CHAPTER 5
Life Cycle Assessment Analysis and Utilization Feasibility in Concrete

5.1 Introduction

Last two chapters deal with the research work done to assess the characterization of FA and CT and their possible leaching effects. Both materials are the byproduct/wastes; one is generated after the burning of coal in thermal power plant, and the other one is generated during processing at copper mining. One can suggest applying limitation on the production of both to reduce the generation of FA and CT at the source. However, electricity is very much essential, and we cannot think about our world without it. Copper is the second-highest conductor of electricity after silver. It possesses an excellent corrosion resistance, malleability, ductility and can serve in different industrial requirements. It is widely used in electrical wiring, printed circuit boards, microchips, semiconductors, etc. Copper can also obstruct the growth of bacterial and viral microorganism in the water. Easy soldering and the malleability make it a good material for tube making. These tubes are widely used in heat exchangers in the refrigeration and cooling system, seawater feed lines, fuel gas distribution, etc. However, on the opposite side, CT, the uneconomical discarded fraction of copper dumped in improperly managed waste sites, is a serious environmental problem.

Hence an economically feasible and sustainable utilization of both FA and CT will help to overcome the ill-effects caused by the heaps of both FA and CT. Fly ash is extensively used in many different applications as an adsorbent, lightweight building blocks, mine backfilling, road base/subbase, liner in landfills, soil amendment, cement manufacturing, waste stabilization, mineral resources, etc. A few uses of copper tailings were also identified in concrete (as fine aggregates), recovery of metals, manufacturing of bricks. There are many earlier attempts made by the researchers to find the feasibility of both, FA and CT individually in the concrete manufacturing but the studies on the combined effect of both FA and CT on concrete as a partial replacement of cement are meager.

Both FA and CT waste materials are enriched with pozzolanic constituents (i.e., silica, alumina, and iron oxide), and can be used in the manufacturing of concrete by replacing cement partially.

The optimal utilization of FA and CT will not only be useful to reduce cement requirement in the construction industry and infrastructure development but also beneficial for the surroundings to maintain a better environment (Schuhmacher et al., 2004). About 40% of the greenhouse gases are released through the development of the built environment (Vieira and Horvath, 2008; BED, 2011). Concrete, a key part of the built environment contributes about 5% of the total worldwide emission (CIE, 2009), chiefly in the processing of clinkers in the manufacturing process of cement. The production of cement is a very much energy-intensive and play a major part in the production part of cement. In clinker processing, many different types of fossil fuels, as well as biomass fuels, are used. It generates a large volume of CO_2 and accounts for about 5-7% global anthropogenic CO_2 emissions (Chen et al., 2010). Cement kiln dust also contributes to the respiratory problem and other adverse health impacts. Fig. 5.1 gives a country-wise global division of cement production.

Concrete, at the micro-level, considered as a heterogeneous mixture of cement, sand, aggregate, and water. Hence it is essential to perform cause-effect analysis associated with the manufacturing of concrete scientifically. In this regard, life cycle assessment (LCA) method demonstrates very proven results (Bhakar and Singh, 2018). It facilitates a diverse, accurate, and quick estimate of the environmental impact of material while considering all its constituent associated with the process of procurement, transportation, manufacturing, utilization, and disposal. Nisbel et al. (2000) and Corinaldesi (2010) have defined life cycle inventories for different kinds of Portland cement concrete and performed LCA analysis. Knoeri et al. (2013) have studied the effect of individual units of production of concrete using LCA from transportation, manufacturing, utilization, and demolition. Although wide ranges of studies have also been conducted to investigate the feasibility of utilization of FA and CT, most of them are confined to assess the effectiveness of individual waste material. In the current chapter, an overview of LCA processes is presented, followed by the utilization feasibility of FA and CT in the concrete as a partial replacement of cement by analyzing the characterization results. Before the casting of cubes physically, the environment impact of the modified concrete has been evaluated using life cycle assessment. The LCA of modified concrete is essential as the abundance of these waste materials in the world market is increasing exponentially.

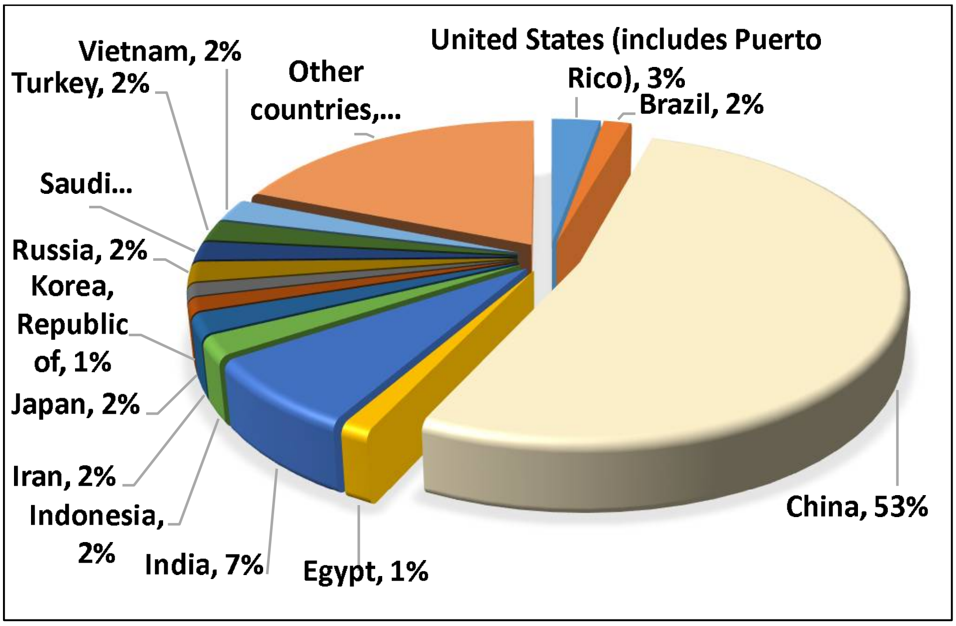

Fig. 5.1 Production of cement in different countries (USGS MCS 2019)

5.2 Life Cycle Assessment

Life Cycle Assessment (LCA), according to ISO 14040, is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle It is a tool to analyze the environmental effect of the material/product throughout its life. The process starts from procurement of material from the resources to the production of individual material used in different parts of the product followed by manufacturing of different parts of the product than the development of the final product, utilization of the product than followed by its usage, by reusing, and recycling or by disposing of the end waste. It consists of four main steps; (a) defining the goal and scope of the analysis; (b) inventory analysis; (c) impact assessment of the process; and (d) analysis of the results. This methodology was initiated in 1991 by the Society for Environmental Toxicology and Chemistry (SETAC). As per Pinheiro (2006), the LCA serves the following purposes:

A. To assess the impact on the environment (EI) from a specific product, any process, or any activity through the identification and quantification of energy consumption and adverse emissions to the environment.

B. To identify and compute alternate plans and opportunities for environmental improvement.

While applying LCA, the goal and scope of the analysis need to be defined first. It is also an essential step to specify the degree and depth of the accuracy along with the purpose of the model that it needs to serve. The main criteria should also be identified so that a proper framework can be developed to help the decision-makers. It is followed by prescribed boundaries of the system for the specific field of study. In the next phase, the Lifecycle Inventories Analysis (LCI) is computed. During the process, all the available inputs are fed, and outputs are evaluated in terms of energy and materials.

A flow chart showing all the processes in the entire life span of the product in a tree form has been prepared. Energy and material for every individual process at each of the stage is required. All the input and output parameters are also needed to be traced. Calculation of the impact assessment about its characterization and severity of the specific environmental condition has been considered. Different LCI indicators have been grouped inappropriate category of the specific environment like a greenhouse gas, ozone layer depletion, damage to human health, etc. In the next stage, appropriate decisions are made by concluding the results of the analysis. The results and decisions are used to compare different product or the manufacturing processes, and this can be an initial deciding factor to identify optimal product or process. The last step in LCA deals with the interpretation of associated results. The conclusions and recommendations are suggested based on the results of LCI and impact assessment.

There are different approaches of LCA which are commonly used in practice (Kurda et al. 2018). These approaches are:

A. Cradle to gate: This approach deals with the partial life cycle assessment of product from its extraction to the place (factory) from where it is transported to the consumer. The disposal and utilization part is not covered in this process (Franklin Associates, 2010).

B. Cradle to grave: It is a primary generic LCA approach that includes extraction of raw materials, quantification of energy utilized, production of material, utilization, recycling and finally disposal (Rebitzer et al., 2004).

C. Cradle to cradle: Cradle to design gives an alternative method of production and design to approach zero-emission and to reduce the intentionally or unintentionally negative impacts in the production and consumption phase (Braungart et al., 2007).

The LCA results facilitate a very heterogeneous audience which is working to manage with environmental-related challenges. The people involved in the process are the decision-makers coming from different backgrounds (scientific standards forming persons, urban planning teams, green building standards developing persons, and construction industries, etc.). Along with that, the material manufacturers are also taking part in the process, who are very eager to facilitate material with a reduced carbon footprint. LCA is very much needed for these material manufacturers to produce greener material (concrete) and to remain competitive in the environment point of view. The LCA process is very diverse, and its accuracy is very much dependent on how much details of the input and output data (volume, mass, energy) are being used while compiling the life cycle inventory (LCI). If the input data is misleading, less accurate or insufficient, the LCI is unable to facilitate reliable LCA results. It can easily be said that the credibility of LCA is entirely dependent on the accuracy of life cycle inventories. A progressive development along with awareness for global environmental protection leads to the initiate many different approaches, concepts, and tools to assess the environmental impact assessment of any product from its production, transportation, utilization to disposal. A summary of the steps followed in LCA is detailed in Fig. 5.2 and it is a widely accepted tool to serve the above-said purpose.

In the current work, LCA is utilized in the manufacturing of concrete; therefore, the cradle to grave analysis is followed to define the impact on the environment. The main steps followed in the study are given as below:

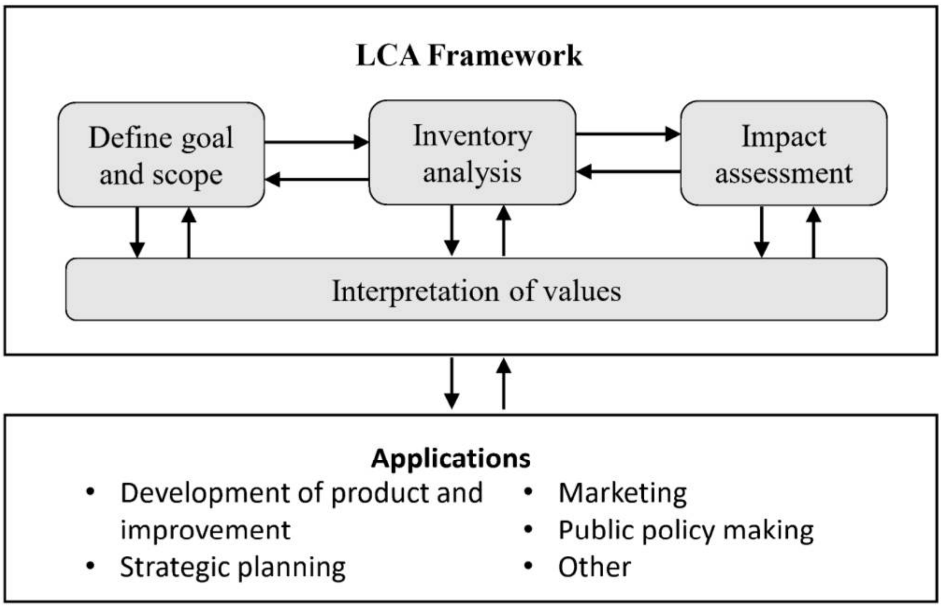

Fig. 5.2 Different steps of LCA and applications (ISO 14040, 2006).

A. Raw material procurement: It contains the consumption of resources, energy, and material during extraction and transportation.

B. Manufacturing: It includes the processing of raw material to make the usable product by taking into consideration of fabrication, cleaning, and transportation to the final user.

C. Utilization, maintenance, and re-utilization: This contains the quantification of the activity and utilization part of the product.

D. Recycling and disposal: The impact due to the disposal of the waste is evaluation in this step.

5.2.1 Brief Description of midpoint and endpoint

Mid-point characterization factors are the pre-defined interlinked cause-effect chain for the impact parameters before the endpoint analysis (Bare et al., 2000). These midpoints are analyzed to reveal the relative values of different emissions. Most commonly used midpoint characterization factors are global warming potential (GWP), damage to human health, ozone layer depletion, photochemical smog, etc. Characterization factors of endpoints are calculated to assess the relative variation in the cause-effect chain and give a ready reckoner to show a direct impact on the society from the whole life cycle of the product.

Different midpoint characteristics are calculated in the form of an equivalent unit of specific pollutants and energy. However, the endpoints are derived score points, calculated based on the impact of midpoint characteristics.

5.3 LCA in Concrete

LCA method is very proven to handle a high volume of concrete production and the native environment issues. The general layout followed in the cradle to grave approach in LCA processes for the concrete mix design is detailed in Fig. 5.3. There are three primary inputs into the system, which are raw material, electricity, and water.

The raw materials themselves may directly put an impact on air, surrounding soil, and water. Further, the constituents of concrete are processed, i.e. cement production, aggregate production, admixture reduction, and processing of secondary cementitious material (SCM). After preparation, the above constituents are sent to the concrete mixing plant, and final concrete is prepared according to the mix design of the requisite strength. For cradle to grave approach following are the midpoint factors considered:

A. Climate change: This midpoint factor is used to assess Global Warming Potential (GWP). It is represented in kg CO_2 equivalent (IPCC, 2013).

