

Supporting Information for Social Cost Benefit analysis of Operating Compressed Biomethane (CBM) Transit Buses in Cities of Developing Nations: A Case Study

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S1. Social Cost Benefit Analysis Calculations of CBM Bus Transportation

Table S1. SCBA CBM and BAU scenarios per functional unit (cost in million INR).

Cost Category	Cost Type	CBM Scenario	BAU Scenario
Fuel ^(a)	Private	24.04	34.49
Open Landfilling/ Dumping ^(b)	Private	0.048	4.32
Biofertilizer ^(c)	Private	−18.84	0
Environmental-Fuel ^(d)	Social	15.09	43.43
Environmental-Open Dumping ^(d)	Social	0	71.43
Total		20.35	149.12

a) Unit cost of CBM = 40 INR/kg [1]; CNG = 49.62 INR/kg [2]; and diesel = 68.65 INR/liter [3].
b) Unit Cost of landfilling / open dumping of MSW in India = 344 INR/ton [4]
c) Unit Cost of compost = 10 INR/kg [5].
d) Unit prices for environmental externality costs is obtained from literature [6].

The detailed calculations reflecting numbers in Table S1 are shown below in Tables S2 to S10

Table S2. Private costs involved in BAU scenario—landfill costs.

Landfill Costs	
Unit Cost Landfill (INR/ton)	344
Waste Sent to Landfill (tons)	12560
Cost of Landfill (INR)/year	4320640

Table S3. Private Costs involved in BAU scenario- fuel costs.

Fuel Costs	
Diesel Costs	
Unit Cost Diesel (INR/Liters)	68.65
Unit Cost Diesel (INR/kg)	82.51
Diesel Consumption(kg/Year)	527812.04
Total Diesel Cost (INR)	43550837.25
CNG Costs	
Unit Cost CNG (INR/kg)	49.62
CNG Consumption(kg/Year)	601242.47
Total CNG Cost (INR)	29833651.56
Total Fuel Cost per Year for Mumbai City	34497494.70

Table S4. Open Dumping Environmental Costs for BAU Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs (INR)
Climate change	kg CO ₂ eq	0.06	80.00	4.56	14192800.00	64719168.00
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.00
Terrestrial acidification	kg SO ₂ eq	5.40	80.00	432.00	1399.69	604664.52
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	19.07	2898.04
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	174968.15	2995454.70
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	6000.75	1008126.59
Particulate matter formation	kg PM ₁₀ eq	69.00	80.00	5520.00	380.32	2099348.74
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	4.04	2871.85
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	1175.30	3469.48
Fossil depletion	kg oil eq	0.05	80.00	4.00	0.00	0.00
Total Landfill Environmental Costs						71436001.93

Table S5. Use stage CNG environmental costs for BAU scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs (INR)
Climate change	kg CO2 eq	0.06	80.00	4.56	2068755.03	9433522.92
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.16	390.50
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	9515.67	4110771.20
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	139.57	21213.97
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	171607.07	2937913.06
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	8439.47	1417831.00
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	4154.27	22931565.33
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	89.52	63666.74
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	8353.41	24659.27
Fossil depletion	kg oil eq	0.05	80.00	4.00	765626.82	3062507.29
Total Costs						44004041.29

Table S6. Use stage diesel environmental costs for BAU Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs (INR)
Climate change	kg CO ₂ eq	0.06	80.00	4.56	1918124.76	8746648.91
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.37	891.11
Terrestrial acidification	kg SO ₂ eq	5.40	80.00	432.00	10872.81	4697054.58
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	43.78	6654.19
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	56188.14	961940.96
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	16457.42	2764847.29
Particulate matter formation	kg PM ₁₀ eq	69.00	80.00	5520.00	4050.53	22358946.80
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	40.22	28604.85
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	2232.21	6589.47
Fossil depletion	kg oil eq	0.05	80.00	4.00	688016.16	2752064.64
Total Costs						42324242.81

