LIFE CYCLE ANALYSIS OF RECYCLED AGGREGATE AND RECYCLED PLASTIC IN CONCRETE

by

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ABSTRACT

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Life cycle analysis [LCA] can compare the environmental impact of products and processes. When waste plastic and waste concrete is not responsibly disposed of, it can end up harming sensitive ecosystems by secreting toxins into its surroundings. To utilize the waste plastic and waste concrete, a study was conducted prior to this one that mixed both recycled wastes in the same mix design. This current study will explore the environmental impacts of the alternatives of the previous study. The analysis is being conducted to determine if the alternative is truly a more sustainable alternative, or if the life of the alternative is more or just as harmful as standard concrete. SimaPro is the LCA software that will be used, and the outputted information will provide quantified environmental impacts and a comparison across all alternatives. The results across the study showed a trend that the amount of recycled concrete included in the mix correlates to the reduction in impacts. Furthermore, mixes that included only recycled plastic consistently had greater negative environmental impacts.

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CHAPTER 1

STATEMENT OF THE PROBLEM

Plastic has a large environmental footprint, not only in terms of the sheer amount of waste plastic but also in the level of environmental impact plastic has. Waste plastic can potentially spread toxic chemicals into the ground and water, therefore contaminating human food supply and the ecosystem surrounding it. Not only does waste plastic cause harmful impacts, but the production of plastic requires a large amount of energy, which means more nonrenewable resources used and harmful emissions are put into the air around us. While the negative side effects of the life cycle of plastics have been thoroughly explored, it is still a very common-place material in our day-to-day lives and the amount of plastic and waste plastic in the world is only growing. According to National Geographic, production of plastic increased from 2.3 million tons in 1950 to 448 million tons in 2015 and is expected to double by 2050 [11].

Concrete is another product that has been analyzed at a life cycle scale. The largest point of impact for concrete has been proven to be the production or manufacturing phase of its life due to the fossil fuels and the waste byproducts of volatile chemicals and alloy waste. Due to how long concrete can be in place, it is not as common to research about what comes after the concrete is no longer viable. Therefore, the push for concrete has been focused on replacing concrete itself with an alternative, while plastic movements have been pushed more towards both the production and afterlife of the product. Life cycle analysis can and has compared alternatives to both concrete and plastic. This research will explore the environmental impacts of an alternative material that disrupts the production phase of concrete and the end-of-life phase of plastic. The goal of this analysis is to determine if the alternative is truly a more sustainable alternative, or if the life of the alternative is more or just as harmful as standard concrete.

CHAPTER 2

BACKGROUND INFORMATION

There have been a few but not many articles aimed at assessing the environmental impacts of recycled concrete. There were no articles found including recycled plastic in the environmental assessments.

"Product-Specific Life Cycle Assessment of Ready-Mix Concrete: Comparison Between a Recycled and an Ordinary Concrete" was written by four authors at a university in Switzerland [7]. This paper presents a life cycle assessment of commercialized recycled concrete and commercialized standard concrete showing the same properties such as strength and certification [7]. The findings showed that the recycled concrete only had slightly better results than the standard concrete as far as greenhouse gas emissions [7]. However, the article used data that they did not directly collect, and the data was from only one company.

In an article about concrete mixes including recycled aggregates, there is a focus on the transportation impacts of the concrete life cycle [3]. The authors used an environmental assessment method with a geospatial analysis to allow accurate impacts to be calculated for transportation of concrete [3]. The results of the paper show that the environmental impacts of transportation become important when there are substitutes and alternatives mixed into the concrete [3]. This is because the paper sees transportation as having the potential to optimize environmentally the alternatives further.

Another collaborative article applies to the manufacturing portion of the life cycle analysis. The article focuses on how the concrete is recycled and explores four systems of high-grade concrete recycling [18]. The four systems include: business as usual stationary wet processing, stationary advanced dry recovery, mobile advanced dry recovery, and mobile advanced dry recovering and heating air classification [18]. Results of the study show the most advantageous way to recycle the concrete is to recycle it onsite into high value secondary products using the mobile advanced dry recovery and mobile advanced dry recovery and heating air classification methods [18].

CHAPTER 3

SIGNIFICANCE OF RESEARCH

This research is significant because the analysis encompasses the entire life cycle of the product and not only a singular part of the product's life. For people to be able to make significant changes when it comes to environmental impacts, it is vital to have a thorough understanding of how a certain product or practice impacts the environment and understand where in its life cycle is the most impact. For example, a toaster may be energy efficient, but the material acquisition and manufacturing phase can have a high environmental impact. Therefore, someone looking to improve the environmental friendliness of the toaster would look at the type of material and how it is collected and look for a better alternative. Researchers can use a life cycle analysis to find data to focus on improving the materials instead of taking conjecture on what is causing the most harm.

Additionally, concrete technology is behind the curve on environmentally friendly practices. If life cycle analysis were used on the materials and practices involved in concrete production, it would be easier to make concrete a greener material. While there have been analyses done of other concrete alternatives, there has been no study to date with the specific mixture that will be evaluated.

