is planned that the CDW caused by the recent Kahramanmaraş-centered earthquakes will be used in the repair of damaged roads and in the construction of sidewalks and walkways as landfill materials. Within this framework, debris dumping sites were created at 47 different points in 11 provinces by the Ministry. The CDW collected is processed. Large stones are crushed, reduced, and made available for recycling by means of crushers placed in all fields [9]. However, the use of CDW as landfill material leads to various environmental impacts, such as decreasing landfill capacity, increasing raw material resource consumption, landfill pollution, increasing carbon footprints, and increasing energy use caused by transportation material resource use. Thus, it should be the last alternative for CDW treatment.

Apart from the land loss and resource consumption caused by landfilling, RAC and natural aggregate concrete (NAC) have environmental effects close to each other [10]. However, in many cases, RA leads to less environmental impact due to the shorter transport distance compared with natural aggregate (NA) [11]. RAC also has some disadvantages compared to natural aggregate concrete. Most importantly, RAC's mechanical features are lower than those of natural aggregate concrete, and to compensate for this loss, an extra amount of cement is added to the RAC mix. This increases the environmental impact of the material [12,13].

To assess the impact of RAC on the environment, the life cycle assessment (LCA) method is widely used. LCA is a protocol that is used for the environmental impact analysis of a product or system [14,15]. The environmental effects of a material through its life cycle begin with raw material extraction and continue through production, usage, treatment, and waste disposal. Then the cycle repeats itself through recycling and reuse of waste materials [16]. In many cases, LCA was used for the estimation of the environmental and economic impacts of RAC. Pradhan et al., 2019 [17], compared the impacts of RA and NA. They stated that cement makes the highest contribution to the environmental effect of concrete, and aggregate transportation is the second highest contributor. They also mentioned that RAC has a lower effect on the environment than NAC due to the aggregate production step. Mah et al., 2018 [18], estimated the environmental and economic impacts of different CDW management options by adopting the LCA method. They indicated that utilizing CDW wastes in concrete production instead of NA provides the highest economic and environmental benefits. Rosado et al., 2017 [19], compared the results of the LCA analysis of RA and NA and emphasized the importance of the location of the RA production facility. They found that RA produced in facilities less than 20 kilometers away from the recycling plant has a lower environmental impact. Dias et al., 2021 [20], compared the environmental effects and costs of alternative ways of producing concrete types containing RA or NA using the LCA approach. They stated that the most important economic criterion determining whether to use NA or RA is the transportation distance. The results showed that the most cost-efficient and environmentally friendly option is using RA produced at the CDW plant. Xiao-shuang et al. 2010 [21], stated that as a result of the Wenchuan earthquake, so much debris that could not be landfilled was generated. Therefore, recycling the debris is crucial for effective post-earthquake waste management. They also indicated that the production of recycled aggregate from the debris of the Wechuan earthquake contributes to the advancements in post-disaster waste recycling techniques used in China and provides environmental benefits. Tsakalakis, Frangiskos and Karka, 2001 [22], investigated the benefits of the production of RA using the debris of the earthquake that hit Athens in 1999. They indicated that RA production has significant financial benefits, avoids overuse of landfill space, and saves resources. Morimoto, Misawa and Hironaka, 2014 [23], investigated the usability of radioactively contaminated waste aggregate obtained from the debris of Fukushima Nuclear Plant devasted by the Great East Japan Earthquake in 2011 in the construction of port structures. They analyzed the mechanical properties, workability and radiation level of the recycled aggregate obtained from the disaster area. They stated that Recycled aggregate obtained from earthquake-stricken areas can be used in port constructions unless the radiation level in very high, and it reduces to cost approximately 30%. Ulucan and Alyamac, 2022 [24], analyzed the mechanical properties, cost, and environmental impacts of using recycled aggregate collected from the debris area of the Elazığ earthquake in 2020 in concrete production. They produced different concrete samples using only recycled aggregate and created various scenarios for environmental and economic analysis. According to their findings, the compressive strengths of the recycled aggregate concrete mixtures are 10–50 MPa. Transportation has the highest significance for energy consumption and global warming potential criteria. RAC production costs less than NAC. Faleschini, Zanini and Pellegrino, 2016 [25], investigated the environmental impact and mechanical properties of RA. They found the adhered mortar’s properties to be the most critical factor that determines the RA’s mechanical properties. According to the LCA conducted for the environmental impact of RA, replacing NA with RA in concrete mixes provides approximately 58% less carbon emission.