Table S7. Environmental Costs of CBM Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs (INR)
Climate change	kg CO ₂ eq	0.06	80.00	4.56	618731.09	2821413.77
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.01	22.13
Terrestrial acidification	kg SO ₂ eq	5.40	80.00	432.00	4166.15	1799775.77
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	17.38	2642.03
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	24453.79	418648.85
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	7089.43	1191024.94
Particulate matter formation	kg PM ₁₀ eq	69.00	80.00	5520.00	1596.55	8812964.41
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	−3.551795166	−2526.036722
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	1370.44	4045.54
Fossil depletion	kg oil eq	0.05	80.00	4.00	11660.40	46641.61
Total Costs						15094653.01

Table S8. Revenue from compost in CBM scenario.

Cost of Disposal of Non Digestible Waste	
Unit Cost Landfill (INR/ton)	344
Non Digestible Waste Sent to Landfill (tons)	141.75
Cost of Landfill (INR)/year	48762
Revenue to the Plant from Compost	
Unit Cost of Compost(INR/kg)	10
Compost Produced per Year (tons)	1884
Revenue from Compost (INR)	18840000

Table S9. Social cost of CBM scenario.

Total Social Cost of CBM Scenario	
	Million INR
Cost of CBM Fuel	24.05
Environmental Cost of CBM System	15.09
Cost of Non Digestible Waste Disposal	0.05
Revenue from Compost	18.84
Total Social Costs of CBM Plant	20.35

Table S10. Social cost of BAU scenario.

Total Social Cost of BAU Scenario to Society	
	Million INR
Cost of Landfilling Food Waste	4.32
Cost of Fuel	34.50
Environmental Cost of Landfilling Food Waste	71.44
Environmental Cost of Fuels	43.43
Total Social Costs of Baseline	153.69

S2. Sustainable Value of CBM Utilization Perspectives of CBM as Transport Fuel

The cost calculations for SRR and PRR determination are shown below in Tables S11 to S19.

Table S11. CBM as transport fuel with respect to Employee Scenario.

Impact category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	399.31	1820.87
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.00
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	0.38	164.40
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.00	0.39
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	4.24	72.56
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	0.75	125.93
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	0.10	538.73
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	0.00	0.54
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	0.43	1.28
Fossil depletion	kg oil eq	0.05	80.00	4.00	1.34	5.34
Total Cost						2730.03

Table S12. Petrol as transport fuel with respect to Employee Scenario.

Impact category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	2029.07	9252.57
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.86
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	3.60	1556.14
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.06	8.45
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	72.17	1235.59
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	3.42	574.94
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	1.16	6425.16
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	0.07	50.23
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	2.58	7.63
Fossil depletion	kg oil eq	0.05	80.00	4.00	680.31	2721.22
Total Cost						21832.79

Table S13. Diesel as transport fuel with respect to Employee Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env. Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	1673.46	7630.97
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.75
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	5.47	2363.91
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.04	5.61
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	93.90	1607.63
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	7.23	1215.08
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	1.97	10877.22
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	0.07	46.93
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	1.89	5.57
Fossil depletion	kg oil eq	0.05	80.00	4.00	579.75	2319.01
Total Cost						26072.67

Table S14. CBM as transport fuel with respect to Cab Driver Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	1796.91	8193.91
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.01
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	1.71	739.79
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.01	1.74
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	19.07	326.51
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	3.37	566.68
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	0.44	2424.27
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	0.00	2.43
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	1.95	5.76
Fossil depletion	kg oil eq	0.05	80.00	4.00	6.01	24.03
Total Cost						12285.12

Table S15. CNG as transport fuel with respect to Cab Driver Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env. Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	6419.92	29274.82
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	1.31
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	17.81	7694.02
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.11	16.83

Table S17. CBM as transport fuel with respect to Bus Provider Scenario.

