Caption: List of Tables and Figures (in order of appearance in manuscript)

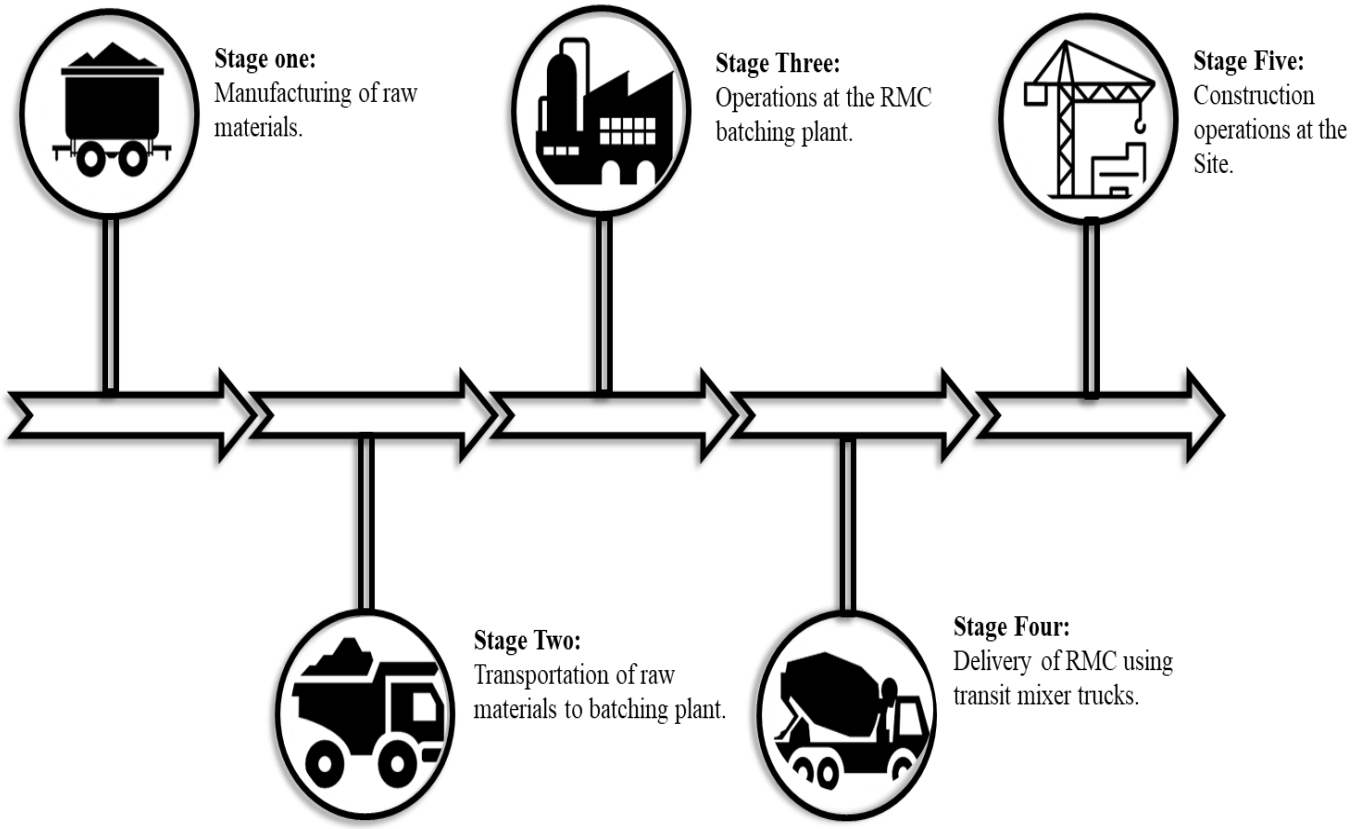

Figure 1: Major phases of ready mixed concrete production

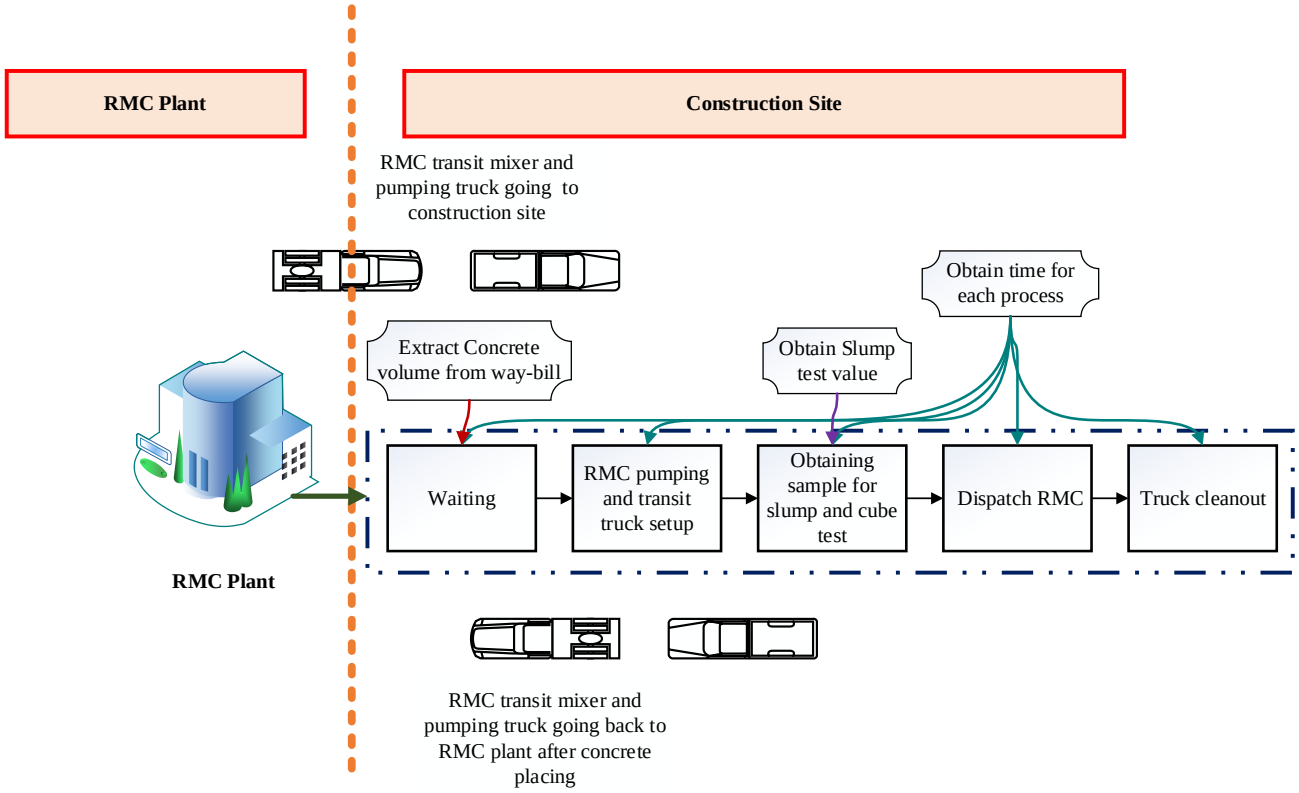

Figure 2: System boundary and site delivery stages

Table 1: Embodied emissions breakdown for different concrete composition

Type	Constituent	Concrete Mix (kg/m^3)	Embodied CO_2 ($kg\ CO_2/te$)	Embodied CO_2 ($kg\ CO_2/m^3$)
Datum for typical calculation of ECO_2	Water	190	2	0.4
	Portland cement*	380	930	353.4
	Sand	630	8	5.0
	5–20-mm granite	1200	25	30.0
	Fresh Concrete Density	**2400**	**Total ECO_2**	**388**
Concrete containing fly ash and coarse aggregate combinations	Water	170	2	0.4
	Portland cement*	260	930	241.8
	EN 450 fly ash (Class S)	130	150	2.6
	Sand	640	8	5.2
	5–20-mm granite	300	25	7.5
	15-mm LWA	300	220	66
	Fresh Concrete Density	**1800**	**Total ECO_2**	**298**
Concrete containing fly ash and natural coarse aggregate	Water	170	2	0.4
	Portland cement*	260	930	241.8
	EN 450 fly ash	120	50	6
	Sand	650	6	3.9
	5–20-mm granite	1200	25	29.6
	Fresh Concrete Density	**2400**	**Total ECO_2**	**282**

Source: MPA (2015); Boarder *et al*. (2016)
*CEM I 42.5R according to EN 197 Standard.