In this study, it is aimed to evaluate the environmental impact of using recycled aggregate in the debris collection area obtained from earthquake debris as aggregate in concrete production. For this, the LCA study of the concrete produced by using the RA obtained from the CDW, which was formed by the buildings that collapsed due to the earthquake in a selected area, was carried out. Then, the concrete produced in the same region using the same amount of natural aggregate was also evaluated according to LCA. Differently from previous studies, while there is a debris collection area in the recycling scenario of the waste concrete generated by the earthquake, in this study, there is no recycling facility in the area. This has necessitated the use of mobile crushers and additional construction equipment for separation. Therefore, it will help to understand the environmental impact of RA production using earthquake debris in the study area and in regions where there is no CDW recycling plant, and it will prove the possibility of RA production in regions that do not have a stationary recycling plant near the earthquake zone. While there is a debris collection area in the waste concrete recycling scenario, which is assumed as a result of the earthquake in this study, there is no recycling facility in this area. This has necessitated the use of mobile crushers and additional construction equipment for separation. However, since the stationary waste concrete recycling facility creates less noise and waste with a wider variety of aggregate sizes than mobile crushers, it ensures that collection, storage, sorting, crushing, and sorting after crushing processes are carried out with higher efficiency despite its higher initial investment cost [26]. Therefore, the presence of a stationary concrete recycling plant in countries where concrete production, construction, and demolition activities are intensively carried out, which causes waste concrete production, is of great importance in reducing the environmental impact of concrete recycling. Since Türkiye, which is one of the countries where construction activities are carried out intensively, is also an earthquake country, it is necessary to establish regional stationary recycling plans for the recycling of both debris and post-earthquake debris in Türkiye.

The results for both materials were compared and analyzed. The limitations, scope, and goal of this study were explained in section 2 as one of the steps of the LCA methodology.

2. MATERIAL METHOD

According to ISO 14040 [14] and ISO 14044 [15], there are four steps to LCA analysis: (1) goal and scope definition; (2) establishment of a life cycle inventory (LCI); (3) environmental impact assessment; and (4) analyzing the results. Since the fourth step of the LCA analysis constitutes the results of this study, this step is given in section 3 under the heading "Research Findings". The software utilized to perform this life cycle assessment (LCA) was openLCA v.2.0, which was released by GreenDelta and is a widely used freeware LCA tool. It creates process models and presents results in Sankey diagram and graph formats. Results can be imported as ILCD, ecoSpold v1, v2, csv, Excel, or JSONLD formats [27]. The Monte Carlo simulation option is also provided in openLCA. The software has a data quality assessment system and allows for economic and social sustainability analysis.

2.1. Goal and Scope Definition

The goal of this study is to compare the environmental effects of the concrete produced using RC obtained from CDW formed after the Kahramanmaraş-centered earthquake and the concrete produced using NA in accordance with the LCA protocol. İskenderun, a district affected by the earthquake, was selected as the study area. RAC production includes these steps: (i) CDW loading to trucks; (ii) CDW transportation to the storage field; (iii) CDW sorting; (iv) crushing and sorting; (v) aggregate transportation to the concrete batching plant; and (vi) concrete production. For natural aggregate concrete (NAC) production, natural aggregate is obtained from a quarry and then transported to the concrete batching plant for production.

In order to assess the impact of all aggregates produced from CDW obtained from the study area on the environmental impact of concrete production, a study was conducted on a scenario where all aggregates that can be produced from CDW in this area are used in concrete production. Therefore, the determinant of the functional unit is the amount of aggregate generated from the CDW generated in the study field. According to the results of the calculation (explained in detail in Section 2.2), 6 415 605 kg of aggregate can be obtained from the CDW in the study field, and 3411.38 m^3 of C25 concrete can be produced entirely using the aggregate obtained. The same proportions of the ingredients in the C25 concrete mixture were used. For 1 m^3 of C25 concrete production, 309 kg of cement, 210 l of water, 602 kg of fine aggregate, and 1279 kg of coarse aggregate are used [28]. In this study, to produce 3411.38 m^3 of C25 concrete, 1 054 116 kg of cement, 716 389.8 l of water, 2 053 650.76 kg of fine aggregate (FA), and 4 361 954.21 kg of coarse aggregate (CA) were used (Table 1). For the production of the same amount of natural aggregate concrete, the same proportions of components were used, but natural aggregate was used in the production.