CHAPTER 4

METHODOLOGY

Environmental impacts for sustainable and traditional concrete alternatives were assessed using the methodology outlined in ISO 14040 “Life cycle assessment – principles and framework” which includes goal and scope definition, inventory analysis, impact assessment, and interpretation. Environmental impacts were estimated using SimaPro software 9.0. Using information on material weights, the program can determine the environmental impacts of the concrete throughout its life cycle: manufacturing, use, transport, and end-of-life. Within SimaPro, impact assessment was conducted using TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts), developed by the United States Environmental Protection Agency. Impact assessment categories included in TRACI are:

- Environmental Impacts (global warming, ozone depletion, tropospheric ozone smog formation, acidification, and eutrophication),
- Human Health (human health potential and respiratory effects),
- Resource Depletion (fossil fuel depletion, water depletion, and cumulative energy demand).

Single Issue and Water footprint analyses were also conducted with TRACI. The single issue analysis was concerned with cumulative energy demand and the water footprint analysis gave water consumption data.

SimaPro inputs were obtained from a separate, lab-based project that involved performing tests on recycled concrete and post-consumer plastic included in the concrete mix. Recycled concrete (RC) replaced the corresponding percentage of concrete aggregate and the plastic was an additive. The recycled concrete aggregate was taken from an active construction site. Two types of plastic were tested: high density polyethylene (HDPE) and polypropelene (PP). HDPE and PP are referred to throughout this paper as "RP1" and "RP2," respectively. These specific plastics were chosen because they were available to be purchased at the plastic recycling company, Packaging One Inc., which cleaned and shredded the plastic, minimizing inconsistencies in the material.

Altogether, nine combinations of recycled materials (RC, HDPE, and PP) were tested, as shown in Table 4.1. The recycled concrete aggregate was added in three different percentages (0%, 10%, and 20%), based on the results of previous studies [1]. The recycled plastic was added at 0.2% per volume, also based on previous studies [4]. The baseline/control was a batch of concrete with no recycled concrete and no waste plastic content. Each of the nine combinations/batches were split into four samples for testing. Three samples were used for a compressive strength [13] and modulus of elasticity test [15], and one sample was cut and used for a water permeability test [14]. In total, 36 samples were tested during this study. The samples were labeled based on which type of plastic was used in that batch and how much recycled concrete was included. Batches with no recycled concrete start with an "A" followed by a number corresponding to the type of plastic included. The batches with 10% recycled concrete start with a "B", batches with 20% recycled concrete start with a "C" and again both are followed by a number corresponding to the type of plastic included. Batches D1 and D2 are the two batches with recycled concrete but no recycled plastic content. D1 has 10% recycled concrete as denoted by the “1” and D2 has 20% recycled concrete as denoted by the “2”.

Table 4.1: Experimental Design Matrix

Combination No.	Recycled Concrete %	Recycled HDPE %	Recycled PP %
1 Baseline/ Control	0%	0%	0%
2 Alternative – A1RP1	0%	0.2%	0%
3 Alternative – A2RP2	0%	0%	0.2%
4 Alternative – D1	10%	0%	0%
5 Alternative – B1RP1	10%	0.2%	0%
6 Alternative – B2RP2	10%	0%	0.2%
7 Alternative – D2	20%	0%	0%
8 Alternative – C1RP1	20%	0.2%	0%
9 Alternative – C2RP2	20%	0%	0.2%

4.1 Assumptions and Limitations

This study was limited based on what material was available in the Simapro database and what could be estimated with the information present. It was also limited to fewer product stages than available. Usually, product stages are broken up by material acquisition, use, transportation, and end-of-life. However, since this is a general study not intended for a specific area or location, transportation was not factored into the analysis. Use was also not factored into the analysis because the longevity of the different mixes is assumed to be similar or the same. End-of-life was not considered in the analysis because use was not factored in.

4.2 Assemblies and Calculations

The functional unit for the analysis was based on the amount of material that would be needed to produce one cubic yard of concrete with a service life of 100 years. Table 4.2 below lists of materials used in the previous study and corresponding materials chosen in Simapro for the analysis. Some materials had to be substituted by similar materials due to lack of availability in the databases used. Each material is in measured in pounds and each mix design assembly has 78.58 MJ of energy included to account for the energy needed to mix the concrete [5].

Table 4.2: Material Correspondence

Material from Previous Study	Material Used in Simapro
Pro Mix All Purpose Cement Mix	Cement, Portland [US] market for | APOS, U
Recycled Concrete	Recycled Concrete
Recycled Polypropylene (RP2)	Polyethylene terephthalate, granulate, amorphous, recycled [US] market for | APOS, U
Recycled High Density Polyethylene (RP1)	Polyethylene, high density, granuate, recycled [US] market for | APOS, U
Plastisol 6400	Plasticizer, for concrete, based on sulfonated melamine formaldehyde
Water	Tap water [GLO] market group for | APOS, U
Sand	Sand [GLO] market for | APOS, U
Coarse Aggregate	Gravel, crushed [RoW] market for gravel, crushed | APOS, U

Recycled concrete was created in Simapro in terms of one pound of recycled concrete. The assembly includes the energy to crush the existing concrete and separately considered the transportation of materials to a different site. The energy to remove the existing concrete from its place was not considered because it is assumed to happen regardless of the recycling process. The energy to crush the concrete was calculated based on a graph relating specific energy and particle size of waste in inches that is assumed to apply to concrete waste [17]. The recycled concrete aggregate was assumed to average one inch in size; therefore, the chart called for 10 kilowatt hours per ton (kWh/ton). This number was converted to the amount of kilowatt hours per pound. This was inputted into Simapro as the amount of energy required to crush the waste concrete. Transportation of the recycled concrete material in tons-kilometer was calculated by converting one pound into tons and 5.15 miles into kilometers. 5.15 miles was used based on a different study concerning concrete pipes [2].