Table 2: Embodied CO_2 emission factor in previous studies

S/N	Source	Description	Emission factor
1	Hammond and Jones (2008)	General concrete (1:2:4)	0.035kgC/kg (84kgCO_2/m^3)
2	Kumanayake *et al*. (2018)	RMC	0.123kgCO_2/kg (295.2kgCO_2/m^3)
3	Chaudhary (2016)	Concrete with 35MPa	133kgCO_2/tonne (319.2kgCO_2/m^3)
		Concrete with 35MPa and 30% fly ash	107kgCO_2/tonne (256.8kgCO_2/m^3)
4	KEITI (2004); KICT (2008); Kang *et al*. (2019)	RMC (25-210-12)	400.4kgCO_2/m^3
		RMC (25-240-15)	419.6kgCO_2/m^3
5	Boarder *et al*. (2016); MPA (2015)	Datum	388kgCO_2/m^3
		Concrete containing fly ash and coarse aggregate combinations	298kgCO_2/m^3
		Concrete containing fly ash and natural coarse aggregate	282kgCO_2/m^3
6	Jun *et al*. (2015)	RMC (25-210-15)	419kgCO_2/m^3
		RMC (25-210-12)	409kgCO_2/m^3
		RMC (25-240-12)	414kgCO_2/m^3
		RMC (25-240-15)	429kgCO_2/m^3

Note: Concrete density = 2400kg/m^3

Table 3: Emission factors and BSFC based on engine category

Engine power (hp)	Tech. type	BSFC (lb/hp-hr)	Emission factors EF_{ss} (g/hp-hr)			
			HC	CO	NO_x	PM_{10}
> 0 to 11	Tier 0	0.408	1.500	5.000	10.000	1.000
	Tier 1		0.763	4.113	5.230	0.447
	Tier 2		0.551	4.113	4.300	0.500
	Tier 4		0.551	4.113	4.300	0.280
> 11 to 16	Tier 0	0.408	1.700	5.000	8.500	0.900
	Tier 1		0.438	2.161	4.440	0.267
	Tier 2		0.438	2.161	4.440	0.267
	Tier 4		0.438	2.161	4.440	0.280
> 16 to 25	Tier 0	0.408	1.700	5.000	8.500	0.900
	Tier 1		0.438	2.161	4.440	0.267
	Tier 2		0.438	2.161	4.440	0.267
	Tier 4		0.438	2.161	4.440	0.280
> 25 to 50	Tier 0	0.408	1.800	5.000	6.900	0.800
	Tier 1		0.279	1.532	4.728	0.339
	Tier 2		0.279	1.532	4.728	0.339
	Tier 4		0.131	0.153	3.000	0.018
> 50 to 75	Tier 0	0.408	0.990	3.490	6.900	0.722
	Tier 1		0.521	2.366	5.599	0.473
	Tier 2		0.367	2.366	4.700	0.240
	Tier 3		0.184	2.366	3.000	0.300
	Tier 4		0.131	0.237	3.000	0.018
> 75 to 100	Tier 0	0.408	0.990	3.490	6.900	0.722
	Tier 1		0.521	2.366	5.599	0.473
	Tier 2		0.367	2.366	4.700	0.240
	Tier 3		0.184	2.366	3.000	0.300
	Tier 4		0.131	0.237	0.276	0.009
> 100 to 175	Tier 0	0.367	0.680	2.700	8.380	0.402
	Tier 1		0.338	0.867	5.652	0.280
	Tier 2		0.338	0.867	4.100	0.180
	Tier 3		0.184	0.867	2.500	0.220
	Tier 4		0.131	0.087	0.276	0.009
> 175 to 300	Tier 0	0.367	0.680	2.700	8.380	0.402
	Tier 1		0.309	0.748	5.577	0.252
	Tier 2		0.309	0.748	4.000	0.132
	Tier 3		0.184	0.748	2.500	0.150
	Tier 4		0.131	0.075	0.276	0.009
> 300 to 600	Tier 0	0.367	0.680	2.700	8.380	0.402
	Tier 1		0.203	1.306	6.015	0.201
	Tier 2		0.167	0.843	4.335	0.132
	Tier 3		0.167	0.843	2.500	0.150
	Tier 4		0.131	0.084	0.276	0.009
> 600 to 750	Tier 0	0.367	0.680	2.700	8.380	0.402
	Tier 1		0.147	1.327	5.822	0.220
	Tier 2		0.167	1.327	4.100	0.132
	Tier 3		0.167	1.327	2.500	0.150
	Tier 4		0.131	0.133	0.276	0.009
> 0.75	Tier 0	0.367	0.680	2.700	8.380	0.402
	Tier 1		0.286	0.764	6.153	0.193
	Tier 2		0.167	0.764	4.100	0.132
	Tier 4		0.131	0.076	2.392	0.028

Source: EPA (2010a)

Table 4: Transient adjustment factors by equipment type for non-road CI equipment

