Life Cycle Assessment (LCA) Report

Carbon Footprint of 3x3 Meter Patio Construction with Concrete Paving Stones

Group 4

Fuqi (Oren) Li, Nibin Koshy and Qiuyan Xu

McMaster University

SEP702 Systems Engineering and Public Policy

Dr. Greg Zilberbrant

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1 Problem Set Scope

Determine the carbon footprint of constructing a 3 x 3 meter patio made with concrete paving stones from extraction to installation of the product using a lifecycle assessment (LCA) approach. Consider the carbon footprint (CO2e) based on 100-year global warming potential exclusively based on CO2, N2O, and CH4 emissions.

In the report, CO2e stands for CO2 equivalent.

2 Common Parameters

2.1 Electricity

The CO2e of using electricity is provided in the assignment description.

Electricity	Electricity (/kWh)
CO2e (kg)	0.1

2.2 Transport Type

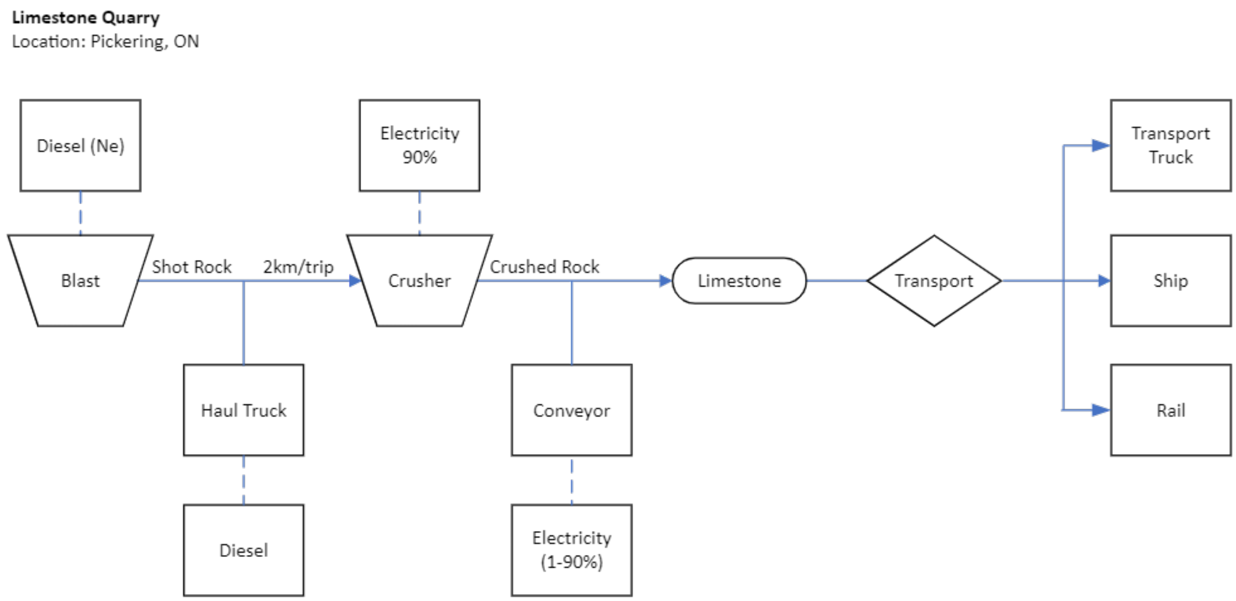
CO2e for different transportation methods can be calculated using LCA common data. Please see detailed calculation in the calculation spreadsheet.

Transportation Type	CO2e kg/(t*km)
Transport Truck	8.04E-02
Ship	2.82E-02
Rail	1.91E-02
Haul Truck	1.73E-01