Impact category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	17230.17	78569.59
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.00	0.11
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	171.51	74090.83
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	0.11	16.98
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	183.80	3146.74
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	289.97	48715.80
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	64.95	358525.19
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	0.03	23.75
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	19.08	56.33
Fossil depletion	kg oil eq	0.05	80.00	4.00	58.77	235.09
Total Cost						563380.40

Table S18. CNG as transport fuel with respect to Bus Provider Scenario.

Impact category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env. Costs
Climate change	kg CO2 eq	0.06	80.00	4.56	91165.20	415713.30
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.01	17.21
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	419.33	181152.07
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	6.15	934.85
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	7562.32	129466.96
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	371.91	62480.50
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	183.07	1010540.47
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	3.94	2805.64
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	368.12	1086.68
Fossil depletion	kg oil eq	0.05	80.00	4.00	33739.38	134957.54
Total Cost						1939155.21

Table S19. Diesel as transport fuel with respect to Bus Provider Scenario.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Qty Diesel	Cost Diesel
Climate change	kg CO2 eq	0.06	80.00	4.56	84527.27	385444.37
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.02	39.27
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	479.14	206988.21
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	1.93	293.23
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	2476.08	42390.49
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	725.24	121840.36
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	178.50	985306.51
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	1.77	1260.55
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	98.37	290.38
Fossil depletion	kg oil eq	0.05	80.00	4.00	30319.26	121277.05
Total Cost						1865130.42

S3. Private and Social Costs of Diesel, CNG and Electricity (Battery) Driven Transit Buses

Table S20. Private costs involved in BAU Scenario- Landfill Costs.

Landfill Costs	
Unit Cost Landfill (INR/ton)	344
Waste Sent to Landfill (tons)	12560
Cost of Landfill (INR)/year	4320640

Table S21. Private costs (fuel costs-diesel) per Functional Unit.

Fuel Costs	
Diesel Costs	
Unit Cost Diesel (INR/Liters)	68.65
Unit Cost Diesel (INR/kg)	82.51
Diesel Consumption(kg/Year)	527812.04
Total Diesel Cost /FU (INR)	43550837.25

Table S22. Private costs (fuel costs-CNG) per functional unit.

Fuel Costs	
CNG Costs	
Unit Cost CNG (INR/kg)	49.62
CNG Consumption(kg/Year)	601242.47
Total CNG Cost (INR)	29833651.56

Table S23. Private costs (electricity costs) per functional unit.

Electricity Costs	
Electricity Costs	
Unit Cost CNG (INR/KWh)	6.0
Electricity Consumption(KWh/Year)	1971286.8
Total Electricity Cost (INR)	11827720.8
Unit Cost of Electricity for Charging in India = 6 INR/KWh [7]	

Table S24. Electricity driven (battery operated) environmental costs of transit buses.

Impact Category	Unit	Unit Cost (€)	€ to INR Conv.	Unit Cost (INR)	Quantity	Env Costs (INR)
Climate change	kg CO2 eq	0.06	80.00	4.56	2642409.87	12049389.00
Ozone depletion	kg CFC-11 eq	30.40	80.00	2432.00	0.03	71.52
Terrestrial acidification	kg SO2 eq	5.40	80.00	432.00	17341.61	7491574.57
Freshwater eutrophication	kg P eq	1.90	80.00	152.00	1677.36	254959.20
Human toxicity	kg 1,4-DB eq	0.21	80.00	17.12	1046374.10	17913924.53
Photochemical oxidant formation	kg NMVOC	2.10	80.00	168.00	8587.08	1442629.29
Particulate matter formation	kg PM10 eq	69.00	80.00	5520.00	25538.77	140974028.70
Terrestrial ecotoxicity	kg 1,4-DB eq	8.89	80.00	711.20	43.61	31017.05
Freshwater ecotoxicity	kg 1,4-DB eq	0.04	80.00	2.95	26763.95	79007.17
Fossil depletion	kg oil eq	0.05	80.00	4.00	595896.48	2383585.91
Total Costs						182620186.90

Social Costs of Diesel and CNG buses is shown in Tables S5 and S6 respectively.

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