The tables below are the individual mix designs and their respective inputs into the Simapro software.

Table 4.3: Baseline/ Control Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	30%	31.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Recycled Plastic	0%	0	lbs
Recycled Concrete	0%	0	lbs

Table 4.4: 2 Alternative – A1RP1 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	30%	31.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene, high density, granuate, recycled [US] market for | APOS, U	0.2%	0.11362	lbs
Recycled Concrete	0%	0	lbs

Table 4.5: 3 Alternative – A2RP2 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	30%	31.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene terephthalate, granulate, amorphous, recycled [US] market for | APOS, U	0.2%	0.13234	lbs
Recycled Concrete	0%	0	lbs

Table 4.6: 4 Alternative – D1 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	20%	21	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Recycled Plastic	0%	0	lbs
Recycled Concrete	10%	10.5	lbs

Table 4.7: 5 Alternative – B1RP1 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	20%	21	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene, high density, granuate, recycled [US] market for | APOS, U	0.2%	0.11362	lbs
Recycled Concrete	10%	0	lbs

Table 4.8: 6 Alternative – B2RP2 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	20%	21	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene terephthalate, granulate, amorphous, recycled [US] market for | APOS, U	0.2%	0.13234	lbs
Recycled Concrete	10%	10.5	lbs

Table 4.9: 7 Alternative – D2 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	10%	10.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Recycled Plastic	0%	0	lbs
Recycled Concrete	20%	21	lbs

Table 4.10: 8 Alternative – C1RP1 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	10%	10.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene, high density, granuate, recycled [US] market for | APOS, U	0.2%	0.11362	lbs
Recycled Concrete	20%	21	lbs

Table 4.11: 9 Alternative – C2RP2 Mix Design SimaPro Input

Ingredient	Per Volume (1 Cubic Yard)	Quantity	Unit
Cement, Portland [US] market for | APOS, U	20%	19	lbs
Sand [GLO] market for | APOS, U	30%	28.5	lbs
Tap water [GLO] market group for | APOS, U	W/C = 0.35	6.65	lbs
Gravel, crushed [RoW] market for gravel, crushed | APOS, U	10%	10.5	lbs
Plasticizer, for concrete, based on sulfonated melamine formaldehyde	8oz/100lb of Cement	0.0988	lbs
Polyethylene terephthalate, granulate, amorphous, recycled [US] market for | APOS, U	0.2%	0.13234	lbs
Recycled Concrete	20%	21	lbs

SimaPro outputs tables of estimated emissions and impacts that were then compared through graphs. Sensitivity analyses were conducted for input variables with substantial impact on model results and high uncertainty.

CHAPTER 5

RESULTS

5.1 TRACI Results

Figure 5.1 shows a graphical comparison of the alternatives for the categories that fall under environmental impacts. The graph shows that alternatives A1RP1 and A2RP2 had consistently higher impacts than the Control. Alternatives B1RP1 and B2RP2 were proportional to A1RP1 and A2RP2 but with lower impacts than the A alternatives. D1 had greater impacts than the Control batch for the smog category but was lower in the other categories. C2 had reduced impacts in most categories, except eutrophication. C1 and D2 had significantly reduced impacts across all categories with D2 having the greatest reduction in impacts.

