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Environmental Impact Assessment of Self-Compacting Concrete made with Marble Dust

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Highlights

- This paper focuses on environmental impacts of using WMD in the production of SCC.
- A LCA approach via CCaLC2 software is proposed for the assessment from cradle to gate.
- The importance of using local waste were obtained.

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Abstract

The marble industry can cause significant environmental impacts due to quarrying, transportation, and shaping of marble. Marble extraction can disrupt the ecological balance of the mining area, from visual and noise pollution to surface and groundwater and agricultural land contamination due to the marble waste. In particular, waste marble dust (WMD) can be carried by the wind into residential areas and cause pollution. However, it can be used directly and recycled in the construction materials. This approach can have many environmental and economic benefits with the production of construction materials. On the other hand, the use of WMD as a substitute material in the construction sector was mainly analyzed for durability, workability, and strength; also, it can be a convenient option as a filler, but the environmental assessment of its use as a filler concrete is limited. This study evaluates using WMD by substituting different proportions of cement and fly ash (FA) in self-compacting concrete. CCaLC2 software was used in a cradle-to-gate assessment. When the amount of WMD used increases from 50 to 200 kg/m3, carbon footprint, acidification, eutrophication, photochemical smog, and human toxicity potentials of the raw materials increases 1,80%,236,97%, 26,48%, 221,48%, 102,22%, respectively. Considering the location of the marble mine and the marble waste storage area, using WMD instead of FA and cement in concrete can save environmental pollution from the clinker process in cement production. In addition, the transport of WMD can be seen as an economical alternative due to its low bulk density and reduced landfill.

1. INTRODUCTION

The construction industry has been experiencing a steady increase in demand in recent years in parallel with rapid urbanization and continued population growth [1,2]. Concrete is one of the most popular building materials [3,4]; therefore, as the use of concrete increases, the production of cement, the main component and primary binding material of concrete, will also increase [5-7]. Recently, studies have also focused on reducing building costs [8]. Since cement is the costliest concrete component, reducing the cement concentration in concrete is an economic strategy [8]. In addition, high carbon dioxide emissions can be associated with cement production [9-11], estimated at 7% of total production worldwide [4,12-14], and 1 ton of cement production results in about 1 ton of CO_2 emissions [15].

Therefore, increased cement production means increased global warming and environmental damage [7], so efforts are being made in the construction industry to partially replace the amount of cement in concrete with by-products or waste with low environmental impact [16-18].
Meanwhile, among many types of concrete, the advantages of Self-Compacting Concrete (SCC) mixes are that they require less labor and have a higher insulation value than conventional concrete [7]. Moreover, it

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does not require vibration or compaction to fill the voids left by the reinforcement during placement, but can flow under its own weight [19]. Furthermore, even if the SCC has a high cement content [7], the workability can be improved by reducing the cement content [20-22]. Since the SCC requires a lot of natural resources, it can be seen as unsustainable [8]. However, the possibility of incorporation with waste and industrial byproducts [16] or mineral admixtures [23] can increase their eco-efficiency [16].

Alternative filler carbonate minerals are also being investigated to reduce the environmental impact of cement [24]. SSC is a concrete technology that contributes to sustainable development using fillers such as limestone dust [22]. Marble waste (MW) is one of these wastes that can be a good option [8]. Marble dust (MD) is a waste material of limestone origin and can be used as an additive or filler in the production of SCC in the same way as limestone powder [22,25]. Limestone dust performs well as a filler in SCC [22,26,27].

The micro-filling and pozzolanic reaction results showed that up to 20% of the MW can be used to improve the strength and durability of the SCC [8, 22, 28]. This allows the MD to be recycled more significantly and prevents environmental pollution [2,22,29]. Although marble is expensive, its structural properties and durability allow it to be shaped and used as a building component, flooring, and for decorative applications [30-32]. The amount of the MW is increasing due to the demand for marble products in the construction sector [32,33].

Natural stone waste requires a critical assessment due to the uncontrolled release of these powdered marble wastes into the environment, such as lands near quarries and facilities, causing pollution of water resources and green areas [19, 34]. By efficiently converting these waste elements into valuable products, using marble power (MP) in concrete solves disposal problems and depletion of natural resources, resulting in cost-effective, sustainable, and eco-friendly outcomes [2,19,25,35,36]. According to studies, using MD in cement mortars can help dispose of waste marble and provide the construction industry with an alternative source of raw materials [2,34,37]. In addition, since cement is the most expensive concrete component, reducing the cement content can be an economical solution [22].

Anjaneyulu and Rao [38] investigated the strength of the concrete produced by partially replacing the cement with marble and granite powder. The results showed that when marble and granite powder were added in weights of 5%, 10%, 15%, 20%, 25%, and 30% instead of cement, all the mechanical strengths decreased steadily after 10% replacement. On the other hand, cement can be replaced with waste marble dust (WMD) up to 15% of the clinker mass [39]; also, as the WMD and calcined clay are combined, the replacement can be increased up to 45% [40]. Moreover, Özkılıç et al. [41] stated that using 10% waste marble power (WMP) as a cement substitute can have optimum benefits from both mechanical and environmental aspects. The maximum compressive strength was noted by Sharma et al. [42] when cement replaced MDP with an extent of roughly 14%. It lowers costs and improves concrete's strength and longevity when added. Lastly, Verma et al. [43] aimed to analyse the effect of partially substituting marble slurry with natural fine aggregates and FA as a supplementary cementitious material (SCM) on SCC, carbon emissions and SCC cost analysis. It was concluded that the marble slurry and FA could be used in certain proportions without compromising the strength or flow properties of the SCC.

It is determined that between 5% and 20% MD replacement without compromising can partially substitute cement the material's strength or longevity [8], has a positive effect on impermeability [32], and yields good strength and quality results, outperforming traditional concrete [19]. Therefore, 20% is the ideal amount of MDP to use as a binder or fine aggregate.

Nowadays, the WMD causes significant economic losses and environmental pollution [25]. When the marble slurry is recovered correctly, MP can be the most convenient ingredient for reducing the impact of the marble industry on the environment [44-46]. Alternative solutions for using mining and industrial waste products have been developed due to the concrete industry's growing concern for environmental protection [2].