Construction Equipment	HC	CO	NO_x		PM_{10}		BSFC
	All Tiers	All Tiers	T0-T2	Tier 3	T0-T2	Tier 3	All Tiers
Pavers	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Tampers/rammers	1.00	1.00	1.00	1.10	1.00	1.20	1.00
Plate compactors	1.00	1.00	1.00	1.10	1.00	1.10	1.00
Rollers	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Scrapers	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Paving equipment	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Surfacing equipment	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Signal boards	1.00	1.00	1.00	1.10	1.00	1.20	1.00
Trenchers	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Bore/drill rigs	1.00	1.00	1.00	1.10	1.00	1.20	1.00
Excavators	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Concrete/industrial saws	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Cement and mortar mixers	1.00	1.00	1.00	1.10	1.00	1.20	1.00
Cranes	1.00	1.00	1.00	1.10	1.00	1.10	1.00
Graders	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Off-highway trucks	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Crushing/proc. equipment	1.00	1.00	1.00	1.10	1.00	1.20	1.00
Rough terrain forklifts	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Rubber tire loaders	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Rubber tire dozers	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Tractors/loaders/backhoes	2.29	2.57	1.10	1.21	1.97	2.37	1.18
Crawler dozer	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Skid steer loaders	2.29	2.57	1.10	1.21	1.97	2.37	1.18
Off-highway tractors	1.05	1.53	0.95	1.04	1.23	1.47	1.01
Dumpers/tenders	2.29	2.57	1.10	1.21	1.97	2.37	1.18
Other construction equipment	1.05	1.53	0.95	1.04	1.23	1.47	1.01

Source: EPA (2010a)

Note: TAFs are not applied to the emission factors for Tier 4 engines (i.e., the model applies a TAF of 1.0). "T0-T3" in this table refers to Tier 3 and prior engines.

Table 5: Deterioration factors for Non-road diesel engines

Pollutant	Relative deterioration factor (DF_{rel})			
	Tier 0	**Tier 1**	**Tier 2**	**Tier 3+**
HC	0.047	0.036	0.034	0.027
CO	0.185	0.101	0.101	0.151
NO_x	0.024	0.024	0.009	0.008
PM	0.473	0.473	0.473	0.473

Source: EPA (2010a)

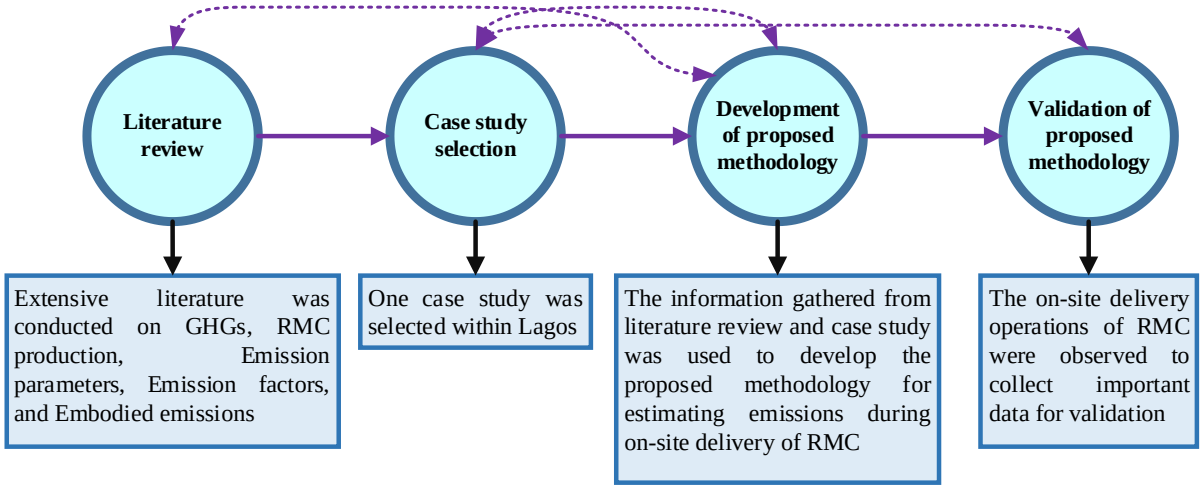

Figure 3: Research process

Table 6: RMC Transit Mixer Trucks in Cycles (C1-C10)

S/N	Brand	Year	Model	Tier	A (m^3)	B (No)	C (Hp)	E (Lt/hr)
C1	Iveco	2006	AD340T35B	Tier 3	8	4	345	17.60
C2	Scania	2012	P360 Liebherr	Tier 4T	9	4	355	15.80
C3	MAN	2008	TGS 32.360 BB + Mixer Stetter	Tier 3	9	4	355	12.67
C4	Volvo	2013	FMX 410 - Stetter	Tier 4T	11	4	404	12.47
C5	MAN	2014	TGS 440	Tier 4	9	4	433	12.42
C6	MAN	2014	TGS 440	Tier 4	9	4	394	13.52
C7	MAN	2014	TGS 440	Tier 4	9	4	394	14.32
C8	Mercedes-Benz	2015	Axor 3340	Tier 4	9	4	394	12.50
C9	Mercedes-Benz	2015	Axor 4140 8x4	Tier 4	9	4	394	12.00
C10	MAN	2004	TGA 35.350	Tier 2	9	4	404	15.95

