Supplementary Information (SI) for Materials Horizons.

Electronic Supplementary Information

Porosity and Basicity Tuned Biomass-derived Activated Carbon Enhancing CO_2 Capture

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Experimental section

Chemicals and reagents

Peanuts (with shell), potassium hydroxide (KOH) pellets (≥ 85%, SDFCL), orthophosphoric acid (H_3PO_4) (88%, SDFCL), zinc(II) chloride ($ZnCl_2$) (≥ 98%, Sigma Aldrich) and melamine (99%, Finar). All chemicals were used without any further purification. Peanuts were purchased from local market in Bengaluru, India.

Synthetic Procedure

Collection and pre-treatment of peanut shells

Peanuts were manually separated from the shells. The collected shells were washed with normal water followed by deionized water to clean the materials. After that, the shells were kept for drying at 100 °C for 6 hrs to reduce the moisture content. Dried shells were grinded well before carbonization using mortar and pestle.

Carbonisation of peanut shells into biochar

Prior to the activation and nitrogen doping, pre-treated peanut shells were dried and carbonized into biochar. The shells were packed in aluminium foil and treated at 450 °C in N_2 atmosphere for 6 hrs in tubular furnace at a heating rate of 5 °C/min.

Activation and nitrogen doping of peanut shell biochar

Peanut shell biochar, activating agent (KOH, H_3PO_4 or $ZnCl_2$) and melamine were taken in 1:3:3 weight ratio (with respect to 1 g of biochar) in a beaker containing 20 mL of deionized water and stirred for 2 hrs. After proper dissolution, the mixture was dried at 100 °C followed by slow pyrolysis at different temperatures (600 °C, 700 °C, 800 °C and 900 °C) for 1.5 hrs at a heating rate of 5 °C /min in N_2 atmosphere. Nitrogen doped activated biochar was collected and washed with hot water (neutral pH) followed by overnight drying at 100 °C.

Material characterisation

X-ray photoelectron spectroscopy (XPS)

The surface composition of different nitrogen entities present in the synthesised materials was analysed using X-ray photoelectron spectroscopy (XPS). The analysis was carried out using Thermo K-alpha+ spectrometer using micro focused and monochromate Al Kα radiation with energy 1486.6 eV. For each core levels, the spectral acquisition pass energy was kept at 50 eV. During data acquisition, charge compensation was performed using electron flood gun followed by individual core-level spectra check using C1s at 284.6 eV as standard and corrected if needed. The peak fitting of the individual core-levels was done using Casa XPS software with a Shirley type background and compared with XPS data in Thermofisher scientific and previous literatures.

Field emission Scanning Electron Microscopy – Energy Dispersive X-ray analysis (FESEM-EDX)

The surface morphology, pore size analysis and elemental mapping studies for C, N and O were done using field emission scanning electron microscope (Zeiss Gemini 500 FE-SEM coupled with Ultim Max EDX detector). Analysis was done using an accelerating voltage of 15 kV, and time taken for each data collection was 100 s. A small amount of the as-synthesized sample was first sonicated with ethanol for 10 minutes and then it was drop-casted over silicon wafer and dried, prior to the analysis.

Fourier transform infrared spectroscopy (FT-IR) analysis

The carbonization and nitrogen doping in the biomass shell was characterized using Bruker 70v vortex FTIR analyser in the range of 400-4000 cm^{-1} wavelength. The analysis was performed in transmission mode using ATR technique with an averaged spectrum of 32 times in each cycle.

N_2 adsorption-desorption analysis

The effect of temperature and activating agent on the surface area and pore size distribution of the materials were analysed using N_2 adsorption-desorption isotherm. The measurement was done at liquid nitrogen temperature (77 K) using BELSORP-maxII instrument. The samples were degassed at 200 °C for 6 hrs followed by the sorption measurements. The specific surface area was confirmed by Brunaur-Emmett-Teller (BET) method and pore size distribution by classical BJH (Barrett, Joyner and Halenda) method.

Powder X-ray diffraction (PXRD) analysis

The powder X-ray diffraction (XRD) data were collected at room temperature on a Rigaku X-ray diffractometer with Cu Kα radiation ($\lambda = 1.5406$ nm) at 45 kV and 40 mA in the 2θ range of 10º–90º performed using step size of 0.02° and a scan rate of 0.5 s/step. The analysis and comparison of resultant PXRD patterns were done using simulated pattern obtained from Pearson database. The XRD patterns of nitrogen doped activated carbon at different temperatures were compared with biochar and activated biochar without nitrogen doping.

Raman spectroscopy analysis

Raman experiments were performed in backscattering geometry (180°) using a commercial Raman spectrometer [Renishaw Centrus 34NJ79] equipped with a solid-state frequency-doubled 532 nm CW Nd-YAG laser and 800 mm focal length monochromator. The room temperature Raman spectra were collected with a laser power of 1 mW at the sample.

Operando DRIFTS analysis

The operando DRIFTS experimental were performed using a Bruker 70v vertex FTIR spectrometer equipped with a Harrick DRIFTS cell. The detector was LN-MCT, optical path length was 1.25 mm. The spectra were recorded at 4 cm^{-1} resolution, and each spectrum was averaged 32 times Each sample was pre-treated at 150 ºC using 1 NLPH N_2 gas flow for 10 minutes after that spectrum of the sample was taken as baseline. Once the temperature is cooled down, a feed gas containing 1 NLPH CO_2 and 1 NLPH of N_2 is passed. During this process, at each minute, the spectrum was recorded till the sample is saturated with CO_2.

In situ Diffuse Reflectance Infra-Red Fourier Transform Spectroscopy (DRIFTS)

The In-situ Diffuse Reflectance Infra-red Fourier Transform Spectroscopy (DRIFTS) was done by using a purged VERTEX FT-IR spectrometer equipped with the A530/P accessory and a mid-band Mercury Cadmium Telluride (MCT) detector. The DRIFTS cell (from HARRICK) with quartz window was used for an in-situ experiment to deconvolute the CO_2 adsorption over the surface. During experimental analysis, every spectrum was measured after 32 scans with a resolution factor of 4 cm^{-1}. The catalyst was loaded inside the DRIFTS cell. Before measurement, the cell was purged with N_2 gas for 30 minutes. Then, CO_2 gas was injected through cell openings in a continuous flow mode using Mass Flow Controller (MFC). Before starting the measurement, background data was collected. Then the data were collected at a fixed interval of 5 minutes after CO_2 flow started.

CO_2 Uptake Experiments

Static CO_2 uptake experiment

CO_2 temperature programmed desorption (TPD) analysis using Altamira AMI-300 Lite instrument was done to evaluate the static CO_2 uptake of the material. The experiment was done using a U-shaped TPD cell in which the sample has been taken. The sample was pre-treated at 150 °C for 1 hr with a ramp rate of 10 °C/min under the flow of helium (20ml/min) to remove any adsorbed gases or impurities from the material. After pre-treatment, the material was then cooled down to 75 °C followed by treatment with 10% CO_2 in helium by passing a gas mixture (5 ml/min CO_2 and 45 ml/min helium) for 30 mins. Excess physiosorbed CO_2 was eliminated using helium post-flushing. After the material is cooled down to 50 °C, TPD analysis was started from 50 °C to 150 °C with a ramp rate of 10 °C with 5 ml/min of helium as carrier gas. TCD detector was used to detect the desorbed CO_2. After every analysis, the amount of desorbed CO_2 was calculated by calibrating the TCD by a known amount of CO_2.

Dynamic CO_2 uptake experiment

An in-house assembled setup via column breakthrough experiment was used to perform the dynamic CO_2 uptake studies of the adsorbent materials. For the experiment, about 500 mg of sample was taken and activated at 100 °C for 4 hrs, then it was loaded in the middle of a quartz column. A feed of 0.5% or 5000 ppm CO_2 balanced with air, was then passed through the adsorbent bed. A LI-COR 850 IR-based gas analyser was used to analyse the change in the concentration during measurement. Based on breakthrough time, which is the time till which the material can adsorb the CO_2 with its maximum capacity, the dynamic uptake was calculated using the following equation (Equation. S1).

$$q_b = \frac{F \times C_0 \times t_b}{W} \qquad \text{......... (S1)}$$

Where, F is the flowrate of the feed gas, C_0 is the concentration of CO_2 in the feed, t_b is defined as the breakthrough time, and W is the weight of the adsorbent.