B. Human Toxicity: This factor is used to find out the effects of chemical emission on human toxicity, freshwater eco-toxicity, and marine eco-toxicity. It is measured in terms of kg 1,4 DCB (para-dichlorobenzene, p-DCB) equivalent. This p-DCB is generally used to control the insects and fungus and as a bathroom deodorizer. However, it adversely affects the health as it carcinogenic and damaged the liver and kidney also (Krieger, 2010). The human factor considered for the carcinogenic effect, eco-toxicity effect, changes in the nature and existence of the different species (Van Zelm et al., 2009).

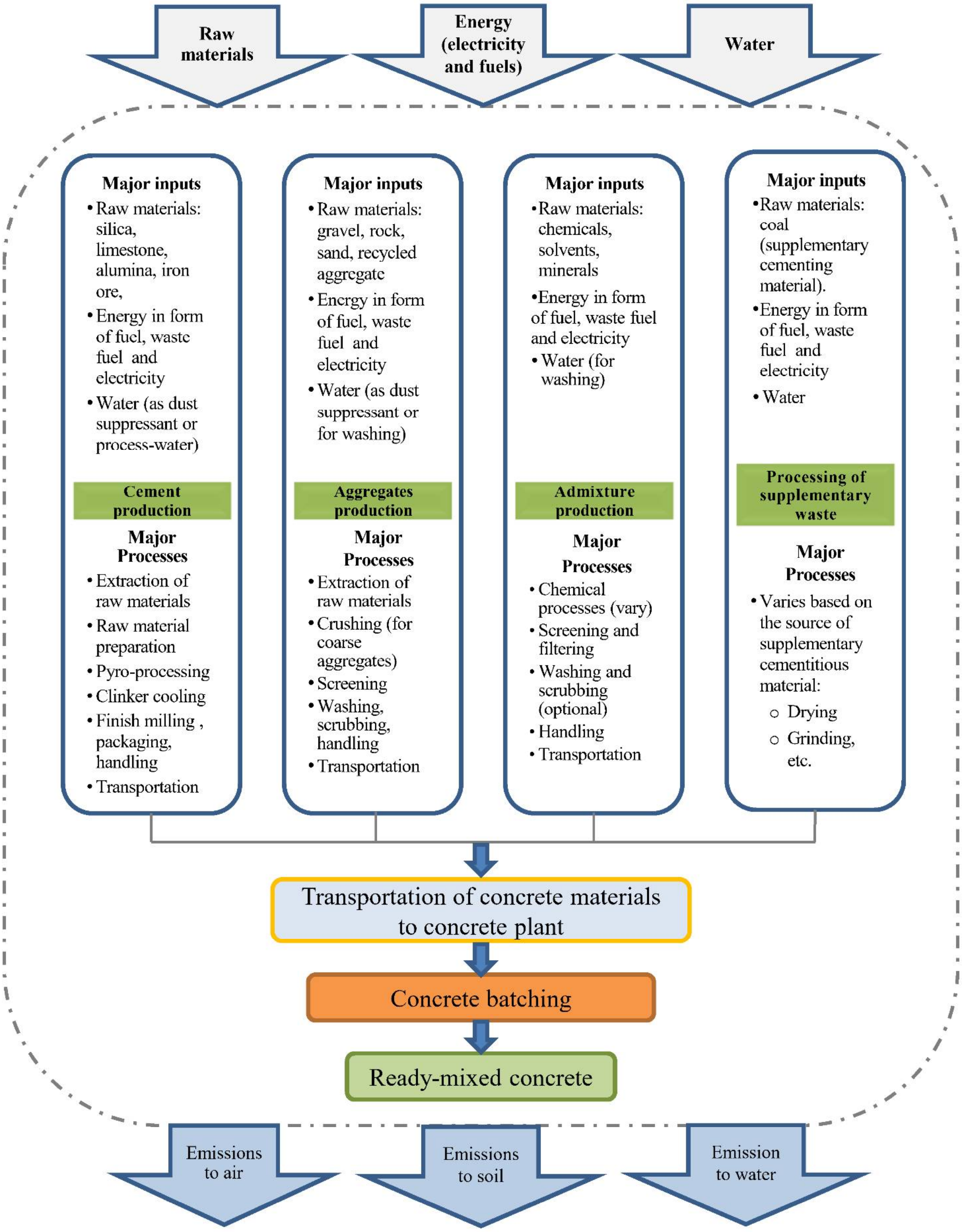

Fig. 5.3 General procedure followed for cradle to grave approach in LCA to produce mixed design concrete (Gursel et al., 2014)

C. Ozone depletion potential (ODP): This midpoint factor is expressed in terms of CFC-11 (trichlorofluoromethane) equivalent. The CFC-11 used predominantly as a propellant in the sprays, as a refrigerant, as a solvent and blowing of foams, etc.

D. Change in the concentration of ozone in the stratosphere for a long duration of time is considered in this category (WMO, 2011).

E. Agriculture land occupation: This is selected based on the loss of different species due to land use. It is measured in terms of m^2 yearly annual crop equivalent (Curran et al. 2014).

F. Water Depletion: This characterization factor is measured as how much is the water (in m^3) consumed for each m^3 of water extraction. Based on the study by Hoekstra and Mekonnen (2012), appropriate assumptions are formalized for the industries.

G. Fossil Depletion: The fossil depletion is measured in kg of oil equivalent, which also termed as Fossil Fuel Potential (FFP). It is evaluated by dividing the heating value of fuel with its energy content (Jungbluth and Frischknecht, 2010).

H. Particulate matter: The Particulate matter midpoint characterization factors considered as a kg of $PM_{2.5}$ equivalent. It is derived by measuring the deviation in the ambient PM_5 concentration as a result of the disposal of precursors like NO_3, NO_x, SO_2 (Van Zelm et al., 2016).

I. Metal depletion potential: It is expressed in kg Fe equivalent. It is the amount of metal produced per kg of metal extracted (Van Zelm et al., 2017).

5.4 LCA Process Followed in the Research Work

In the current work, UMBERTO NXT tool has been used to perform LCA analysis. Both FA and CT have been considered as the inert material. It has been assumed that the density of the concrete remains uniform and the whole mass was considered as inert waste after its service life is over. In all the calculations, one cubic meter for materials in concrete and one kWh for power is taken as the functional unit.

From the literature and standards, it has been suggested that the maximum replacement limit of cement with FA should be 30% of cement. This replacement marginally increases the compressive strength of concrete, and beyond 30% replacement of cement, the strength of concrete has been found to reduce. If CT alone is used to replace cement in concrete partially, the compressive strength of mix reduces as the proportion of CT increases. It is mainly due to the low reactiveness of tailings particles (Kundu et al., 2016). Optimum partial replacement of CT is 10% of cement in concrete to get acceptable compressive strength as suggested by Kundu et al. (2016). Taking the guidance from earlier findings of researchers and code provisions, the categories for replacements are as follows: M1 (FA 10% and CT 5%), M2 (FA 10% and CT 10%), M3 (FA 20% and CT 5%), M4 (FA 20% and CT 10%), M5 (FA 30% and CT 5%), and M6 (FA 30% and CT 10%) for two different water-cement ratios 0.45 and 0.5 according to IS 10262:2009. Considering 30 MPa target strength of concrete as per IS 10262:2009, 14 mix design proportions (12 modified mix proportions + 2 control mix) have been considered as given in Table 5.1.

The analysis is performed for all mix proportions (M1-M6 and control mix) for each of the water-cement ratio (0.45 and 0.5). Eco inventory 3.0 dataset available with the UMBERTO NXT tool has been used to consider inventory data for cement, gravel, sand, water, inert waste, and electricity production. The Life cycle inventory (LCI) model for LCA analysis is shown in Fig. 5.4. This framework is divided into three sections, viz. raw material, manufacturing process, and waste disposal. In the raw material section, cement, sand (fine aggregates) and gravel (coarse aggregates), used to produce concrete, are defined through process T1, T2, and T3, as shown in Fig. 5.4. P1, P4 and P7 (represented with a green circle) show the input for the initial phase of the processes T1, T2, and T3. P3, P6 and P9 are the end of the process and show the fraction of disposal of wastes during the above processes. Fly ash, copper tailings, and the admixtures are considered as inert material which is an essential component of the raw material section (shown by P10, P11 and P12). Next step in the model is the manufacturing section where “T” represents the concrete manufacturing process in which appropriate raw material quantity is mixed with water as per the mix design of concrete. Process for water is defined by T4, and electricity consumption for mixing is shown as T5.

Table 5.1 Mix design details of different proportion used for casting concrete cubes of target compressive strength of 30 MPa

Quantity of water, cement, sand, FA, CT, aggregate, and admixture for one cubic meter of M30 grade concrete

Category of Sample	Water binder ratio	FA (% of Cement)	CT (% of Cement)	Water (in kg)	Cement (in kg)	FA (in kg)	CT (in kg)	Admixture (in kg)	Coarse Aggregate* (in kg)		Fine Aggregate (in kg)
									10 mm	20 mm	
1	0.45	10	5	157.80	298.07	35.07	17.53	1.75	484.03	726.04	773.65
2		10	10	157.80	280.54	35.07	35.07	1.75	484.08	726.13	773.74
3		20	5	157.80	263.00	70.13	17.53	1.75	480.30	720.46	767.70
4		20	10	157.80	245.47	70.13	35.07	1.75	480.36	720.54	767.79
5		30	5	157.80	227.94	105.20	17.53	1.75	476.58	714.88	761.75
6		30	10	157.80	210.40	105.20	35.07	1.75	476.64	714.96	761.85
7	0.5	10	5	160.00	272.00	32.00	16.00	1.60	481.44	722.17	802.41
8		10	10	160.00	256.00	32.00	32.00	1.60	481.50	722.24	802.49
9		20	5	160.00	240.00	64.00	16.00	1.60	478.10	717.16	796.84
10		20	10	160.00	224.00	64.00	32.00	1.60	478.16	717.23	796.93
11		30	5	160.00	208.00	96.00	16.00	1.60	474.76	712.14	791.27
12		30	10	160.00	192.00	96.00	32.00	1.60	474.82	712.22	791.36
C1	0.45	Control Mix		157.80	350.67	-		1.75	487.69	731.53	779.50
C2	0.5			160.00	320.00			1.60	484.73	727.10	807.89

*The coarse aggregate of size 10 mm and 20 mm are taken as 40 % and 60% of the total weight of the coarse aggregate.

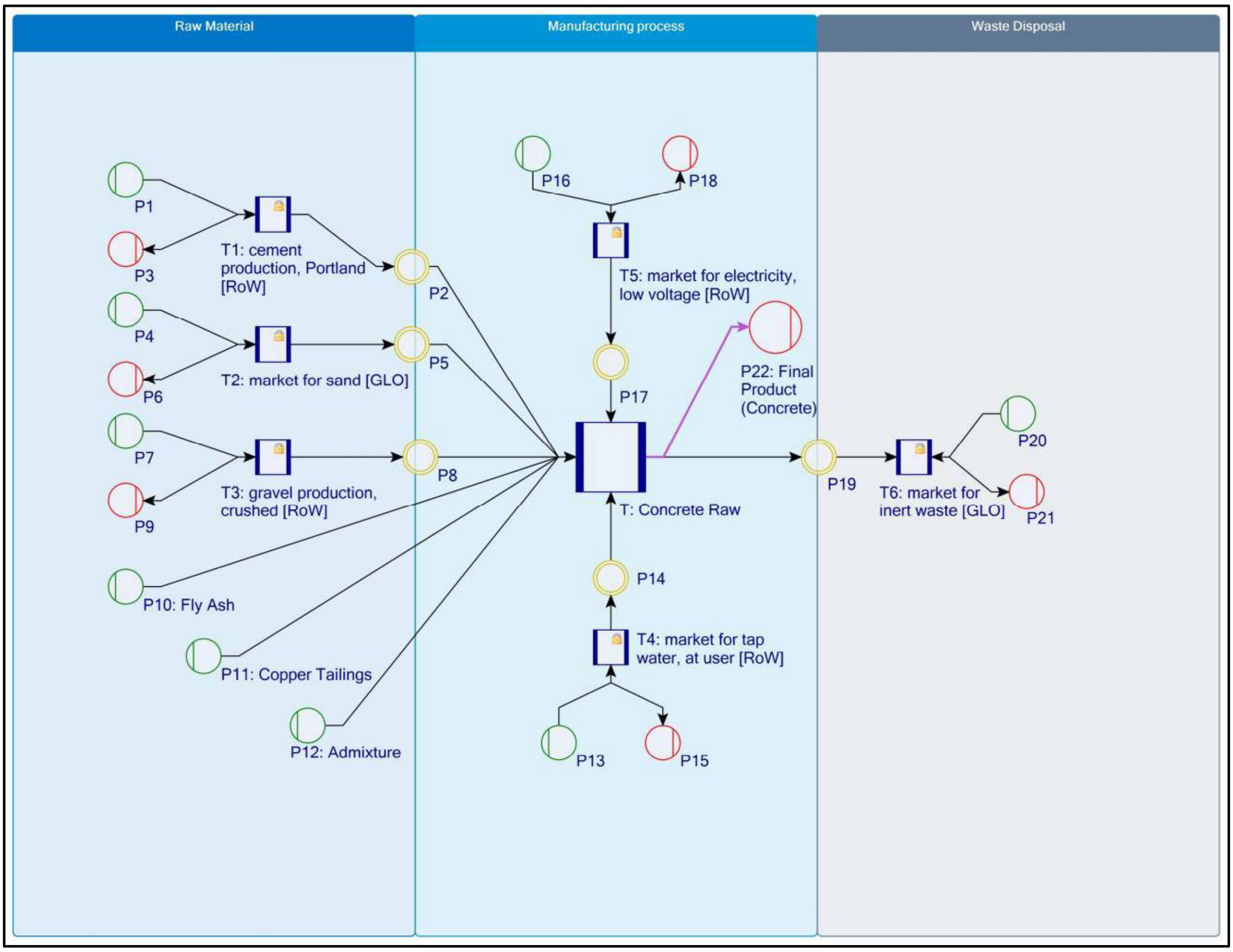

Fig. 5.4 Framework of LCA analysis used in the study

The consumption of electricity is uniform as it has been used only for the mixing of concrete with equal mixing time for all mix proportions. Final produced concrete is shown in the manufacturing section denoted as P22. After the completion of the service life of concrete, it has been treated as an inert waste which is shown as process T6 in the waste disposal section.