Recently, researchers have evaluated the use of WM in SCC to analyse the advancements in compressive strength, durability, and microstructure. The MP contains CaO (from $CaCO_3$), which is an excellent concrete binding material [19].

The marble industry is one of the most critical sectors of the economy and is growing every day. Afyonkarahisar, one of Turkey's most crucial marble industrial centers [25], has around 500 marble processing plants and 60-70 active marble quarries [34]. About half of the industries in the Afyonkarahisar region are related to marble [47]. As a result of all these production activities in the Afyonkarahisar region, approximately 8 million 640 thousand tons of waste are generated annually from natural stone quarries, and 3 million tons of sludge is generated annually from natural stone factories [34]. The 40 marble processing plants in the Afyonkarahisar Organized Industrial Zone generate 60,000 tons of solid and 120,000 tons of aqueous MW annually [48]. Therefore, Afyonkarahisar is experiencing a significant increase in the use of MD as a waste material [22]. These waste marble products harm the ecosystem and contaminate our natural resources [49], the MW is one of the leading environmental problems in the Afyonkarahisar province [25] (Figure 1).

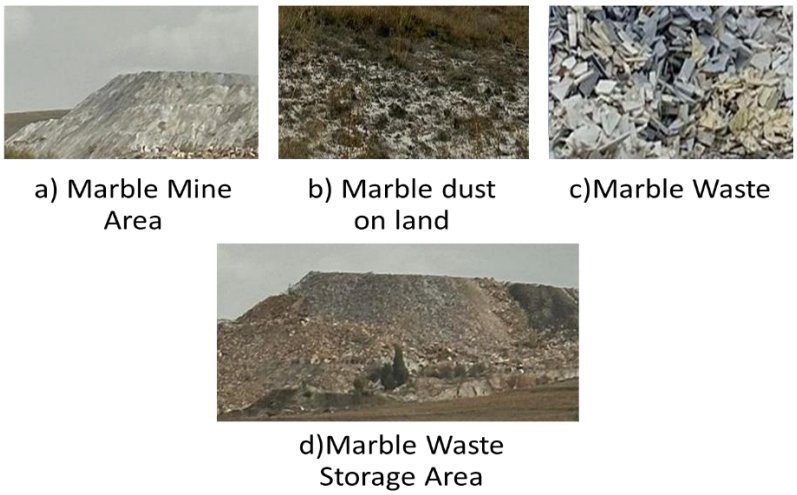


Figure 1. *Marble Waste in nature [49]*

However, a comprehensive study is necessary to pinpoint the environmental impact of WM use in the SCC [8]. Life cycle assessment (LCA) can be applied to calculate the environmental impacts, water footprints, and cumulative energy demand to manage the waste and greenhouse gas (GHG) emissions of a product throughout its entire life cycle [46,50,51]. LCA has already been applied to several building materials and products across their life cycle stages to estimate and assess the environmental impact potentials, such as global warming, acidification, eutrophication potential, or toxicity [47]. Some software for LCA development from the literature can be listed as SimaPro [52], Gabi [53], Umberto [54], and OpenLCA [55,56], but the CCalC2 was chosen because it is free, user friendly and used in many studies for carbon footprint analysis.

Güller and Balcı [57] used the CCalC2™ software to evaluate the carbon footprint of a wastewater treatment plant. Üçtuğ et al. [58] investigated the environmental impact of yoghurt production and distribution in Turkey using a cradle-to-grave approach with the CCalC2™ software and CML2001 methodology. Amin et al. [59] analyzed the various processes involved in producing cotton knitwear in Bangladesh using the CCalC2™ software. Thapa et al. [60] analyzed food waste treatment using the CCalC2™ software. Finally, Khan et al. [61] developed a model for analyzing the energy demand and the carbon footprint of textile waste in Australia, with the aim of identifying the most sustainable end-of-life management practices [61].

Nonetheless, many materials lack Life Cycle Inventory (LCI) data or still need to complete data [62]. One of the significant parameters of the LCA is the location. Therefore, among these solutions, one possibility is substituting WMD with limestone filler on a regional scale [63].

This study aims to determine whether FA or MD in concrete has more environmental benefits than the other. Therefore, this study assesses the environmental performance of using WMD in SCC as an ingredient by partially replacing the PC and FA as a binder. The environmental impacts and energy demands were examined from the MD production to the SCC production gate in Afyonkarahisar via the CCalC2 software.

2. MATERIALS METHOD

2.1. Life Cycle Assessment (LCA) Methodology

The LCA methodology was employed to address the environmental impacts of SCC production with different rates of MD partially replaced with cement in this study.

This methodology was applied with four phases of the LCA. First, goal and scope were defined. Second, the life cycle inventory was assessed. The amount of the ingredients and the properties of the ingredients of the SCC mix design were presented (Tables 1 and 2). Third, the environmental impacts and energy demand of the mixed designs were assessed via the CCaLC2© for Windows Manual (V1.0) LCA tool. The CCalC2 software was developed by the University of Manchester according to the ISO 14044 and PAS2050 standards [64,65]. Lastly the results were interpreted (Figure 2).

