American Concrete Institute

Always advancing

ECOCONCRETE STUDENT COMPETITION 2021

EcoConcrete calculation tool instruction

Last update: 05/28/2021

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1. EcoConcrete Student Competition

1.1 Introduction to LCA

In this competition, a simplified life cycle assessment (LCA) tool is used to assess the environmental aspect of concrete mixtures. Generally, LCA helps to quantify, analyze, and compare environmental impacts of different types of materials from raw material extraction to their end-of-life. LCA methodology is generally divided into the following steps: 1) goal and scope definition; 2) Inventory collection and analysis; 3) life cycle impact assessment, and 4) interpretation of the obtained results.

In the first phase (goal and scope definition), we define the aim of LCA, its intended audience, and its application. In addition, the scope of study must be defined considering the function of the product, the functional unit (quantification of the defined function), and system boundary (i.e. the processes are to be included in the assessment). Following the goal and scope definition, all the environmental exchanges in the system boundary are identified and quantified in the inventory analysis. The list of inventory will be shortened to some environmental impact categories by assigning relevant substances to these categories considering the magnitude and significance of their environmental impacts. Finally, the significant issues based on the obtained results are identified and the completeness of the results will be evaluated.

1.2 Goal and scope definition

In order to follow the current orientation of concrete industry, this student competition aims to promote the idea of environmental performance in concrete mix design as an important aspect of sustainability. Teams thus have the mission to develop an innovative concrete mixture, which has the lowest environmental impacts while maintaining or improving the durability performance. To achieve this goal, teams are encouraged to seek out and use local sources of concrete materials such as supplementary cementitious materials (SCMs) with reasonable environmental impacts.

The functional unit will be "producing one cubic meter of concrete mixture incorporating environmentally friendly components located in marine spray zone in Tampa, Florida". Hence, the system boundary of this environmental assessment is regarded as raw material extraction to final production of the concrete mixture; from cradle to gate. Finally, the environmental impacts of the environmentally friendly mixture (Alternative-Case Scenario) are compared to an ordinary concrete mixture (Base-Case Scenario) (i.e., a concrete produced with ordinary portland cement).

1.3 Life cycle inventory

All the environmental inputs and outputs come from the supply chain of concrete materials are quantified in this stage. To simplify the calculation of environmental performance in the tool, the inventory results of materials have been already calculated, characterized and assigned to their corresponding impact categories.

1.3.1 Life cycle impact assessment method (TRACI v.2.1)

The Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) 2.1 is developed by the US EPA to conduct impact assessment with the best applicable methodologies. This method they provide a North American context for the mandatory category indicators. In the case of the EcoConcrete Student Competition, five most relevant categories were selected as presented in Table 1.

Table 1 : Impact categories and their definition

Category	Unit	Definition
Climate change	kg $CO_{2\ eq}$	Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human-induced. In common usage, "global warming" often refers to the warming that can occur as a result of increased emissions of greenhouse gasses from human activities.
Carcinogenic	CTU_h	This category is expressed in comparative toxic units (CTU_h), providing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted.
Ozone depletion	kg CFC-11 $_{eq}$	Ozone within the stratosphere provides protection from radiation, which can lead to increased frequency of skin diseases and cataracts in the human populations.
Ecotoxicity	CTU_e	Ecotoxicity involves the effects of toxic chemicals on biological organisms, especially at the population, community, ecosystem, and biosphere levels.
Resource fuel depletion	MJ surplus	Resource depletion categories addressed within TRACI be fossil fuel use, land use, and water use.

*Notice that no conclusions can be drawn about the relative importance of the scores when compared across impact categories

2. EcoConcrete calculations tool user manual

This tool is a spreadsheet platform provided to estimate and compare the environmental impacts of the innovative and the ordinary concrete in the same geographical region. In this section, a brief description of the tool is provided. A systematic instruction of the tool is given in the next section.

2.1 Description of sheets

The tool consists of five sheets: cover page, base-case scenario, alternative-case scenario, summary, and database. The details of each sheet are presented in following sections. In addition, the procedure of modeling the environmental aspect of the mixtures are described, accordingly.

2.1.1. Cover page

All the information about team members and specimens' codes is to be found in this sheet.