5.5 Results and Discussion

Results of environmental impact assessment analysis using LCA technique have been summarized in the form of bar chart as shown in Figs. 5.5 to 5.26. As the production of cement is one of the major contributors of CO_2 emission among all others, being a significant greenhouse gas, resulting in an adverse effect on climate and human along with an increase in global warming potential (GWP). The inert concrete waste disposal has no severe impact on midpoint attributes except particulate matter and metal depletion. Equal consumption of electricity in concrete preparation is also not giving any variation in midpoint environmental impact for all the mix proportions. However, the reduction of the quantity of cement in the raw material results in a very significant decrease in ozone layer depletion, climate change, and decrease in human toxicity effect. This variation in climate change further leads to a decrease in the water and fossil fuel depletion and the occupation of agriculture land. The detailed midpoint results, shown in Fig. 5.5 to Fig. 5.20, summarize the effect on climate change, human toxicity, ozone depletion, agriculture land occupation, water depletion, fossil depletion, particulate matter, and metal depletion potential due to the different modified concrete mix proportions.

5.5.1 Midpoint factors of LCA results

In Fig. 5.5 and Fig 5.6, results of midpoint life cycle assessment of climate change for concrete at w/c ratio 0.45 and 0.5 are presented. The climate change factor is influencing the GWP and represented in kg CO_2 equivalent. The kg CO_2 eq is nearly same, about 36 kg for the disposal and about 2.4 kg for all the modified mix as well as control mix due to similar process and an equal amount of consumption of electricity. However, in raw phase, the cement manufacturing part shows a significant variation for both w/c ratios. For control mix the CO_2 eq is 445.63 kg if w/c ratio is 0.45 and 408.92 kg if w/c ratio is 0.5. Successive edition of FA and CT leads to a decrease in CO_2 eq for mix M1. It has been observed that in the modified mix it decreases to 382 kg of CO_2 equivalent in M1 to 275.9 kg of CO_2 equivalent in M6 for 0.45 w/c ratio and 350.85 kg of CO_2 equivalent for M1 to 254.03 kg of CO_2 equivalent for M6 for 0.5 w/c ratio. The GWP is directly or indirectly responsible to increase in a number of diseases, malnutrition, damage to freshwater along with other terrestrial species. The decrease in GWP with partial replacement of cement with FA and CT indicates the positive impact on the environment.

Effect of FA and CT replacement on human toxicity factor are presented in Fig. 5.7 and Fig. 5.8 respectively. This factor shows how the replacement affects human health and causes the carcinogenic problem, ecotoxicology for different ecosystems, and the existence of different species. In this factor, almost no variation observed in all the concrete mix proportions for the disposal phase. However, the disposal of concrete plays a vital role to affect human toxicity as its value is much higher (ranging from 9730 kg 1,4 DCB-eq to 9570 kg 1,4 DCB-eq) which is a cause of concern. In the manufacturing phase, no variation has been observed. About 39.35 kg of 1,4 DCB-eq (i.e., 1,4-Dichlorobenzene-equivalent) has been estimated with respect to both w/c ratios. In the case of raw phase, a notable decrease has been observed ranging from 1543.18 for M1 to 1039.16 for M6 in kg 1,4 DCB-eq for w/c ratio of 0.45. In case of w/c ratio of 0.5, the notable reduction has also been noticed ranging from 1436.59 kg 1,4 DCB-eq for M1 to 976.67 kg 1,4 DCB-eq for M6 are observed.

Ozone depletion potential is defined with reference to a substance which is known as chlorofluorocarbon-11 and is expressed in kg CFC-11-equivalent. An increase in its value will cause a problem in the respiratory system. A higher rate of ozone depletion will cause an increase in the risk for terrestrial species. In Fig. 5.9, and Fig. 5.10 it has been observed that in raw phase there is a significant decrease in CFC-11 release from 12.5% in mix M1 (for both w/c ratio 0.45 and 0.5) to 33% for mix M6 (for both w/c ratio 0.45 and 0.5). However, there is no variation in CFC-11 release has been observed in the manufacturing and disposal phase.

Fig. 5.11, and Fig. 5.12 show the agricultural land occupation factor of midpoint analysis. It is the amount of agriculture or urban area occupied during a fixed period of time. The amount of either agricultural land or urban land occupied in a certain time frame. Change in this factor leads to damage to the terrestrial species. In the disposal phase, there is no significant variation seen for all the mix proportions and w/c ratios. However, In the raw phase, a gradual decrease of annual crop equivalent (m^2 year) has been observed for both the w/c ratios. For control mix, its value for w/c ratio 0.45 has been found 2.64 m^2 year. It decreases to 2.32 for M1 to 1.8 m^2 year for M6 for w/c ratio of 0.45 as shown in Fig. 5.11. In case of w/c ratio of 0.5 value of control mix found as 2.46 m^2 year, which reduced to 2.17 m^2 year for M1 to 1.7 m^2 year for M6 as shown in Fig. 5.12. The values for the disposal phase also decrease, but very marginally (0.5% to 1.5%).

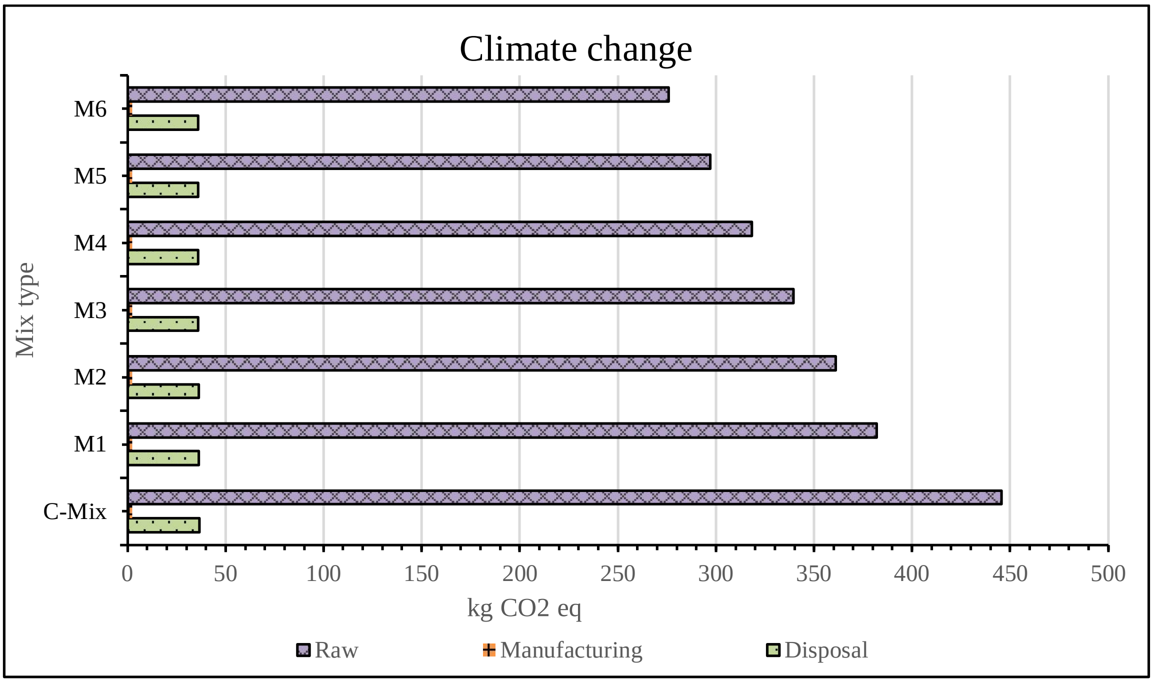

Fig. 5.5 Midpoint life cycle assessment of climate change for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

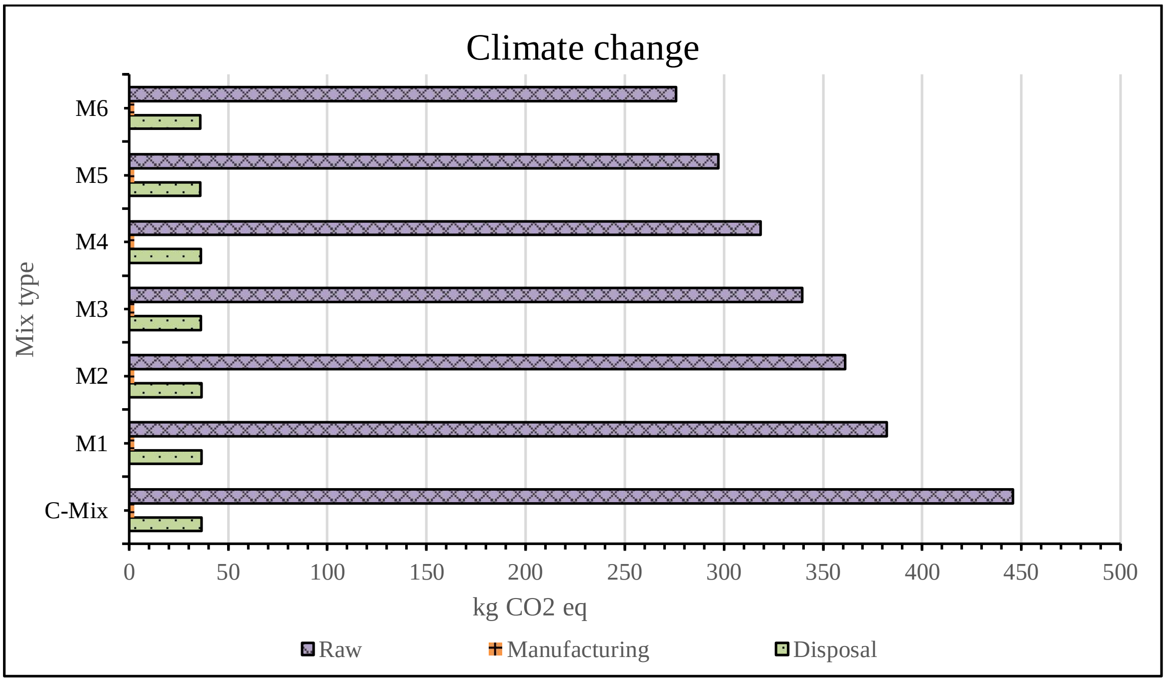

Fig. 5.6 Midpoint life cycle assessment of climate change for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

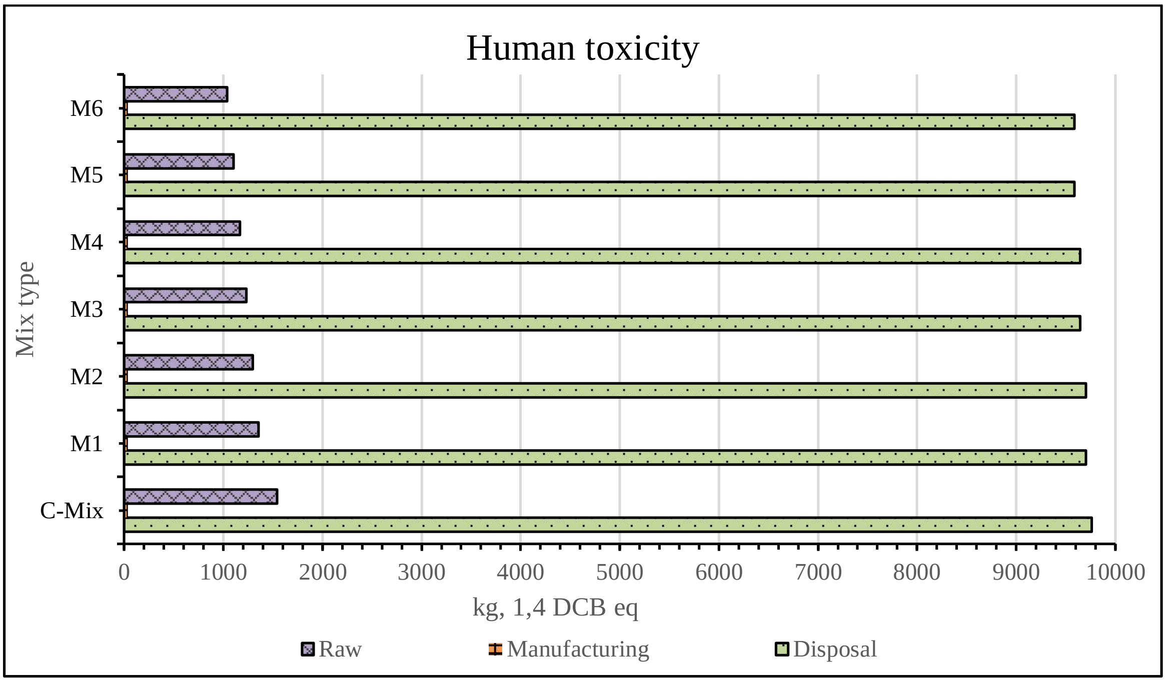

Fig. 5.7 Midpoint life cycle assessment of human toxicity for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