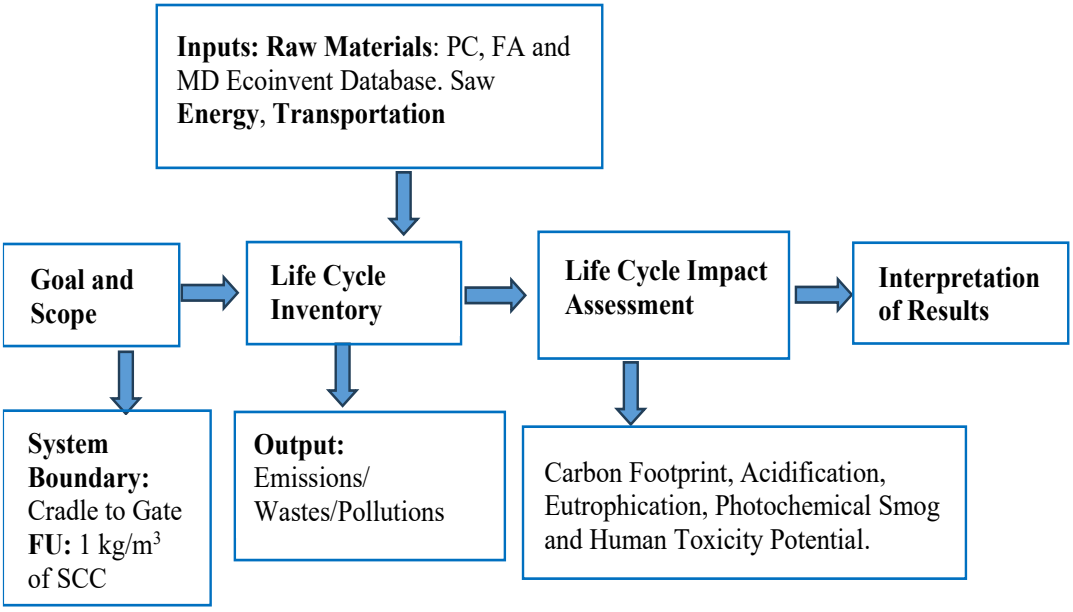


Figure 2. *LCA framework for this study*

2.2. Goal and Scope

The goal of this study is to define the ideal combination of the SCC by examining the usage of the MDW material. The objective of this study was to evaluate the environmental impact of SCC production with different rates of MD partially replaced with PC and FA as a binder. The functional unit (F.U.) selected as kg/m^3 of SCC for this study.

2.3. Life Cycle Inventory (LCI)

2.3.1. Raw materials

The ingredients of the SCC mix design consist of Portland cement (PC), marble dust (MD), superplasticizer and water. The PC (CEM I 42.5R) and FA were used as the binder material in the SCC mixtures.

2.3.2. Raw materials' properties

The specific surface area by Blaine of the cement is 449 m^2/kg. The FA can be classified as an F class according to ASTM C 618 [22]. The chemical properties of the PC, FA, and MD in the SCC are shown in Figure 3 and Table 1. The specific surface area by Blaine of FA and MD were 176 m^2/kg and 614 m^2/kg, respectively [22]. SCC relies heavily on superplasticizers, which are high-range water-reducing admixtures. These admixtures help increase the concrete mix's fluidity without increasing the water content. They are essential for achieving self-compacting properties. A polycarboxylate-based superplasticizer was also used in the mixtures. The solid content and pH of the superplasticizer were 22% and 8%, respectively. Lastly, tap water was used in the mixtures.



Figure 3. *MD, FA and PC Chemicals*

Table 1. *Chemical compositions of MD, FA and PC*

Chemical Properties (%)	**PC**	**FA**	**MD**
SiO_2	19.3	51.5	4.67
Al_2O_3	5.57	23.08	–
Fe_2O_3	3.46	6.07	0.03
MgO	0.86	2.42	0.4
CaO	63.56	10.53	51.8
Na_2O	0.13	0.77	–
SO_3	2.91	1.32	–
K_2O	0.8	2.54	–
LOI	2.78	1.06	41.16

The PC and FA were used as binders in the SCC mixture. FA was a 10% by-weight replacement for cement in all the mixes. The ratios between the binder and water were 0.35- 0.38- 0.43-0.49 and 0.55. The ratio between the water and (PC+FA+MD) was 0.35 for each mixture.

The amount of MD increases, and the amount of the SCC, FA, and superplasticizer decreases. These mixes can show the impact of the MD on the environment.

When the 28th day compressive strengths and flexural strengths of the SCC were analyzed, the M250 and M300 series showed the lowest compressive and flexural strengths indicating poor workability. In addition, MD contents up to 200 kg/m^3 showed acceptable hardened concrete properties in terms of workability [22]. The SCC mixes have 0, 50, 100, 150, and 200 kg/m^3 of WMD as a substituted binder material because the maximum amount of WMD used was found to be 200 kg/m^3 to obtain the best performance of the SCC [22]. The amount of superplasticizer was also used as a ratio of 2.5% by weight of the binder materials to reduce the water/binder ratio of SCC [22].

The ratio of the ingredients of the SCC can be found in Table 2.

Table 2. *Mix proportions of SCC incorporating MD for 1 m³*

Materials (kg/m³)	Specific gravity	MD0	MD50	MD100	MD150	MD200
PC	3.07	495	450	405	360	315
FA	2.2	55	50	45	40	35
MD	2.47	0	50	100	150	200
Superplasticizer	1.1	13.75	12.5	11.25	10	8.75
Tap Water		190	191	192	194	195

2.3.3. System boundary of the production scc

The life cycle assessment of this study covers the inputs of the SCC production, which are the raw materials, energy consumption and transportation.

The life cycle boundary covers the environmental impact of the production of the raw materials PC, FA, MD, and superplasticizer. The raw material properties were defined using the CCaLC2 LCA tool. The CCaLC2 LCA tool can have the Ecoinvent database section. The datasets can be provided from Ecoinvent 3 as well as updating all previous Ecoinvent 2 datasets [66]. In the mixes, Portland cement, strength class Z52.5, was selected as PC, Hard coal at regional storage was selected as FA, Natural stone plate, cut, at regional storage (Afyonkarahisar) was selected as MD, Polycarboxylates, 40% active substance, at plan-based superplasticizer was chosen and tap water at user Europe was selected. After the definition of the raw materials' environmental impact, transportation from the cradle of the PC, FA and MD production location (the structure material laboratory at the Civil Engineering Department of Afyon Kocatepe University, Afyonkarahisar). The environmental impact of this transportation and sawing energy during the shaping of the marble to collect the MD was assessed. Therefore, the boundary is called a cradle-to-gate. Figure 4 shows the system boundary of the production SCC.