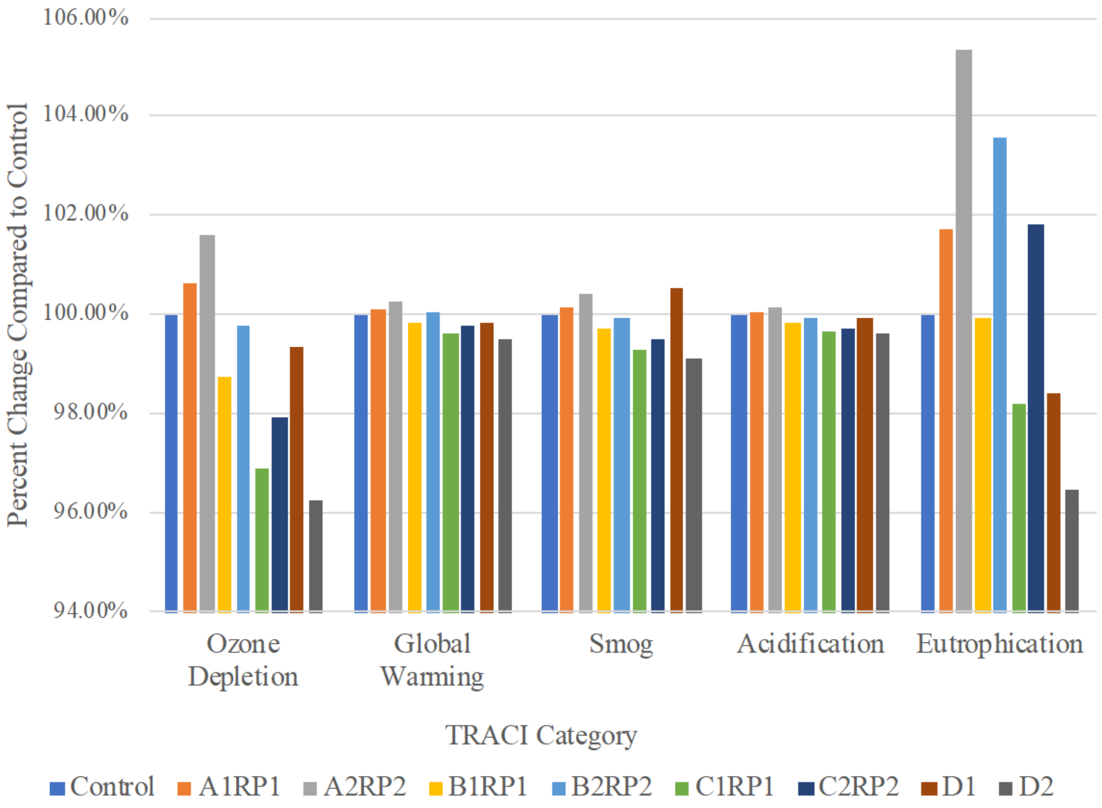

Figure 5.1: SimaPro Results: Environmental Impacts Categories

Figure 5.2 graphically depicts the comparison of the alternatives' human health impact. A1RP1, A2RP2, and B2PR2 all had increased impacts on all three human health categories. B1RP1 and D1 had reduced impacts across the three categories and C2 had decreased impacts in carcinogenics category but increased in the non-carcinogenics and the respiratory effect categories. D2 had the greatest amount of reduction in impacts.