The procedure of using the tool starts from the cover page, where the information of participants should be stated. The blue cells in this sheet (see **Figure 1**) should be filled with appropriate information.

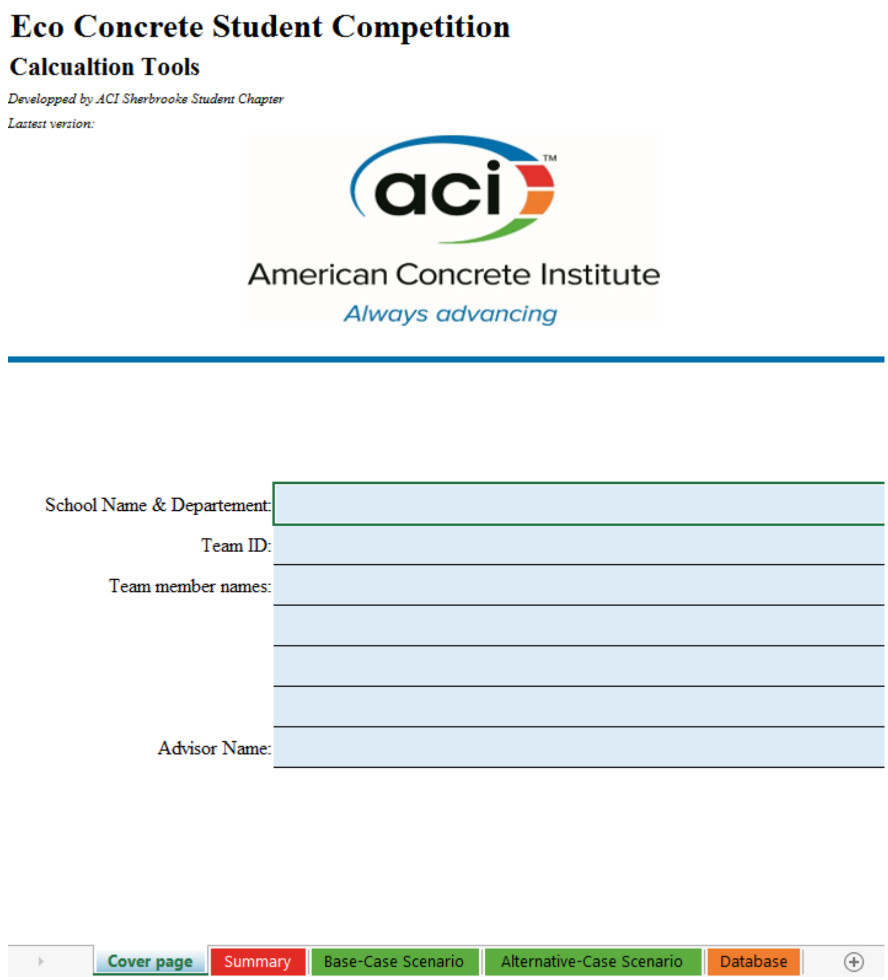
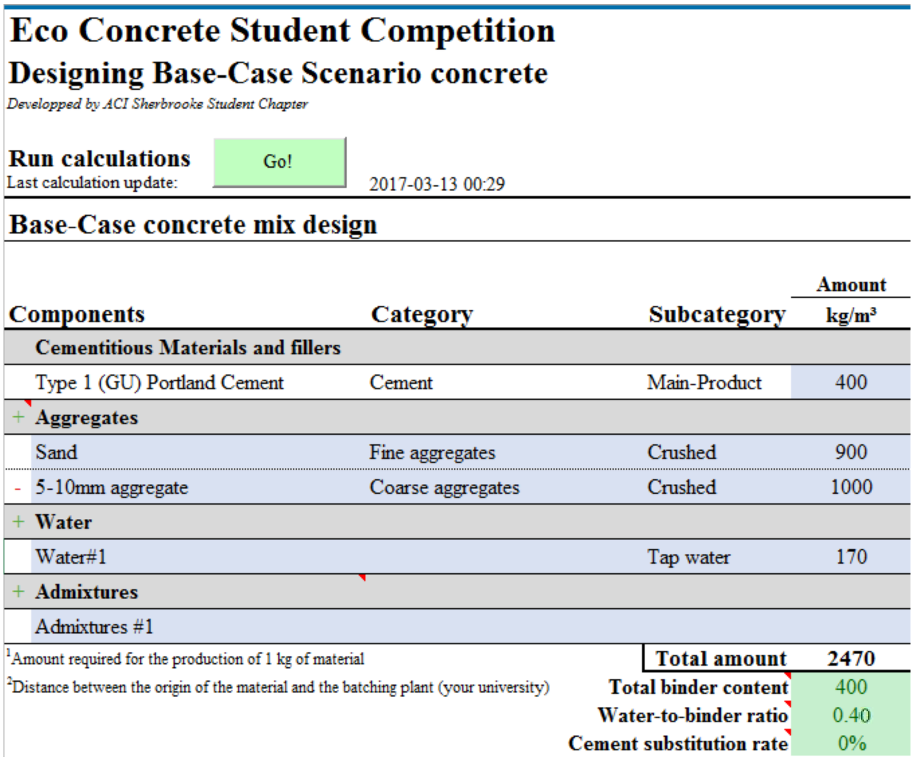