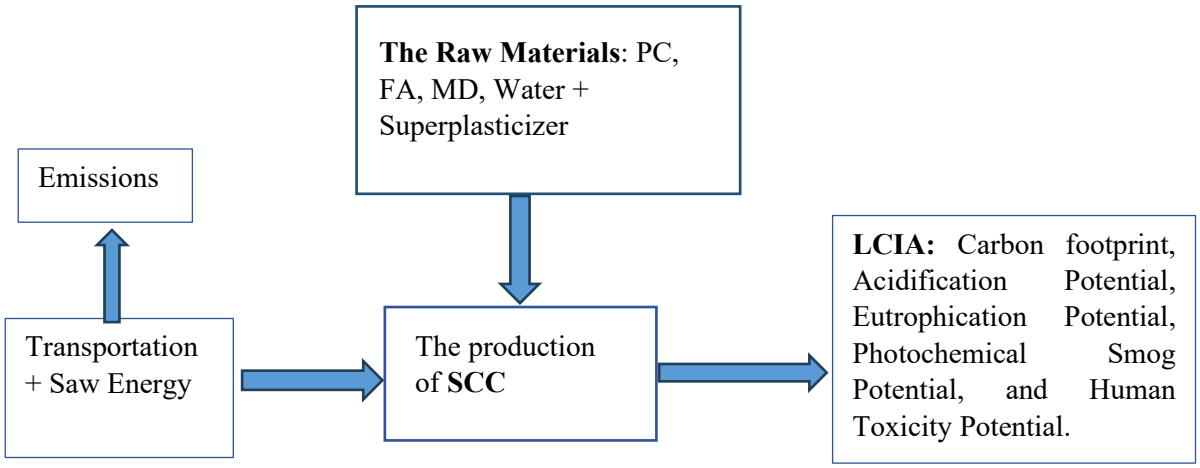


Figure 4. *System Boundary of production SCC*

2.3.4. Assumptions

The MD is the crystalline waste that is often generated during the extraction step, cutting, shaping in the processing unit, and polishing of the stones and tiles directly; in addition, marble rocks are cut by rock crushers, saws, or vertical cutters, and high electricity consumption can be measured [25, 46, 50, 67-70]. Since the cutting process is carried out with water, these wastes mix directly with water and are taken from the treatment plants in settling ponds as slurry [26]. Then, these wastes are loaded into dump trucks by loaders and dumped in a heap in the quarry waste dump area, which is converted into waste marble sludge [69]. As a result of the recovery of this water, residual powders are obtained [25]. The volume of the WMD produced ranges from 20% to 80% in proportion [25,32]. One ton of slurry containing 70% water and 30%

WMD can be produced, while the cutting process via saw 1 ton of marble stone [46,71]. When marble is processed from its raw state to its polished state, between 30 % and 70 % is wasted [19]. The MW is about 30% of the blocks cut during production and manufacturing [25].

It is estimated that 980,000 tons of MD are produced from the 3,450,000 tons of marble processed annually in Turkey [25]. The majority of the MD consists of marble particles smaller than 1 mm. Since the cutting process is carried out with water, these wastes are mixed directly with water and discharged as sludge from the settling ponds or as cake from the treatment plants [25,72].

Around the world, MDP production during quarrying amounts to several million tons [19,37]. One thousand four hundred tons of WMD daily are stored in areas that can be productive land or close to the settlements in Turkey [22,73,74].

2.3.5. Location of marble: Transportation

At the production stage, PC, FA, and MD ingredients of the SCC mixes were carried to the structure material laboratory at the Civil Engineering Department of Afyon Kocatepe University, Afyonkarahisar. PC was carried from an average 25 km distance. FA provided by Yatağan Thermal Power Plant. The transportation distance is about 380 km between the Yatağan Thermal Power Plant and the Civil Engineering Department of Afyon Kocatepe University structure material laboratory. In this study, the MD was transported from the Afyon Organised Industrial Zone and placed directly into the SCC without pre-processing. The transport distance is about 3,0 km between the Afyon Organised Industrial Zone and the Structural Materials Laboratory of the Civil Engineering Department of Afyon Kocatepe University.

2.3.6. Energy-usage

Determining the tools for cutting different marble types is a critical issue [74]. The most significant energy impact comes from the marble sawmill. This is where the marble is cut and processed to make slabs and tiles [30]. The MW is obtained as a result of cutting in a multiwire diamond sawing machine [63].

Table 3. *Energy inputs of marble production*

Material	Dimensions	MD200	MD150	MD100	MD50
Marble Dust Mass	kg	200	150	100	50
Marble Dust Volume	m^3	0.08	0.06	0.04	0.02
Marble stone Volume	m^3	0.27	0.20	0.13	0.07
Marble saw blade electricity	mj	107.52	80.64	53.76	26.88

First, this study used 50,100,150 and 200 kg/m^3 MD to produce SCC. As an LCA boundary, the energy use of MD production was assumed and added to the environmental impact as the contribution of this research. To produce MD, the marble stone was cut using a sewing machine. Second, to produce 200, 150, 100 and 50kg/m^3 MD, the volume of the MD should be calculated. The Marble Density is 2.5 g/cm^3 =2500 kg/m^3. Therefore, 0.08- 0.06- 0.04 and 0.02 m^3 MD were produced, respectively. It is assumed that the MD is the 30% of the marble stone during cutting. Therefore, marble stone volume is 0.27-0.20-0.13 and 0.07m^3, respectively. To cut these marble stones according to Çınar [75] study, saw blade cutting depth (HK = 50mm), rotation speed Vd = 1432 rpm, and workpiece travel speed (VK = 0,4m/min) were assumed, and to cut the 1 m^3 marble stone, 112 kw energy was calculated. One kw/h equals 3,6 megajoule, so 107.52-80.64-53.76 and 26.88 megajoule were consumed (Table 3). These energy values were entered into the CCaLC2 tool as a source of hard coal from the coal mine power plant to calculate the environmental impact.

2.4. Life Cycle Impact Assessment (LCIA)

The impact assessment includes the following categories: Carbon footprint (kg CO_2 eq./f.u.), Acidification Potential (kg SO_2 eq./f.u.), Eutrophication Potential (kg PO_4 eq./f.u.), Photochemical Smog Potential (kg C_2H_4 eq./f.u.), and Human Toxicity Potential (kg DCB eq./f.u.).

3. THE RESEARCH FINDINGS AND DISCUSSION

3.1. Results

This study assessed the life cycle assessment (cradle to gate) of the addition of MD in the SCC mixtures via the CCaLC2 LCA tool. The results indicate the environmental impacts of the ingredients of the SCC production, the transportation from the cradle of the production location of the FA and MD, and the energy consumption of the cutting marble tile.