3 Scenario A: Flow charts and CO2e for each process

3.1 Limestone Quarry

3.1.1 Process flowchart

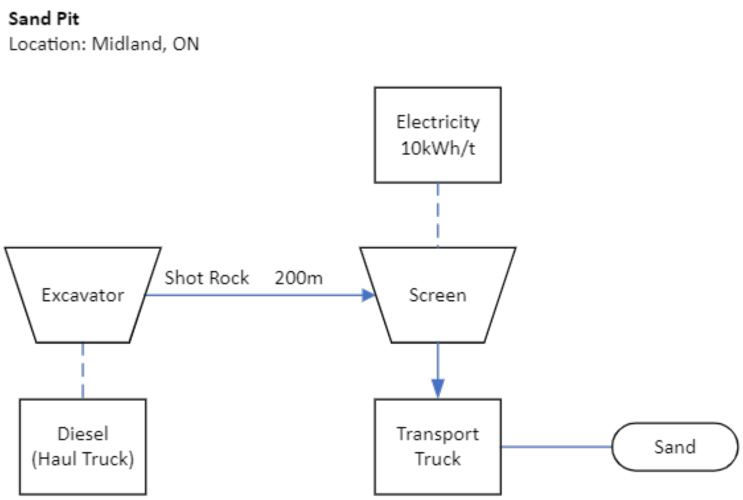


3.1.2 CO2e for production of 1 tonne Limestone

Limestone Quarry	CO2e (kg/unit)	Amount
Electricity (kWh)	0.1	50
Haul Truck (km)	1.73E-01	2
Total CO2e (kg/tonne)	5.35E+00	

3.2 Sand Pit

3.2.1 Process flowchart

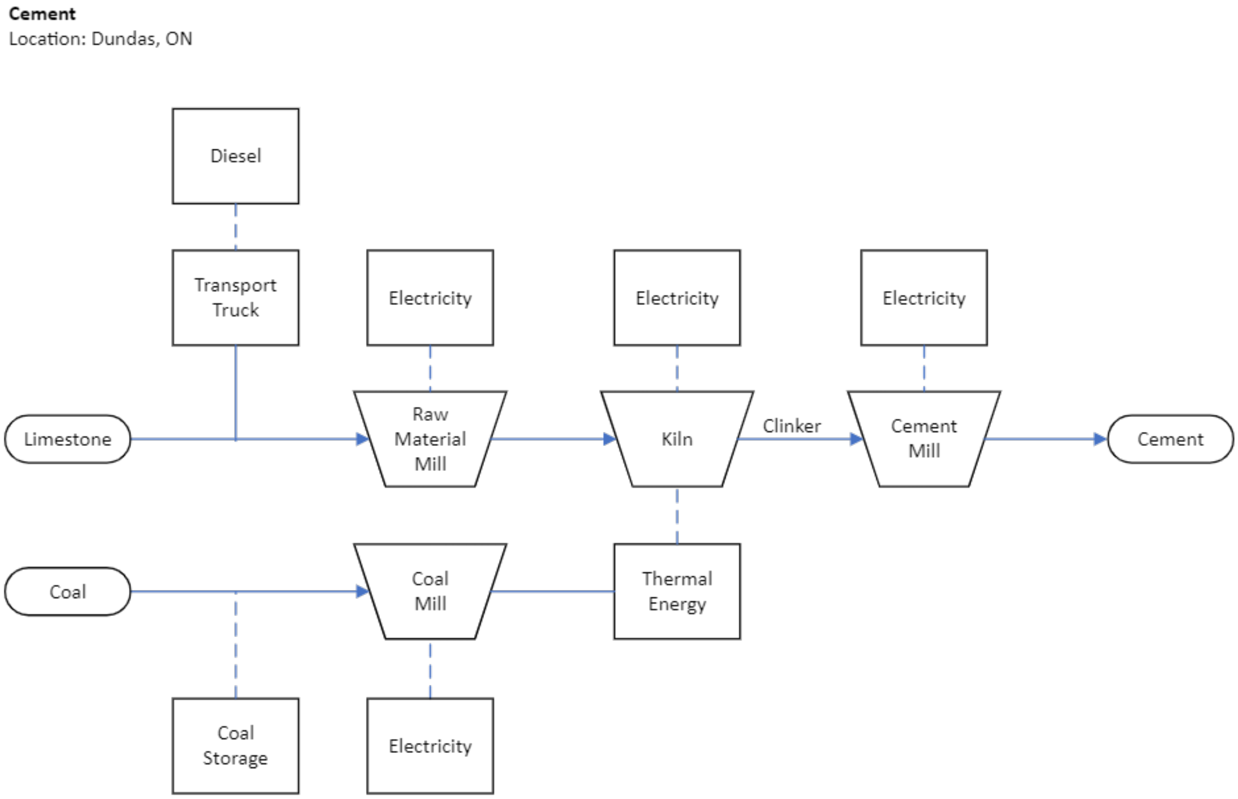


3.2.2 CO2e for production of 1 tonne sand

Sand Pit	CO2e (kg/unit)	Amount
Electricity (kWh)	0.1	10
Excavator (Haul Truck) (km)	1.73E-01	0.2
Total CO2e (kg/tonne)	1.03E+00	

3.3 Cement Production

3.3.1 Process flowchart



3.3.2 CO2e for production of 1 tonne cement

3.3.2.1 Calculate amount of coal used for 1 tonne cement

According to the emission factor provided in the assignment description, 0.134 tonnes of coal is used to generate 4000MJ thermal energy.