Figure 1. Overview of the cover page

2.1.2. Base-Case Scenario

The Base-Case Scenario is modeled in the *Base-Case Scenario* sheet of the EcoConcrete Calculations tool. This scenario consists of an ordinary concrete mixture made with Type I (GU) Portland cement, fine and crushed coarse aggregates and water. Its binder content, water-to-binder ratio and cement substitution rate shall equal 0.40 and 0%, respectively (See **Figure 2**).



Eco Concrete Student Competition

Designing Base-Case Scenario concrete

Developped by ACI Sherbrooke Student Chapter

Run calculations | Go!

Last calculation update: 2017-03-13 00:29

Base-Case concrete mix design

Components	Category	Subcategory	Amount kg/m³
Cementitious Materials and fillers			
Type 1 (GU) Portland Cement	Cement	Main-Product	400
+ **Aggregates**			
Sand	Fine aggregates	Crushed	900
- 5-10mm aggregate	Coarse aggregates	Crushed	1000
+ **Water**			
Water#1		Tap water	170
+ **Admixtures**			
Admixtures #1			

[1]Amount required for the production of 1 kg of material

[2]Distance between the origin of the material and the batching plant (your university)

Total amount	**2470**
Total binder content	400
Water-to-binder ratio	0.40
Cement substitution rate	0%

Figure 2 : Overview of the Base-Case Scenario sheet

In this sheet, the user must follow this procedure for defining the ordinary concrete information:

- Select the type of materials used for the ordinary concrete mixture (the mixture containing only Portland cement as a binder). For aggregates, you can select the type of material (crushed, natural, or recycled) and for water, it is possible to select tap or recycled water.
- Enter the mass of materials including portland cement, fine and coarse aggregates, water, and possibly chemical admixture for producing one cubic meter concrete.
- Check concrete unit weight, binder content, and water-to-binder ratio to make sure the values entered in the previous step are entered correctly (See **Figure 2**).
- Enter the transportation distance between your university (i.e. the batching plant) and the mine, cement plant, or the factory, where the materials are processed. It is possible to select different types of transportation (by road, rail, and water) as shown in **Figure 3**.
- After entering all the information, click on "Go!" and wait to see the message box "The environmental scores of your Base-Case Scenario has been successfully computed and saved in the Summary sheet".

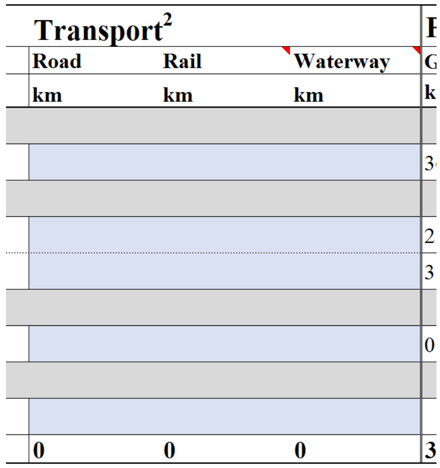


Figure 3 : Overview of the Transport inputs

2.1.3. Alternative-case scenario

The information about the environmentally friendly mixtures designed by the user must be entered here. The Portland cement can be partially replaced by supplementary cementitious materials according to the rule of competition. The water-to-binder ratio must be kept at 0.40, similar to the base-case scenario. This sheet must be filled out, accordingly:

- Select the type of materials you have used for producing your alternative mixture. It can be a recycled material, a co-product, or a single product of the corresponding process.
- Enter the mass of materials including Portland cement and its alternative binder(s), fine and coarse aggregates, water, and possibly chemical admixture for producing one cubic meter concrete. It should be noted that the user can use more than one type of cement alternative binder and aggregates by clicking on the “green cross” on the right gray rows.
- In the case of selecting “co-product” or “recycled material” for a material, enter the amount of electricity and heating energy used to produce 1 kg of the material.
- Check concrete unit weight, binder content, water-to-binder ratio, and cement substitution rates to make sure the values entered in the previous step are entered correctly (See **Figure 4**).
- Enter the transportation distance between your university (i.e. the batching plant) and the mine, cement plant, or the factory, where the materials are processed. It should be noted that selecting different types of transportation (i.e. by road, rail, and water) is possible (See **Figure 3**).
- After entering all the information, click on “Go!” at the top-left of the sheet and wait to see the message box “The environmental scores of your Alternative-Case Scenario have been successfully computed and saved in the Summary sheet".

Eco Concrete Student Competition

Designing Alternative-Case Scenario concrete

Developped by ACI Sherbrooke Student Chapter

Run calculations Go!

Last calculation update: 2017-03-13 18:10

Alternative-Case concrete mix design

Components	Category	Subcategory	Amount kg/m³
+ Cementitious Materials and fillers			
Type 1 (GU) Portland Cement	Cement	Main-Product	240
SCM	Coal fly ash	Co-Product	100
- SCM	Granulated Blast-Furnace Slag	Co-Product	50
- ASCM	Biomass ash	Co-Product	10
+ Aggregates			
Sand	Fine aggregates	Recycled	900
- 5-10mm aggregate	Coarse aggregates	Crushed	1000
+ Water			
Water#1		Tap water	170
+ Admixtures			
Admixtures #1			
		Total amount	**2470**
		Total binder content	400
		Water-to-binder ratio	0.40
		Cement substitution rate	40%

[1] Amount required for the transformation of 1 kg of material

[2] Distance between the origin of the material and the batching plant (your university)

Figure 4 : Overview of the Alternative-Case Scenario sheet

Note that if teams have used the materials that do not have a pre-set environmental impact (e.g. recycled aggregates or alternative supplementary cementitious materials (ASCM)), the corresponding environmental impacts must be calculated manually according to the following procedure:

- Select the type of materials you have used. It can be a recycled material, a co-product, or a single product of the corresponding process.
- The environmental modeling of materials should be consistent with the processes described in **Figure 5** in including the energy consumed for treatment processes (e.g. recycling equipment) and transportation to university.

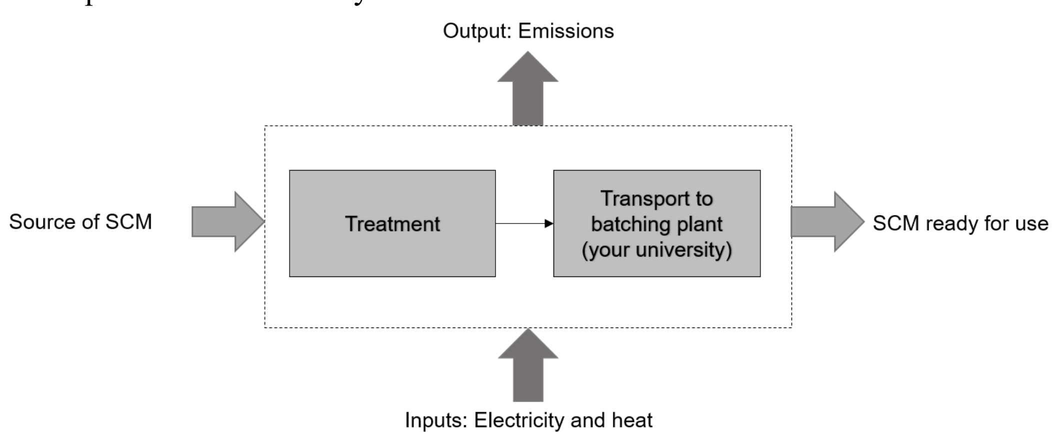


Figure 5 : Material production boundary

- The electricity and heating energy for materials processing should be exactly calculated or extracted from similar reports (In terms of kWh or MJ per kilogram of material).
- As shown in **Figure 6**, the amount of energy must be entered in corresponding cells. Select the region where the energy sources are produced. For the U.S. and Canada, the regions are divided into nine areas according to **Figure 7**. Other countries can use “Rest of the world” between the options as shown in **Figure 6**.