On the other hand, post-breakthrough uptake is calculated using a modified version of Equation (S2) based on the Avrami kinetics model, where t_q denotes the stoichiometric time (Equation. S3). In order to calculate the stoichiometric time, the exhaustion time is considered at which the relative concentration of CO_2 is 0.9, as after the exhaustion time to saturation point is a very slow process and the uptake in this phase is also negligible. Thus, the total uptake is calculated as the sum of breakthrough and post-breakthrough uptake value.

$$q_a = \frac{F \times C_0 \times t_q}{W} \qquad \text{......... (S2)}$$

$$t_q = \int_{t_b}^{t_{ex}} (1 - \frac{C_t}{C_0}).dt \qquad \text{......... (S3)}$$

Long-term regeneration study

An in-house assembled setup via column breakthrough experiment was used to perform the long-term regeneration study of the adsorbent materials. For the experiment, about 2 g of sample was taken and activated at 100 °C for 4 hrs, then it was loaded in the middle of a quartz column (0.8 cm). A feed of 0.5% or 5000 ppm CO_2 balanced with air, was then passed through the adsorbent bed. A LI-COR 850 IR-based gas analyser was used to analyse the change in the concentration during measurement. The adsorption process was allowed for 15 mins. After that the inlet is switched with pure nitrogen stream for 15 mins for the regeneration. The cycle of adsorption and desorption was repeated multiple times to examine material's withstand ability in multiple sorption cycle. Based on the saturation time the extent of regeneration is evaluated.

Life Cycle Assessment (LCA)

The life cycle assessment (LCA) is a system modelling technique that measures the environmental burdens or hotspots linked to each step during the processes/products life cycle, beginning with raw materials.[1–4] Herein, the environmental impacts of N-doped activated carbon (adsorbent) synthesis and adsorption of CO_2 on activated carbon was conducted using LCA methodology according to ISO 14040 and 14044 standards. Initially, the goal and scope of the analysis were fixed with 1 kg as functional unit for adsorbent synthesis (waste peanut shell; raw material) and CO_2 adsorption on activated carbon. Fig. S14 and Table S4 illustrates the system boundaries and life cycle inventory (LCI) that includes all the inputs and outputs of the system. The study adopts a cradle-to-gate approach, starting with the processing of waste peanut shell biomass as primary feedstock and extending to the final 1 kg of carbon capture. The process-based bottom-up approach was adopted to produce the life cycle inventory (LCI) data for each individual phase, and were systematically constructed until all chemical inputs could be matched with experimental data in the Ecoinvent LCI database (as shown in Table

S.4) without any proxy LCI data for chemicals. The input material or chemicals in each synthesis process, including solvents, reactants, and process aids were scaled up linearly for 1 kg, and energy inputs were calculated from process flows using mass and energy principles.[5–7] The conservative estimate of by-products was assumed in the LCI calculations, and accounted in output product allocation. The energy input for producing 1 kg of the final compound, which includes reaction temperature, stirring, are explored based on lab-scale synthesis data and normalized calculations. The study also evaluated energy related impacts by comparing renewable energy (RE; solar photovoltaic) with the existing non-renewable energy (NRE; Indian-Southern; majorly coal) sources. By understanding the degree of recyclability of catalyst (35 cycles operation) for carbon capture, LCIs was modelled by reducing the captured CO_2 (0.43 kg/kg catalyst) for each operated cycle. Results for initial (1st cycle), tenth and final (35th) cycle data were shown in **Table S5-8**. Findings suggested that an RE grid could reduce overall energy input by >95% during the industrial scale. The burdens and credits of auxiliary outputs, pollution control processes and fugitive emission have not been considered. Finally, the modelled LCI was analyzed with SimaPro, v.9.6.0.1 using Ecoinvent v3.10 databases as background activity source data. The life cycle impact assessment (LCIA) method, ReCiPe 2016 Midpoint (H) V1.08 / World (2010) H and Endpoint (H) V1.08 / World (2010) H/A was employed to analyze the Global warming potential (GWP; kg CO_2 eq), midpoint and endpoint (damage) categories as reported.[1,2,8] The Sankey representation of the GWP for different cycles are shown in **Fig. S15-18.**

Table

Table S1. Summary abbreviation and description of materials with synthesis parameters

Material Abbreviation	Description	Activating Agent	Reaction Condition
PS	Peanut Shell	-	-
PSBC	Peanut Shell Biochar	-	Temperature: 450 ºC Time: 6 hr Atmosphere: N_2
PSAC	Peanut Shell Activated Carbon	-	-
PSNAC600	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 600 ºC using KOH activating agent	KOH	Temperature: 600 ºC Time: 1.5 hr Atmosphere: N_2
PSNAC700	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 700 ºC using KOH activating agent	KOH	Temperature: 700 ºC Time: 1.5 hr Atmosphere: N_2
PSNAC800	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 800 ºC using KOH activating agent	KOH	Temperature: 800 ºC Time: 1.5 hr Atmosphere: N_2
PSNAC900	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 900 ºC using KOH activating agent	KOH	Temperature: 900 ºC Time: 1.5 hr Atmosphere: N_2
PSNAC-H_3PO_4	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 700 ºC using H_3PO_4 activating agent	H_3PO_4	Temperature: 700 ºC Time: 1.5 hr Atmosphere: N_2
PSNAC-$ZnCl_2$	Peanut Shell derived Nitrogen doped Activated Carbon synthesized at 700 ºC using $ZnCl_2$ activating agent	$ZnCl_2$	Temperature: 700 ºC Time: 1.5 hr Atmosphere: N_2

Table S2. Comparison of BET surface area and MP pore distribution based on N_2 physisorption measurements for carbonaceous sorbents.

Material	BET Surface Area (m^2/g)	MP Pore Diameter (nm)	Pore Volume (cm^3/g)
PSBC	5.01	0	0
PSNAC600	1079	1.4	0.47
PSNAC700	1411	1.3	0.65
PSNAC800	994	1.9	0.51
PSNAC900	272	0.7	0.12

Table S3. CHN analysis for the Activated carbons.

Sample	C (wt%)	N (wt%)	N/C ratio
PSNAC 600	54.84	35.62	0.65
PSNAC 700	33.36	10.75	0.32
PSNAC 800	60.29	17.19	0.28
PSNAC 900	52.43	6.32	0.12

Table S4. Comparison of different nitrogenous species present in activated carbon sorbent.

Sample	% of Pyridinic Nitrogen N-6	% of Pyrrolic Nitrogen N-5	% of Graphitic Nitrogen GN
PSNAC 600	54.87	28.72	16.41
PSNAC 700	49.87	46.63	3.49
PSNAC 800	48.09	35.34	16.57
PSNAC 900	35.82	39.79	24.37

Table S5. Lifecycle inventory for Utilization of Waste biomass for N-doped Activated carbon and adsorption of CO_2 on activated carbon.

<table>
<tr><th colspan="5">Synthesis of Peanut shell derived N-doped activated carbon (PSNAC) : 1 kg</th></tr>
<tr><th>Steps</th><th>Inputs</th><th>Quantity</th><th>Output</th><th>By-products /recovery</th></tr>
<tr><td>Drying</td><td>a. Peanut shells
b. Water
c. Energy</td><td>2 kg
2 L
100 °C for 6 hrs. (0.5 kW × 6 h) = 3 kWh</td><td>Peanut shells 1.80 kg</td><td>Water (Recoverable)</td></tr>
<tr><td>Biochar preparation</td><td>a. Peanut shells
b. Energy
c. Nitrogen atmosphere</td><td>1 k g
450 °C for 6hrs. (2 kW × 6 h) = 12 kWh</td><td>Biochar 0.356 kg</td><td>–</td></tr>
<tr><td>N-doped activated carbon</td><td>a. Biochar
b. Potassium hydroxide
c. Melamine
d. Water
e. Energy</td><td>1 kg
10 % (w/w)
16 % (w/w)
22 L
100 °C for 24 hrs. 700 °C for 1.5 hrs. (Total: 14 kWh)</td><td>N-doped activated carbon 1 kg</td><td>Water (Recoverable)</td></tr>
<tr><th colspan="5">Adsorption of CO_2 on 1 kg activated carbon</th></tr>
<tr><td>Carbon dioxide capture</td><td>a. N doped activated carbon
b. CO_2</td><td>1 kg
(0.5 % CO_2 or 0.5 kg or 5000 ppm CO_2)
100 °C for 4 hrs.</td><td>0.86 kg CO_2 Capture</td><td>–</td></tr>
</table>

	c. Electricity	(0.5 kW × 4 h) = 2 kWh		

Table S6. LCA of Impact Categories for the N-doped activated carbon (PSNAC) with Renewable (RE) and non-renewable energy (NRE) grid supply

Impact category	**Unit**	**N-doped activated carbon (NRE condition)**	**N-doped activated carbon (RE condition)**
Global warming	kg CO_2 eq	25.1	1.9911532
Stratospheric ozone depletion	kg CFC11 eq	6.37E-06	3.13E-07
Ionizing radiation	kBq Co-60 eq	1.15	0.034
Ozone formation, Human health	kg NO_x eq	0.05	0.0036
Fine particulate matter formation	kg PM2.5 eq	0.06	0.0026
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.05	0.0039
Terrestrial acidification	kg SO_2 eq	0.08	0.006
Freshwater eutrophication	kg P eq	0.02	0.00046
Marine eutrophication	kg N eq	0.0015	5.05E-05
Terrestrial ecotoxicity	kg 1,4-DCB	57.98	8.16
Freshwater ecotoxicity	kg 1,4-DCB	1.43	0.10
Marine ecotoxicity	kg 1,4-DCB	1.87	0.14
Human carcinogenic toxicity	kg 1,4-DCB	1.6	0.25
Human non-carcinogenic toxicity	kg 1,4-DCB	36.68	1.42
Land use	m^2a crop eq	0.37	0.16
Mineral resource scarcity	kg Cu eq	0.031	0.019
Fossil resource scarcity	kg oil eq	6.31	0.59
Water consumption	m^3	0.18	0.03

