COMPARATIVE LCA OF NATURAL AND RECYCLED COARSE AGGREGATE PRODUCTION IN INDIA

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ABSTRACT. In India 25 – 30 million tonnes of C&D waste are generated, whereas only 5% of it is recycled. Hence, the life cycle assessment (LCA) of the production of recycled coarse aggregate (RCA) is conducted and compared with that of natural coarse aggregate (NCA) in accordance to the Indian scenario. In this context, the primary data during the production process of RCA and NCA are collected from the respective processing facilities. The system boundary of the process is based on cradle-to-gate theory. The LCA analysis is conducted using SimaPro platform and Ecoinvent 3.1 database. The environmental impacts are estimated using Impact 2002+ methodology, which are represented in impact category as well as damage category. Both in NCA and RCA, transportation is the major contributor in each of the impact categories, which is followed by the impact due electricity consumption. It is observed that, for the considered transport scenario the processed RCA can be transported to a higher distance NCA. The analysis shows that, the initial transport distance of raw materials (basalt or C&D waste) highly influences the transport distance of the end product (NCA or RCA).

Keywords: Recycled Coarse Aggregate, Life Cycle Assessment, Cradle-to-gate, Impact 2002+

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INTRODUCTION

Concrete is the second most consumed material in the world after water [1,2] and approximately 70 to 80% of the total volume of concrete is occupied by aggregates [3,4], which is mined from nature. India being a developing nation invests about 10% of the total GDP on construction activities [5]. A downside to the construction activities, enormous construction and demolition (C&D) waste is generated, which is approximately 30 – 35% of the total global waste [6,7]. Moreover, approximately 25 – 35% of the C&D waste comprises of waste concrete. The consumption of non-renewable natural resources by concrete industries for aggregate can be minimized by replacing natural aggregate with suitable qualified material. In this context, the recycled aggregate extracted from waste concrete is a viable and sustainable alternative. In addition, the problems associated with the landfilling of C&D waste can be overcome.

About 7% of the total global energy is consumed in the extraction, processing and handling of the raw materials used for concrete preparation [8]. Moreover, in construction industries about 40% of the total energy consumption is inflicted by the transportation activities involved in the raw materials extraction and preparation and their supply to the concrete batching plant [8,9]. The extraction and processing of RA from C&D waste is different with respect to the natural coarse aggregate (NCA) and consequently, the consumption of energy and natural resources will not be similar. Hence, it is an imperative task to conduct the Life Cycle Assessment (LCA) of the production of RA and compare it with the LCA of NCA production. As LCA is a standard protocol to assess the environmental impact of a product or system according to ISO [10,11], it will help to understand the scope of utilizing RA as a replacement of NCA from the environmental prospects.

According to the scope of the present study, the comparative LCA studies on the extraction of recycled coarse aggregate (RCA) from C&D waste and processing of NCA is discussed in this paper. The study of Simion et al. [12] revealed that, the CO_2 emission in the processing of RCA is seven times lower than NCA production. Coelho and de Brito [13,14] reported about 10 times and 8 times less CO_2 eq emissions and energy consumption, respectively due to the replacement of RA with virgin aggregate. The environmental impact by the recycling facility is mainly dependent on its production capacity and the transportation facilities. In this context, Coelho and de Brito [13,14] suggested for larger capacity of recycling plant and alternative and optimized transportation facility to the heavy duty diesel powered vehicles. Guignot et al. [15] observed significant reduction in environmental impacts by coupling the RA and cementitious material extraction processes from C&D waste. The greenhouse gases emission is 65% less in RA production as compared to NCA processing and the use of RA saves 58% non-renewable resources [8]. The sensitivity analysis showed that, upto 20% variation in transportation distance of the collection of C&D waste does not influence the environmental impact of RA production with respect to NA processing [8]. Ghanbari et al. [16] considered the scenario in Iran and estimated a reduction of 36% and 30% in CO_2 emission and annual energy consumption, respectively. The research on LCA of the production of NA and RA in Brazil showed lower environmental impacts for the latter case [17]. Moreover, the sensitivity analysis indicates that, the recycling plant farther upto 20 tkm distance than the NA production facility imparts lesser environmental impacts [17].

India generates approximately 25 – 30 million tonnes of C&D waste and only 5% of it is processed to extract RA [18]. Hence, the RCA processing scenario in India is different to that discussed in the earlier research in terms of transport distance of C&D waste, recycling facility and transport distance of the processed RCA. Consequently, the LCA of NCA production and RCA extraction from C&D waste considering different transport scenario usually experienced in India are compared. The system boundary of the present study includes the inventory for the production of NCA and processing of C&D waste to extract RCA, which is based on the cradle-to-gate theory.