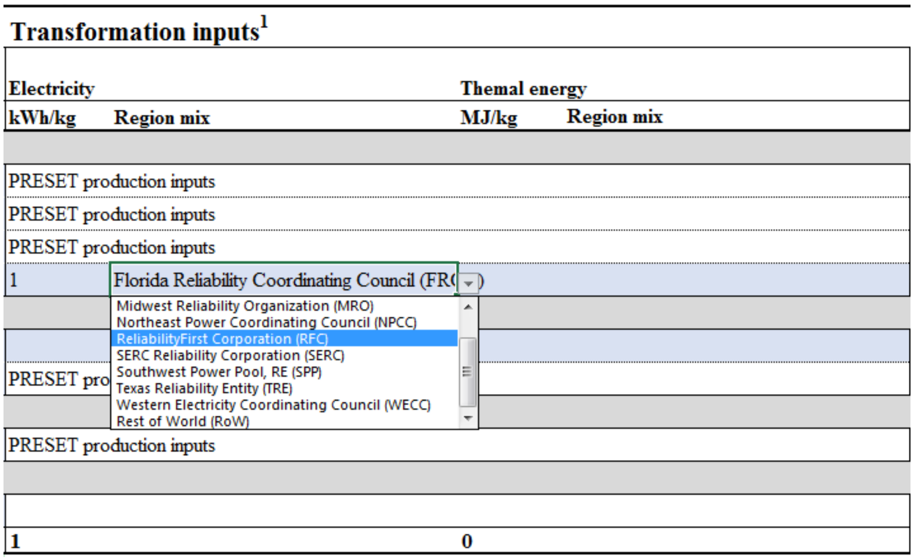


Figure 6 : Overview of the Production inputs

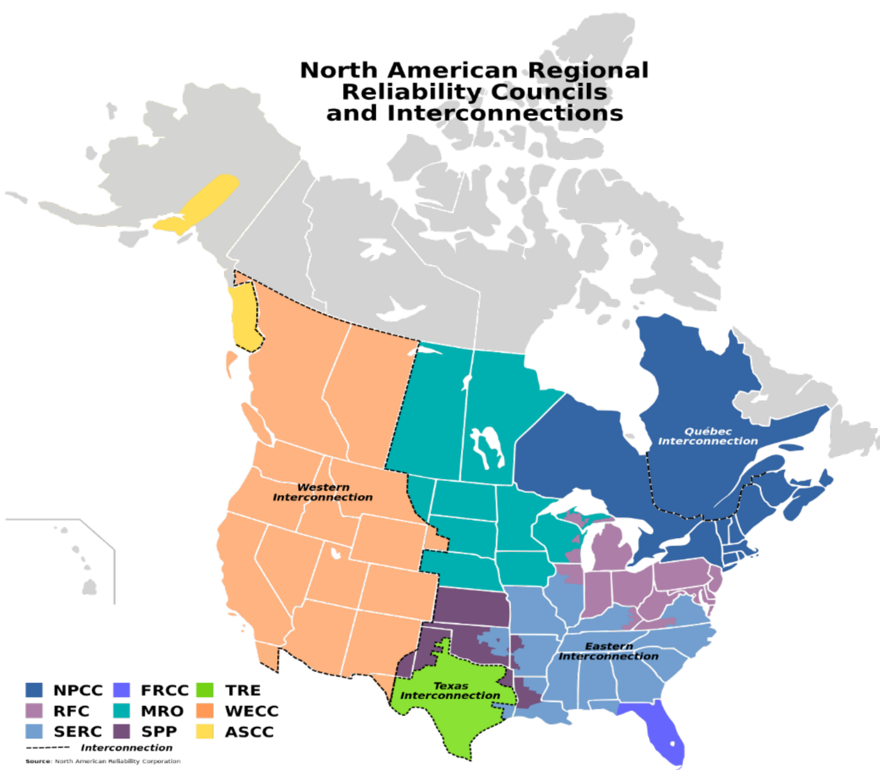


Figure 7 : Selecting the adequate mix of energy by region

- Enter the transportation distance between your university (i.e. the batching plant) and the mine, cement plant, or the factory, where the materials are processed. It should be noted that selecting different types of transportation (i.e. by road, rail, and water) is possible (See **Figure 3**).