Table 1. *Mix proportion of C25 concrete [28]*

Amount (m^3)	Cement (kg)	Water (l)	Fine aggregate (kg)	Coarse aggregate (kg)
1	309	210	602	1279
3411.38	1 054 116	716 389.8	2 053 650.76	4 361 954.21

The system boundaries of the production processes of concretes produced using RA and produced using NA are defined in Figures 1 and 2, respectively. Life cycle assessments of these processes have some limitations. There is no stationary CDW recycling plant in the debris storage area, in the process of RAC production. For the production of aggregate from concrete waste, it is assumed that a mobile impact crusher and jaw crusher, which work with electricity and can perform sorting and monitoring, are used. It is assumed that the steel in the reinforced concrete is separated by magnetic separation, but this process is not included in the evaluation due to a lack of related data. The dust emissions from this process and the recycling process of the steel were also neglected. In concrete production, weakening the mechanical properties of concrete caused by RA used in concrete production is preferred to adding cement.

In the production process of NAC, it is considered that natural aggregate is obtained from a local supplier as fine and coarse aggregate. The distance traveled by the equipment while coming to the working area and the transportation distance in concrete and aggregate production facilities are not taken into account. Both processes end with concrete production.

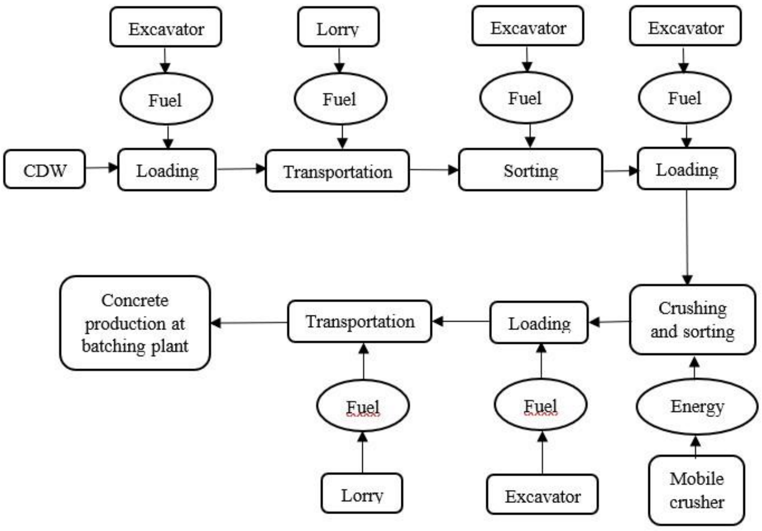

Figure 1. *RAC production process*

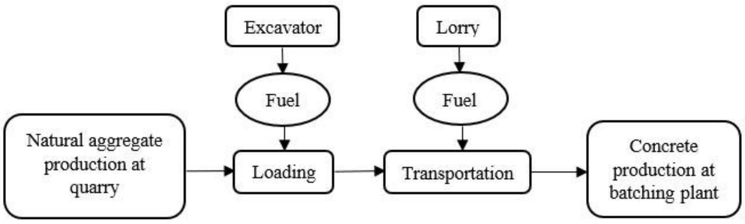

Figure 2. *NAC production process*

2.2. Life Cycle Inventory

LCA is the data gathering step of LCA, and it evaluates the quantities of all essential inputs (natural resources, raw materials, energy forms, and products) and outputs (emissions, pollution, energy, and products) employing appropriate methods within the framework's boundaries [29]. Input data for natural resources, raw materials, energy forms, and products and output data for emissions, pollution, energy, and products were gathered from the ReCiPe Midpoint V1.13 database. ReCiPe is a special methodology used to evaluate the environmental impact of a product or process throughout its life cycle. Life cycle impact assessment (LCIA) converts emissions and resource extractions into a concise set of environmental impact scores using characterization factors as indicators [30].

The block numbered 2028, located in the Şevre neighborhood in the İskenderun district of Hatay province, was selected (Figure 3). The selected area is located at coordinates 36° 33' 44.03" N and 36° 9' 22.07" E. There is debris from two 7-storey reinforced concrete frame apartments, one with a floor area of 250 m^2 and the other with a floor area of 650 m^2.