METHODOLOGY

ISO 14040 (2006) [10] and ISO 14044 (2006) [11] specified the guidelines to conduct the LCA of a product or system to measure its environmental impacts during the life cycle of the same. The analysis is conducted in following four defined steps; i.e. (1) goal and scope definition, (2) creation of life cycle inventory (LCI), (3) assessment of the environmental impacts, and (4) interpretation of the results.

Goal and Scope Definition

Based on cradle-to-gate theory the present study aims to: (a) establish a LCI for NCA and RCA production in India based on the data collected from a representative basalt quarry and recycling plant, respectively, and (b) assess the environmental impacts of NCA and RCA preparation by conducting the comparative LCA study.

Functional unit

The functional unit of the assessment of the present study is the production of 1 t of NCA and RCA.

System boundaries

The stages considered within the system boundary to prepare concrete are, (a) extraction and production of raw materials, (b) transportation of raw materials to the processing or crushing plant, and (c) preparation of NCA and RCA at the crushing plant and recycling plant, respectively. The system boundaries for NCA and RCA preparation are illustrated in Figure 1 and Figure 2, respectively. The data considered to assess the environmental impact for the processing of NCA and RCA are discussed in the following sections.

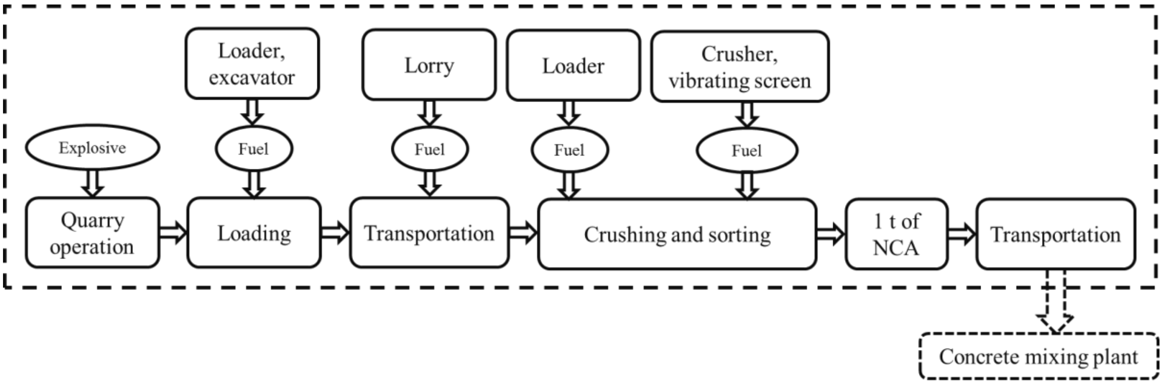

Figure 1 System boundary of NCA preparation

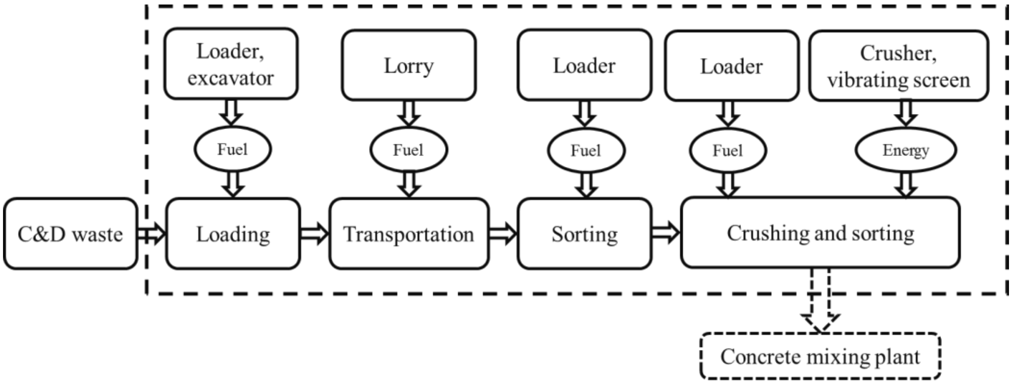

Figure 2 System boundary of RCA preparation

Assumptions:

a) The C&D waste are generated by both natural process or artificial activities. Hence, the stages involved in the C&D waste generation are not accounted.
b) The recovery and recycling of steel scrap are not accounted in the present study.
c) Transportation within the NCA processing plant and recycling plant is not considered.
d) The reclamation ratio (recycled coarse aggregate : recycled fine aggregate) is 60:40.
e) The material losses during the processing of NCA and RCA are minimal and hence, this burden is not considered in this study.
f) The dust emission during the processing of NCA and RCA are not accounted owing to the lack of information provided by the respective companies.