The impact assessment includes the following categories: Carbon footprint (kg CO_2 eq./f.u.) of the Raw Materials, Carbon footprint (kg CO_2 eq./f.u.) from the transportation, Acidification Potential (kg SO_2 eq./f.u.), Eutrophication Potential (kg PO_4 eq./f.u.), Photochemical Smog Potential (kg C_2H_4 eq./f.u.), and Human Toxicity Potential (kg DCB eq./f.u.).

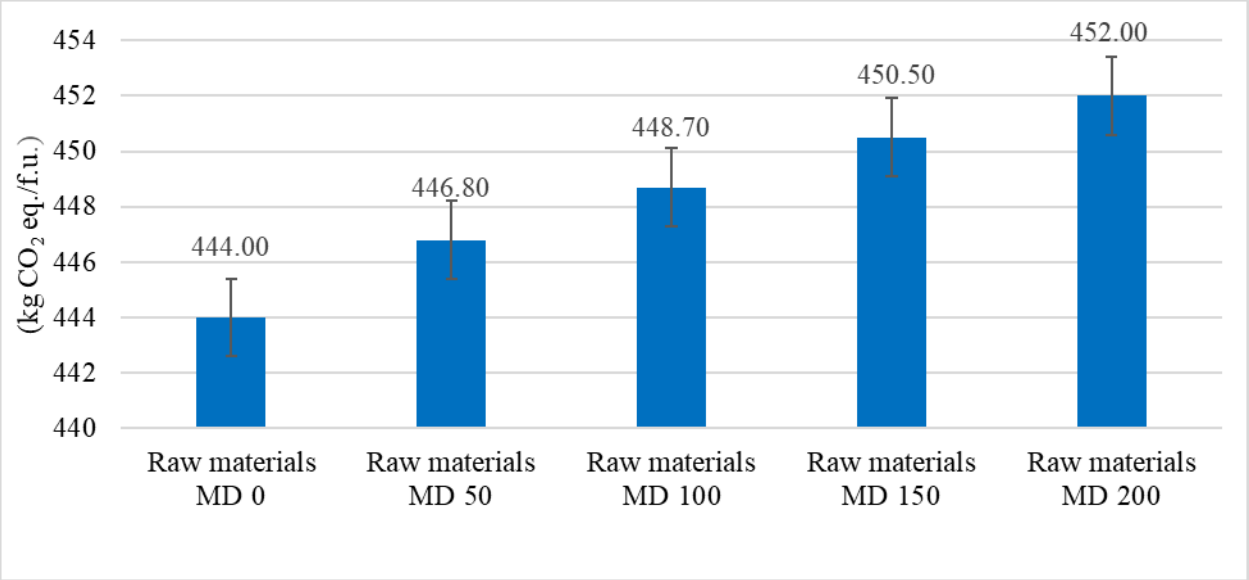


Figure 5. *Carbon footprint (kg CO_2 eq./f.u.) of the Raw Materials*

The carbon footprints of the raw materials used in the SCC production can be seen in Figure 5. As the amount of MD increases, the carbon footprint increases, while the amount of the combination of PC and FA as binders decreases.

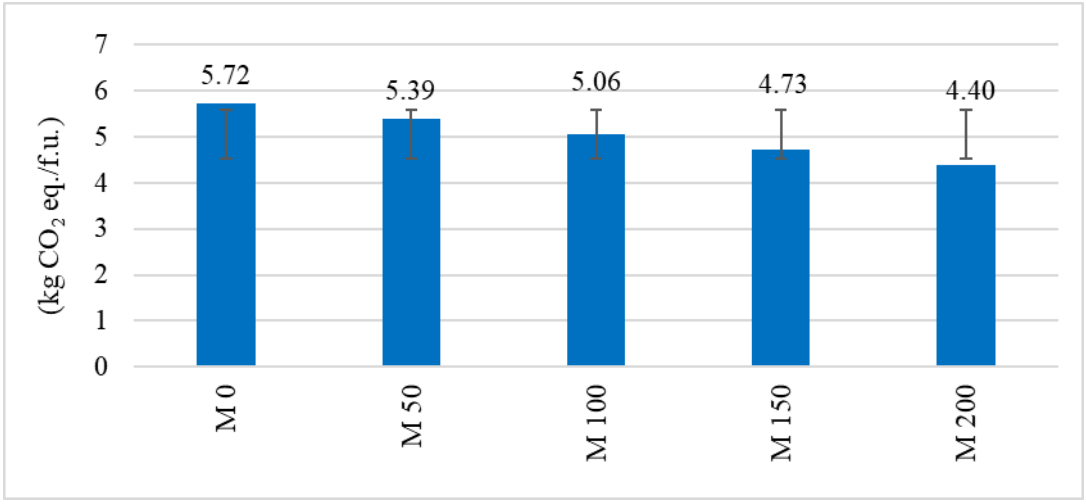


Figure 6. *Carbon footprint (kg CO_2 eq./f.u.) from the transportation*

The carbon footprints of the transportation of the raw materials used in the SCC production can be seen in Figure 6. As the amount of the MD increases, the carbon footprint decreases. This transport parameter is used to analyze the impact of the transport of raw materials and the distance reductions PC, FA, and MD, respectively.