Figure 3. *The debris field selected as the study field*

According to " *Management Plan for Debris that May Be Caused by a Potential and Destructive İstanbul Earthquake*, 2021" [31], created by the Istanbul Metropolitan Municipality; a building with 5 floors, 2 flats, and 10 residences with a construction area of 1.200 m^2 from 120 m^2, will produce 600 m^3 of concrete waste, which is equal to 1.500 tons. Considering this calculation, 875 m^3 concrete rubble was generated from the demolition of 7-storey reinforced concrete frame apartment with a floor area of 250 m^2, and the apartment with 7-storey and 650 m^2 led to the creation of 2275 m^3 of concrete rubble. In total, 3150 m^3 of concrete rubble were generated in the study field.

In previous studies [2,3], it has been stated that approximately 40% by weight of CDW consists of concrete. Lu et al., 2021 [32], estimated that the density of mixed CDW is 528 kg/m^3, and Neville, 1995 [33], indicated that the average value of concrete density is 2.200–2.600 kg/m^3. Considering the results of the abovementioned studies, the proportion of concrete material in debris is accepted as 40% by mass, and the concrete density is assumed to be 2400 kg/m^3. Therefore, the weight of 31500 m^3 of concrete rubble is 7 560 000 kg (7560 t). This value also means 40% of the CDW weight, which is 18 900 t. The volume of 3780 tons of CDW with a density of 528 kg/m^3 is 35795 m^3.

A mobile jaw crusher might be able to crush around 600 tons in an hour and may include a crusher, screening, and return conveyor belt from the screening unit to the crusher intake for refining large aggregates to the desired size [34]. One mobile crusher has the capability to produce a range of 1,800 to 2,400 tons of recycled concrete aggregate (RCA) on a daily basis [35]. In this process, it is assumed that the jaw crusher produces 400 m^3 of aggregate and consumes 150 kW of electricity per hour [36]. In this scenario, a CAT 330 model excavator with a capacity of 1.54 m^3 and consuming 18 l of diesel per hour is used in debris removal, sorting, and loading operations [37]. Transportation calculations were made according to the truck capacity, which is a maximum payload of 17.3 tons. Particles smaller than 5 mm are considered fine aggregate, and those with a particle size greater than 5 mm are classified as coarse aggregate. Wang et al., 2021 [38] stated that up to 39.39% by mass of mortar remains on the aggregate surface obtained from waste concrete. According to Verian et al., 2018 [39], this rate is 28.9%. In the calculations, the amount of mortar on the aggregate surface was accepted as 30%. Musbah et al., 2019 [28], indicated that 1m^3 of concrete weighing 2400 kg contains 1881 kg of aggregate and 519 kg of mortar. Considering that 30% of the amount of mortar remains on the aggregate surface, 2036.7 kg of RA can be produced from 1 m^3 of concrete. In this case, 6 415 605 kg of RA can be produced from 3150 m^3 of waste concrete obtained from the debris field.

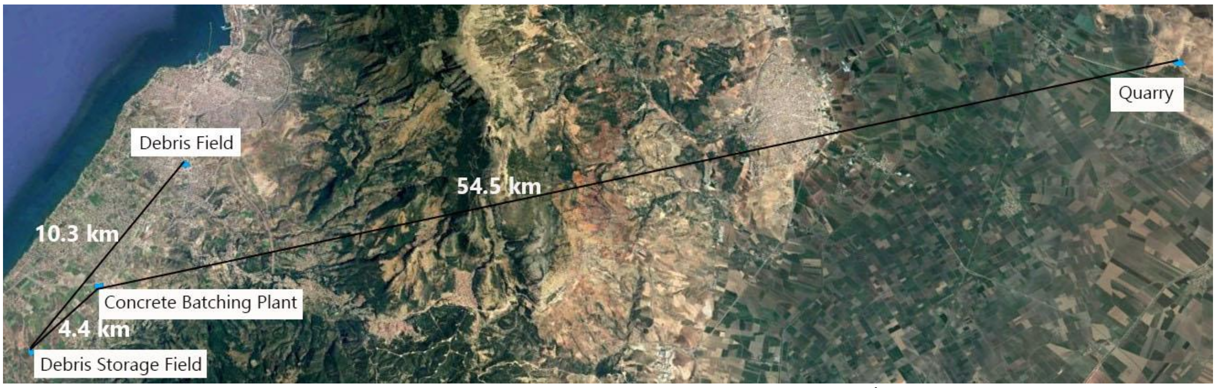

Figure 4. *Transport distances between the operation fields in İskenderun region*