Ontario - US Bituminous	EF	Coal Amount	CO2 (kg)
EF (kg CO2/GJ)	81.5		
EF (kg CO2/MJ)	0.0815	4000	326
EF (kg CO2/tonne coal)	2430	1.34E-01	326

3.3.2.2 CO2e for production of 1 tonne cement

- On site CO2e for 1 tonne cement production

Cement	CO2e (kg/unit)	Amount	
Kiln			
Electricity (kWh)	0.1	3	0.3
Thermal Energy (MJ)		4000	
Thermal Coal (tonne)	2.44E+03	1.34E-01	3.27E+02
Limestone(t)	5.35E+00	2	1.07E+01
Coal Mill			
Electricity (kWh)	0.1	2.68E+00	0.268312757
Material Mill			
Electricity (kWh)	0.1	100	10
Cement Mill			
Electricity (kWh)	0.1	150	15
		Total CO2e (kg/tonne)	3.63E+02

- CO2e for transportation of limestone

Based on the production calculation, 2 tonnes of limestone need to be transported from limestone quarry (Pickering, ON) to cement plant (Dundas, ON). The distance is approximately 110 km.

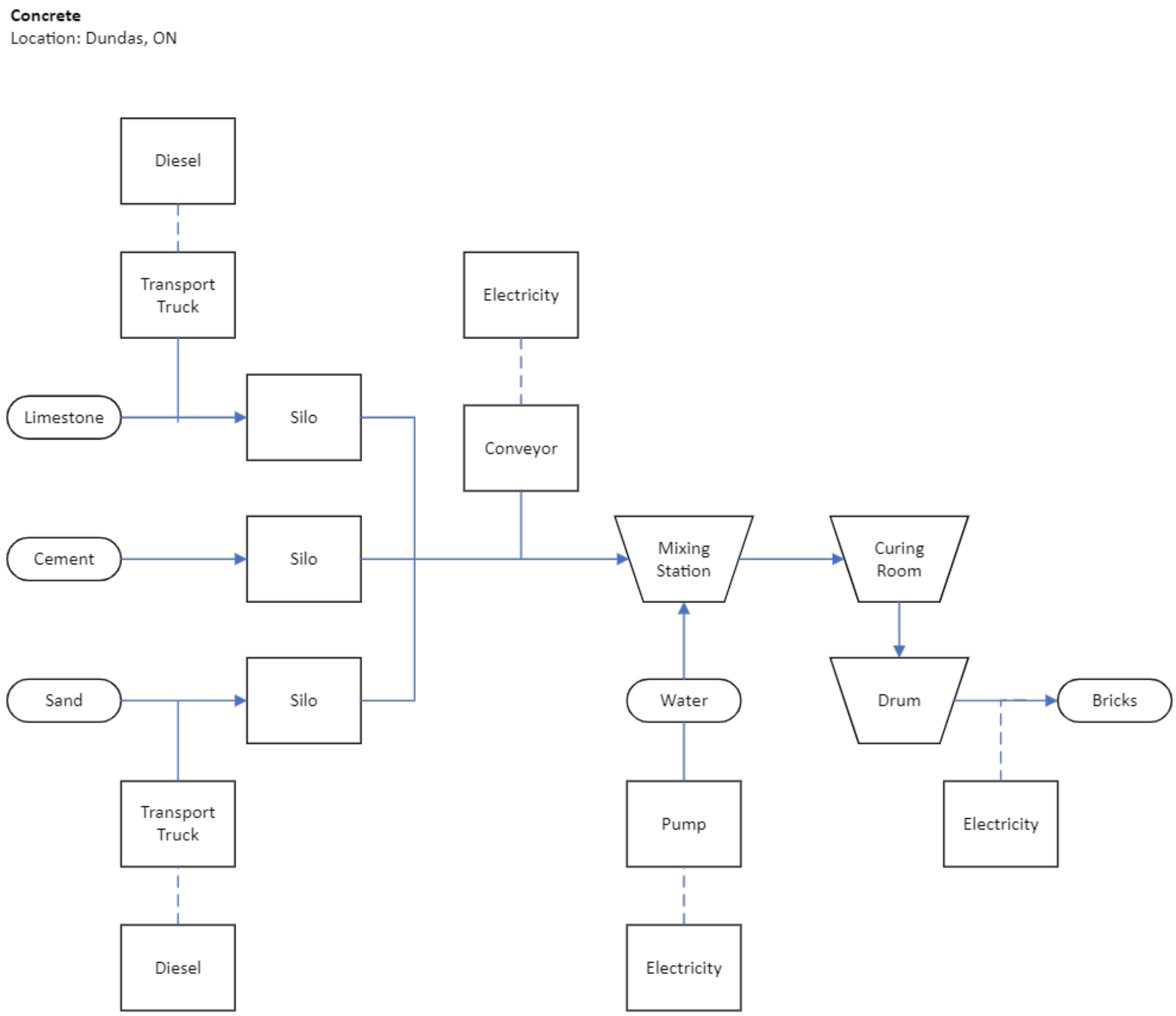
Transportation	CO2e kg/(t*km)	Amount (Tonne)	Distance to cement (km)	Total CO2e (kg)
Limestone Transport Truck	8.04E-02	2	110	1.77E+01