Table S7. Damage categories for N-doped activated carbon (PSNAC) with Renewable (RE) and non-renewable energy (NRE) grid

Damage category	**Unit**	**N-doped activated carbon (NRE condition)**	**N-doped activated carbon (RE condition)**
Human health	DALY	7.64E-05	4.75E-06
Ecosystems	species.yr	1.18E-07	9.82E-09
Resources	USD2013	0.57	0.17

Table S8. LCA of Studied Impact Categories for the Carbon Capture using PSNAC over various operated cycles with RE and NRE grid supply

Impact category	Unit	Capture (cycle 1): NRE	Capture (cycle 10): NRE	Capture (cycle 35): NRE	Capture (cycle 1): RE	Capture (cycle 10): RE	Capture (cycle 35): RE
Global warming	kg CO$_2$ eq	31.09	22.09	-2.90	1.5	-7.4	-32.49
Stratospheric ozone depletion	kg CFC11 eq	8.13E-06	8.13E-06	8.13E-06	4.33E-07	4.33E-07	4.33E-07
Ionizing radiation	kBq Co-60 eq	1.47	1.47	1.47	0.053	0.05	0.053
Ozone formation, Human health	kg NO$_x$ eq	0.07	0.07	0.07	0.0048	0.0048	0.0048
Fine particulate matter formation	kg PM2.5 eq	0.079	0.079	0.079	0.0034	0.003	0.003
Ozone formation, Terrestrial ecosystems	kg NO$_x$ eq	0.071	0.071	0.071	0.0051	0.0051	0.005
Terrestrial acidification	kg SO$_2$ eq	0.105	0.105	0.105	0.008	0.008	0.0088
Freshwater eutrophication	kg P eq	0.031	0.031	0.031	0.0006	0.00064	0.00064
Marine eutrophication	kg N eq	0.001	0.0019	0.0019	6.79E-05	6.79E-05	6.79E-05
Terrestrial ecotoxicity	kg 1,4-DCB	73.97	73.97	73.9	14.1	14.1	14.1
Freshwater ecotoxicity	kg 1,4-DCB	1.83	1.833	1.8	0.16	0.16	0.16
Marine ecotoxicity	kg 1,4-DCB	2.39	2.39	2.3	0.21	0.21	0.21
Human carcinogenic toxicity	kg 1,4-DCB	2.08	2.08	2.08	0.33	0.33	0.33
Human non-carcinogenic toxicity	kg 1,4-DCB	46.8	46.8	46.8	2.13	2.13	2.13
Land use	m^{2}a crop eq	0.48	0.48	0.48	0.26	0.26	0.26
Mineral resource scarcity	kg Cu eq	0.03	0.03	0.03	0.024	0.02	0.02
Fossil resource scarcity	kg oil eq	8.04	8.04	8.04	0.742	0.74	0.74
Water consumption	m^3	0.22	0.22	0.22	0.051	0.05	0.051

Table S9. LCA of Studied damage Categories for the Carbon Capture using PSNAC over various operated cycles with RE and NRE grid supply

Damage category	Unit	Capture (cycle 1): NRE	Capture (cycle 10): NRE	Capture (cycle 35): NRE	Capture (cycle 1): RE	Capture (cycle 10): RE	Capture (cycle 35): RE
Human health	DALY	9.66E-05	8.82E-05	6.50E-05	5.24E-06	-3.11E-06	-2.63E-05
Ecosystems	species.yr	1.48E-07	1.23E-07	5.28E-08	1.02E-08	-1.50E-08	-8.50E-08
Resources	USD2013	0.72	0.72	0.72	0.21	0.21	0.21

Table S10. Literature summary of some of the best biomass derived adsorbents for CO_2 capture.

Material	**Biomass source**	**Activating agent**	**Mode of CO_2 uptake**	**Highest uptake (mmol/g)**	**Adsorption conditions**	**Reference**
N- doped AC*	Peanut shell	KOH	**Dynamic**	**9.75**	**Ambient**	**This work**
Amine modified Hydrogel	*Konjac glucomannan* and Hydroxypropyl cellulose	KOH	Static	3.60	1 bar, 209 K	9
N- doped AC	Air-carbonized date seed, *Phoenix dactylifera*	KOH	Static	25	20 bar, 298 K	10
Multiscale carbon supraparticles	Lignin nano/micro beads and cellulose microfibrils	Physical activation	Static	1.74	1 bar, 313 K	11
N- doped AC	Tobacco stem	KOH	Static	29.5	30 bar, 298 K	12
Ultra microporous AC	Pecan nutshell	KOH	Static	5.3	1.1 bar, 273 K	13
3D- Monolithic graphene	Balsa wood	KOH	Static	6.93	1.1 bar, 298 K	14
N- doped AC	*Citrus aurantium* waste leaves and microalgae (Spirulina)	$ZnCl_2$	Static	8.43	1 bar, 273 K	15
AC	Coffee grounds	KOH	Static	6.91	273 K	16
Porous AC	Casein	Potassium citrate ($K_3C_6H_5O_7$)	Static	5.3	1 bar, 273 K	17
N- doped porous AC	Bean drugs	KOH	Static	6.3	1 bar, 298 K	18
B-doped porous carbon	Chitosan	N and B doping	Static	7.62	1 bar, 273 K	19
ZIF-modified Biochar	Bamboo Chips	Zn containing MOF	Dynamic	3.5	298 K	20

Figures

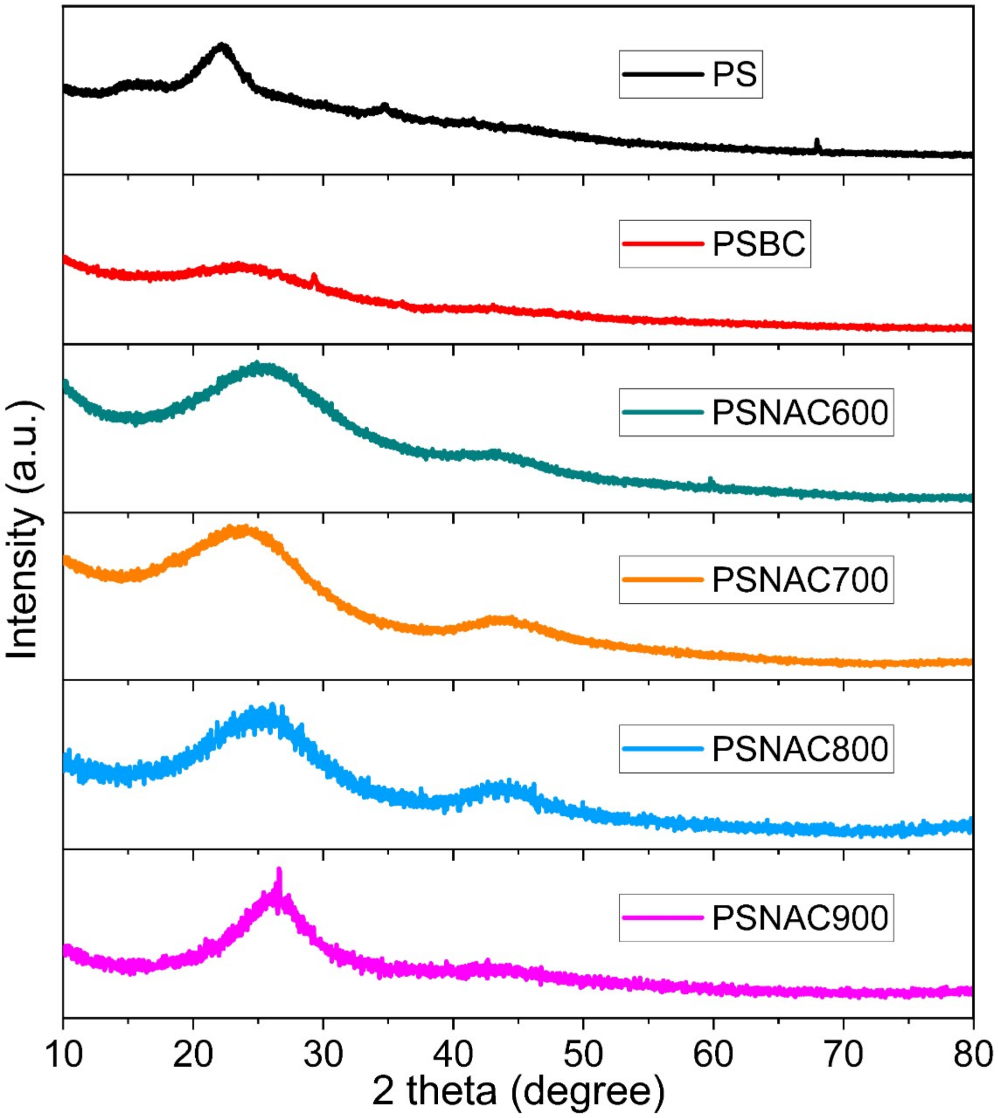


Fig. S1 XRD patterns of peanut shell (PS), peanut shell derived biochar (PSBC) and peanut shell derived nitrogen doped activated carbon, PSNAC-T (T = 600 °C, 700 °C, 800 °C and 900 °C).