For RAC production, 18.900 tons of CDW in the debris field are transported to the debris storage field, which is determined by the ministry. CDW sorting, concrete waste crushing, sorting, and monitoring are performed in the debris storage field, which is 10.3 km away from the debris field. Then, the 6415.6 tons of prepared fine and coarse aggregate are transported to the concrete batching plant. The distance between the debris storage field and the concrete batching plant is 4.4 kilometers (Figure 4). The natural aggregate required to produce the same amount of concrete that could be produced using RCA obtained from CDW was taken from the quarry 54.5 km away from the debris collection area (Figure 4).

Table 2. *ReCiPe (midpoint) data used for inputs of RAC and NAC production*

Type of concrete	Input	Amount	Description
RAC	Cement	1 054 116.42 kg	Portland cement (CEM I)
	Water	716 389.8 l	From groundwater
	Diesel (Loader)	18 783 l	200 ppm EU-15
	Electricity	4252.5 MJ	Mix, at consumer, AC 220V EU
	Transportation	222 899.6 t.km	Lorry/ 17.3 t max. payload
NAC	Cement	1 054 116.42 kg	Portland cement (CEM I)
	Water	716 389.8 l	From groundwater
	Coarse aggregate	4 361 954.21	Quarry
	Fine aggregate	2 053 650.76 kg	Quarry
	Diesel	703.76 l	200 ppm EU-15
	Transport	347 725.8 t.km	Lorry/ 17.3 t max. payload

After determining the RAC and NAC production stages, the materials used, the amount and resources of energy consumed, the raw material sources used, the type and amount of material transported, and the transportation distances, LCI was created using the ReCiPe database (Table 2).

2.3. Life Cycle Impact Assessment (LCIA)

One of the three steps of life cycle assessment (LCA) called life cycle impact assessment (LCIA) measures how much each elementary flow, such as airborne pollutants or raw material and energy consumption of a production process, contributes to the environmental impact. Its goal is to use the inventory analysis findings, impact categories, and category indicators to assess the production process from an environmental standpoint [40]. There are three procedures that must be followed in the LCIA step: selection of impact categories, category indicators, and characterization models [14,15].

For LCIA, as an impact assessment method, the ReCiPe Midpoint (V1.13) database imported into openLCA (V 2.0) was used. ReCiPe Midpoint provides output data in the form of agricultural land occupation (ALOP), climate change (GWP20), fossil depletion (FDP), freshwater ecotoxicity (FETP100), freshwater eutrophication (FEP), human toxicity (HTP100), ionizing radiation (IRP_I), marine ecotoxicity (METP100), marine eutrophication (MEP), metal depletion (MDP), natural land transformation (NLTP), ozone depletion (ODinf), particulate matter formation (PMFP), photochemical oxidant formation (POFP), terrestrial acidification (TAP20), terrestrial ecotoxicity (TETP100), urban land occupation (ULOP), and water depletion (WDP).

3. RESEARCH FINDINGS

Life cycle interpretation, which is the last step of the LCA process, is the main constituent of the results of this study. In this step, the findings of one or both LCIAs and LCIs, or both, are analyzed as a foundation for conclusions, suggestions, and decisions in line with the goal and scope description [14,15].

Table 3. *The environmental impacts of RAC and NAC in terms of ReCiPe midpoint criteria*

Impact category	Reference unit	RAC	NAC
Terrestrial ecotoxicity (TETP100)	kg 1.4-DCB-Eq	6.60946648	6.512196
Climate change (GWP20)	kg CO_2-Eq	902.7170594	931.9143
Terrestrial acidification (TAP20)	kg SO_2-Eq	1233.726062	1226.857
Photochemical oxidant formation (POFP)	kg NMVOC-Eq	354.3858044	354.9933
Marine ecotoxicity (METP100)	kg 1.4-DCB-Eq	44.16639251	42.29263
Human toxicity (HTP100)	kg 1.4-DCB-Eq	16656.96525	16629.49
Freshwater ecotoxicity (FETP100)	kg 1.4-DCB-Eq	1.859348327	1.810985
Ozone depletion (ODPinf)	kg CFC-11-Eq	0.046523666	0.047493
Particulate matter formation (PMFP)	kg PM10-Eq	377.1821191	379.4308
Marine eutrophication (MEP)	kg N-Eq	3.816457795	3.814357
Ionizing radiation (IRP_I)	kg U235-Eq	1681.137716	1814.117