A = Capacity; B = Number of axles; C = Engine power; D = Fuel efficiency

Table 7: RMC Pumping Truck in Cycles (C1-C10)

S/N	Pump truck brand	Year	Pump truck model	Concrete pump brand	Tier	A	B	C	D	E
						(m)	(No)	(No)	(Hp)	(Lt/hr)
C1	Mercedes-Benz	2015	Axor 3340	Putzmeister - BSF 38.5.16H	Tier 4	38	5	3	394	18.96
C2	Mercedes-Benz	2014	Axor 3340	Putzmeister - BSF 38.5.16H	Tier 4	38	5	3	394	17.98
C3	Mercedes-Benz	2012	Axor 3340	JunJin	Tier 4T	38	4	3	394	20.57
C4	Mercedes-Benz	2015	Axor 3340	Putzmeister - BSF 38.5.16H	Tier 4	38	5	3	394	21.5
C5	Mercedes-Benz	2015	Axor 4140 8x4	Putzmeister - BSF 47.5.14H	Tier 4	47	5	4	394	19.58
C6	MAN	2006	26.41	Schwing-34XG	Tier 3	34	5	3	404	26.87
C7	MAN	2007	26.36	Schwing-34XG	Tier 3	34	5	3	355	27.56
C8	Iveco	2006	Eurotrakker 380E38	Cifa - K35	Tier 3	34	5	3	355	25.25
C9	MAN	2004	TGA 35.350	Cifa - K40XRZ	Tier 2	40	5	4	355	26.47
C10	Mercedes-Benz	2010	Axor 4140 8x4	Putzmeister - BSF 47.5.14H	Tier 3	47	5	4	394	20.45

A = Pumping head of concrete; B = Number of pumping sections; C = No. of axles; D = Engine power; E = Fuel efficiency