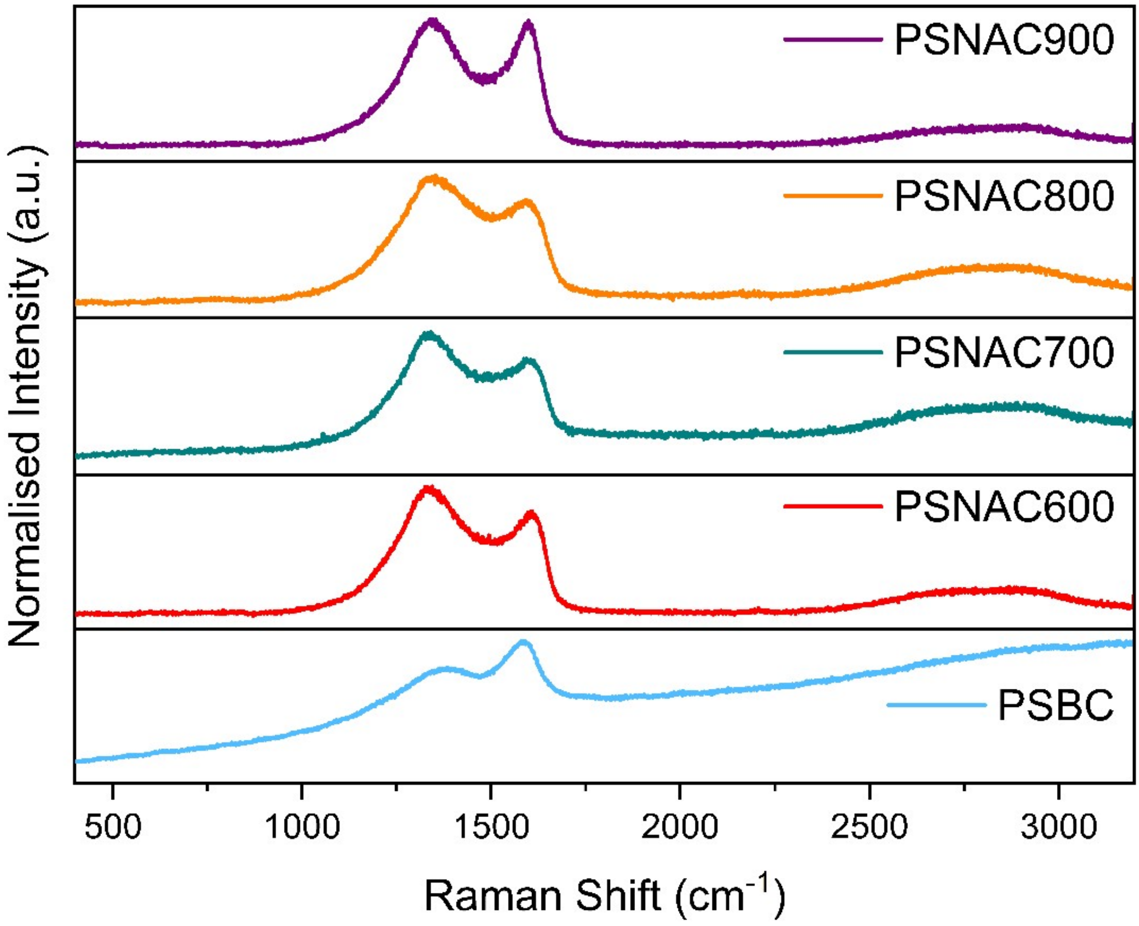
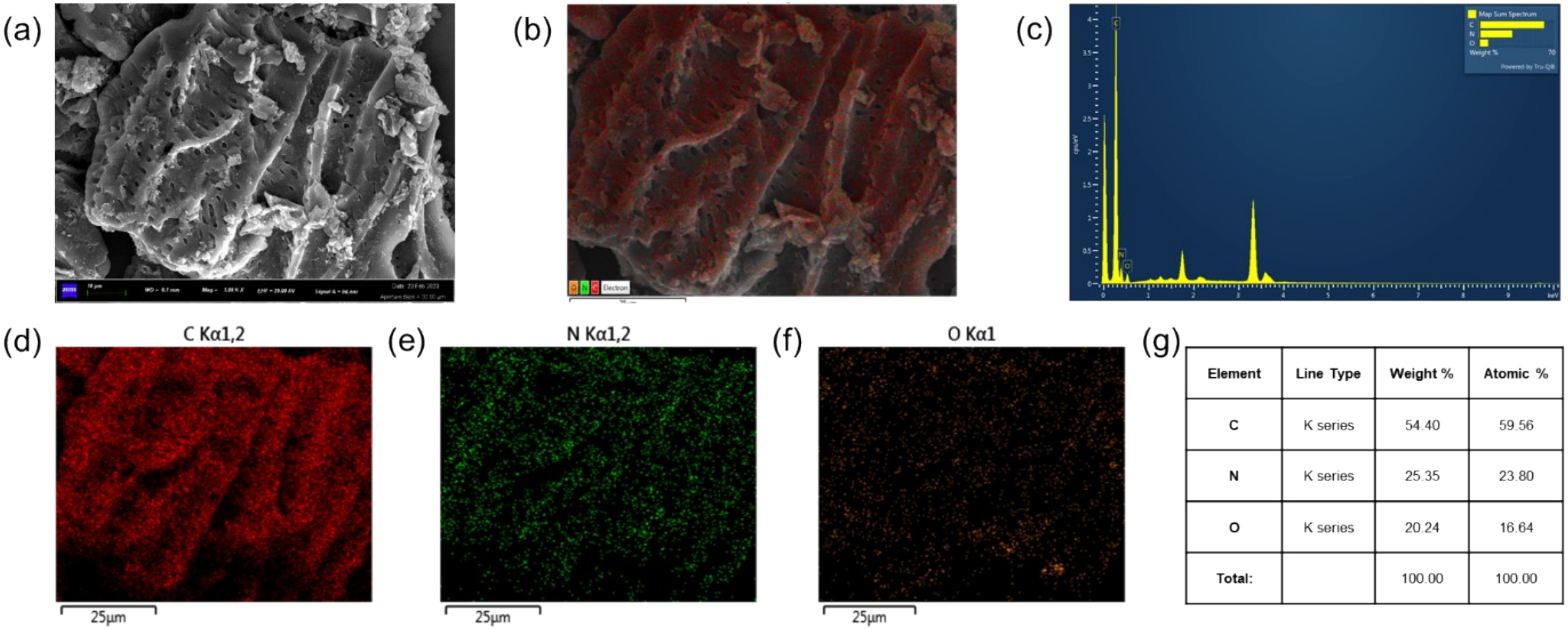
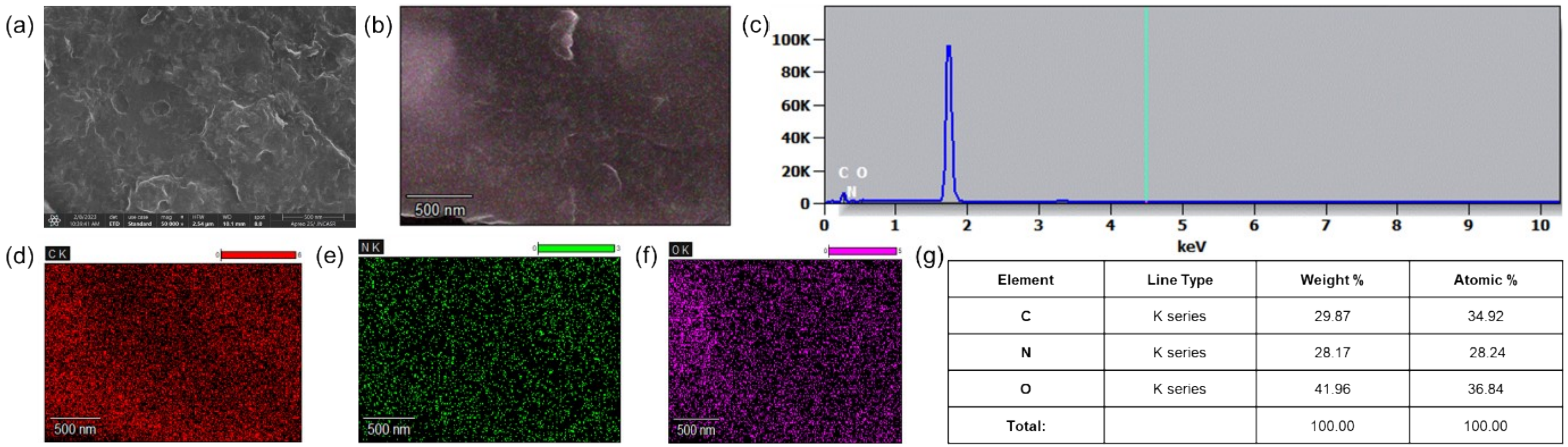


Fig. S2 Raman spectra of PSNAC-T, where T indicates 600 °C, 700 °C, 800 °C and 900 °C.