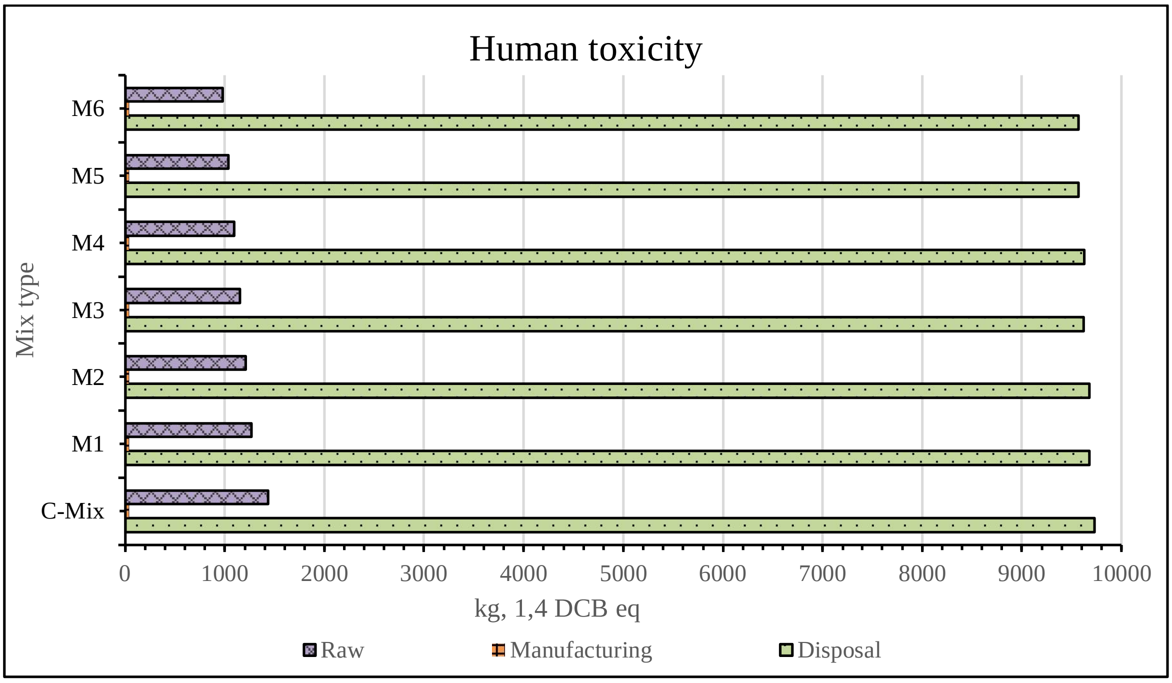

Fig. 5.8 Midpoint life cycle assessment of human toxicity for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

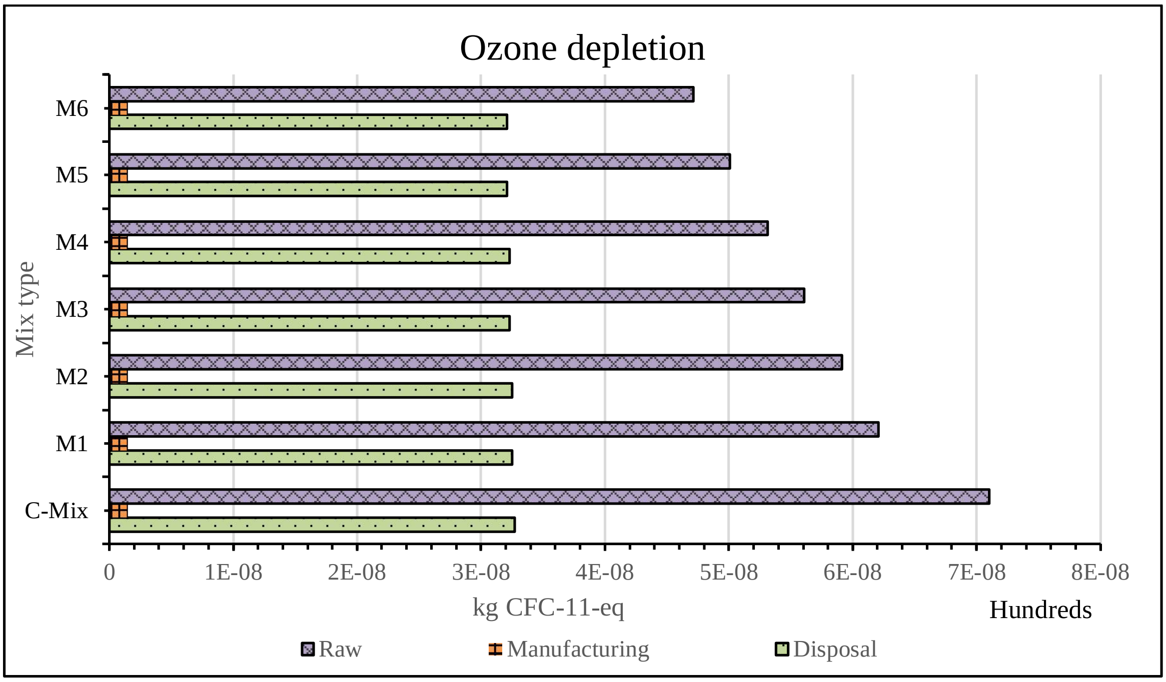

Fig. 5.9 Midpoint life cycle assessment of ozone depletion for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

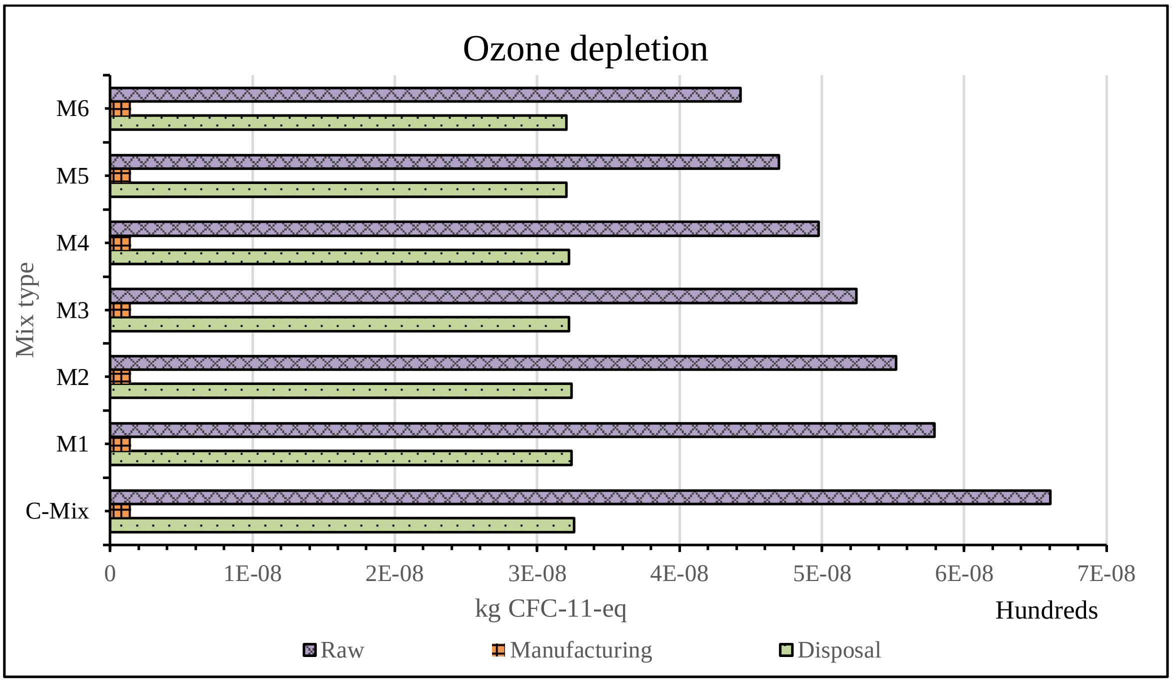

Fig. 5.10 Midpoint life cycle assessment of ozone depletion for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

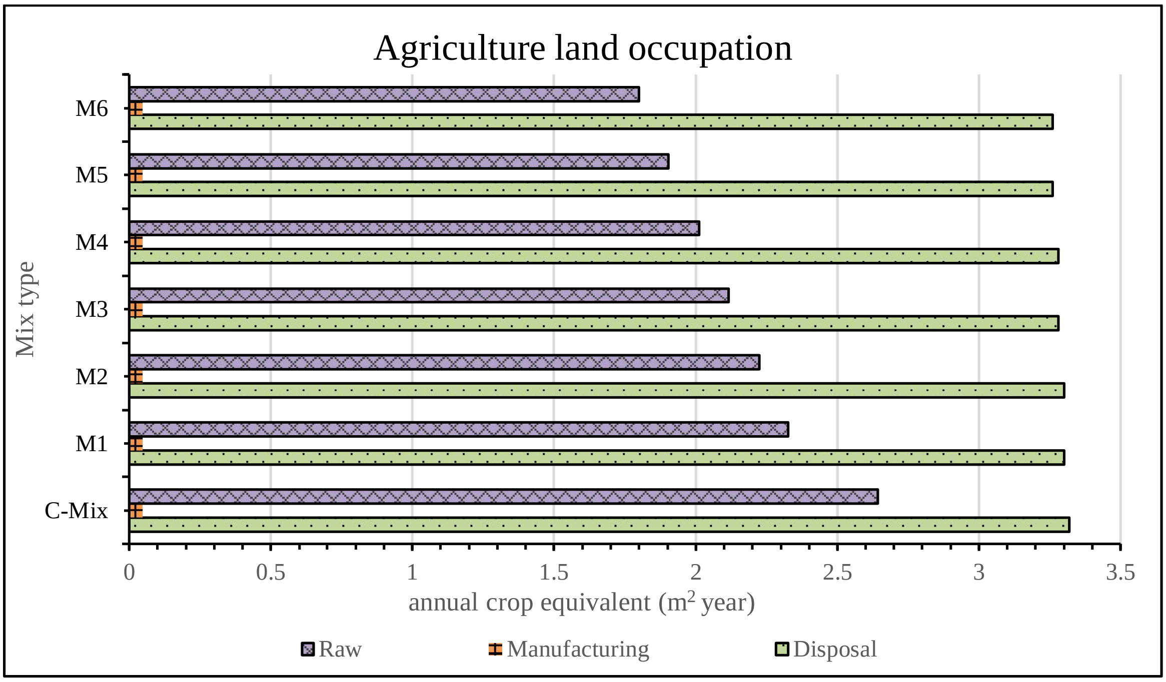

Fig. 5.11 Midpoint life cycle assessment of agriculture land occupation for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

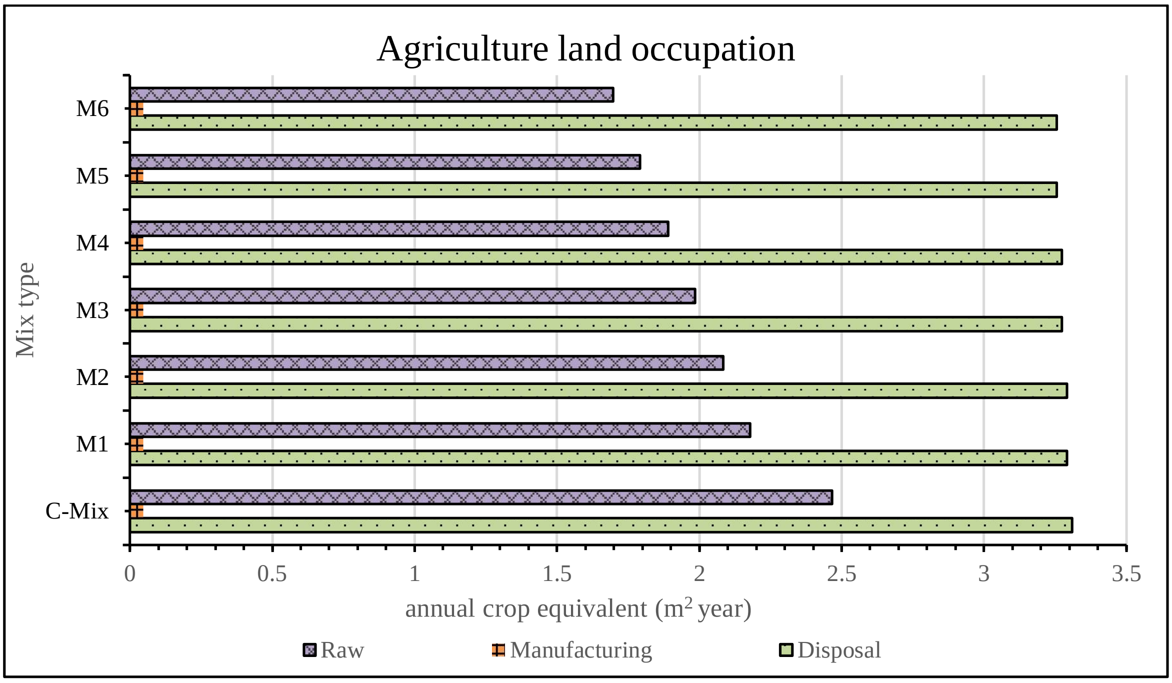

Fig. 5.12 Midpoint life cycle assessment of agriculture land occupation for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

Fig. 5.13, and Fig. 5.14 show the water depletion midpoint factor. It is measured in the volume of water consumed in the cubic meter for each cubic meter extraction. Depletion of water can not only affect all water species adversely at greater extent but also can lead to different water-borne diseases and increase in malnutrition. In the case of raw phase, depletion of water is 0.56 m^3 for control mix at 0.45 w/c ratio and 0.52 m^3 for 0.5 w/c ratio. Water depletion is deceases with the reduction in the cement content from 0.49 m^3 for mix M1 to 0.37 m^3 for mix M6 at w/c ratio of 0.45. For w/c ratio 0.5 water depletion value is 0.45 m^3 for mix M1 which successively reduces to 0.34 m^3 for mix M6. The reduction in water depletion has been observed mainly because a lesser amount of cement is being used in all modified mix. The manufacturing process is affecting the water depletion (about 0.19 m^3) and disposal (about 0.093 m^3) but no impact of modified concrete mixes has been observed for both w/c ratios.