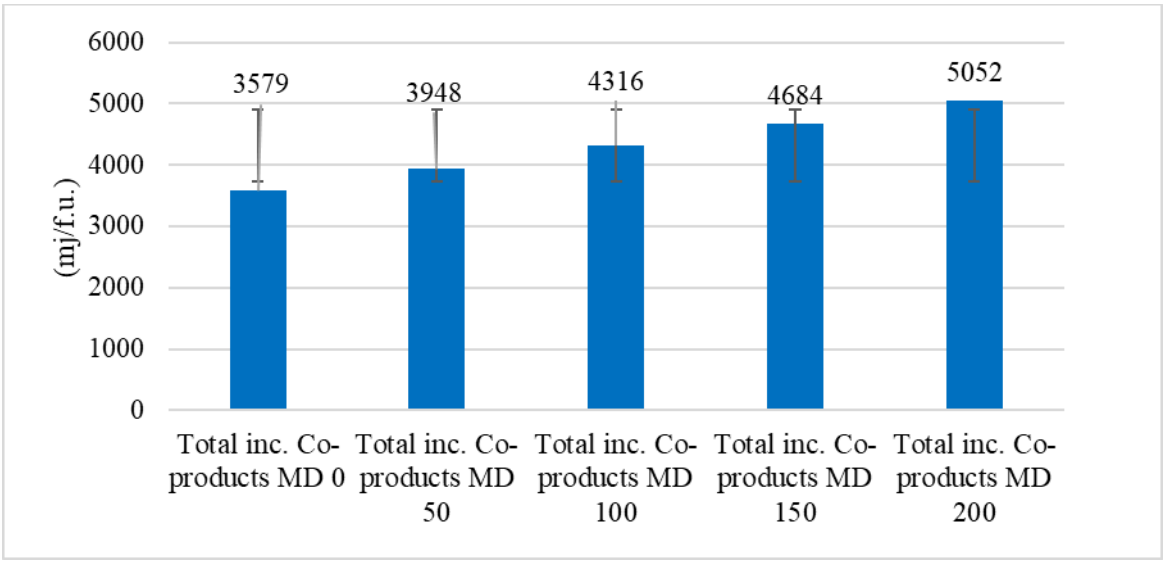


Figure 7. *Energy Demand (mj/f.u.)*

The energy demand for the raw materials used in the SCC production can be seen in Figure 7. As the amount of the MD increases, the energy demand increases. This assessment is essential due to the addition of electrical use, but it limits the production of MD. Due to the lack of data, other ingredients could not be added to the energy demand.

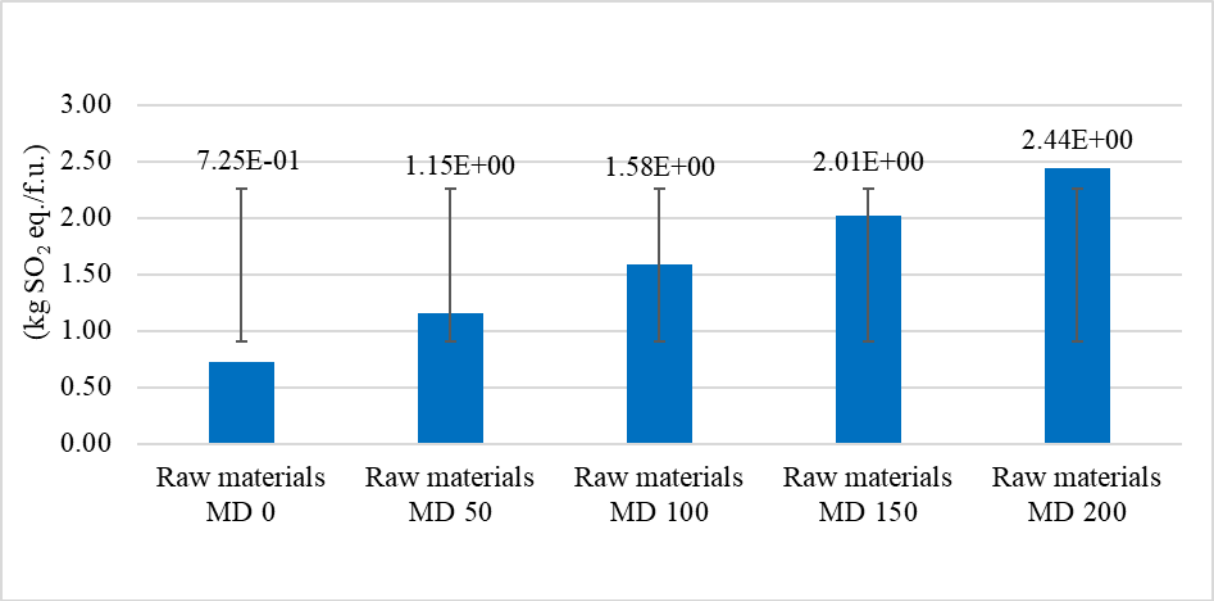


Figure 8. *Acidification Potential (kg SO_2 eq./f.u.)*

The acidification potential (kg SO_2 eq./f.u.) of the raw materials used in the production of the SCC can be seen in Figure 8. As the amount of the MD increases, the acidification potential increases, while the amount of the combination PC and FA as the binder decreases.

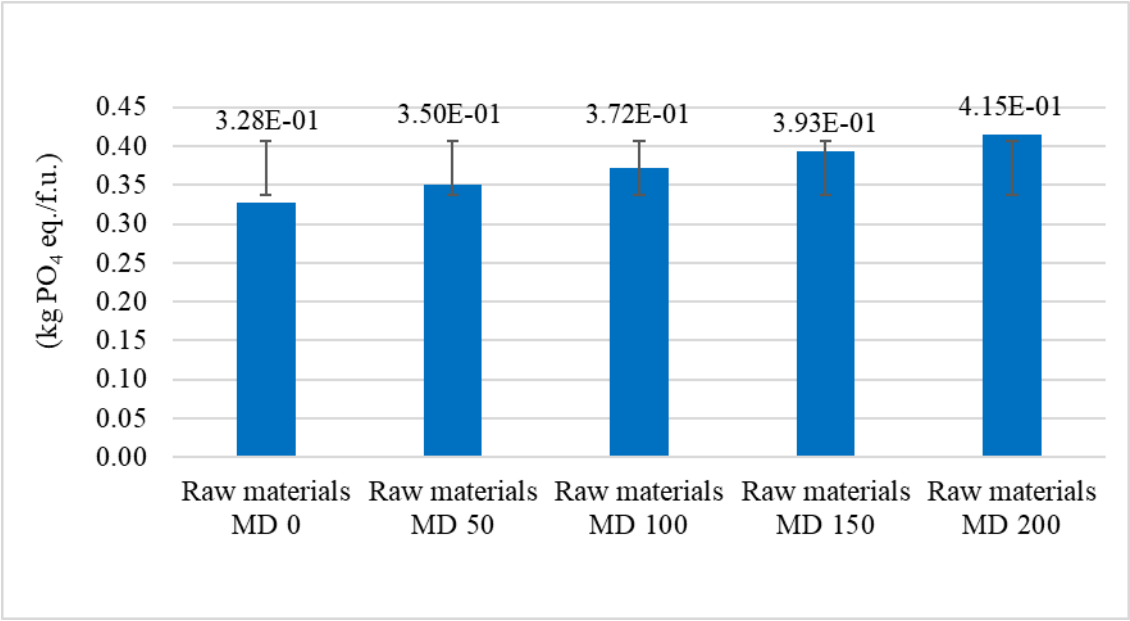


Figure 9. *Eutrophication Potential (kg PO_4 eq./f.u.)*

The eutrophication potential (kg PO_4 eq./f.u.) of the raw materials used in the production of the SCC can be seen in Figure 9. As the amount of the MD increases, the eutrophication potential increases, while the amount of the combination PC and FA as binder decreases.