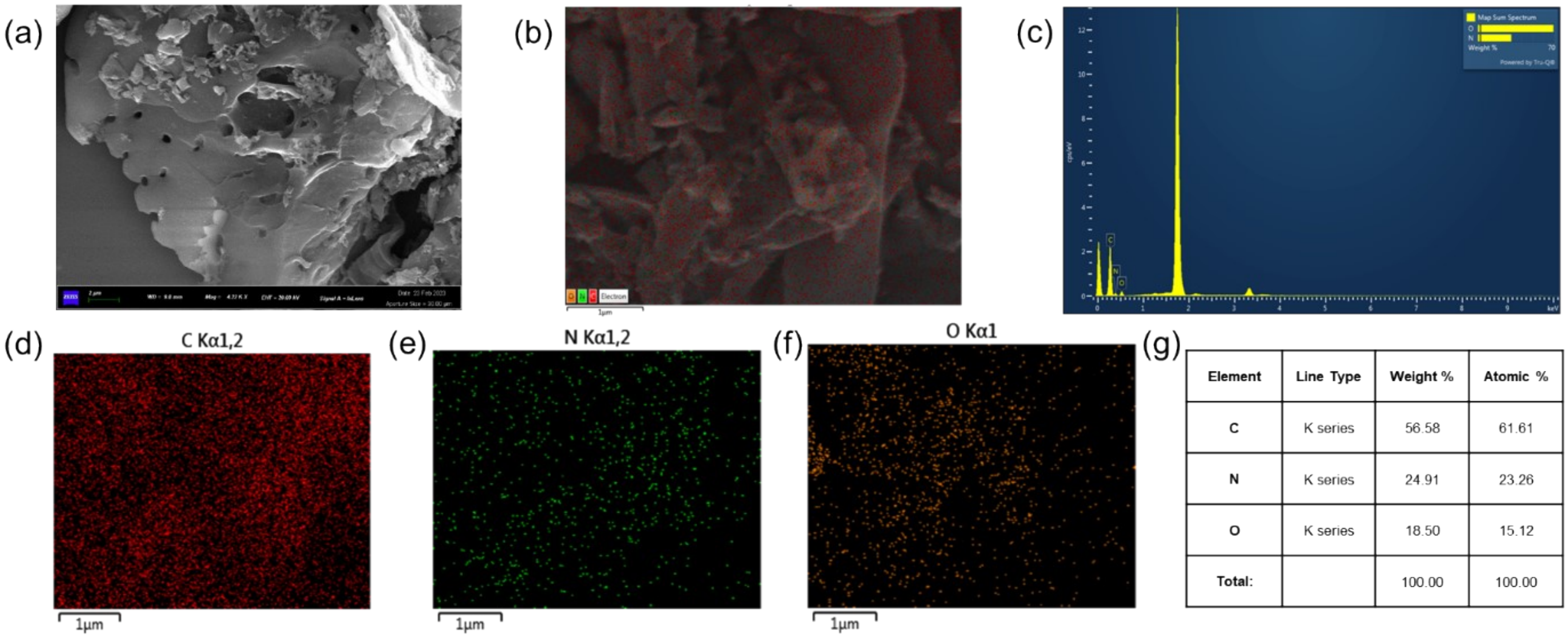
Element	Line Type	Weight %	Atomic %
C	K series	54.40	59.56
N	K series	25.35	23.80
O	K series	20.24	16.64
Total:		100.00	100.00

Fig. S3 (a) SEM image, (b) EDS layered image, (c) EDS spectrum, (d-f) Elemental mapping (C, N and O respectively), and (g) elemental composition of PSNAC-600.



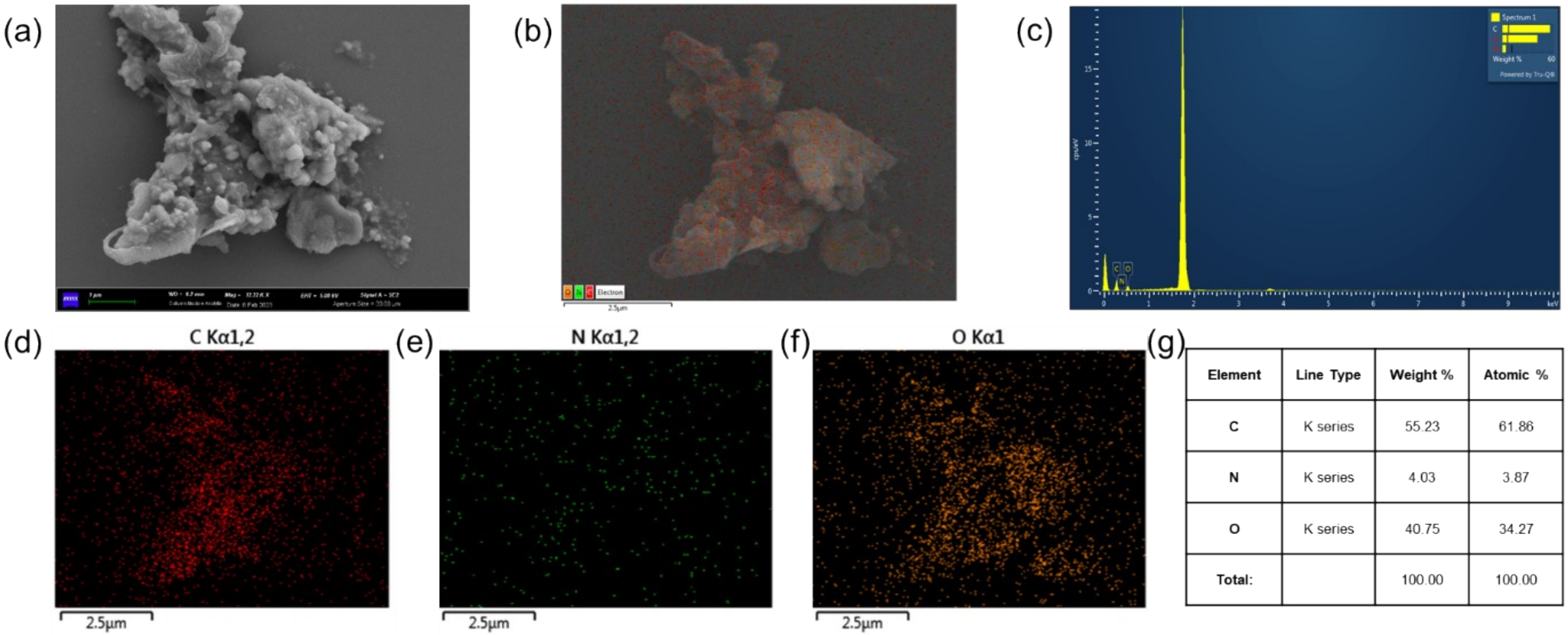
Element	Line Type	Weight %	Atomic %
C	K series	29.87	34.92
N	K series	28.17	28.24
O	K series	41.96	36.84
Total:		100.00	100.00

Fig. S4 (a) SEM image, (b) EDS layered image, (c) EDS spectrum, (d-f) Elemental mapping (C, N and O respectively), and (g) elemental composition of PSNAC-700.



Element	Line Type	Weight %	Atomic %
C	K series	56.58	61.61
N	K series	24.91	23.26
O	K series	18.50	15.12
Total:		100.00	100.00

Fig. S5 (a) SEM image, (b) EDS layered image, (c) EDS spectrum, (d-f) Elemental mapping (C, N and O respectively), and (g) elemental composition of PSNAC-800.



Element	Line Type	Weight %	Atomic %
C	K series	55.23	61.86
N	K series	4.03	3.87
O	K series	40.75	34.27
Total:		100.00	100.00

Fig. S6 (a) SEM image, (b) EDS layered image, (c) EDS spectrum, (d-f) Elemental mapping (C, N and O respectively), and (g) elemental composition of PSNAC-900.