Variation in the results of the midpoint factor with regards to fossil fuel depletion is shown in Fig. 5.15 and Fig. 5.16. This is measured in kg of oil equivalent. The value is nearly equal (0.68 kg-oil-eq) in manufacturing section for all the concrete mixes with respect to w/c ratio values of 0.45 and 0.5. However, the minimal variation has been observed for the disposal section. In the raw section, the value varies considerably with a higher percentage of the addition of FA and CT. In the case of w/c ratio value of 0.45, fossil fuel depletion has been estimated as 51.58 kg-oil-eq for control mix, whereas it reduces in modified mixes ranging from 44.85 kg-oil-eq for M1 to 33.63 kg-oil-eq for M6. For w/c ratio value of 0.5, fossil fuel depletion has been found as 47.79 kg-oil-eq for control mix and reduces to 41.66 kg-oil-eq in M1 to 31.42 kg-oil-eq for M6 in the modified mixes. It is mainly due to a reduction in cement consumption by sustainable utilization of waste materials which is responsible for reducing fossil fuel depletion.

Fig. 5.17, and Fig. 5.18 present the results of the midpoint factor for particulate matter. The disposal section shows a successive reduction with an increase in the percentage of FA and CT content. Particulate matter is measured in PM10-eq, and its higher amount leads to an increase in respiratory diseases. The manufacturing and disposal do not show any variation with the modification in the concrete mix proportions. Its value ranges 0.0057 PM10-eq for manufacturing phase and 0.1 PM10-eq for disposal phase for both w/c ratios 0.45 and 0.5 for all the mix proportions. However, in raw phase, a considerable successive decrease has been

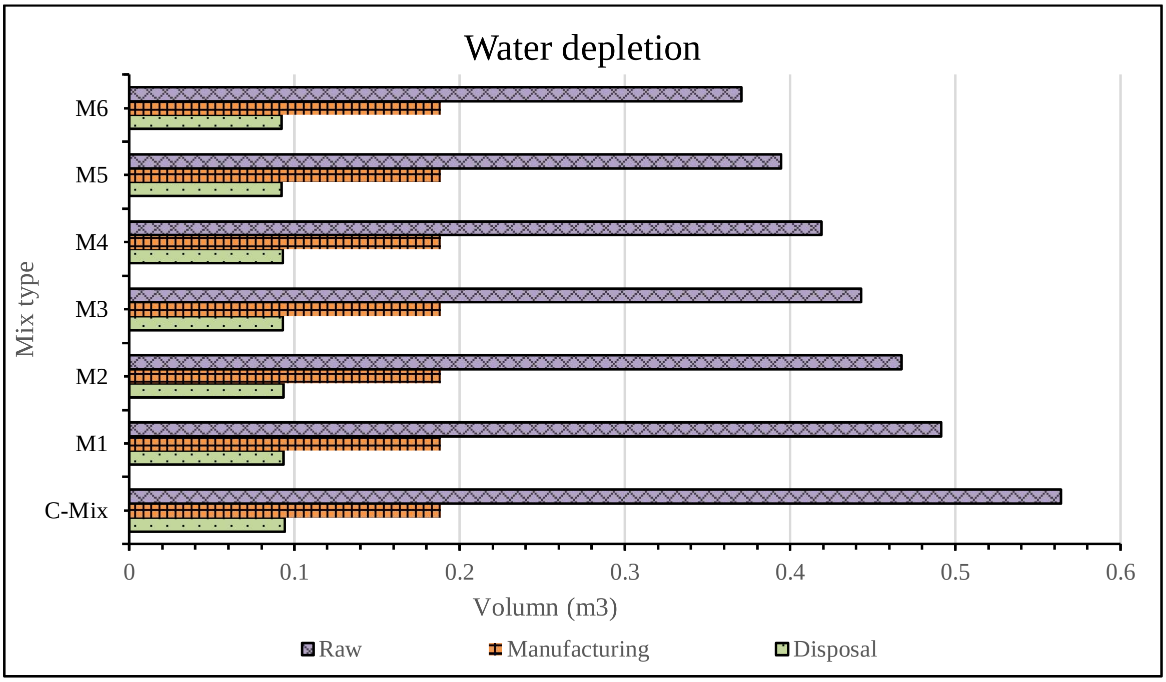

Fig. 5.13 Midpoint life cycle assessment of water depletion for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

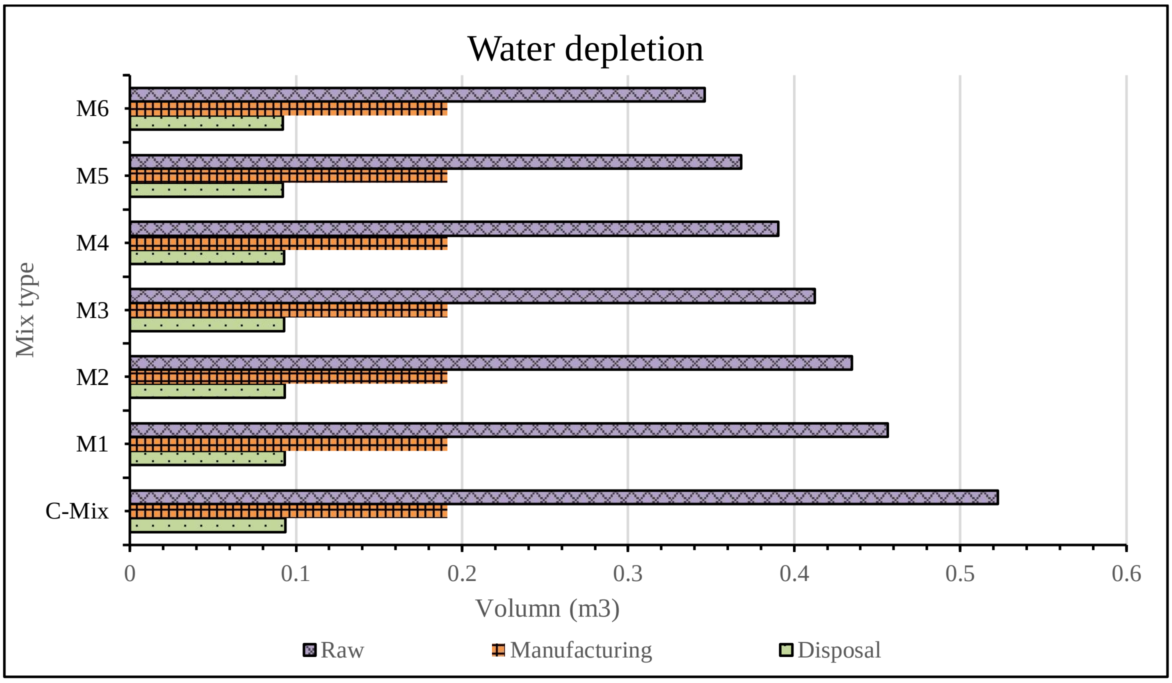

Fig. 5.14 Midpoint life cycle assessment of water depletion for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

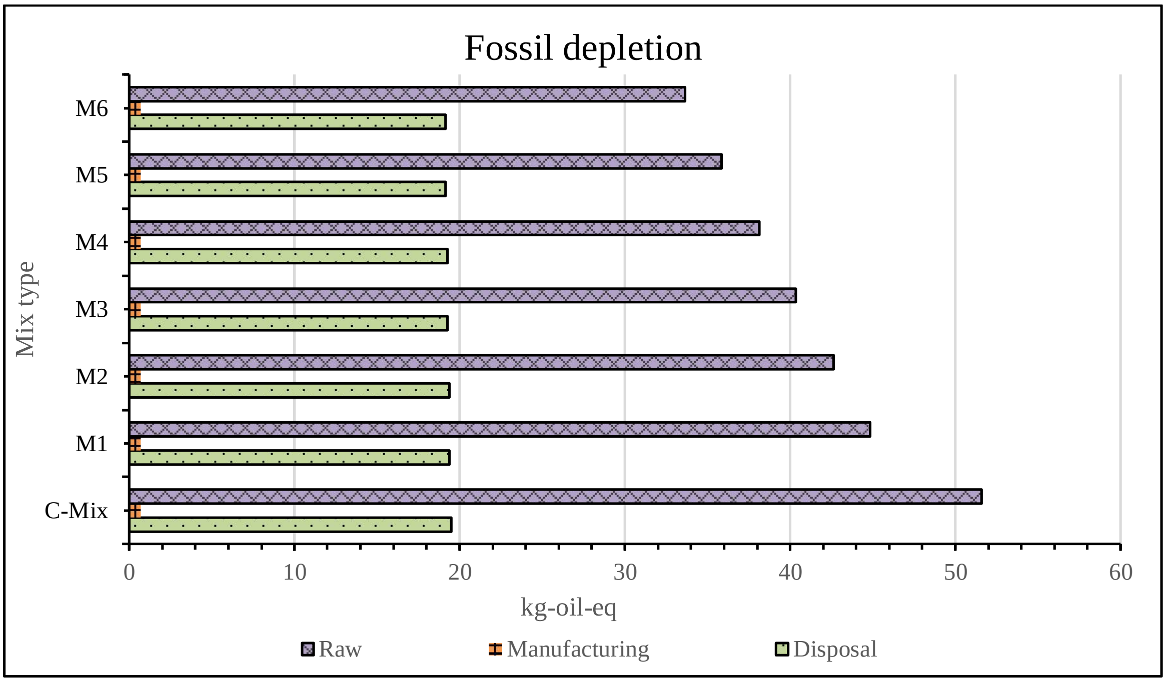

Fig. 5.15 Midpoint life cycle assessment of fossil depletion for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

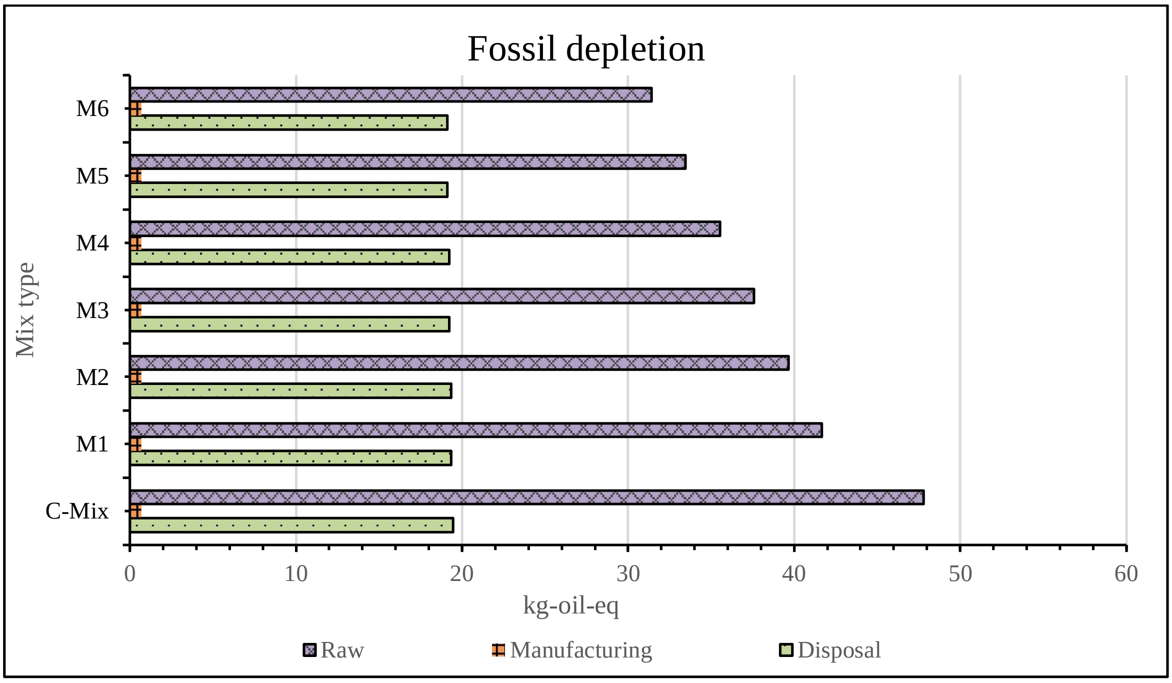

Fig. 5.16 Midpoint life cycle assessment of fossil depletion for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

observed in the modified mix proportions. For control mix, at w/c ratio of 0.45, the value of particulate matter is 0.54 PM10-eq and for 0.5 w/c ratio it is 0.48 PM10-eq. It ranges from 0.45 PM10-eq for M1 to 0.34 PM10-eq for M6 for w/c ratio of 0.45, as shown in Fig. 5.17. In the case of w/c ratio of 0.5, its value has been estimated as 0.42 PM10-eq for M1 to 0.31 PM10-eq for M6 as shown in Fig. 5.18.

