Supplementary Table S2 Carbon emissions of biochar cement composites (A1/B1/C1/D1)

Materials/Processes (10^{-5} kg)	Without BC	A1/B1/C1/D1 (1%)	A1/B1/C1/D1 (2%)	A1/B1/C1/D1 (3%)	A1/B1/C1/D1 (5%)	Ecoinvent inputs
OPC	29400	29100	28800	28500	27900	Cement production, Portland
Water	2.69	2.69/4.93/ 4.37/6.61	2.69/7.17/ 6.05/10.53	2.69/9.41/ 7.73/14.45	2.69/13.89/ 11.09/22.29	Tap water production, conventional treatment
BC300 production (-)	-	149.32/174.21/149.32/ 174.21	298.64/348.42/298.64/ 348.42	447.97/522.63/447.97/ 522.63	746.61/871.05/746.61/ 871.05	Biochar preparation
NaOH	-	0/0/636/636	0/0/1272/ 1272	0/0/1908/ 1908	0/0/3180/ 3180	China carbon emissions database
Transportation	164.4	167.02/167.11/167.02/ 167.11	169.63/169.82/169.63/ 169.82	172.24/172.52/172.24/ 172.52	177.47/177.9 4/177.47/ 177.94	Transportation distance: 30 km
Avoided emission (-)	-	0.44/0.45/ 0.44/0.45	0.87/0.89/ 0.87/0.89	1.31/1.34/ 1.31/1.34	2.18/2.23/ 2.18/2.23	-
Net emission	29567.088	29119.95/29097.38/29757.63/ 29735.06	28672.81/28627.68/299 48.17/ 29903.04	28225.65/28157.96/301 38.69/ 30071.00	27331.37/27 218.55/3051 9.77/ 30406.95	-

comment:

1) According to the <Construction Carbon Emission Calculation Standard> issued by China, the carbon emission factors of OPC and water are 735 kg·tonne^{-1} and 0.168 kg·tonne^{-1} , respectively. Moreover, energy losses from transportation aren't considered as the water is assumed to be directly sourced from the laboratory [S1].

2) The energy consumption for biomass collection is 241.992 kg·MJ^{-1}, with diesel carbon emissions at 3.1863 kg CO_{2e} kg^{-1} [S2, S3]. Refer to the calculation formula as shown in Equation (S1) [S4].

$$G_H = \frac{M_o \times 241.992 \times 3.1863}{43} \quad \text{(S1)}$$

Where, M_o and G_H represent biomass mass and CO_2 emissions during biomass transportation, respectively.

3) The heat loss rate of the biomass drying process is 25%, and the energy consumption of its pretreatment is calculated as follows (S2) [S5]. Based on the actual conditions of local corn straw, the moisture content is set at 20%. Moreover, the electrical energy required per unit of biomass pulverized was 273.382 MJ·t^{-1}, referring to the calculation formula as

shown in Equation (S3) [S6, S7].

$$H_{dry} = \frac{M_{water} \times T \times C_{water} + M_{biomass} \times T \times C_{biomass} + H \times M_{water}}{(1-0.25)} \quad \text{(S2)}$$

$$H_{grind} = M_{biomass} \times 273.382 \quad \text{(S3)}$$

Where, M_{water}, T, and $M_{biomass}$ represent the total dry weight of water, the temperature difference during drying (the value is 80 ℃ in this study), and biomass transported to the plant (t), while C_{water} and $C_{biomass}$ represent the specific heat capacity of water and biomass ($kg \cdot (kg \cdot C)^{-1}$), respectively. Moreover, H_{grind} and $M_{biomass}$ represent the electricity consumed for biomass pulverization ($MJ \cdot t^{-1}$) and the mass of biomass (t), respectively.