According to the results of the LCIAs of RAC and NAC, they generally have close impact figures. RCA has lower climate change potential (GWP20), marine ecotoxicity (METP100), freshwater ecotoxicity (FETP100), ozone depletion (ODPinf), particulate matter formation (PMFP), and ionizing radiation (IRP_I) than NAC. However, NAC is less detrimental to the environment in terms of terrestrial ecotoxicity (TETP100), terrestrial acidification (TAP20), human toxicity (HTP100), marine ecotoxicity (METP100), and freshwater ecotoxicity (FETP100). In terms of photochemical oxidant formation (POFP) and marine eutrophication (MEP), they almost have the same impact (Table 3).

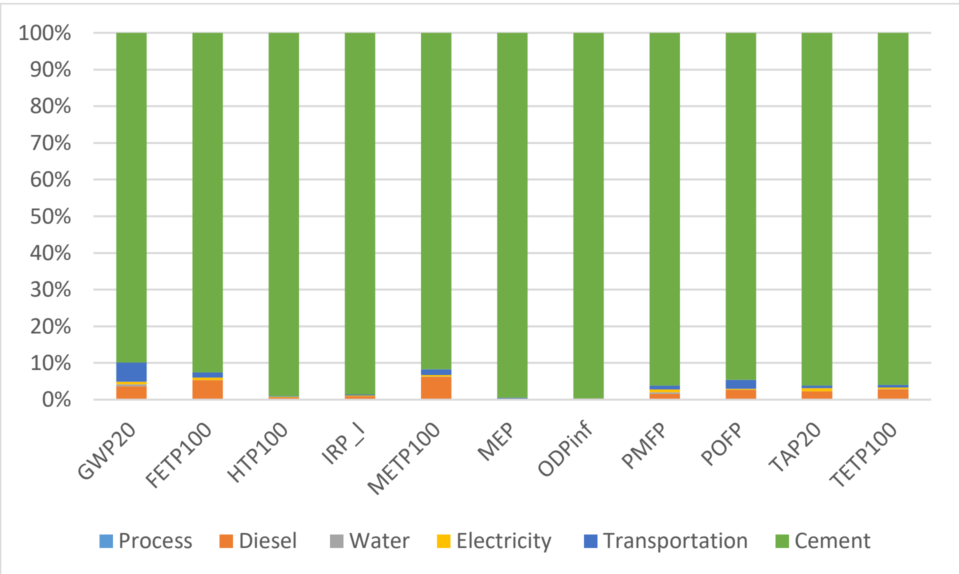

Figure 5. *RAC's environmental impacts at different LCA stages, in terms of varied impact categories*