Results of metal depletion midpoint factor are shown in Fig. 5.19, and Fig. 5.20. It is calculated in kg of Fe-equivalent. No effect of the manufacturing process and disposal are observed on metal depletion with the variation in mix proportions. However, the impact of disposal is higher (2.39 kg-Fe-eq) than that in the case of the manufacturing phase for both w/c ratios. The raw section (phase) has been affecting metal depletion at a greater extent. In metal depletion also manufacturing and disposal do not show any remarkable variation with the modification in the concrete mix proportions. The values are 0.68 kg-Fe-eq for manufacturing phase and 2.3 kg-Fe-eq for disposal phase for both w/c ratios 0.45 and 0.5 for all the mix proportions. But, in the raw phase, the considerable successive decrease has been observed in the modified mix proportions. For control mix, at w/c ratio of 0.45, the value of metal depletion is 6.65 kg-Fe-eq and for 0.5 w/c ratio it is 6.62 kg-Fe-eq. In modified mixes, the values are 6.03 kg-Fe-eq for M1 to 4.97 kg-Fe-eq for M6 for w/c ratio of 0.45 as shown in Fig. 5.19. In the case of w/c ratio of 0.5, its value has been estimated as 5.75 kg-Fe-eq for M1 to 4.79 kg-Fe-eq for M6 as shown in Fig. 5.20.

5.5.2 Endpoint factors of LCA results

Endpoint factors, the results of the cause-effect analysis of chosen midpoint factors, are presented in Fig. 5.21 to Fig. 5.26. Initially, damage to ecosystem quality are detailed in Fig. 5.21 and Fig. 5.22, are the results of midpoint factors global warming, water depletion, and agriculture land occupation. It shows the effect on water species and terrestrial species. The results reveal the positive impact on the ecosystem due to the replacement of cement with FA and CT in concrete in the raw section of the model.

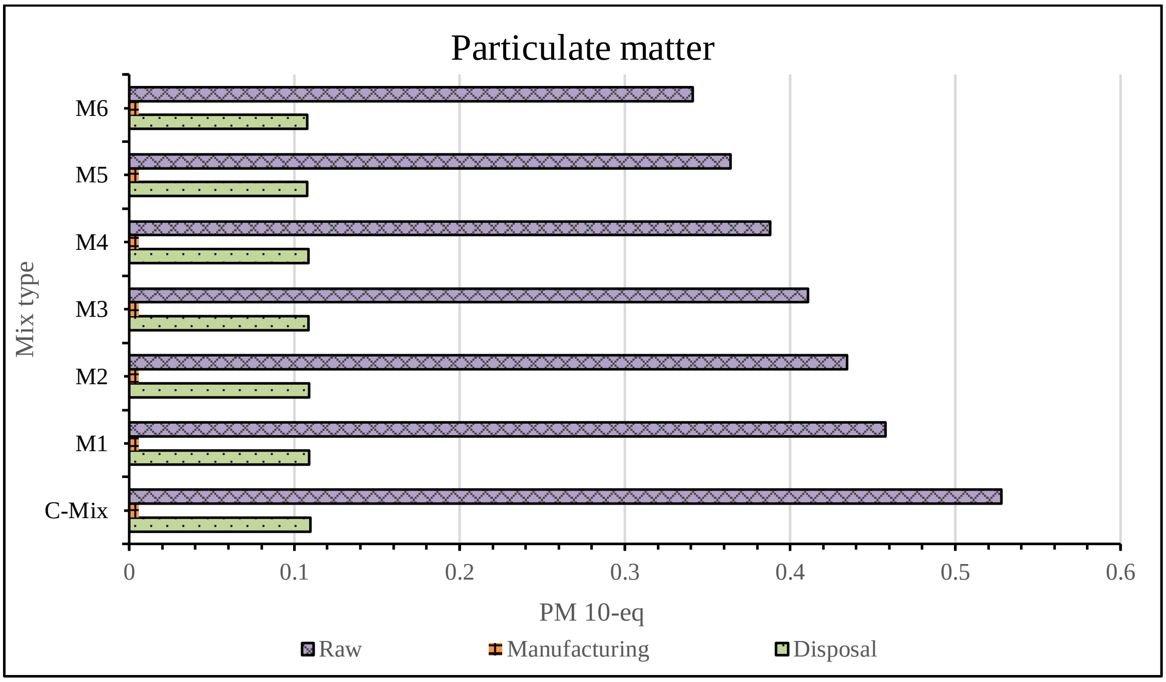

Fig. 5.17 Midpoint life cycle assessment of particulate matter for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

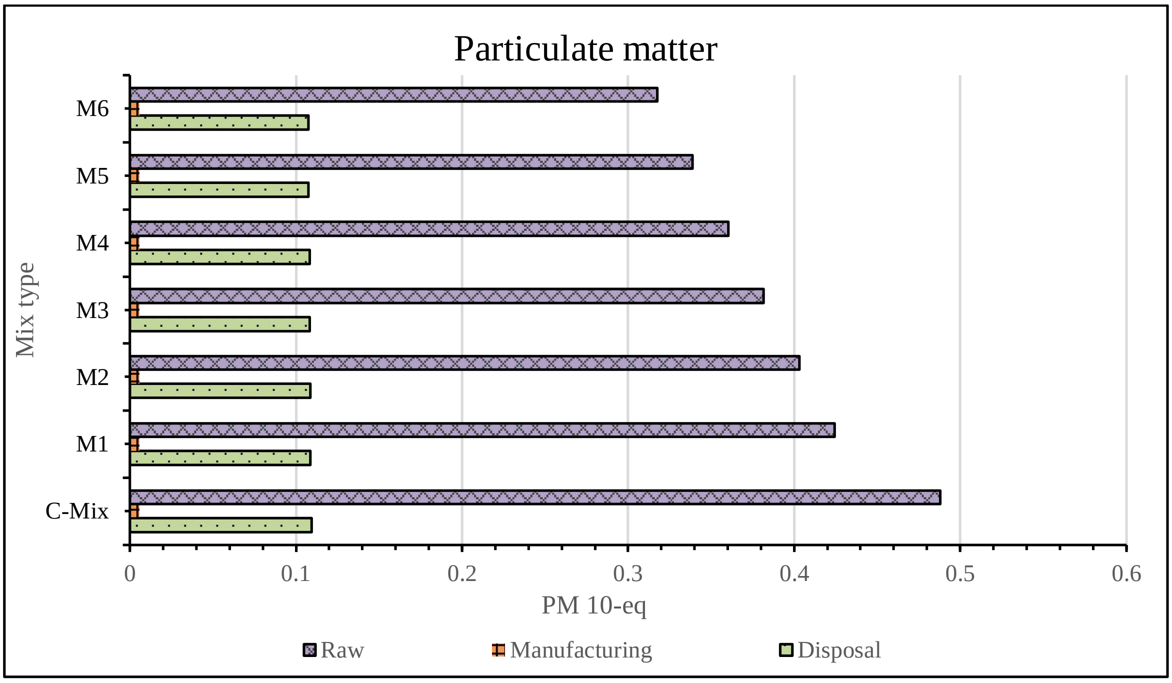

Fig. 5.18 Midpoint life cycle assessment of particulate matter for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

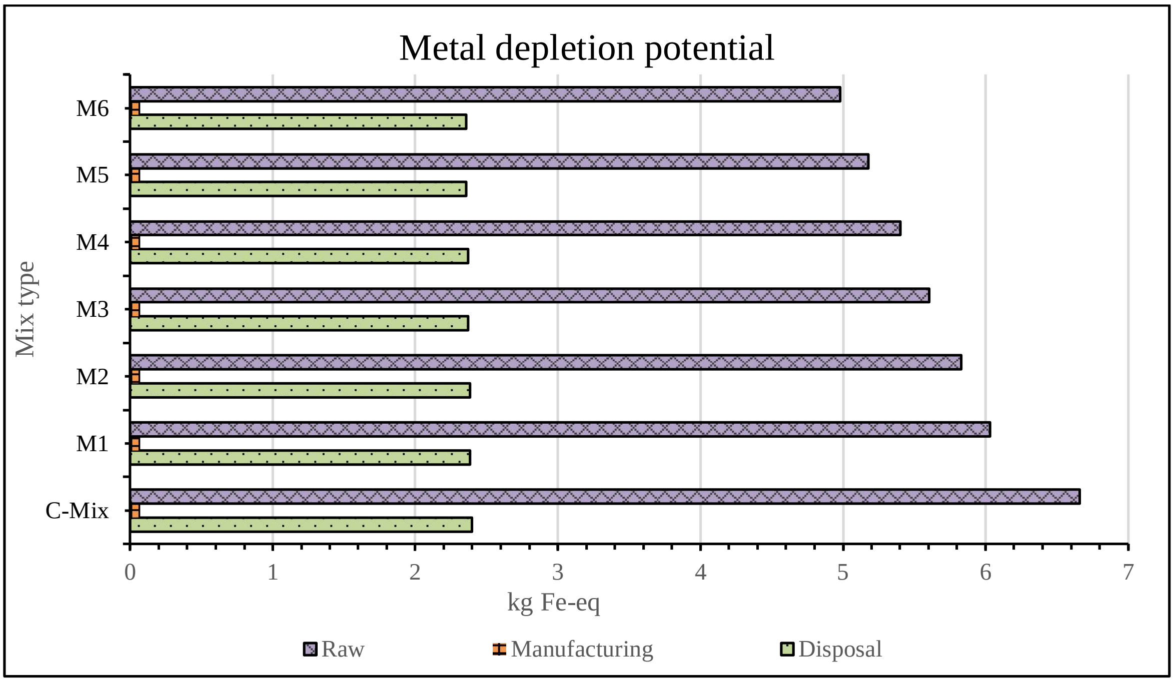

Fig. 5.19 Midpoint life cycle assessment of metal depletion potential for concrete at w/c ratio 0.45 with different proportion of FA, CT, and Cement

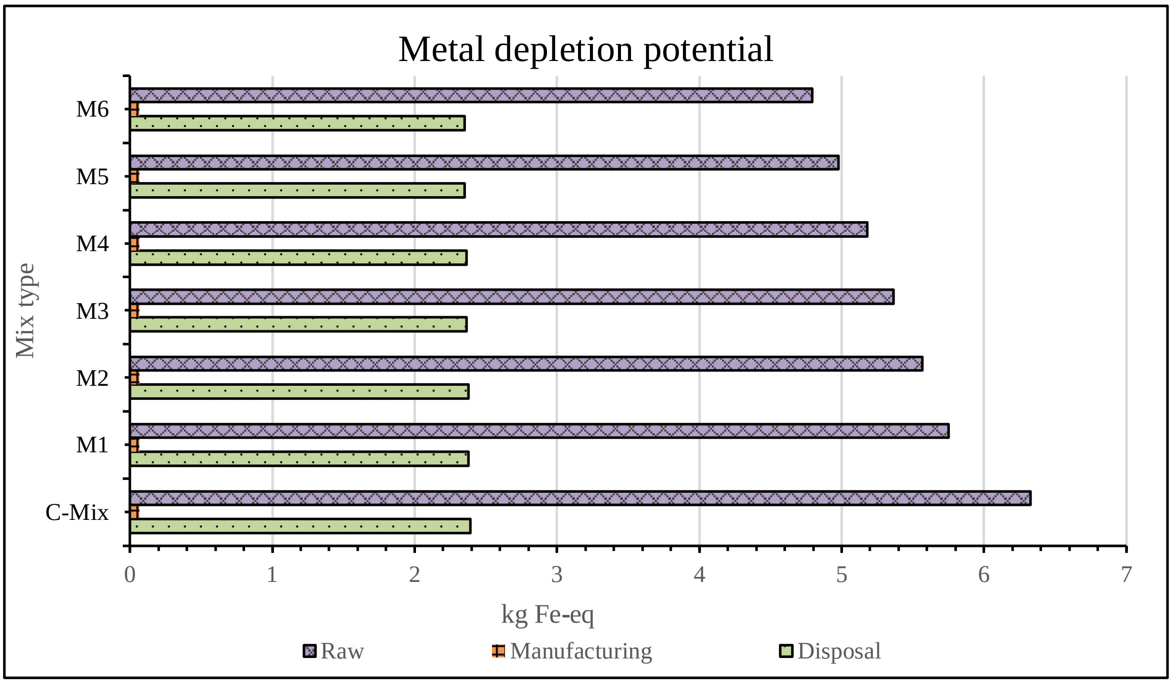

Fig. 5.20 Midpoint life cycle assessment of metal depletion potential for concrete at w/c ratio 0.5 with different proportion of FA, CT, and Cement

The partial addition of FA and CT in place of cement in raw phase and for control mix samples the value (in points) of the ecosystem are 22.75 points for w/c 0.45 and 21.66 points at w/c 0.5. A successive decrease has been observed in the raw phase for the modified mix proportions. The values are 20.64 points for M1 to 17.13points for M6 for w/c ratio of 0.45 as shown in Fig. 5.21. In the case of w/c ratio of 0.5, its value has been estimated as 19.75 points for M1 to 16.54 points for M6 as shown in Fig. 5.22. The disposal of the material affects the ecosystem (4.9 points), but no significant variation in modified mixes has been observed. A little impact in manufacturing (0.1 points) is observed, which is constant for all mixes for both w/c ratios.