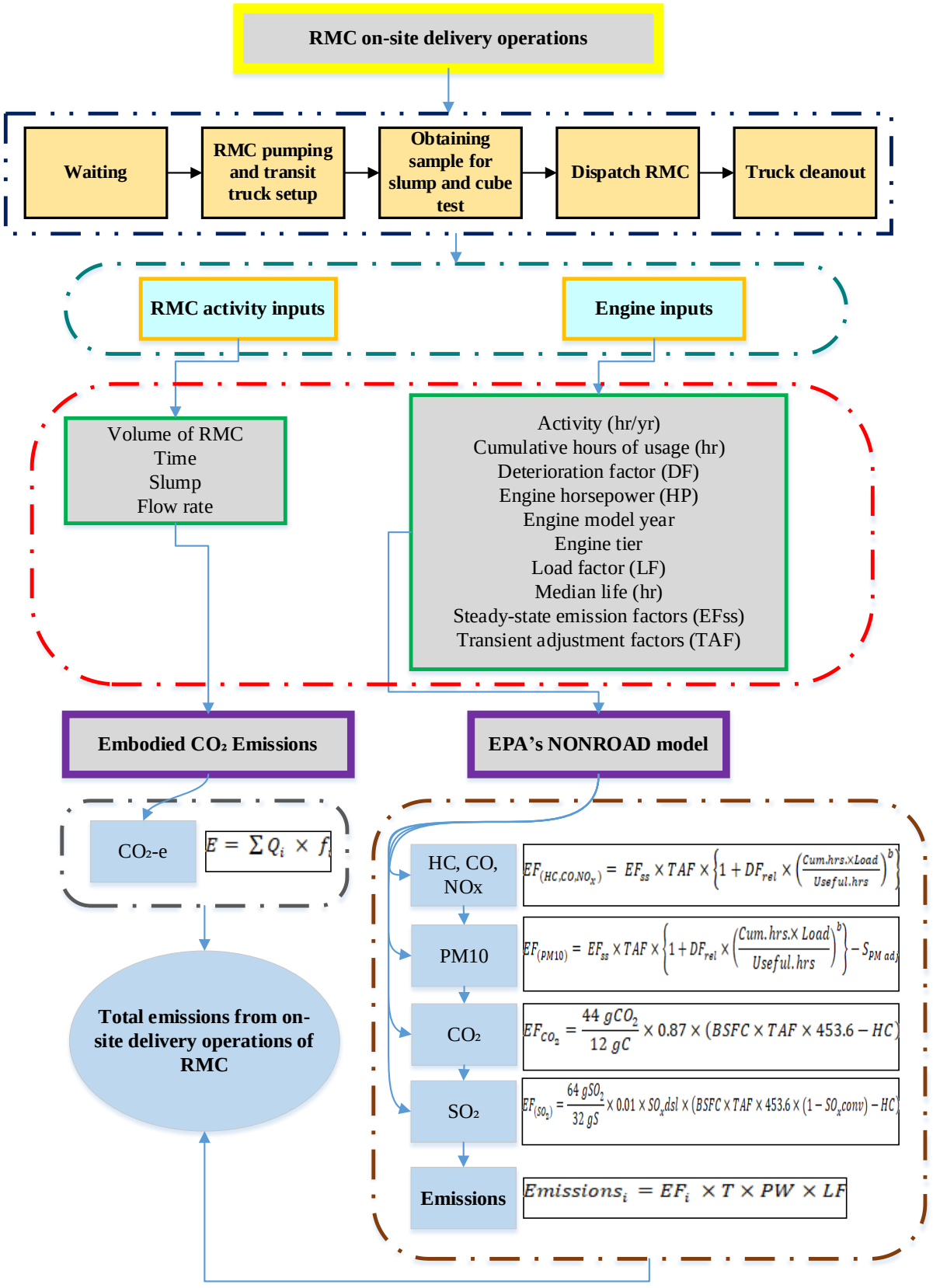

Figure 4: Proposed methodology for estimating emissions from RMC on-site Delivery