Life Cycle Inventory (LCI) Data

The Life Cycle Inventory (LCI) is a list of inputs in terms of raw materials, energy and fuel and outputs in terms of emissions to the air, water and land within the system boundary to process each functional unit [17,19]. The LCI for the production of NCA and RCA are prepared by collecting the necessary data from the crushing plant and recycling plant, respectively. However, the LCI for fuel (diesel), electricity, water consumption, loading operation (loader or excavator) and transportation (lorry) are obtained from Ecoinvent 3.1 database. The details of the direct burdens (consumption of explosive, diesel, electricity and water) during the production of NCA and RCA are reported in Table 1.

Table 1 Direct burdens for production of 1 t of aggregate

TYPE OF AGGREGATE	PROCESS	EXPLOSIVE (G)	DIESEL (MJ)	ELECTRICITY (KWH)	WATER (KG)	DISTANCE (TKM)
NCA	Extraction of basalt	150	1.67	-	-	-
	Truck loading	-	4.24	-	-	-
	Transportation	-	-	-	-	5
	Crushing and screening	-	-	2.72	3	-
	Storing in open air pile	-	2.88	-	-	-
RCA	Transportation	-	-	-	-	35
	Feeding of waste concrete	-	3.6	-	-	-
	Crushing and screening	-	-	2.13	5	-
	Storing in open air	-	4.32	-	-	-

pile

Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment (LCIA) phase estimates the magnitude of the environmental impacts and resources used for the specified LCI phase, which includes the following three basic steps specified in the ISO [10,11]; (1) selection of the impact categories, (2) classification and characterisation of the assigned LCI to the selected impact categories, and (3) conversion into indicator result by aggregating the LCI results [8,19].

The two approaches for the impact assessment are; (1) problem-oriented mid-points approach, and (2) damage-oriented end-points approach [8,19]. In the present study Impact 2002+ method is used to assess both the impact and damage caused by the inventory by using the SimaPro software which contains Ecoinvent 3.1 database. In the impact category the environmental impact is measured in terms of carcinogens (kg C_2H_3Cl eq), non-carcinogens (kg C_2H_3Cl eq), respiratory inorganics (kg PM2.5 eq), ionizing radiation (Bq C-14 eq), ozone layer depletion (kg CFC-11 eq), respiratory organics (kg C_2H_4 eq), aquatic ecotoxicity (kg TEG water), terrestrial ecotoxicity (kg TEG soil), terrestrial acid/nutrition (kg SO_2 eq), aquatic acidification (kg SO_2 eq), aquatic eutrophication (kg PO_4 P-lim), global warming (kg CO_2 eq), non-renewable energy (MJ) and mineral extraction (MJ), whereas human health (DALY), ecosystem quality (PDF m^2 yr), climate change (kg CO_2 eq), and resources (MJ) are the damage category indicators.

RESULTS AND DISCUSSION

The different transportation situations and distances (km) experienced in the present study during the production of NCA and RCA respectively from basalt and C&D waste are discussed in Table 2.

Table 2 Actual transportation distances of different raw materials in the present study

MATERIAL	FROM	TO	DISTANCE (km)	VEHICLE TYPE
Loose basalt	Mine	Crushing plant	5	16 – 32 t
NCA	Crushing plant	Concrete batching plant	50	7.5 – 16 t
C&D waste	Demolition site	Recycling plant	35	16 – 32 t
RCA	Recycling plant	Concrete batching plant	25	7.5 – 16 t

Interpretation of Results

The contribution of different inventory for the production of 1 t of NCA and RCA on discussed impact and damage categories are depicted in Figure 3 and Figure 4, respectively. It can be observed that, for both NCA and RCA production the major environmental impact is caused by the transportation activities. In the impact categories the transport activities contribute 53%-90% and 63%-95%, respectively for NCA and RCA production. In this context, terrestrial ecotoxicity is the most affected category, whereas aquatic eutrophication is the least affected category due to the transportation activities. After transportation activities, the consumption of electricity is the major contributor in most of the impact category parameters. Aquatic eutrophication, respiratory inorganics, global warming and aquatic acidification are the impact category parameters affected significantly by electricity consumption. Mineral extraction, non-carcinogens and carcinogens impact category parameters are affected by the use of explosive for basalt extraction. Apart from aquatic ecotoxicity impact parameter, the influence of water is negligible for the production of NCA and RCA.