Fig. 23, and Fig. 24 shows the effect on human health due to the utilization of FA and CT in concrete. This endpoint factor depends on the results of particulate matter, ozone depletion, human toxicity, global warming, and use of water depletion midpoint factors. Increase in the respiratory disease, various types of cancers, malnutrition may happen if the value of this factor is higher. The disposal of concrete is putting a considerable impact (about 67 points). There is no significant variation seen with different mixes and both w/c ratios. Manufacturing also not putting much effect (0.36 points) on human health and nearly equal in all cases. The raw material is shown a considerable successive reduction in the effect on human health in modified concrete mixes. For control mix samples, the value of the human health are 27.08 points for w/c 0.45 and 25 points at w/c 0.5. For mix M1 values is 23.44 points to 17.37 points for M6 for w/c ratio of 0.45, as shown in Fig. 5.23. In the case of w/c ratio of 0.5, its value has been estimated as 21.68 points for M1 to 16.13 points for M6 as shown in Fig. 5.24.

Endpoint factors damage to the resource is on the metal depletion potential and fossil depletion. The higher value of these factors increases the price and scarcity of the said commodities. The results show that the manufacturing phase of the model does not put any significant impact on the resources for all mix. However, the in-disposal phase of concrete results are nearly constant (about 2.07 points) for all the mix proportions and w/c ratios. Similar trends have been observed in resource also. With the replacement to cement with FA and CT, a successive decrease is points related to resources have been observed. For control mix samples the value for the resources are 5.51 points for w/c 0.45 and 5.12 points at w/c 0.5.

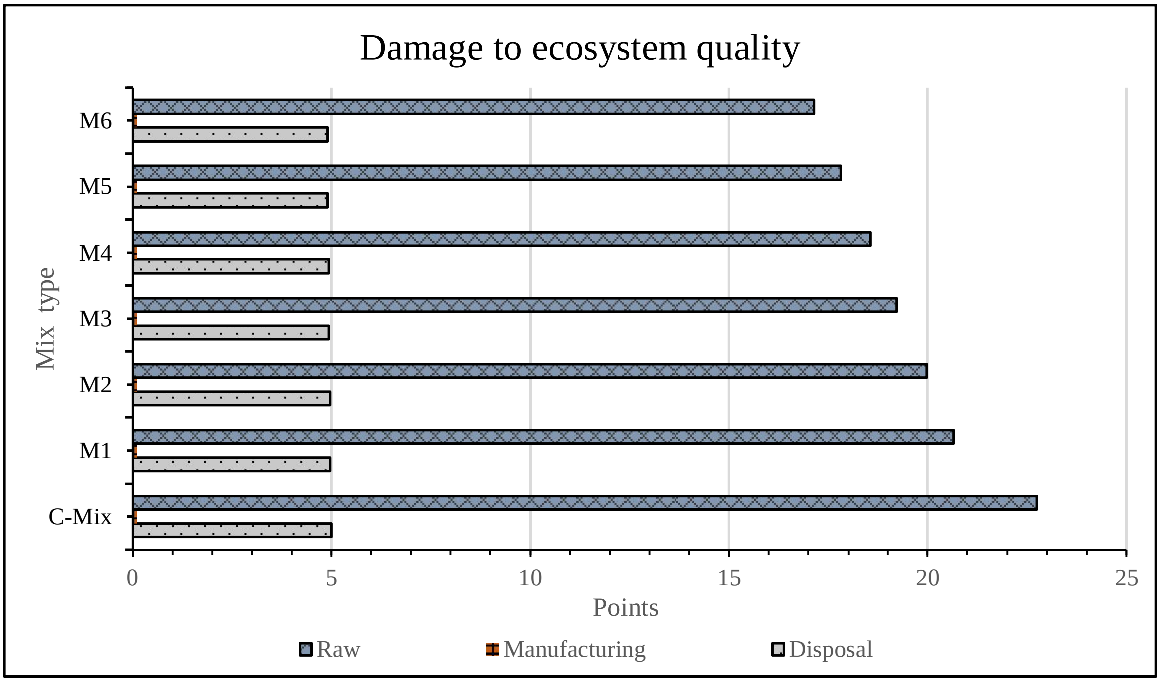

Fig. 5.21 Endpoint environmental impacts for damage to ecosystem quality at w/c ratio 0.45 for different mix of concrete

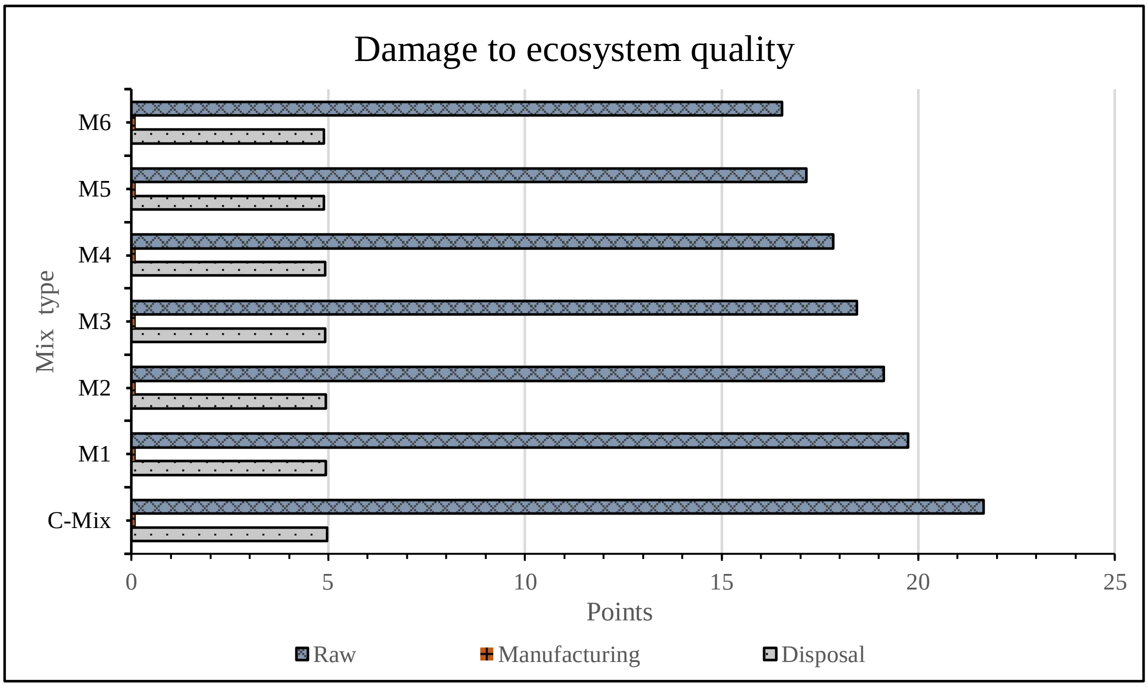

Fig. 5.22 Endpoint environmental impacts for damage to ecosystem quality at w/c ratio 0.5 for different mix of concrete

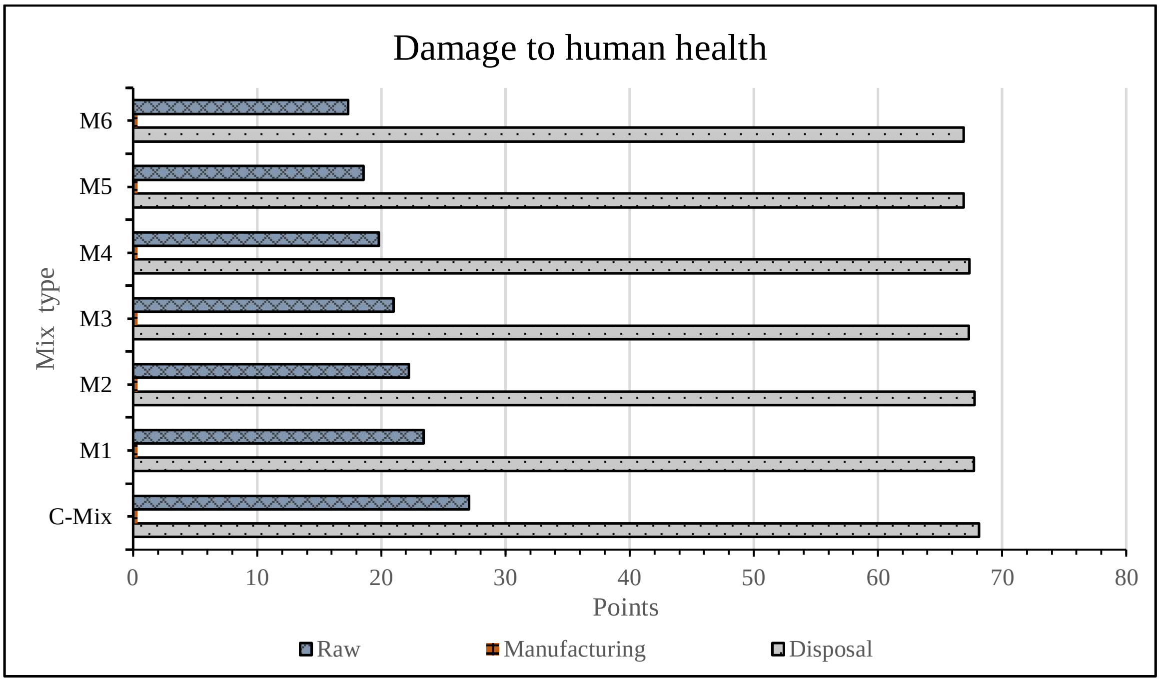

Fig. 5.23 Endpoint environmental impacts for damage to human health at w/c ratio 0.45 for different mix of concrete

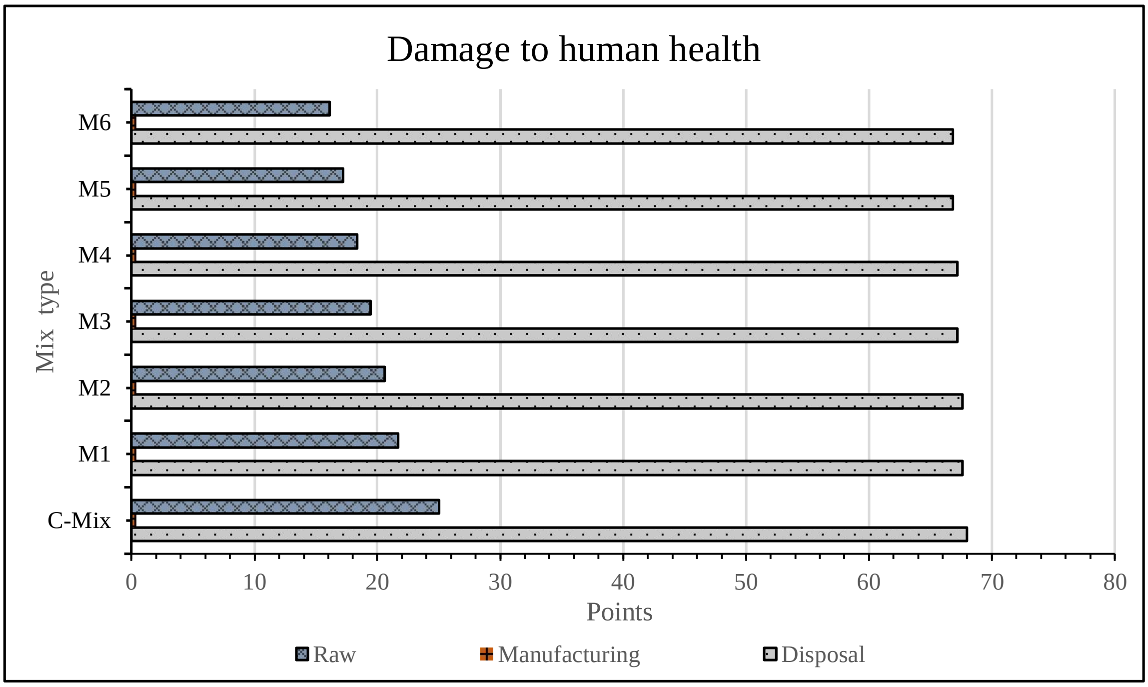

Fig. 5.24 Endpoint environmental impacts for damage to human health at w/c ratio 0.5 for different mix of concrete

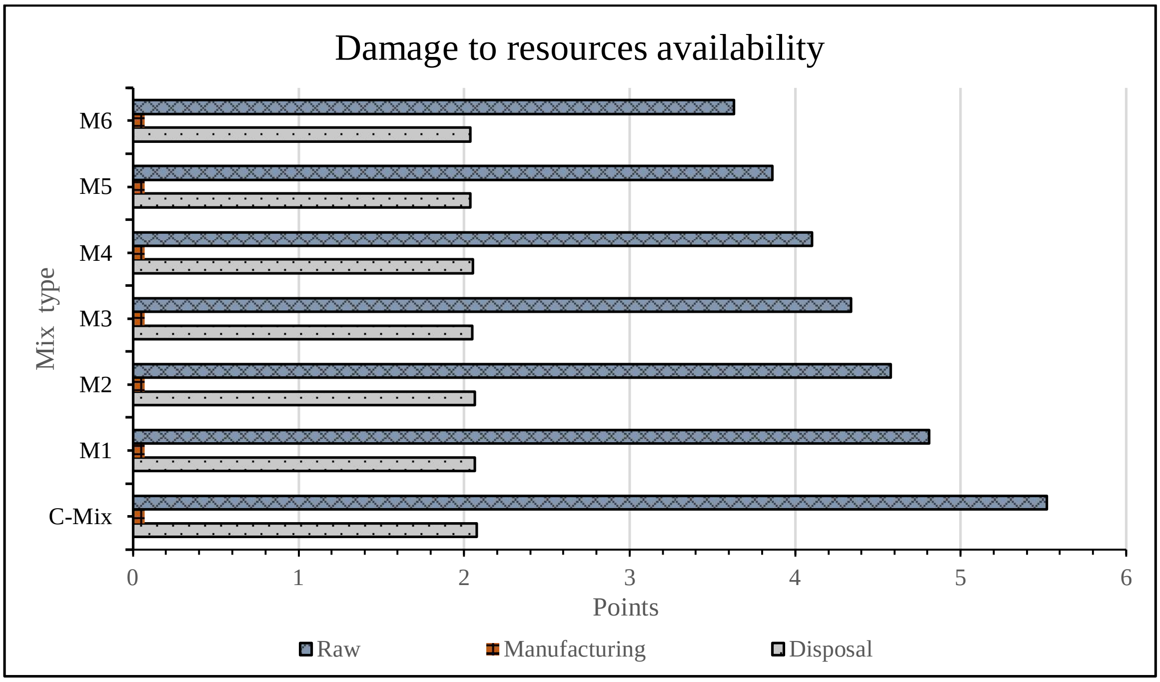

Fig. 5.25 Endpoint environmental impacts for damage to resources availability at w/c ratio 0.45 for different mix of concrete