- After entering all the information, click on “Go!” at the top-left of the sheet and wait to see the message box “The environmental scores of your Alternative-Case Scenario have been successfully computed and saved in the Summary sheet". After entering the amount of process energy and transportation and clicking on “Go!” you can see the corresponding environmental impacts of the materials at the right of the sheet (see **Figure 8)**.

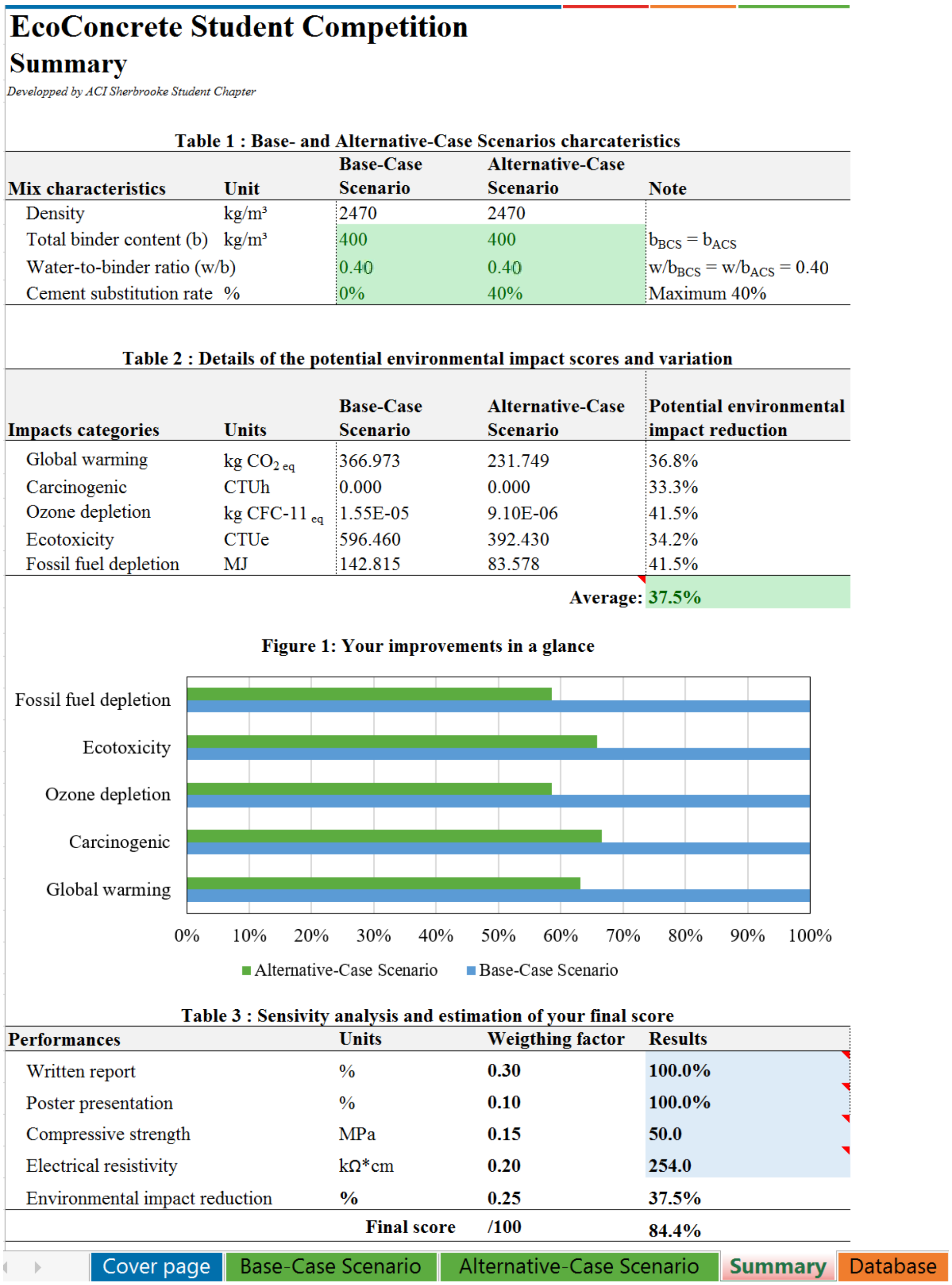
It should be noted that this procedure must be precisely described in the poster and report and appropriate references must be placed in the text.