4) Bio-oil is assumed to be used as the energy source for biomass pyrolysis and the syngas offset equivalent of coal is calculated using Equation (S4) [S8]. The calorific value of syngas, the power conversion efficiency, and the CO_2 emissions from coal-fired power generation are 3.98 $MJ \cdot kg^{-1}$, 35%, and 1.07 $kg \cdot (kW \cdot h)^{-1}$, respectively, as shown in Equation (S4) [S9, S10]. Moreover, 80% of the stabilized carbon is used as permanently sequestered carbon [S11, S12]. Refer to the calculation formula as shown in Equation (S5).

$$G = \frac{M_{gas} \times H_{heat} \times L \times B \times 1000}{3.6} \quad \text{(S4)}$$

$$H = M \times C \times 80\% \times 3.67 \quad \text{(S5)}$$

Where, M_{gas} is the mass of syngas, H_{heat} is the calorific value of biogas, L is the power conversion factor, B is the CO_2 emissions from coal power production, H is the carbon sequestration capacity of biochar, M is the mass of biochar, and C is the carbon content of biochar. In addition, the conversion factor for C-CO_2 is 3.67 [S11].

5) According to the [S13] biomass landfill-related emissions of CO_2 is 11.13 g $(m_2 \cdot h)^{-1}$ and CH_4 is 0.98 g $(m^2 \cdot h)^{-1}$. Furthermore, the landfill time is assumed to be one month.

6) The carbon emission factor of NaOH is 1.59 kg $CO_{2e} \cdot kg^{-1}$, and the capacity of ultrasonic cleaner is 15L [S14].

References

S1. GB/T 51366-2019. 2019. "Standard for calculating carbon emissions from buildings"

S2. Xu Y, Tian Y, Zhao L, Yao Z, Hou S, et al. 2014. Comparation on cost and energy consumption with different straw's collection-store-transportation modes. *Transactions of the Chinese Society of Agricultural Engineering* 30(20):259-267

S3. Jiang Z. 2013. *Assessment of the mitigation potential of greenhouse gasemissions for biochar technology*. Thesis. Ocean University of China, China pp. 25−51.

S4. Liu R. 2022. *Process Chemistry, Mechanisms, and Environmental Benefits for the Pyrolysis of Waste Biomass*. Thesis. University of Science and Technology of China, China pp. 127−156.

S5. Huang Y, Anderson M, Mcllveen-Wright D, Lyons GA, McRoberts WC, et al. 2015. Biochar and renewable energy generation from poultry litter waste: a technical and economic analysis based on computational simulations. *Applied Energy* 160:656-663

S6. Roberts KG, Gloy BA, Joseph S, Scott NR, Lehmann J. 2010. Life cycle assessment of biochar systems: estimating the energetic, economic, and climate change potential. *Environmental Science & Technology* 44(2):827-833

S7. Cheng F, Luo H, Colosi LM. 2020. Slow pyrolysis as a platform for negative emissions technology: An integration of machine learning models, life cycle assessment, and economic analysis. *Energy Conversion and Management* 223:113258

S8. Laird DA, Brown RC, Amonette JE, Lehmann J. 2009. Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels, Bioproducts and Biorefining 3*(5):547-562

S9. Shackley S, Hammond J, Gaunt J, Ibarrola R. 2011. The feasibility and costs of biochar deployment in the UK. *Carbon Management* 2(3):335-356

S10. Gaunt JL, Lehmann J. 2008. Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. *Environmental Science & Technology* 42(11):4152-4158

S11. Roberts KG, Gloy BA, Joseph S, Scott NR, Lehmann J. 2020. Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential. *Environmental Science & Technology* 44(2):827-833

S12. Xiao J, Li A, Ding T. 2016. Emission for recycled aggregate concrete Life cycle assessment on CO_2. *Natural Science Edition* 46(5):1088-1092

S13. Wang T, Li M, Wang Q, Miao X, Xu L, et al. 2024. Long-time Study of Carbon Emission Levels of Domestic Waste Incineration, Waste Landfill and Wastewater Disposal. *Environmental Sanitation Engineering* 32(02):75-84

S14. Carbon Emission Factor Database. https://esg.epmap.org/efdb.