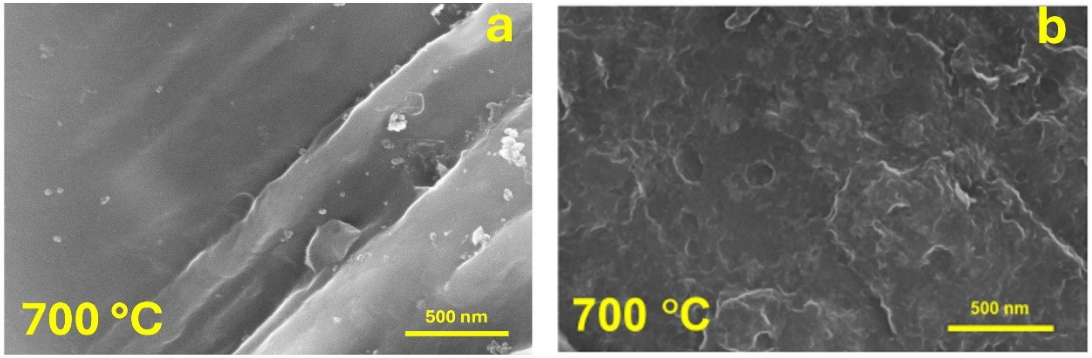


Fig. S7 FESEM morphology of (a) PSAC@700°C and (b) PSNAC@700°C

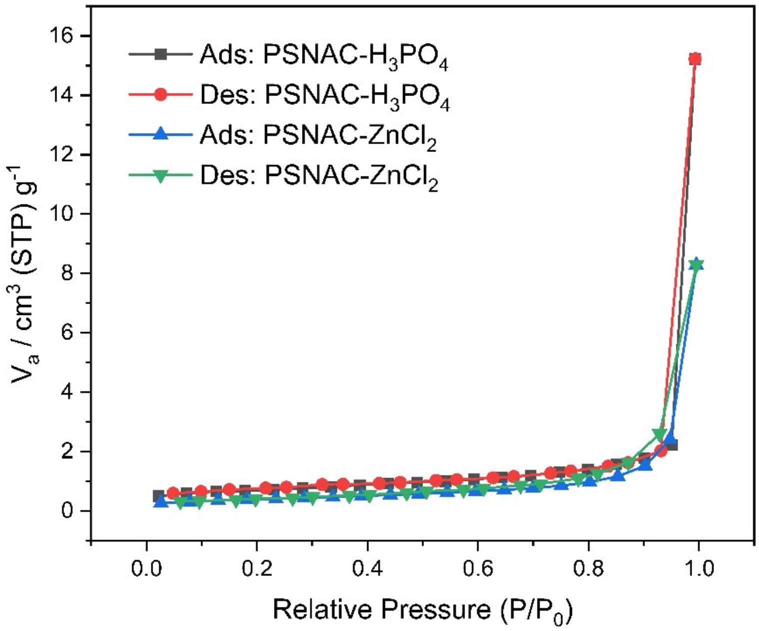


Fig. S8 Nitrogen adsorption-desorption isotherm for PSNAC with different activating agent.

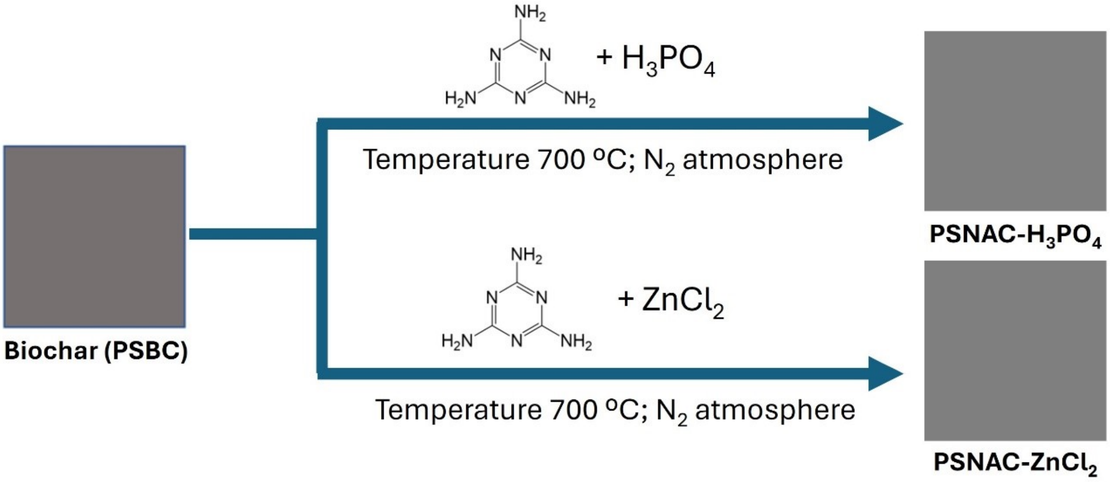


Fig. S9 Schematic of biochar activation in presence of H_3PO_4 and $ZnCl_2$ in the presence of melamine as nitrogen precursor.

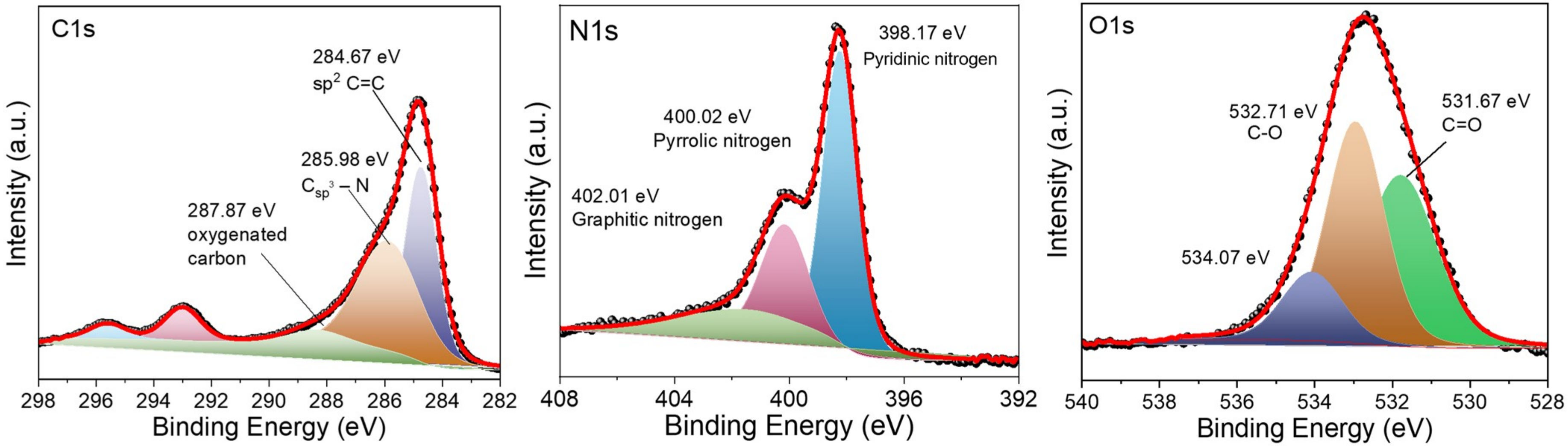


Fig. S10 XPS spectra of PSNAC600; C1s, N1s and O1s.

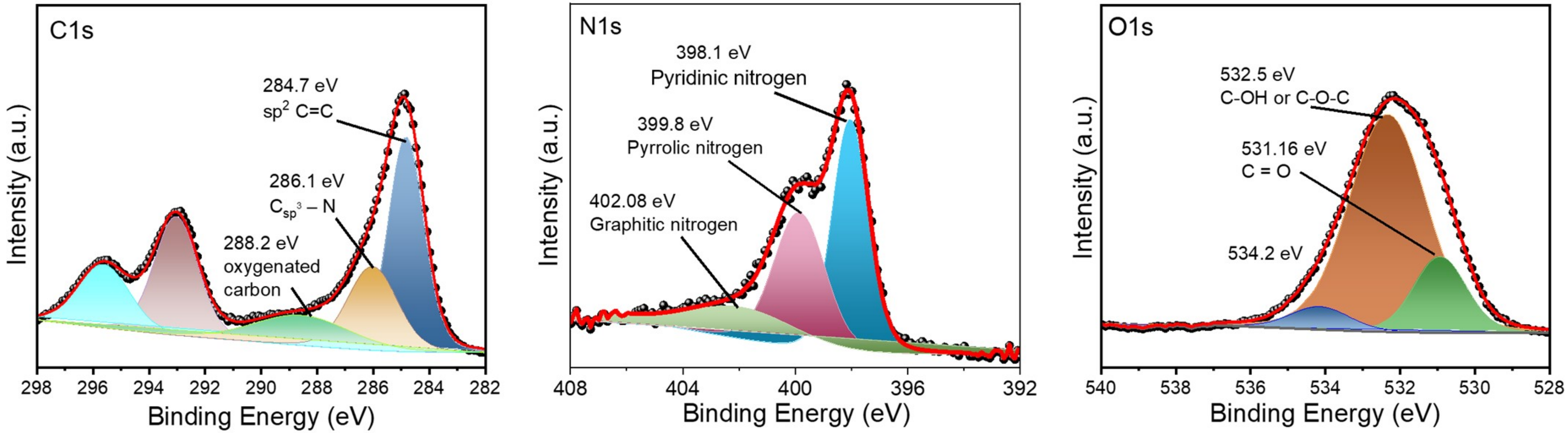


Fig. S11 XPS spectra of PSNAC700; C1s, N1s and O1s.