Potential Environmental impacts				
Global warming	**Carcinogenic**	**Ozone depletion**	**Ecotoxicity**	**Fossil fuel depletion**
kg $CO_{2\ eq}$	**CTUh**	**kg CFC-11 $_{eq}$**	**CTUe**	**MJ**
361.200	4.24E-06	1.45E-05	476.000	134.400
2.124	2.46E-07	5.97E-07	23.130	3.807
3.620	6.73E-07	4.91E-07	66.900	4.580
0.029	2.30E-08	3.47E-09	30.430	0.028
366.973	**5.18E-06**	**1.55E-05**	**596.460**	**142.815**

Figure 8 : Calculated potential environmental impacts

2.1.4. Summary

The *Summary* sheet presents the overview of all the characteristics of the Base and Alternative-Case scenario as shown in **Figure 9**. The comparative environmental results of base-case and alternative-case will be shown in this section. The users must enter the average compressive strength and electrical resistivity of their mixtures, which have already been measured at their university, in this section.



EcoConcrete Student Competition

Summary

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Table 1 : Base- and Alternative-Case Scenarios charcateristics

Mix characteristics	Unit	Base-Case Scenario	Alternative-Case Scenario	Note
Density	kg/m³	2470	2470	
Total binder content (b)	kg/m³	400	400	$b_{BCS} = b_{ACS}$
Water-to-binder ratio (w/b)		0.40	0.40	$w/b_{BCS} = w/b_{ACS} = 0.40$
Cement substitution rate	%	0%	40%	Maximum 40%

Table 2 : Details of the potential environmental impact scores and variation

Impacts categories	Units	Base-Case Scenario	Alternative-Case Scenario	Potential environmental impact reduction
Global warming	kg $CO_{2\ eq}$	366.973	231.749	36.8%
Carcinogenic	CTUh	0.000	0.000	33.3%
Ozone depletion	kg CFC-11 $_{eq}$	1.55E-05	9.10E-06	41.5%
Ecotoxicity	CTUe	596.460	392.430	34.2%
Fossil fuel depletion	MJ	142.815	83.578	41.5%
			Average:	37.5%

Figure 1: Your improvements in a glance

Table 3 : Sensivity analysis and estimation of your final score

Performances	Units	Weigthing factor	Results
Written report	%	**0.30**	**100.0%**
Poster presentation	%	**0.10**	**100.0%**
Compressive strength	MPa	**0.15**	**50.0**
Electrical resistivity	kΩ*cm	**0.20**	**254.0**
Environmental impact reduction	%	**0.25**	**37.5%**
Final score	**/100**		**84.4%**

Cover page | Base-Case Scenario | Alternative-Case Scenario | Summary | Database

Figure 9 : Overview of the Summary sheet

2.1.5. Database

All the preset environmental impacts, such as the amount of emissions and consumption in material production, electricity and heat generations, and transportation can be observed in this sheet (**Figure 10**). This sheet in placed for the information of the team to enable them to compare the environmental impacts of different processes for achieving the most environmentally friendly alternatives.