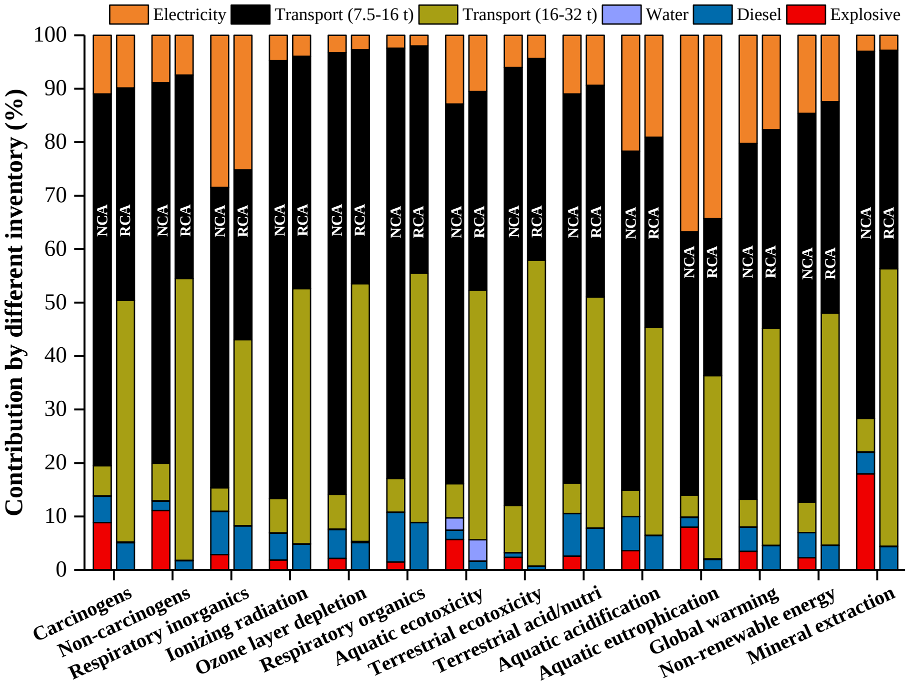

Figure 3 Contribution by different inventory to the impact category

Similar to the impact category, the damage category parameters are affected mostly by the transportation activities and followed by electricity consumption (Figure 4). The influence of the use of explosive and diesel for the production of NCA and RCA is minimal.

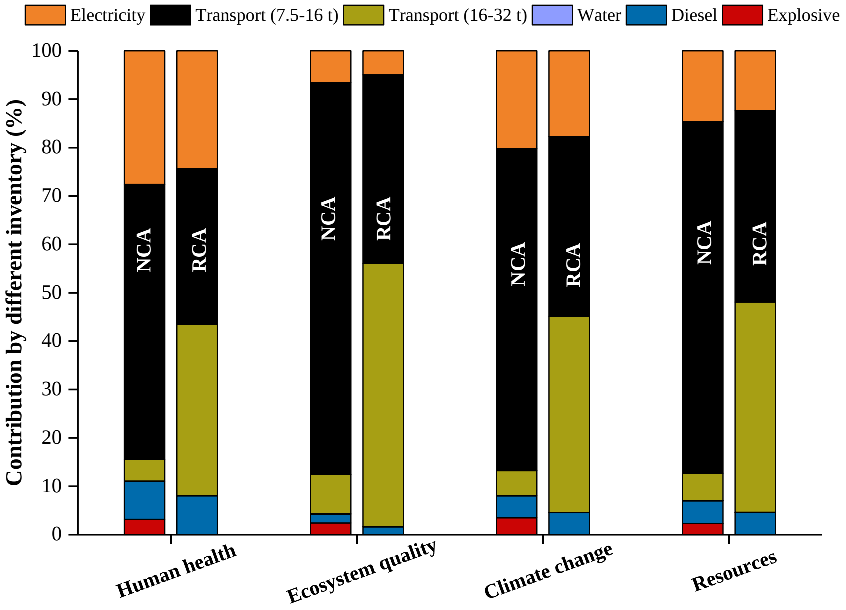

Figure 4 Contribution by different inventory to the damage category

CONCLUSIONS

The study assessed the environmental impacts of concrete using CML baseline method and the comparative analysis was conducted by considering two types of coarse aggregates (NCA and RCA) and two mix design methods (IS code method and PPM). Following conclusions can be highlighted from the present study.

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