Figure 5: Map showing available routes from Plant A to the site

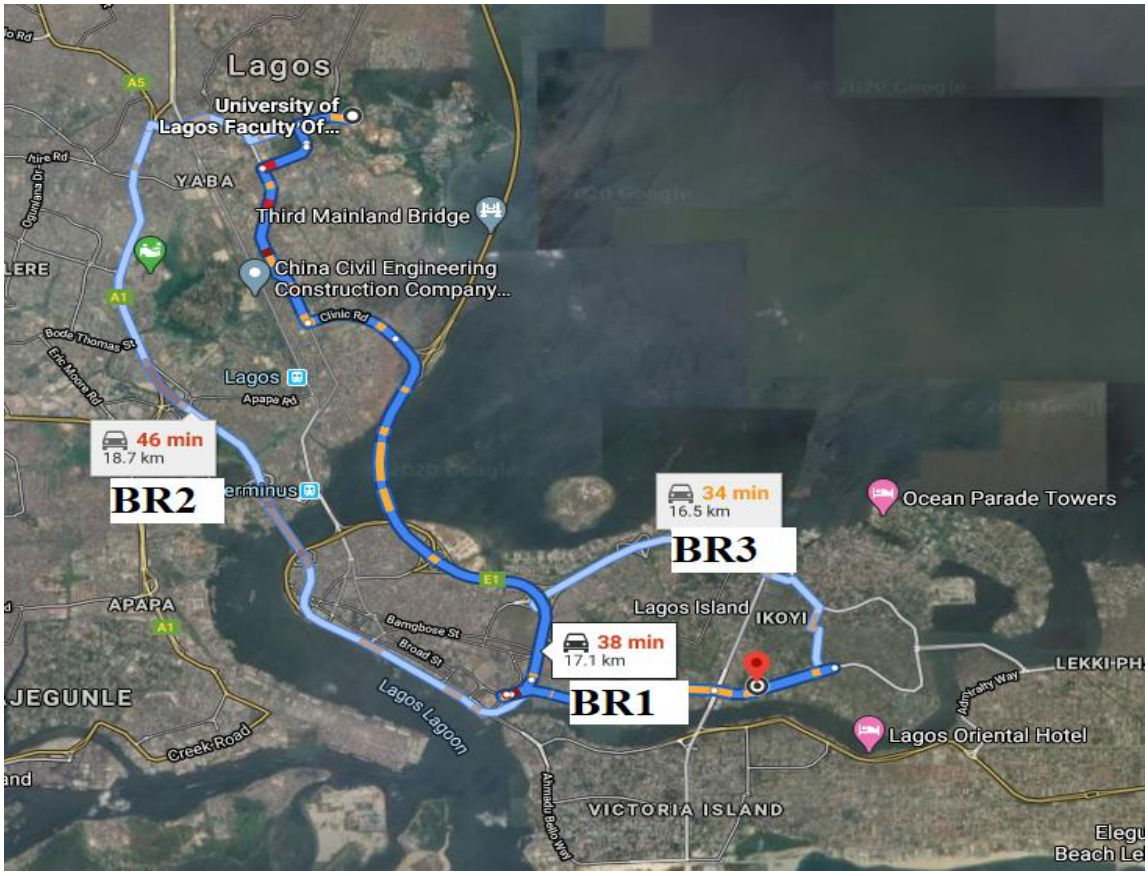

Figure 6: Map showing available routes from Plant B to the site

Table 8: Case study data for emission computation

S/N	Concrete Volume (m3)	Slump (mm)	Time (Sec)					Route	
			A	B	C	D	E	Truck	Pump
C1	8	150	270.00	306.00	306.00	540.00	288.00	AR1	BR3
C2	9	170	258.00	312.00	312.00	432.00	252.00	BR1	AR2
C3	9	140	228.00	342.00	300.00	468.00	360.00	BR3	AR1
C4	11	170	294.00	360.00	288.00	648.00	432.00	BR2	AR1
C5	9	130	240.00	300.00	282.00	540.00	288.00	BR1	AR1
C6	9	160	234.00	390.00	276.00	648.00	288.00	BR3	BR3
C7	9	180	150.00	324.00	372.00	648.00	468.00	AR1	BR3
C8	9	200	120.00	258.00	348.00	468.00	432.00	BR3	AR1
C9	9	110	180.00	294.00	300.00	720.00	468.00	BR3	AR2
C10	9	130	96.00	300.00	288.00	1008.00	540.00	AR2	BR3
Average	**9.1**	**154**	**207.00**	**318.60**	**307.20**	**612.00**	**381.60**		

Note: A = Waiting; B = RMC pumping and transit trucks setup; C = Slump and cube test; D = Dispatch; E = Truck clean-out

Table 9: Emission factors for equipment in cycles

Cycle	RMC Transit Mixer Truck						RMC Pumping Truck					
	Emission Factor (g/hp-hr)						Emission Factor (g/hp-hr)					
	HC	**CO**	**NO_x**	**PM_{10}**	**CO_2**	**SO_2**	**HC**	**CO**	**NO_x**	**PM_{10}**	**CO_2**	**SO_2**
C1	0.176	1.336	2.605	0.262	530.482	1.073	0.132	0.087	0.277	0.010	530.622	1.073
C2	0.132	0.087	0.277	0.010	530.622	1.073	0.132	0.087	0.277	0.010	530.622	1.073
C3	0.176	1.336	2.605	0.262	530.482	1.073	0.132	0.087	0.277	0.010	530.622	1.073
C4	0.132	0.087	0.277	0.010	530.622	1.073	0.132	0.087	0.277	0.010	530.622	1.073
C5	0.132	0.087	0.277	0.010	530.622	1.073	0.132	0.087	0.277	0.010	530.622	1.073
C6	0.132	0.087	0.277	0.010	530.622	1.073	0.176	1.336	2.605	0.262	530.482	1.073
C7	0.132	0.087	0.277	0.010	530.622	1.073	0.176	1.336	2.605	0.262	530.482	1.073
C8	0.132	0.087	0.277	0.010	530.622	1.073	0.176	1.336	2.605	0.262	530.482	1.073
C9	0.132	0.087	0.277	0.010	530.622	1.073	0.177	1.320	4.127	0.180	535.789	1.084
C10	0.177	1.320	4.127	0.180	535.789	1.084	0.176	1.336	2.605	0.262	530.482	1.073
Average	**0.145**	**0.460**	**1.128**	**0.077**	**531.111**	**1.074**	**0.154**	**0.710**	**1.593**	**0.128**	**531.083**	**1.074**