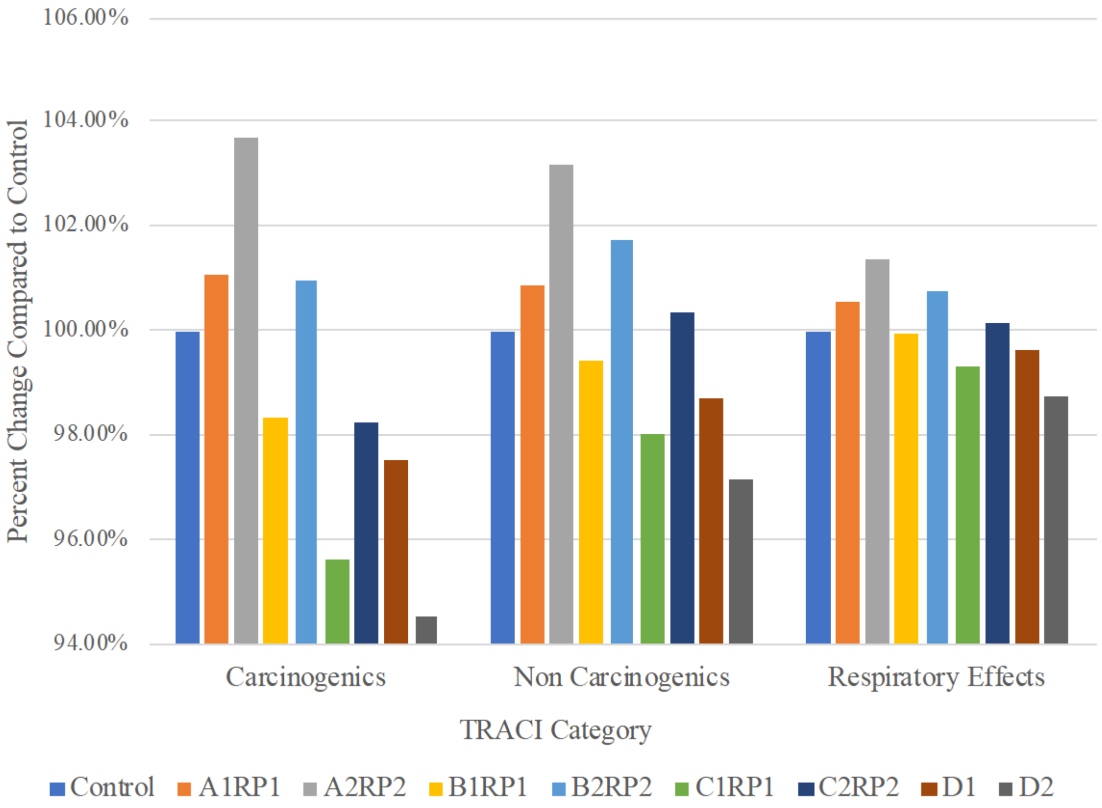

Figure 5.2: SimaPro Results: Human Health Impacts Categories

Figure 5.3 shows the comparison for the resource depletion categories. Alternatives A2RP2, B2RP2, and C2RP2 all had significantly higher impacts in the ecotoxicity category than the Control. A1RP1 and B1RP1 also had increased impacts in ecotoxicity, but not as great as the alternatives mentioned previously. C1RP1 and D1 had reduced ecotoxicity impacts and D2 had the greatest reduction of impacts. For fossil fuel depletion, there were little differences between all the alternatives and the control. A1RP1 and A2RP2 had barely more impact than the Control, while B2RP2 had approximately the same amount of impact as the Control. B1RP1, C1RP1, C2RP2, D1, and D2 all had decreased impacts with D2 having the greatest reduction.

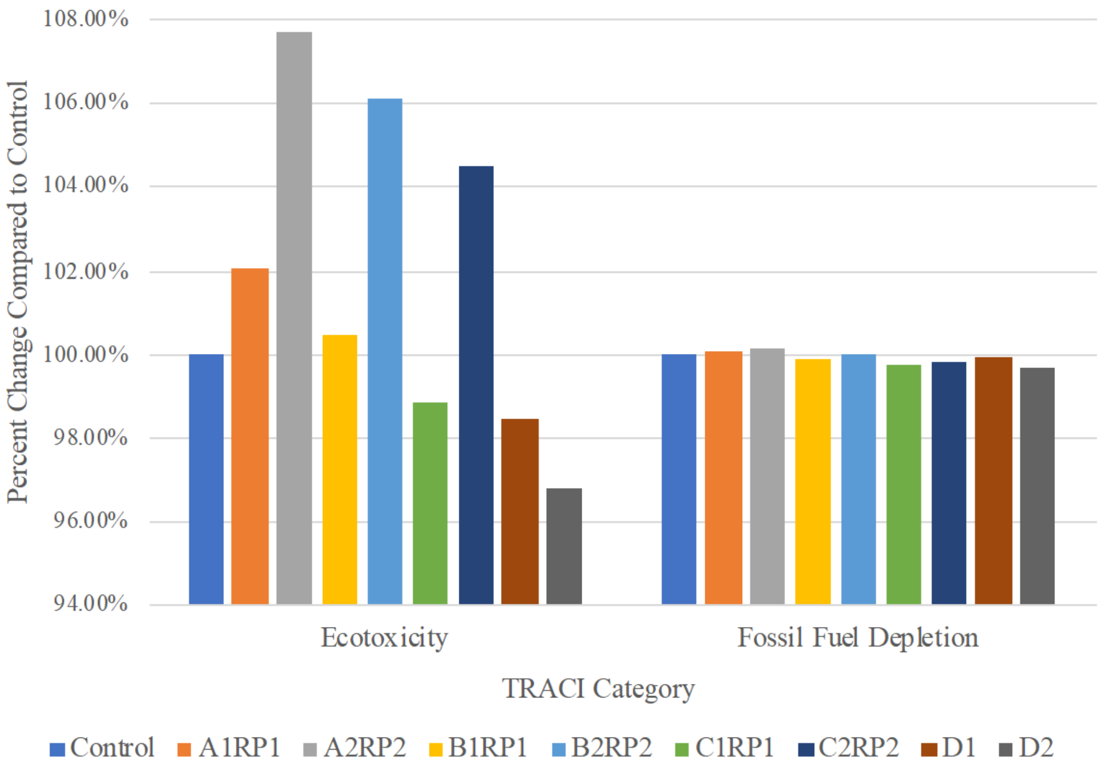

Figure 5.3: SimaPro Results: Resource Depletion Impacts Categories

5.2 Single Issue Results

Figure 5.4 has a graph comparing the non-renewable energy demand for the different mix designs compared to the Control. It shows the fossil fuel category of the non-renewables had very little differences between the alternatives, much like the fossil fuel depletion category in Figure 5.3. A1RP1 and A2RP2 had increased energy demand across all three non-renewables, especially in nuclear and biomass. B2RP2 had increased energy demand in the non-renewable nuclear category, but decreased demand in the other two categories. C1RP1, C2RP2, D1, and D2 all had reduced energy demand in all three categories with D2 having the greatest amount of reduction when compared to the Control.