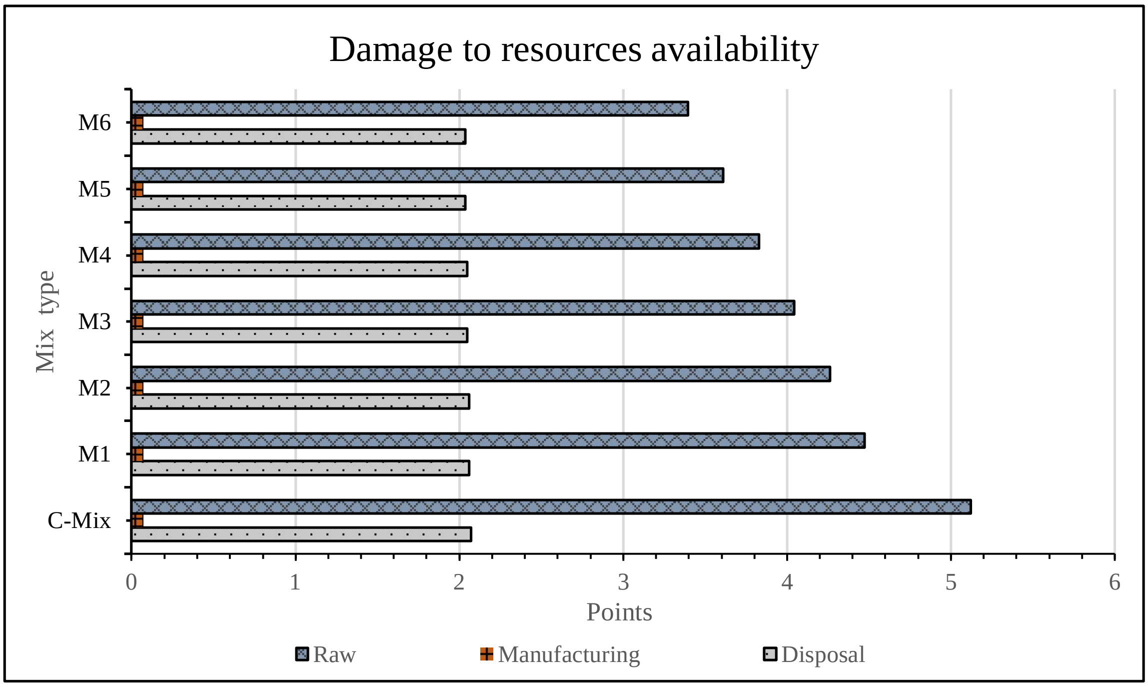

Fig. 5.26 Endpoint environmental impacts for damage to resources availability at w/c ratio 0.5 for different mix of concrete

The values are reduced to 4.81 points for mix M1 to 3.62 points for M6 for w/c ratio of 0.45 as shown in Fig. 5.25. In the case of w/c ratio of 0.5, its value has been estimated as 4.47 points for M1 to 3.39 points for M6 as shown in Fig. 5.24.

5.6 Cost Estimation of the Modified Concrete Mixes (Economic Viability)

The economic feasibility of the utilization of FA and CT in partial replacement of cement in concrete is also an essential step before performing the strength test of the design concrete mixes. The details of the cost estimate of all the concrete mix proportions along with control mixes for water-cement ratios of 0.45 and 0.5 are presented in Table 5.2 and Table 5.3, respectively. The cost is calculated based on the amount (in INR) required for making of one cubic meter volume of concrete. The rates of each material have been taken from the schedule of rates followed in district Gwalior, Madhya Pradesh, India for the year 2018. The total expenditure for making each proposed mix combination of concrete of all suggested combinations have been compared with the cost of the control mix.

From the cost analysis, it is observed that the partial replacement of cement with CT and FA results in a significant reduction in the cost of concrete. In Fig. 5.27, the relative cost of each mix proportion is presented in the form of bar charts. The production cost of one cubic meter of concrete as compared to control mix is reduced by 6.72%, 8.81%, 11.36%, 13.44%, 16% and 18.08 % for modified mixes M1, M2, M3, M3, M4, M5, and M6 respectively at w/c ratio of 0.45. Similarly, the reduction in production cost has been found about 6.50%, 8.51%, 10.97%, 12.98%, 15.45%, and 17.46 for mix composition M1, M2, M3, M4, M5, and M6 respectively as compare to that in the case of control mix at w/c ratio of 0.5.

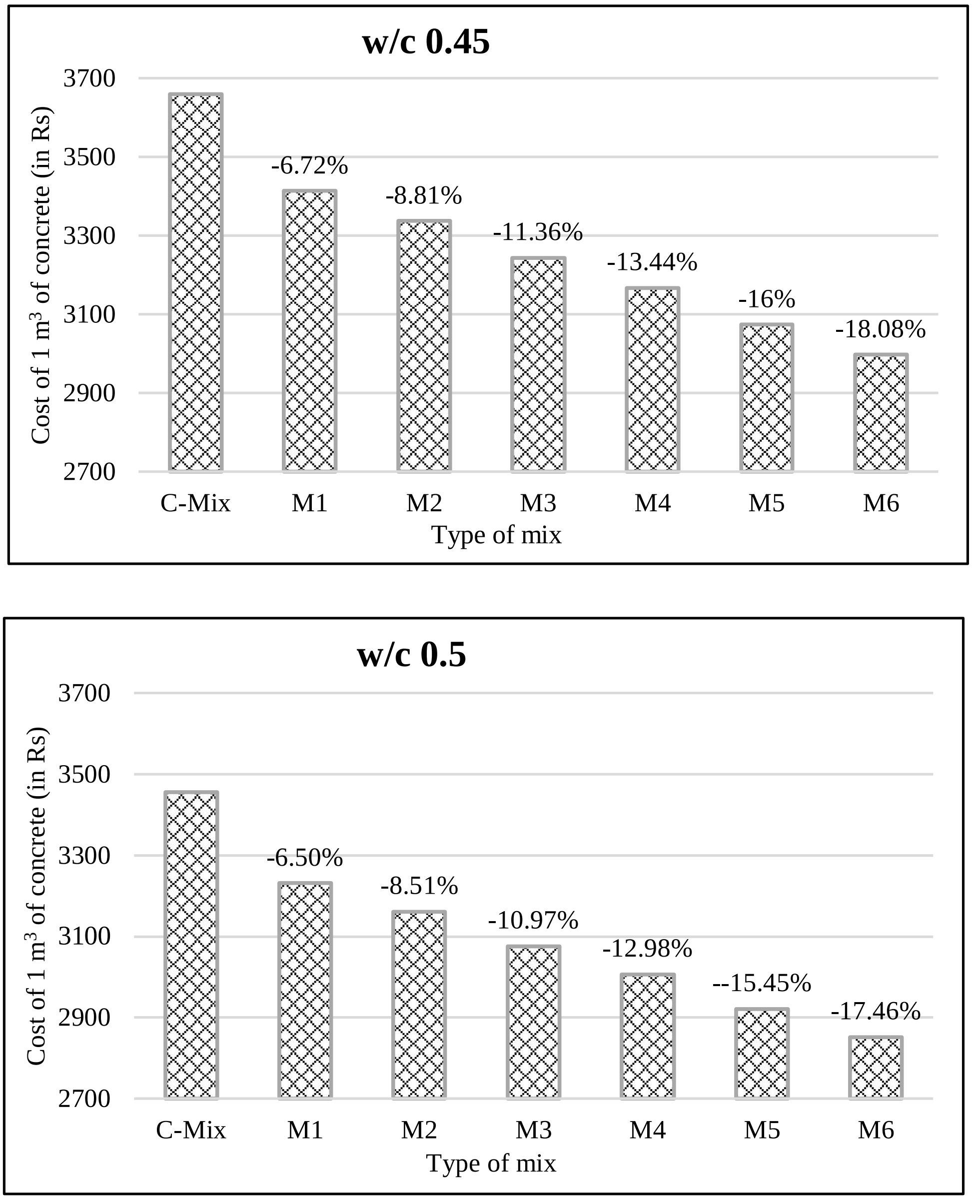

Fig. 5.27 Cost reduction in percentage in different category mix with respect to control mix

Table 5.2 Cost analysis of one m^3 of concrete for mix combination M1, M2, M3, M4, M5 and M6 for water-cement ratio 0.45

Water Cement ratio 0.45		M	Cement	Fine aggregate	Coarse Aggregate	Fly Ash (loading, unloading transportation)	Copper tailings (loading, unloading transportation)	Super Plasticizer	Total cost for 1 cu m of concrete
	Amount of material per cum of concrete (in kg)	**Control Mix**	350.67	779.50	1219.22	-	-	1.75	
		M1	298.07	773.65	1210.07	35.07	17.53	1.75	
		M2	280.54	773.74	1210.21	35.07	35.07	1.75	
		M3	263.00	767.70	1200.76	70.13	17.53	1.75	
		M4	245.47	767.80	1200.90	70.134	35.06	1.75	
		M5	227.93	761.75	1191.46	105.201	17.53	1.75	
		M6	210.4	761.85	1191.6	105.2	35.07	1.75	
	Cost of 1 cum of concrete (in Rs)	**Control Mix**	2349.49	383.52	853.46	-	-	71.89	**3658.36**
		M1	1997.07	380.64	847.05	74.83	41.03	71.89	**3412.50**
		M2	1879.59	380.69	847.15	74.83	82.06	71.89	**3336.20**
		M3	1762.12	377.72	840.53	149.67	41.03	71.89	**3242.95**
		M4	1644.64	377.76	840.64	149.67	82.06	71.89	**3166.65**
		M5	1527.17	374.79	834.02	224.50	41.03	71.89	**3073.39**
		M6	1409.68	374.84	834.12	224.50	82.06	71.75	**2996.95**

Table 5.3 Cost analysis of one m^3 of concrete for mix combination M1, M2, M3, M4, M5 and M6 for water-cement ratio 0.5

		M	Cement	Fine aggregate	Coarse Aggregate	Fly Ash (loading, unloading transportation)	Copper tailings (loading, unloading transportation)	Super Plasticizer	Total cost for 1 cu m of concrete
Water cement ratio 0.5	Amount of material for 1 cum of concrete (in kg)	**Control Mix**	320.00	807.89	1211.83	-	-	1.60	
		M1	272.00	802.41	1203.61	32.00	16.00	1.60	
		M2	256.00	802.49	1203.74	32.00	32.00	1.60	
		M3	240.00	796.84	1195.26	64.00	16.00	1.60	
		M4	224	796.92	1195.38	64	32	1.6	
		M5	208	791.27	1186.90	96	16	1.6	
		M6	192	791.36	1187.04	96	32	1.6	
	Cost of 1 cum of concrete (in Rs)	**Control Mix**	2144.00	397.49	848.28	-	-	65.60	**3455.37**
		M1	1822.40	394.79	842.53	68.29	37.44	65.60	**3231.05**
		M2	1715.20	394.83	842.62	68.29	74.88	65.60	**3161.42**
		M3	1608.00	392.05	836.68	136.58	37.44	65.60	**3076.35**
		M4	1500.80	392.10	836.77	136.58	74.88	65.60	**3006.72**
		M5	1393.60	389.31	830.84	204.86	37.44	65.60	**2921.65**
		M6	1286.40	389.36	830.93	204.86	74.88	65.60	**2852.03**

5.7 Summary

In this chapter initially, a brief detail of FA, CT, and cement utilization production and their environmental impacts are discussed. The discussion reveals a possible utilization potential of both FA and CT in concrete as a partial replacement of cement. A detailed overview of the LCA process is also presented in the chapter. The midpoint and endpoint process used in the LCA analysis, are discussed in context to their application in the concrete mix design. Different approaches followed in LCA analysis viz. cradle to gate, cradle to grave, and cradle to cradle have been discussed with their significance in LCA. In this study, cradle to grave approach has been applied to analyze the research study as its suitability has been explained by various researchers. A model is developed for the LCA assessment of modified concrete mix proportion using UMBERTO NXT tool. The cause-effect analysis has been performed using different midpoint factors of the model, which is presented in the later part of the chapter. The results of LCA are analyzed and compared for different designed mix proportions of modified concrete. Also, endpoint factors have been considered to analyze the results. All the results of LCA analysis show that the modified concrete mixes have lesser impacts on the environment, society, ozone depletion, human toxicity, etc. as compare to the control mix. In the end, the economic feasibility of this utilization also been assessed. A significant decrease in the production cost of the modified concrete mix proportion has been observed form the results.