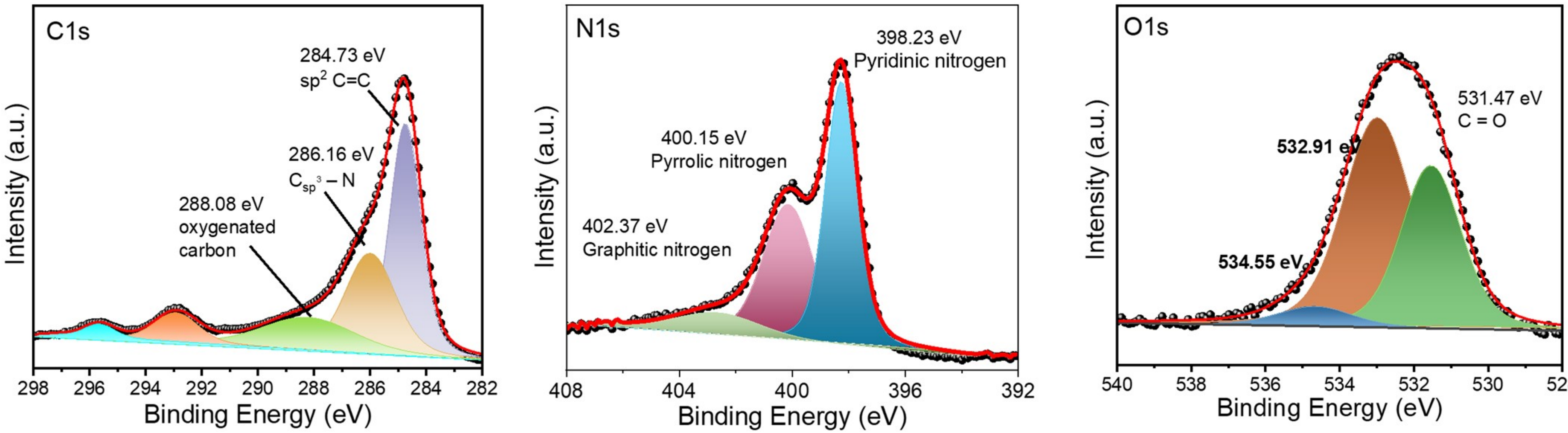


Fig. S12 XPS spectra of PSNAC800; C1s, N1s and O1s.

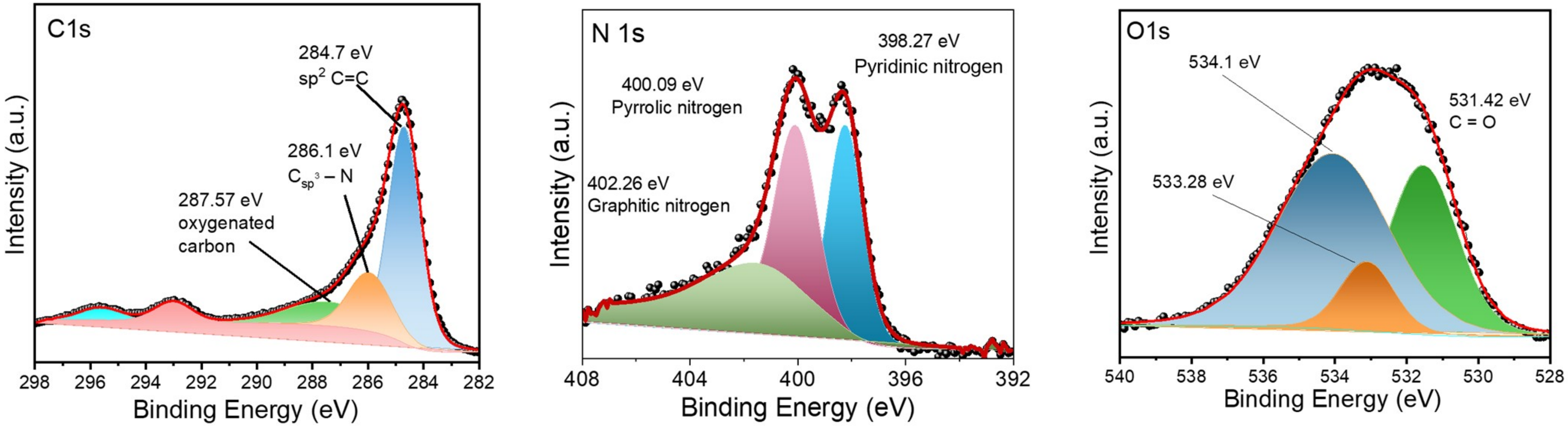


Fig. S13 XPS spectra of PSNAC900; C1s, N1s and O1s.

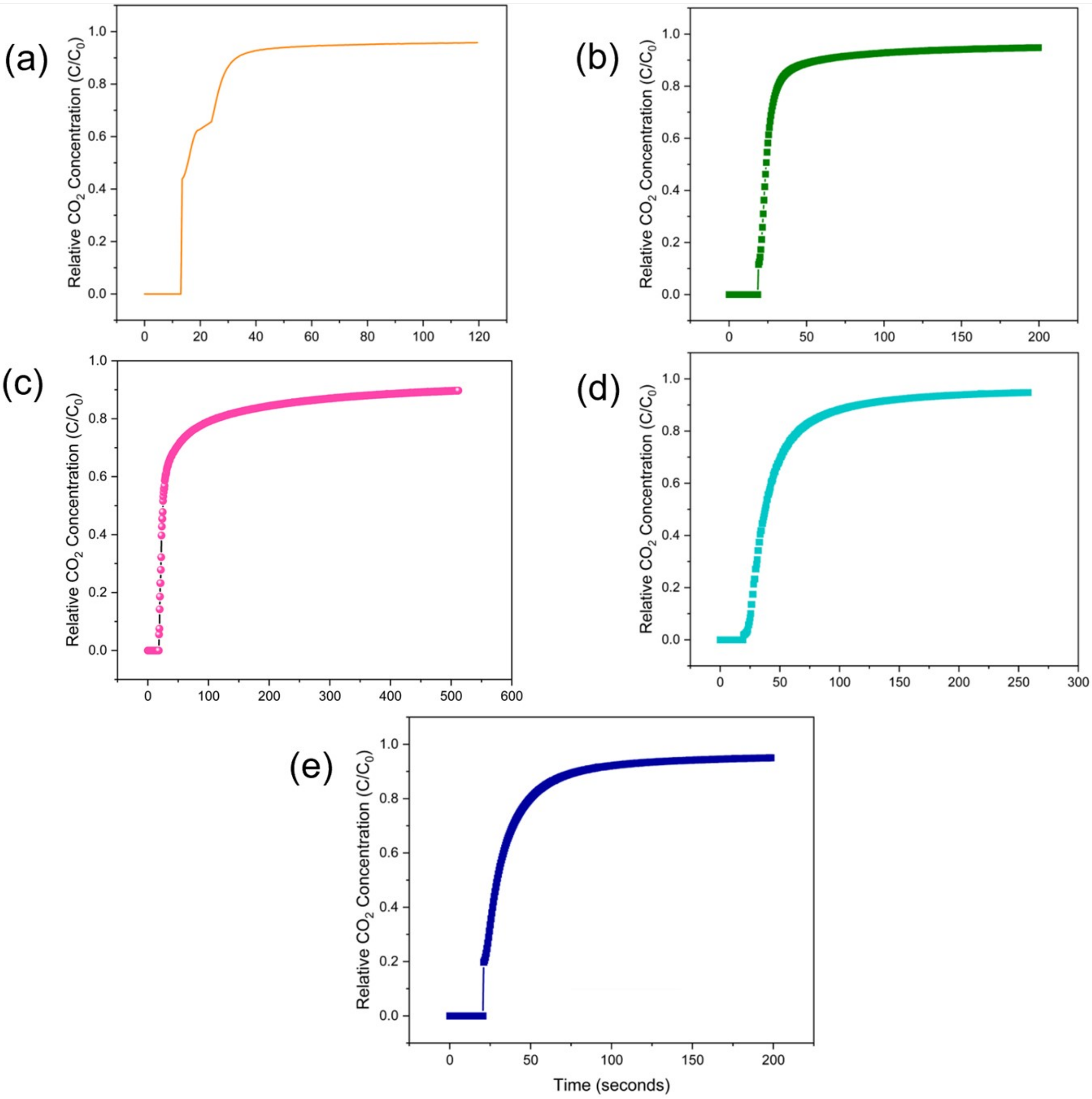


Fig. S14 Dynamic uptake of CO_2 via column breakthrough experiment using 0.5% CO_2. (a) PSBC, (b) PSNAC600, (c) PSNAC700, (d) PSNAC800, and (e) PSNAC900.