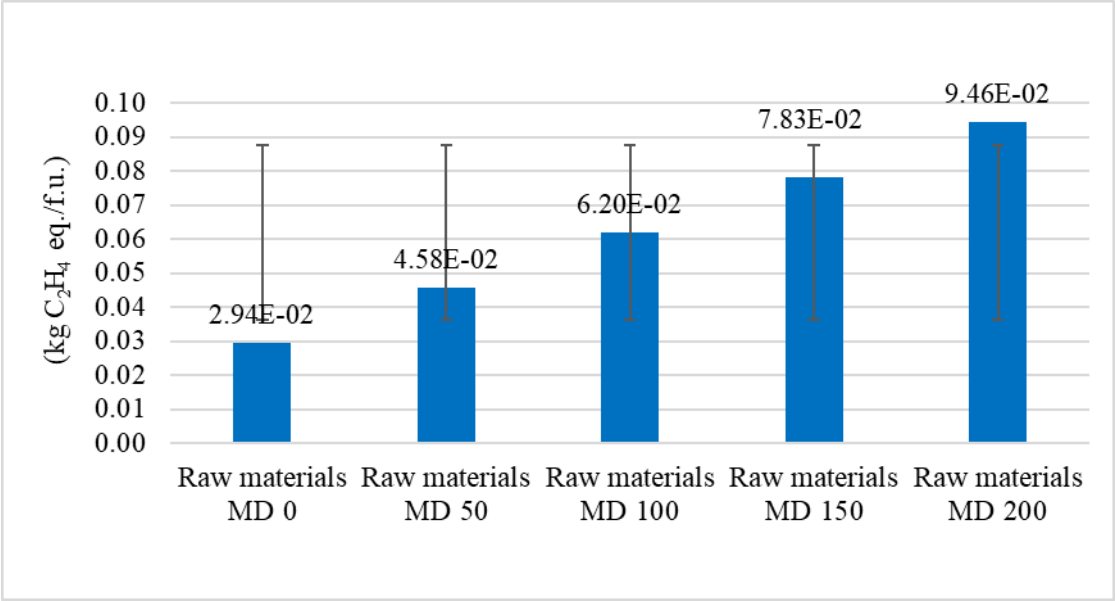


Figure 10. *Photochemical Smog Potential (kg C_2H_4 eq./f.u.)*

The photochemical smog potential (kg C_2H_4 eq./f.u.) of the raw materials used in the production of the SCC can be seen in Figure 10. As the amount of the MD increases, photochemical smog potential increases, while the amount of the combination PC and FA as binder decreases.

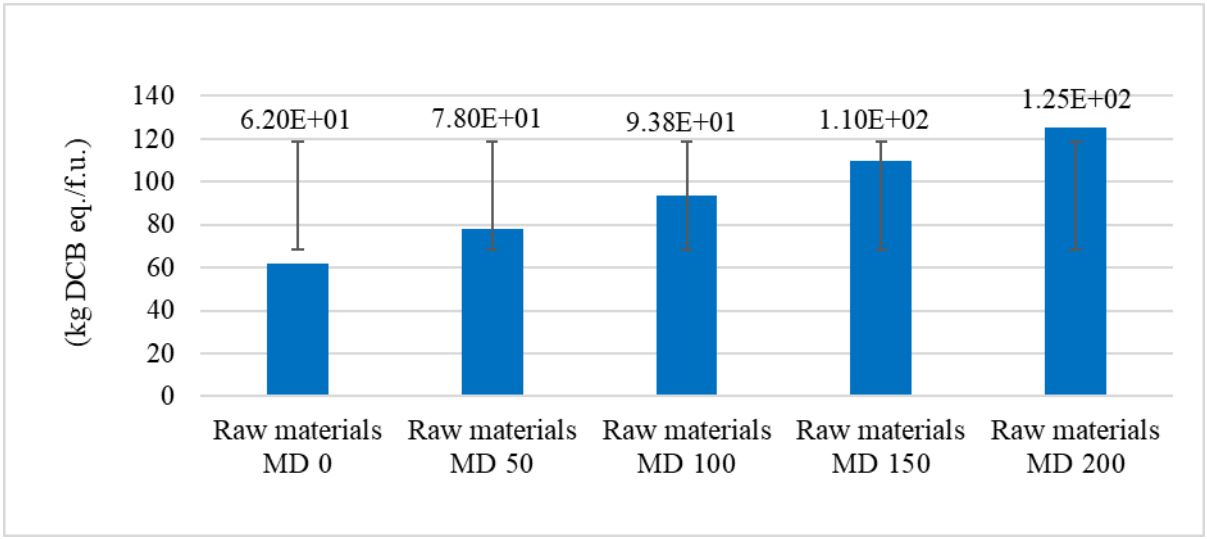


Figure 11. *Human Toxicity Potential (kg DCB eq./f.u.)*

The human toxicity potential (kg DCB eq./f.u.) of the raw materials used in the production of the SCC can be seen in Figure 11. As the amount of the MD increases, human toxicity potential increases, while the amount of the combination PC and FA as a binder decreases.

3.2. Discussion

Storing or disposing of waste marble products in the natural environment can cause pollution and lead to resource problems such as resource depletion. Oza et al. [76] added that the MD contains hazardous chemicals that harm health. In the production of concrete, the reuse or recycling of waste can help to reduce the use of natural resources, thus protecting nature and minimizing landfill [25]. According to Figure 5, the replacement of MD partially with cement in concrete has a more significant impact on increasing carbon emission compared to the amount of FA in the concrete; similarly, according to Orozco et al. [77], the replacement of FA partially with cement in concrete has more significant on decreasing carbon emission.