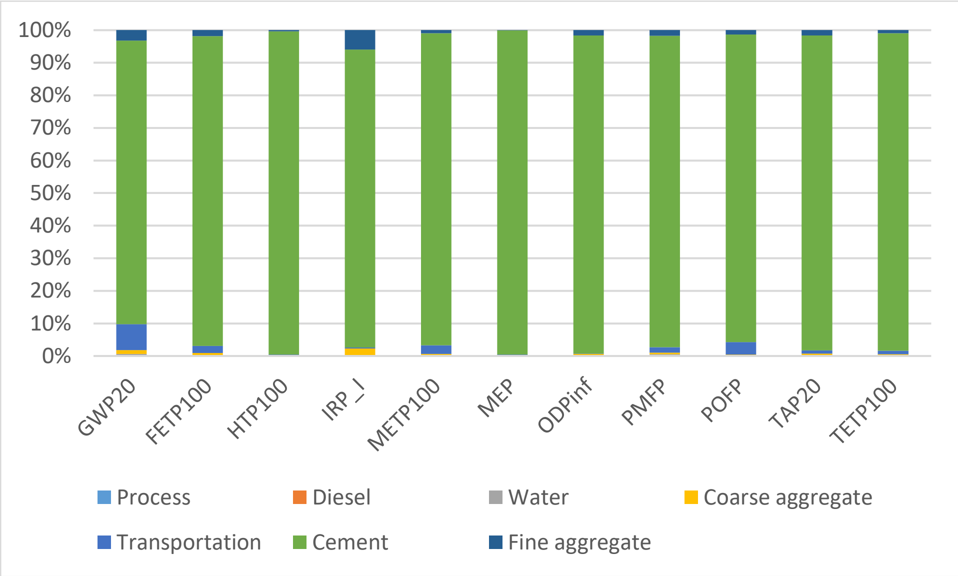

Figure 6. *NAC's environmental impacts at different LCA stages, in terms of varied impact categories*

Figures 5 and 6 show the environmental contributions of the production steps of RAC and NAC, respectively, in several impact categories, and the shares of the steps in each category are illustrated in the charts. It can be easily seen that cement is by far the biggest cause of environmental impact, while water use has the lowest impact in each assessment category during the production phase of both types of concrete. The step that makes the second-largest contribution to the environmental impact resulting from RAC production is the diesel consumption during loading in terms of each impact factor. Transportation has the third-greatest impact on most of the impact categories and has a notable effect on GWP20 and POFP during RAC production (Figure 5). In the NAC production process, coarse aggregate is the second-largest contributor to the environmental impact in every category but MEP (Figure 6). In general, fine aggregate and transportation also increase the environmental impact of RAC considerably.

In previous studies [13,41], as well as in this study, it was found that cement was the greatest contributor to each impact category in the LCA processes of RAC and NAC. However, unlike the previous studies, the second-greatest contribution to the impact categories of concrete production was not made by transportation but by diesel consumption and coarse aggregate. It is thought that the reason for this difference is that transportation has a significant effect on the LCA of concrete production, as stated by Pradhan et al., 2019 and Estanqueiro et al., 2018 [17, 42, 43], and that the operations in the case study of this study were completed at a relatively shorter transport distance compared to previous studies.

4. RESULTS

The environmental effects of the concrete produced using RA obtained from the CDW of the buildings destroyed in Iskenderun as a result of the Kahramanmaraş-centered earthquake and the concrete produced using the same amount of NA in that region were calculated by adopting the LCA method. The results were then compared and evaluated.

According to the results, while RAC and NAC have similar impacts in various categories. Among 11 impact categories, RAC makes slightly lower contributions to GWP20, POFP, ODPinf, PMFP, and IRP_I than NAC. The GWP20 of RAC and NAC are 902.71 and 931.91 kg CO_2-Eq, respectively. RAC causes 354.38 kg NMVOC-Eq POFP. The POFP led by NAC is 355 kg NMVOC-Eq. The ODPinf of RAC is 0.0465 kg CFC-11-Eq, and NAC' ODPinf is 0.01 kg CFC-11-Eq higher than RAC. RAC has 377.18 kg PM10-Eq PMPF, which is 2.25 kg PM10-Eq lower than NAC. RAC also has 132.98 kg U235-Eq lower IRP_I than NAC.

The shorter transportation distance significantly reduces the environmental impacts of RAC and NAC production. RAC raises the environmental impact of concrete production less than NAC at this stage due to the closer transportation distance.

Cement is overwhelmingly the factor that increases the environmental effects of both RAC and NAC in all categories. It was stated that transportation is the second stage that increases the environmental impact the most. In terms of GWP and ODPinf, similar results were obtained in previous studies, but diesel makes the second highest contribution to the other nine impact categories during the RAC production process. In the NAC production process, transportation is the step that increases the environmental impact in terms of GW20, FETP100, METP100, POFP, and TETP100. In all other categories, fine aggregate consumption has the second highest share of the increase in environmental impact.

In future studies, it is important to conduct a comprehensive LCA on a building where concrete produced using RA obtained from CDW is used, in which all the life cycle stages of the building are evaluated. Comparing the LCA results of RAC productions carried out with different types and numbers of equipment will be useful to understand the effect of time and equipment on LCA. Making comparisons between the mechanical properties and LCA results of concretes containing different ratios of RA will be effective in determining what percentage of RA the material should contain according to its intended use. Social and economic aspects of LCA should be considered and studied.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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