- Total CO2e for production of 1 tonne cement

Total CO2e kg/tonne	3.81E+02

3.4 Concrete Production

3.4.1 Process Flowchart



3.4.2 CO2e for production of 1 cubic meter concrete

- CO2e for 1 cubic meter concrete production (on site)

Concrete (1 cubic meter)			
(160 bricks)	CO2e (kg/unit)	Amount	
Electricity - water(kWh/m3)	0.1	0.3	3.00E-02
Sand (tonne)	1.03E+00	0.6	6.21E-01
Electricity - sand(kWh/tonne)	0.1	1.2	1.20E-01
limestone(tonne)	5.35E+00	0.8	4.28E+00
Electricity - limestone(kWh/tor	0.1	1.6	1.60E-01
cement(tonne)	3.81E+02	0.3	1.14E+02
Electricity - cement(kWh/tonne	0.1	0.6	6.00E-02
Electricity - brick	0.1	0.016	1.60E-03
		Total CO2e (kg)	1.20E+02

- CO2e for transportation of materials

Based on the on-site production calculation, 0.8 tonnes of limestone and 0.6 tonnes of sand need to be transported to concrete plant (Dundas, ON) separately. The distance is approximately 110 km (limestone) and 200km (sand).

Transportation	CO2e kg/(t*km)	Amount(tonne)	Distance to concrete (k	Total CO2e (kg)
Sand Transport Truck	8.04E-02	0.6	200	9.65E+00
Limestone Transport Tru	8.04E-02	0.8	110	7.08E+00

- Total CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	1.36E+02

3.5 CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.36E+02
1 brick	1	8.51E-01
3X3 meter patio	144	**1.23E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **122.6538** kg of CO_2

4 Scenario B

Scenario B Ship all limestone from quarry to cement plant by rail instead of truck.

Therefore, modify CO2e for transportation of limestone.

Transportation	CO2e kg/(t*km)	Amount (Tonne)	Distance to cement (l	Total CO2e (kg)
Limestone Rail	1.91E-02	2	110	4.20E+00

Transportation	CO2e kg/(t*km)	Amount(tonne)	Distance to concrete (km)	Total CO2e (kg)
Sand Transport Truck	8.04E-02	0.6	200	9.65E+00
Limestone Rail	1.91E-02	0.8	110	1.68E+00

Accordingly, the total CO2e for production of 1 tonne cement:

Total CO2e kg/tonne	3.67E+02

Total CO2e for production of 1 cubic meter concrete:

Total CO2e (kg/cubic meter)	1.27E+02

Total CO2e for production of 3X3 meter patio:

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.27E+02
1 brick	1	7.94E-01
3X3 meter patio	144	**1.14E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **114.3086** kg of CO_2

Please see the detailed calculation in the excel spreadsheet.

5 Scenario C

Scenario C Ship all limestone from quarry to cement plant by ship instead of truck.