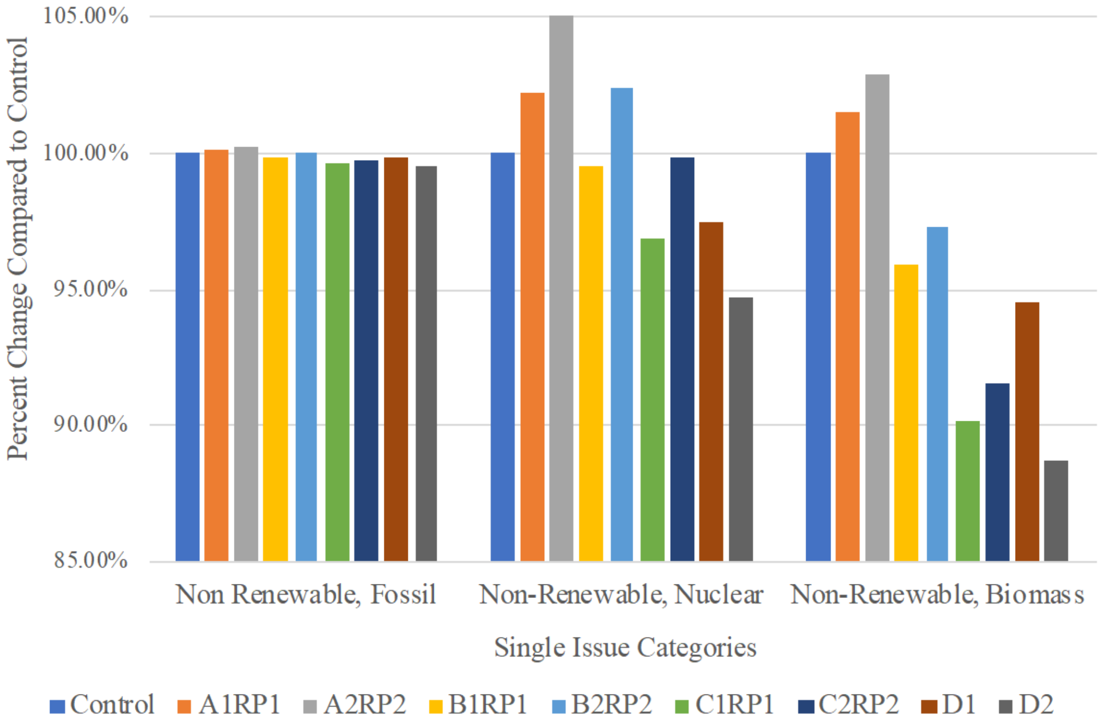

Figure 5.4: SimaPro Results: Non Renewable Energy Demand Categories

Figure 5.5 shows a graphical comparison of energy demand but with renewable energy categories. It shows that A1RP1 and A2RP2 had an increased energy demand across all categories and B2RP2 only had an increase in the solar, wind, and geothermal category. B1RP1, C1RP1, C2RP2, D1, and D2 all had reduced energy demand compared to the Control, with D2 having the greatest reduction between the alternatives

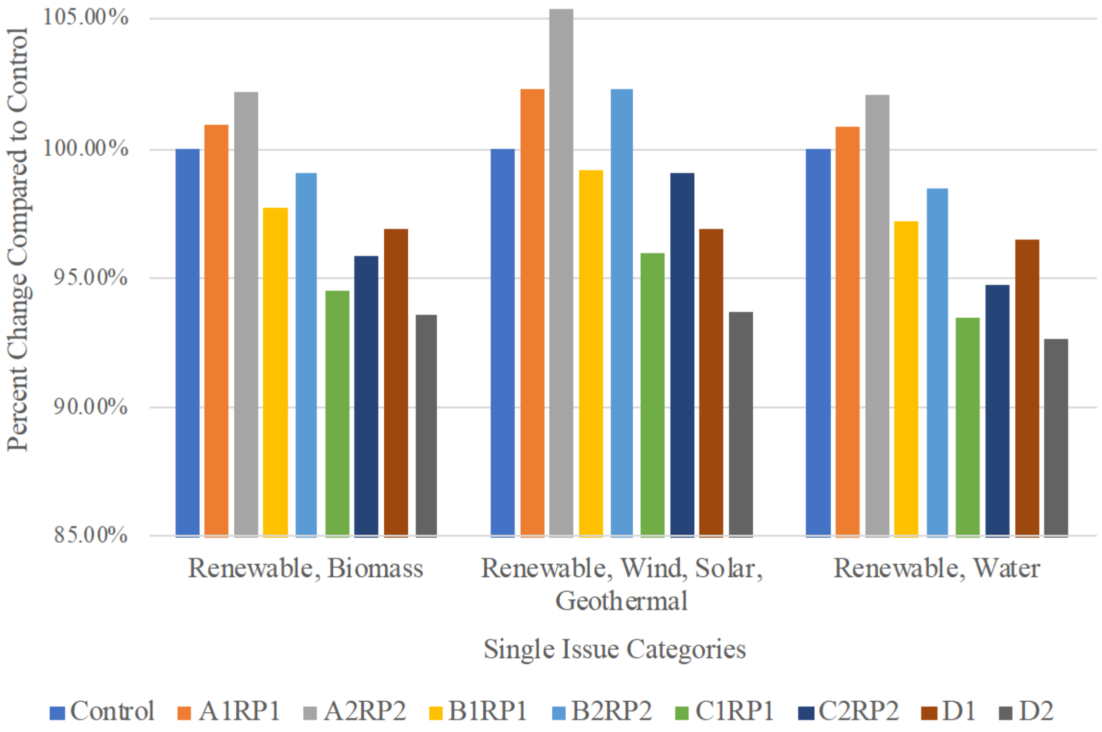

Figure 5.5: SimaPro Results: Renewable Energy Demand Categories

5.3 Water Footprint Results

Figure 5.6 is a graph that shows the comparison of the water footprint for all the alternatives. Water footprint and water usage are used interchangeably in this study. The graph shows that A1RP1 and A2RP2 were the only alternatives to have an increase in water usage while all other alternatives had a reduced footprint compared to the Control. D2 had the greatest reduction in water footprint.