Table 10: Non-road emissions from each cycle of delivery operations

Cycle	RMC Transit Mixer Truck						RMC Pumping Truck					
	Emissions (g)						Emissions (g)					
	HC	CO	NO_x	PM_{10}	CO_2	SO_2	HC	CO	NO_x	PM_{10}	CO_2	SO_2
C1	17.0	129.2	251.9	23.7	51290.3	103.7	14.6	9.6	30.6	1.1	58590.5	118.5
C2	12.0	7.9	25.2	0.9	48345.4	97.8	13.3	8.8	28.0	1.0	53656.5	108.5
C3	17.4	132.0	257.3	25.9	52406.6	106.0	14.5	9.5	30.4	1.1	58179.3	117.6
C4	17.7	11.6	37.1	1.3	71039.1	143.7	17.2	11.4	36.2	1.3	69280.7	140.1
C5	15.5	10.2	32.4	1.2	62130.8	125.6	14.1	9.3	29.5	1.1	56534.7	114.3
C6	15.6	10.3	32.8	1.2	62907.7	127.2	21.4	162.4	316.7	31.8	64487.3	130.4
C7	16.7	11.0	35.1	1.3	67224.9	135.9	20.1	152.5	297.4	29.9	60554.7	122.5
C8	13.9	9.1	29.1	1.0	55712.4	112.7	16.6	126.4	246.4	24.8	50184.4	101.5
C9	16.7	11.0	35.1	1.3	67224.9	135.9	20.2	150.7	471.1	20.5	61160.4	123.7
C10	26.2	195.1	609.9	26.6	79180.6	160.2	25.4	192.6	375.4	37.8	76455.8	154.6
Sum	**168.7**	**527.5**	**1346.0**	**84.4**	**617462.5**	**1248.7**	**177.4**	**833.1**	**1861.7**	**150.4**	**609084.4**	**1231.9**
Average	**16.9**	**52.8**	**134.6**	**8.4**	**61746.3**	**124.9**	**17.7**	**83.3**	**186.2**	**15.0**	**60908.4**	**123.2**
St. Dev	**3.7**	**70.8**	**190.9**	**11.7**	**9800.2**	**19.8**	**3.9**	**79.2**	**173.4**	**15.3**	**7632.9**	**15.4**

Table 11: Emissions in each process of on-site delivery

Pollutant	Delivery Operation Emissions (g)					Average (g)	Total (g)	Emissions (g)/m^3
	A	B	C	D	E			
HC	39.2	60.4	58.2	116.0	72.3	69.2	346.1	3.8*
CO	154.2	237.3	228.9	455.9	284.3	272.1	1360.6	15.0*
NO_x	363.6	559.6	539.5	1074.9	670.2	641.5	3207.7	35.2*
PM_{10}	26.6	41.0	39.5	78.7	49.1	47.0	234.8	2.6*
CO_2	139014.0	213960.7	206304.9	410998.0	256269.3	245309.4	1226546.9	13478.5*
SO_2	281.14	432.72	417.23	831.21	518.28	496.1	2480.6	27.3*
Total	**139878.8**	**215291.7**	**207588.2**	**413554.6**	**257863.5**			
%	**11.33**	**17.44**	**16.82**	**33.51**	**20.89**			

Note: A = Waiting; B = RMC pumping and transit trucks setup; C = Slump and cube test; D = Dispatch; E = Truck clean-out

*Based on 91m^3 (total volume of concrete delivered)

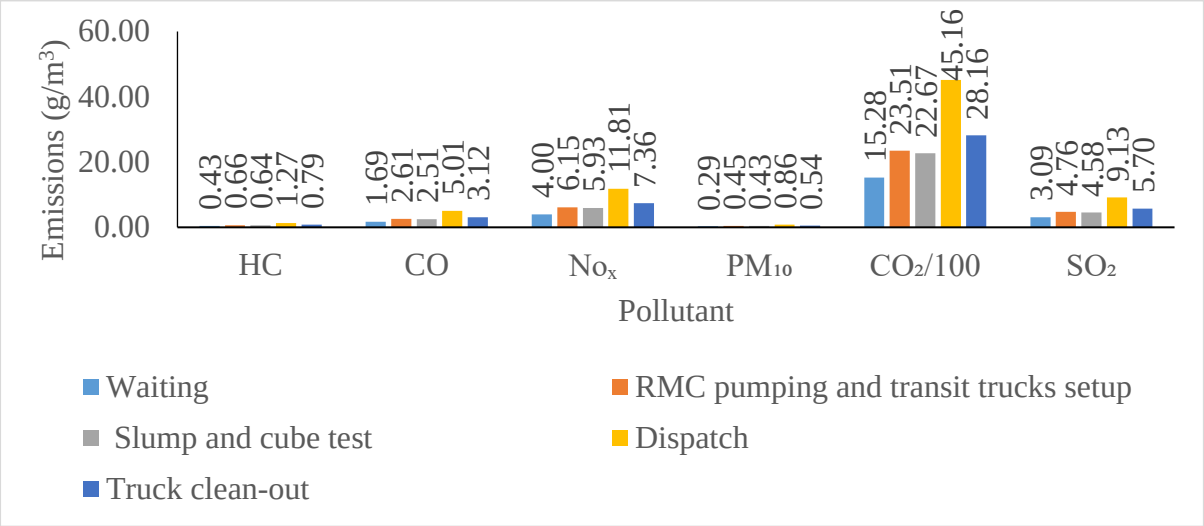

Figure 7: Normalized emissions using concrete volume and on-site delivery operations