Therefore, modify the CO2e for transportation of limestone as follows:

Transportation	CO2e kg/(t*km)	Amount (Tonne)	Distance to cement (km)	Total CO2e (kg)
Limestone Ship	2.82E-02	2	110	6.20E+00

Transportation	CO2e kg/(t*km)	Amount(tonne)	Distance to concrete (km)	Total CO2e (kg)
Sand Transport Truck	8.04E-02	0.6	200	9.65E+00
Limestone Ship	2.82E-02	0.8	110	2.48E+00

Accordingly, the total CO2e for production of 1 tonne cement is changed to

Total CO2e kg/tonne	3.69E+02

Total CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	1.28E+02

Total CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.28E+02
1 brick	1	8.01E-01
3X3 meter patio	144	**1.15E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **115.4084** kg of CO_2

Please see the detailed calculation in the excel spreadsheet.

6 Scenario D

Scenario D improves fuel efficiency of all diesel equipment at limestone quarry and sand pit by 50%.

Therefore, amount of diesel used for haul truck and excavator in limestone quarry and sand pit is only half of scenario A.

CO2e for production of 1 tonne of Limestone is changed to

Total CO2e (kg/tonne)	5.17E+00

CO2e for production of 1 tonne of sand

Total CO2e (kg/tonne)	1.02E+00

CO2e for production of 1 tonne of cement

Total CO2e kg/tonne	3.80E+02

CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	1.36E+02

Total CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.36E+02
1 brick	1	8.50E-01
3X3 meter patio	144	**1.22E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **122.4267** kg of CO_2

Please see the detailed calculation in the excel spreadsheet.

7 Scenario E

Scenario E Substitute 100% of coal at cement plant for natural gas.

According to the emission factor provided in the assignment description, the CO2e of natural gas for every 1 MJ thermal energy can be calculated.

Thermal energy	Natural Gas (/MJ)	GWP (100 yr.)	
CO2 (kg)	4.90E-02	1	0.04903
N2O (kg)	8.87E-07	265	0.000235055
CH4 (kg)	9.66E-07	28	0.000027048
CO2e (kg)			0.049292103

For 4000MJ thermal energy, the CO2e of natural gas is 1.97E+02 kg.

CO2e for production of 1 tonne of cement

Total CO2e kg/tonne	2.51E+02

CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	9.73E+01

Total CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	9.73E+01
1 brick	1	6.08E-01
3X3 meter patio	144	**8.75E+01**

Total equivalent CO_2 emission for 3X3 meter patio = **87.455 kg** of CO_2

Please see the detailed calculation in the excel spreadsheet.

8 Scenario F

Scenario F Substitute 100% of coal at cement plant with agricultural byproducts.

According to the emission factor provided in the assignment description, the CO2e of agricultural byproducts for every 1 MJ thermal energy can be calculated.

Thermal energy	By Products(/MJ)	GWP (100 yr.)	
CO2 (kg)	1.12E-01	1	0.112
N2O (kg)	0.00E+00	265	0
CH4 (kg)	0.00E+00	28	0
CO2e (kg)			0.112

For 4000MJ thermal energy, the CO2e of agricultural byproducts is 4.48E+02 kg.

CO2e for production of 1 tonne of cement

Total CO2e kg/tonne	5.02E+02

CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	1.73E+02

Total CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.73E+02
1 brick	1	1.08E+00
3X3 meter patio	144	**1.55E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **155.132** kg of CO_2

Please see the detailed calculation in the excel spreadsheet.

9 Scenario G

Scenario G Substitute 15% of clinker for limestone (from quarry) in cement mill.

Therefore, the materials and energy used in the raw material mill and kiln are all decreased by 15%. There is additional 0.15 tonne of limestone used in cement mill. The transportation of limestone changed accordingly, that is from 2 tonnes to 1.85 tonnes.