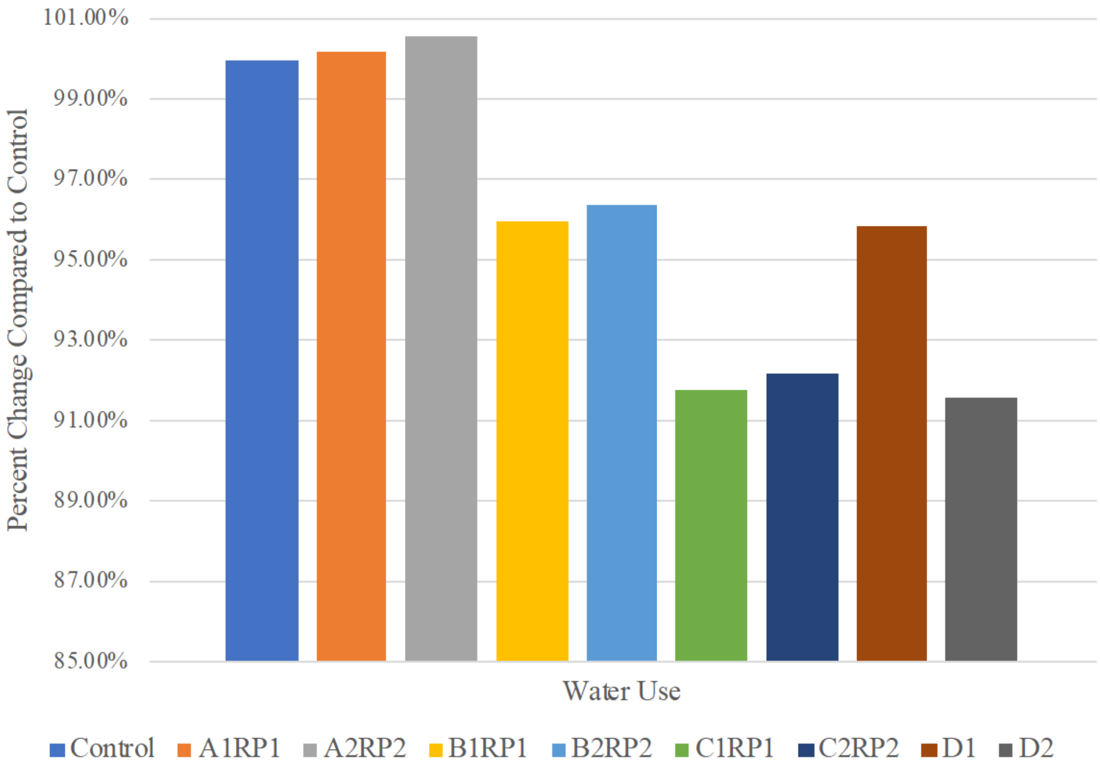

Figure 5.6: SimaPro Results: Water Usage

CHAPTER 6

DISCUSSION

Looking at the results across all analyses there is a trend that the amount of recycled concrete included in the mix correlates to the reduction in impacts. As the amount of recycled concrete increases, the greater the reduction in the impacts. This is shown clearly with alternative D2, which had the greatest amount of reduction in impacts in all analyses conducted. Mixes that had the same amount of recycled concrete as D2, C1RP1 and C2RP2 did not have as great of a reduction due to the recycled plastic content. Furthermore, mixes that included recycled plastic but did not include recycled concrete consistently had greater impacts than the Control. This is most likely because of the added energy and resources needed to recycle the plastic and the recycling of the plastics causing more impacts than the process of recycling the concrete. Therefore, it can be deduced that the plastic was the cause of most of the increases in negative environmental impacts. Between the different plastics themselves there was not a consistent trend on which plastic performed better. Each plastic had differing influences on the impacts of the mixes. Therefore, the types of plastic used will heavily influence the overall sustainability of the mix design. This could be due to the differing recycling processes for the different plastics or due to the different chemical makeup of the plastics.

CHAPTER 7

CONCLUSIONS

Both waste plastic and concrete have large negative environmental impacts involved in their lifecycles. This study analyzed the life cycle environmental impacts of different mix design alternatives to determine which mixes had reduced impacts. The following conclusions may be made based on the results from this study.

1. As the amount of recycled concrete content increases, the amount of negative environmental impacts decreases.
2. Adding recycled plastic without adding recycled concrete will not yield a reduction in the negative environmental impacts of the concrete.
3. The type of plastic will directly influence the amount of recycled concrete required to make the mix design more sustainable than standard concrete.
4. Recycled plastic was the cause of the increased impacts when compared to the baseline and not the recycled concrete.