Components	Unit	Global warming kg $CO_{2\,eq}$	Carcinogenic CTUh	Ozone depletion kg CFC-11 $_{eq}$	Ecotoxicity CTUe	Fossil fuel depletion MJ
		Potential Environmental impact				
Materials | Data source: Ecoinvent V3.1 | US and CA dataset						
Portland cement (Type 1) GU	/kg	0.9030	1.06E-08	3.61E-08	1.190	0.3360
Water	/kg	0.0002	1.35E-10	2.04E-11	0.179	0.0002
Fine aggregate, manufactured	/kg	0.0024	2.73E-10	6.63E-10	0.026	0.0042
Gravel, crushed	/kg	0.0036	6.73E-10	4.91E-10	0.067	0.0046
Granulated Blast-Furnace Slag	/kg	0.3920	1.04E-08	1.63E-08	1.150	0.1130
Coal fly ash	/kg	0.1500	8.87E-09	4.25E-09	0.764	0.0291
Silica fume	/kg	1.4500	7.70E-03	8.45E-08	0.004	0.0757
Metakaolin	/kg	0.4320	1.38E-08	1.11E-07	1.970	0.9800
Electricity Region mix | Data source: Ecoinvent V3.1 | US and CA dataset						
Alaska System Coordinating Council (ASCC)	/kWh	0.8220	1.61E-08	1.48E-07	9.530	1.8000
Florida Reliability Coordinating Council (FRCC)	/kWh	0.8970	2.01E-08	1.53E-07	9.800	1.7400
Midwest Reliability Organization (MRO)	/kWh	1.1400	7.15E-08	5.26E-08	14.300	0.3020
Northeast Power Coordinating Council (NPCC)	/kWh	0.4351	1.45E-08	9.77E-08	9.340	0.7954
ReliabilityFirst Corporation (RFC)	/kWh	0.8074	3.84E-08	6.96E-08	11.200	0.3028
SERC Reliability Corporation (SERC)	/kWh	0.7653	3.75E-08	7.90E-08	11.200	0.4768
Southwest Power Pool, RE (SPP)	/kWh	1.1300	5.30E-08	7.06E-08	12.600	0.6813
Texas Reliability Entity (TRE)	/kWh	0.8107	3.28E-08	1.01E-07	11.000	1.0924
Western Electricity Coordinating Council (WECC)	/kWh	0.6572	3.01E-08	7.69E-08	10.700	0.7830
Rest of World (RoW)	/kWh	0.7171	2.66E-08	1.18E-07	12.000	1.0351
Thermal energy | Data source: Ecoinvent V3.1 | US and CA dataset						
Alaska System Coordinating Council (ASCC)	/MJ	0.2284	4.48E-09	4.11E-08	2.650	0.5002
Florida Reliability Coordinating Council (FRCC)	/MJ	0.2492	5.57E-09	4.25E-08	2.720	0.4833
Midwest Reliability Organization (MRO)	/MJ	0.3159	1.99E-08	1.46E-08	3.970	0.0838
Northeast Power Coordinating Council (NPCC)	/MJ	0.1209	4.04E-09	2.72E-08	2.600	0.2210
ReliabilityFirst Corporation (RFC)	/MJ	0.2243	1.07E-08	1.93E-08	3.120	0.0841
SERC Reliability Corporation (SERC)	/MJ	0.2126	1.04E-08	2.19E-08	3.100	0.1324
Southwest Power Pool, RE (SPP)	/MJ	0.3139	1.47E-08	1.96E-08	3.510	0.1893
Texas Reliability Entity (TRE)	/MJ	0.2250	9.11E-09	2.81E-08	3.050	0.3034
Western Electricity Coordinating Council (WECC)	/MJ	0.1826	8.36E-09	2.14E-08	2.970	0.2175
Rest of World (RoW)	/MJ	0.1992	7.39E-09	3.27E-08	3.320	0.2875
Transport | Data source: Ecoinvent V3.1 | US and CA dataset						
Freight, lorry 16-32 tons	/tkm	0.1673	4.93E-09	4.05E-08	1.460	0.3625
Rail	/tkm	0.0598	5.27E-09	1.17E-08	0.266	0.1048
Waterway	/tkm	0.0115	2.67E-10	2.47E-09	0.022	0.0219

References

C. Chen, G. Habert, Y. Bouzidi, A. Jullien, A. Ventura, LCA allocation procedure used as an incitative method for waste recycling: An application to mineral additions in concrete, Resources, Conse

Cover page | Base-Case Scenario | Alternative-Case Scenario | Summary | Database

Figure 10 : Overview of the Database