On the other hand, reducing the amount of clinker added in cement production and replacing it with WMD material reduces the greenhouse gases and energy consumption from the clinker process [78]. The WMD and limestone-filled cement can be a way to reduce environmental liabilities and promote circularity in the cement industry [63].

Moreover, as the distance between the MD and the FA is considered in Figure 6, the storage area of the MD and the production location of the SCC are close, so that the carbon emission due to transportation decreases compared to the FA transportation location. The growing amount of the MW being produced, alongside the significant carbon footprint of cement production, presents a major environmental challenge. Using FA instead of cementitious admixtures and incorporating residual MW as a fine aggregate in concrete can reduce costs and carbon emissions while promoting sustainable development [43]. Additionally, Sufian et al. [31], Toubal Seghir et al. [79], and İnce et al. [80] discovered that WMP can be significantly cost-effective due to the low solid density [32]. Kuoribo and Mahmoud [32] and Arel [81] mentioned that using MD can reduce costs from 40 to 33 US$/m^3. The WMD can be seen as an economical alternative [38]. As demonstrated by Verma et al. [43], utilizing the sustainable SCC mix resulted in a substantial 21,44% cost reduction and an impressive 47,71% decrease in carbon dioxide (CO_2) emissions when compared to conventional concrete. Significantly, local marble production and use may produce different results for each location.

Among the other similar studies, this study examines the impact of electrical energy on the MD production from the saws in Figure 7. Yılmaz and Göktan [82] said that higher feed rates and lower cutting depths increase the process's efficiency in cutting forces, power, and specific energy when faster sawing speeds are needed. Many operating parameters (such as depth of cut, sawblade peripheral speed, feed rate, cutting mode, blade specifications, coolant flow rate), as well as the characteristics of the rock (abrasiveness, mechanical strength, mineralogical properties, and petrographically properties, etc.), can affect a circular sawblade's sawing performance.

4. CONCLUSION

The marble industry sector can have significant adverse environmental impacts due to quarrying, transportation, and shaping because marble extraction can affect the environment of the mining area, causing noise, land surface water pollution, and dust in the air. Because of these, specifically, the management of the WMD can be significant. Fortunately, it can be used directly and recycled in many alternative sectors. One can be the construction material sector because as it is used as a filler, the material's durability, workability, and strength properties are suitable for use.

A number of studies have previously analyzed the use of WMD as a substitute material in the construction sector with regarding durability, workability and strength. However, the environmental impact of its use as a filler concrete is limited. Many studies concentrate on the material suitability of usage, but this study attempts to assess the environmental benefits of using WMD in the construction sector. Furthermore, there is a need for more studies on the use of local MDW, given that it can produce different results in each location. Additionally, one of the significant parameters of the LCA is the location. The present study focuses on the environmental impact of WM use in the SCC in Afyonkarahisar, with the energy use of MD production assumed as an LCA boundary and added to the environmental impact as the contribution of this research. These energy values were entered into the CCLAC2 tool as a source of hard coal from the coal mine power plant to calculate the environmental impact.

This study examines the environmental impacts of the SCC with WMD by replacing the PC and FA partially via the CCalC2 software. The environmental impact of the use of 50,100,150, and 200 kg/m^3 WMD in SCC by reducing the combination of PC and FA as binder partially were investigated from cradle to gate.

The properties of the raw materials were determined according to the ecoinvent database of the CCalC2 software. The input was PC, FA, MD, superplasticizer and water, transportation of these ingredients and the saw energy usage during the cutting marble to produce SCC. The SCC was produced in the structure material laboratory at the Civil Engineering Department of Afyon Kocatepe University, Afyonkarahisar.

The PC, FA and MD were carried to the lab so the transportation emissions of them were considered but the usage and carried of SCC were not in the study aim. Marble is a local product in Afyonkarahisar with many limitations of management as a waste but it is a convenient ingredient in concrete so it was chosen.

According to the results, when considering the environmental impacts of raw materials use, WMD can have significant environmental impacts when decreasing the amount of the PC and FA combination as the binder. When the amount of WMD used increased from 50 to 200 kg/m^3, the carbon footprint (kg CO_2 eq./f.u.) of the raw materials increased by 1.80%, the acidification potential (kg SO_2 eq./f.u.) increased by 236.97%, the eutrophication potential (kg PO_4 eq./f.u.) increased by 26,48%, the photochemical smog potential (kg C_2H_4 eq./f.u.) increased by 221,48%, and the human toxicity potential (kg DCB eq./f.u.) increased by 102,22%, which could be a result of the environmental impacts of marble quarrying. On the other hand, when the location parameter is considered for the same raw materials, the carbon footprint (kg CO_2 eq./f.u.) of the transportation decreases; this could be because was the WMD is a local waste and FA is sourced from a distant location. Therefore, using local waste has many environmental benefits, such as reducing the use of fossil fuels for transport and landfill sites.

4.1. Recommendations

Furthermore, among the other studies, this study assessed the environmental impact of cutting the marble. Figure 7 indicates the energy demands of the MD production; as the amount of the MD increases, the energy demand increases. The process of crushing and grinding marble can vary depending on the type of marble and the use of the machines. Therefore, studies can examine different marble types and machines for shaping.

The use of WMD can be more damaging to carbon emissions in the atmosphere than the use of FA and cement. In this context, this study indicated that local WMP can be used as a possible alternative to cement to reduce the environmental impact significantly. This approach is indispensable for evaluating the environmental benefits of using MW in SCC production. Lastly, this study was conducted in Afyonkarahisar to establish the necessary database for the marble industry. Local waste types should be examined for alternative usage instead of landfilling, but when considering supplementary material replacing cement, the location distance and the solid density of the material should be considered. Different results may be found for each location; the usage of local waste is significant. Many ingredients' properties lack Life Cycle Inventory (LCI) data.

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The environmental impacts of the design mix (Table 1) were assessed via CCaLC2 (Windows Manual (V1.1) in this study. The Sustainable Industrial Systems research group developed the CCaLC2 at the University of Manchester as part of a project funded by the Carbon Trust, EPSRC and NERC. CCaLC2 http://www.ccalc.org.uk/ccalc2.php. 2021 November.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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