CO2e for production of 1 tonne of cement

Total CO2e kg/tonne	3.28E+02

CO2e for production of 1 cubic meter concrete

Total CO2e (kg/cubic meter)	1.20E+02

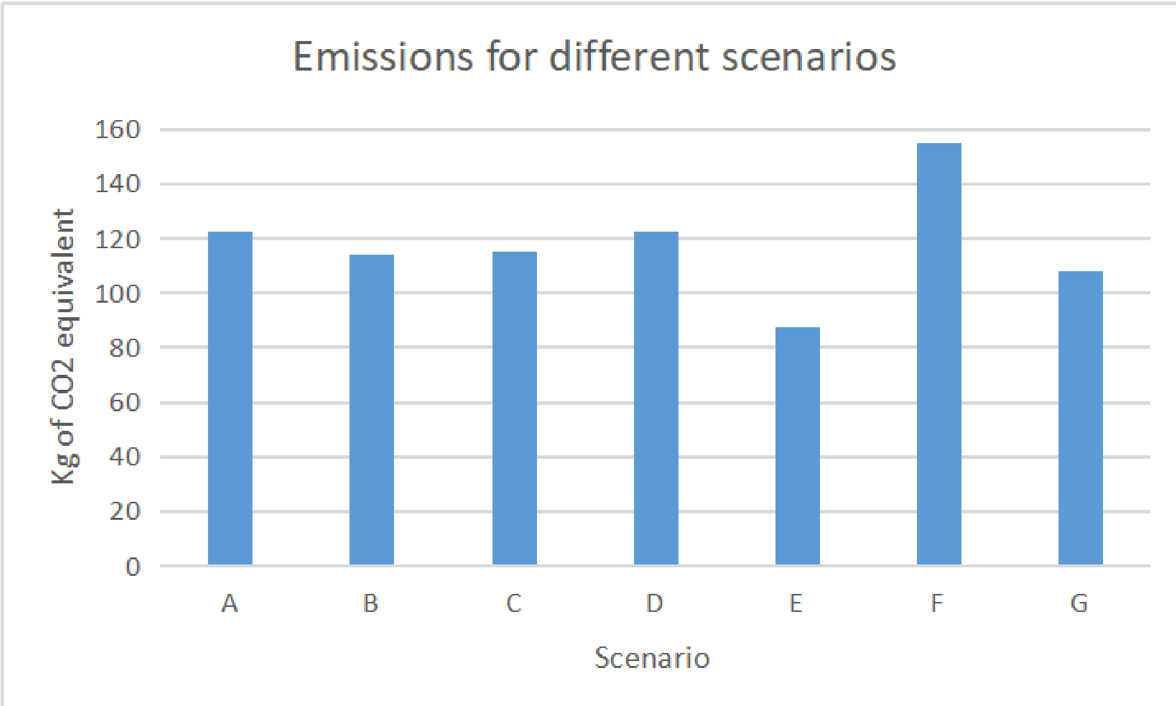
Total CO2e for production of 3X3 meter patio

	Brick Amount	Total CO2e(kg)
1cubic meter concrete	160	1.20E+02
1 brick	1	7.53E-01
3X3 meter patio	144	**1.08E+02**

Total equivalent CO_2 emission for 3X3 meter patio = **108.2764** kg of CO_2

Please see the detailed calculation in the excel spreadsheet.

10 Comparison and Interpretation of Scenarios



According to the above calculation, except for the increase in carbon equivalent emissions caused by Scenario F (using agricultural byproducts instead of coal) from 123kg to 155 kg, the other 5 scenarios can reduce carbon equivalent emissions.

Among them, scenario E (using natural gas instead of coal) has the smallest carbon equivalent emissions (87.5kg) and is the most effective choice for reducing carbon equivalent emissions among the current six scenarios. However, in the actual application process, it is also necessary to consider the cost of natural gas, technical feasibility, transportation, required equipment, and other factors. In addition, the value of Scenario G (substituting clinker for limestone) is also low (109kg). The value of Scenario D (improving fuel efficiency of diesel equipment) is almost consistent with the original data.

According to the analysis of the above calculation results, E is the most recommended way, and G is the second way. However, in the actual application process, it is also necessary to consider the specific situation, such as cost, technical feasibility, transportation loss, local policies, energy security, etc., to choose among the five effective ways. Scenario F is not recommended as it will increase carbon equivalent emissions.

11 Limitations and Recommendations

- Missing Processes in the Life Cycle:

Issue: Excluding the carbon footprint for transportation to the customer may lead to underestimating the overall impact.

Recommendation: Include the transportation to the customer and usage stages in the assessment to provide a more comprehensive analysis.

- Neglected Small Impacts:

Issue: Neglecting CO2e from diesel production, ignoring differences in route distances for various transport types, and using average values for materials introduce inaccuracies.

Recommendation: Include CO2e from diesel production, consider route distance variations, and use specific emission factors for materials for more precise calculations.

- Scenario Details Uncertainty:

Issue: Ambiguity in scenarios B and C, particularly regarding changes in the shipping method.

Recommendation: Clarify the specifics of shipping method changes, specifying whether alterations apply only to transportation to the cement plant or include other stages.

Addressing these limitations will enhance the accuracy and completeness of the life cycle assessment, providing a more reliable understanding of the carbon footprint associated with patio construction.