REFERENCES

[1] Bendimerad, Ahmed Zakarya, et al. “Drying of Recycled Aggregate Concrete: Plastic Shrinkage, Cracking Sensitivity, and Durability.” *Key Engineering Materials*, vol. 711, 2016, pp. 111–117.

[2] Chilana, Lalit. “Carbon Footprint Analysis of a Large Diameter Water Transmission Pipeline Installation.” May 2011, pp. 37.

[3] Göswein, Verena, et al. “Transportation Matters – Does It? GIS-Based Comparative Environmental Assessment of Concrete Mixes with Cement, Fly Ash, Natural and Recycled Aggregates.” *Resources, Conservation and Recycling*, Vol. 137, Oct. 2018, pp. 1–10.

[4] Gu, Lei, and Togay Ozbakkaloglu. “Use of Recycled Plastics in Concrete: A Critical Review.” *Waste Management*, vol. 51, 2016, pp. 19–42.

[5] Guidetti, Francesco. “Energy Consumption in Production of Concrete.” *Geoplast*, 3 Oct. 2019, https://www.geoplastglobal.com/en/blog/energy-consumption-production-of-concrete/.

[6] Jonsson, Asa, Thomas Bjorklund, and Anne -. Tillman. "LCA of Concrete and Steel Building Frames." *The International Journal of Life Cycle Assessment*, vol. 3, no. 4, 1998, pp. 216-224. *ProQuest*, https://www-proquest-com.ezproxy.uta.edu/scholarly-journals/lca-concrete-steel-building-frames/docview/667166648/se-2?accountid=7117, doi:http://dx.doi.org.ezproxy.uta.edu/10.1007/BF02977572.

[7] Kleijer, A. L., et al. “Product-Specific Life Cycle Assessment of Ready Mix Concrete: Comparison between a Recycled and an Ordinary Concrete.” *Resources, Conservation & Recycling*, vol. 122, July 2017, pp. 210–218. *EBSCOhost*, doi:10.1016/j.resconrec.2017.02.004.

[8] Knoblauch, Jessica A. “The Environmental Toll of Plastics.” *EHN*, EHN, 8 Mar. 2021, www.ehn.org/plastic-environmental-impact-2501923191.html.

[9] Nealer, Rachael. “What Is Lifecycle Assessment-and Why Does It Matter?” *Union of Concerned Scientists*, 18 Dec. 2013, blog.ucsusa.org/rachael-nealer/what-is-lifecycle-assessment-lca-349.

[10] Old Farmer's Almanac. “Which Plastics Are Recyclable By Number?” *Old Farmer's Almanac*, 2021 www.almanac.com/content/which-plastics-are-recyclable-number.

[11] Parker, Laura. “Plastic Pollution Facts and Information.” *Environment*, National Geographic, 3 May 2021, https://www.nationalgeographic.com/environment/article/plastic-pollution.

[12] “Plastics: Material-Specific Data.” *EPA*, Environmental Protection Agency, 30 Oct. 2019, www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data.

[13] “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.” *ASTM Compass*, UTA Library, compass-astm-org.ezproxy.uta.edu/EDIT/html_annot.cgi?C39+21.

[14] “Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes.” *ASTM Compass*, UTA Library, compass-astm-org.ezproxy.uta.edu/EDIT/html_annot.cgi?C1585+20.

[15] "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression." *ASTM Compass*, UTA Library, compass-astm-org.ezproxy.uta.edu/EDIT/html_annot.cgi?C469+14e1.

[16] Storm, Birgit K. *Production of Recyclates – Compared with Virgin Plastics – a LCA Study.* vol. 112, EDP Sciences, Les Ulis, 2017. *ProQuest*, https://www-proquest-com.ezproxy.uta.edu/conference-papers-proceedings/production-recyclates-compared-with-virgin/docview/2039210254/se-2?accountid=7117, doi:http://dx.doi.org.ezproxy.uta.edu/10.1051/matecconf/201711204024.

[17] Trezek, G.I. and G. Savage. 1975 "Report on Comprehensive Refused Comminution Study" Waste Age (July): 49-55

[18] Zhang, Chunbo, et al. "Eco-Efficiency Assessment of Technological Innovations in High-Grade Concrete Recycling." *Resources, Conservation and Recycling*, Vol. 149, Oct. 2019, pp. 649–663.

BIOGRAPHICAL INFORMATION

Allison Fenske came to UT Arlington in Fall of 2018 and will be earning an Honors Bachelor of Science in Construction Management and an Honors Bachelor of Arts in Interdisciplinary Studies in Spring of 2022. At UT Arlington she was involved in a variety of programs, the most notable being the Peer Academic Leader program, Leadership Honors Program, the Honors College, and McNair Scholar's program. Allison was able to create two interlocking but separate senior projects for the Honors College and completed both a semester early. In Fall of 2022, she will be attending a graduate school with the intent of earning a doctorate in philosophy in a field related to environmental engineering. Her research interests lie within the field of sustainable construction with a specialization in life cycle assessment and sustainable alternatives to construction materials. During graduate school she hopes to continue to teach undergraduate students and continue to be involved in a variety of research projects. After completing her graduate schooling, she intends to stay in academia to take her research further and teach about sustainable construction practices.