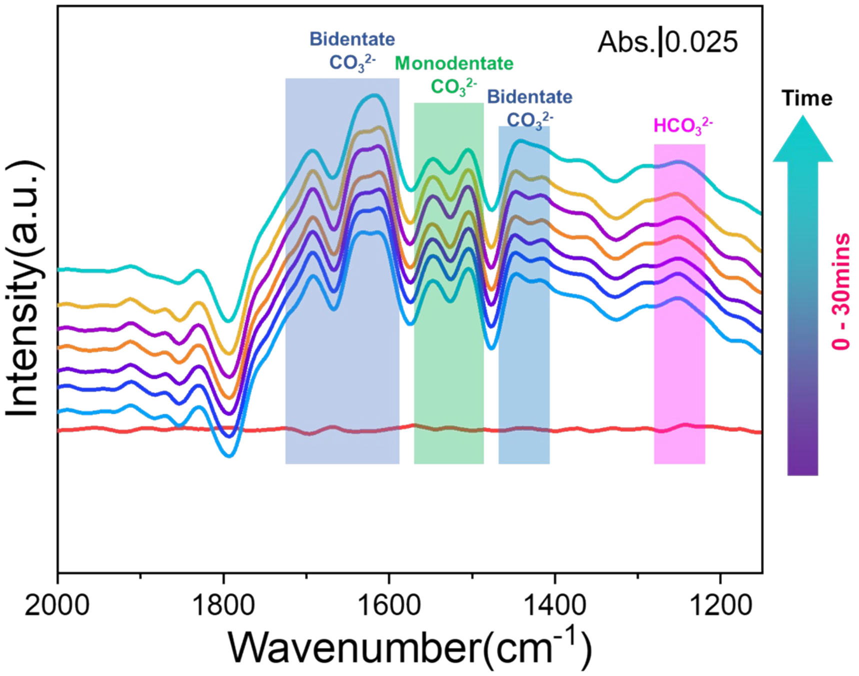


Fig. S15 In situ DRIFTS measurements performed during CO_2 exposure for 0–30 mins

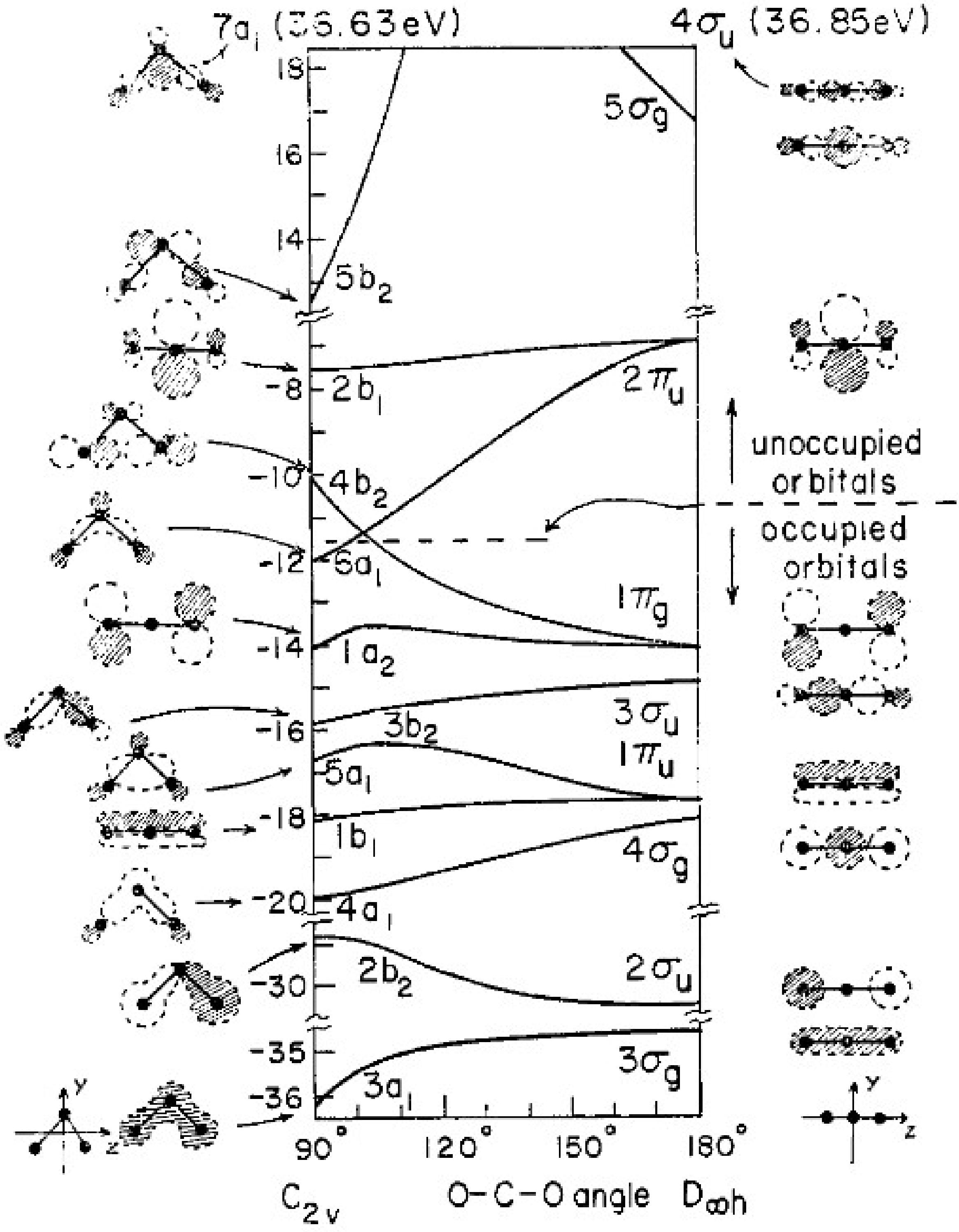


Fig. S16 Walsh correlation diagram of CO_2 molecule. Reproduced with a permission from ref. [21]Copyright 1971 American Chemical Society

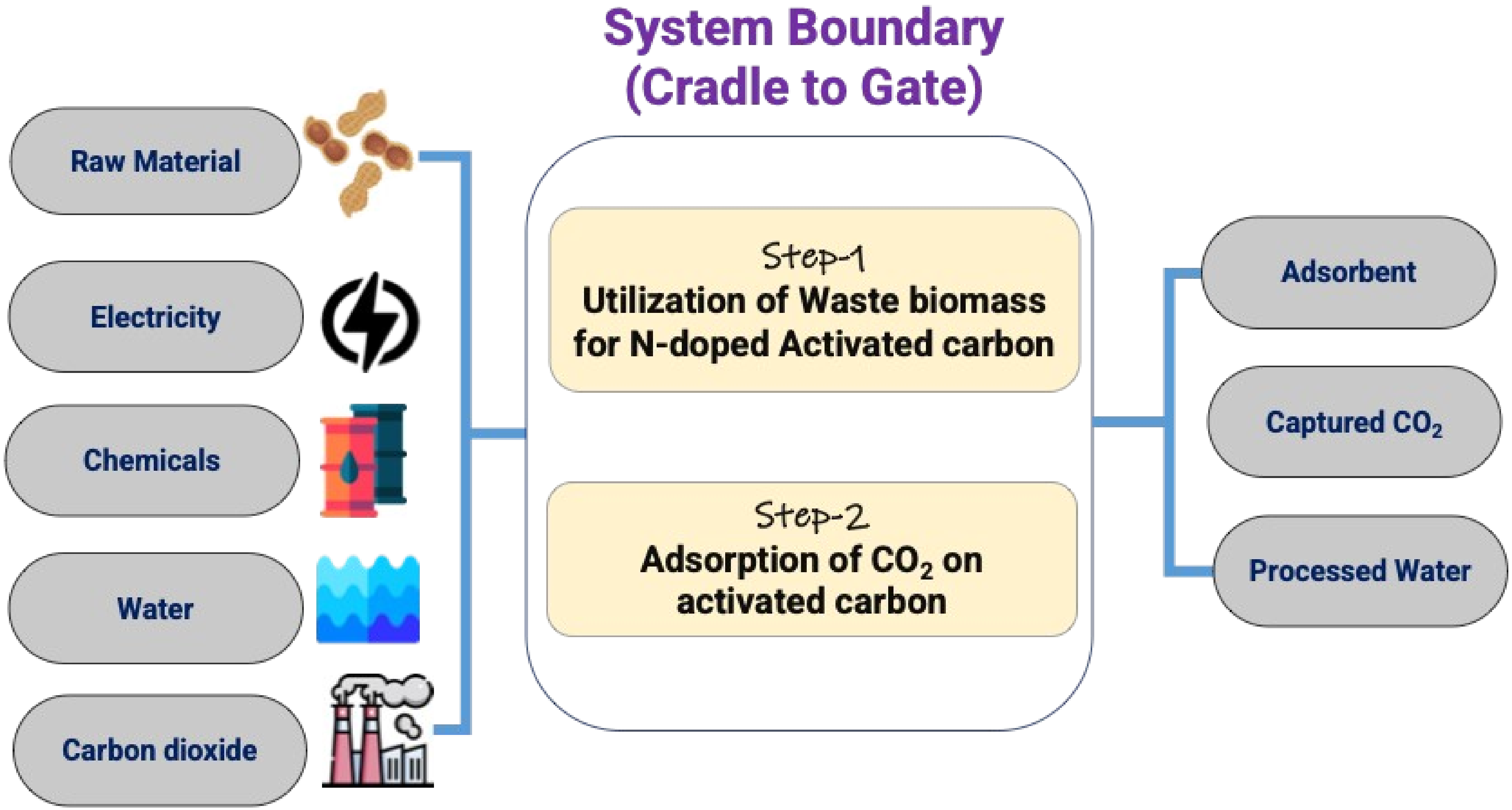


Fig. S17 System boundary for Utilization of Waste biomass for N-doped Activated carbon and adsorption of CO_2 on activated carbon**.**

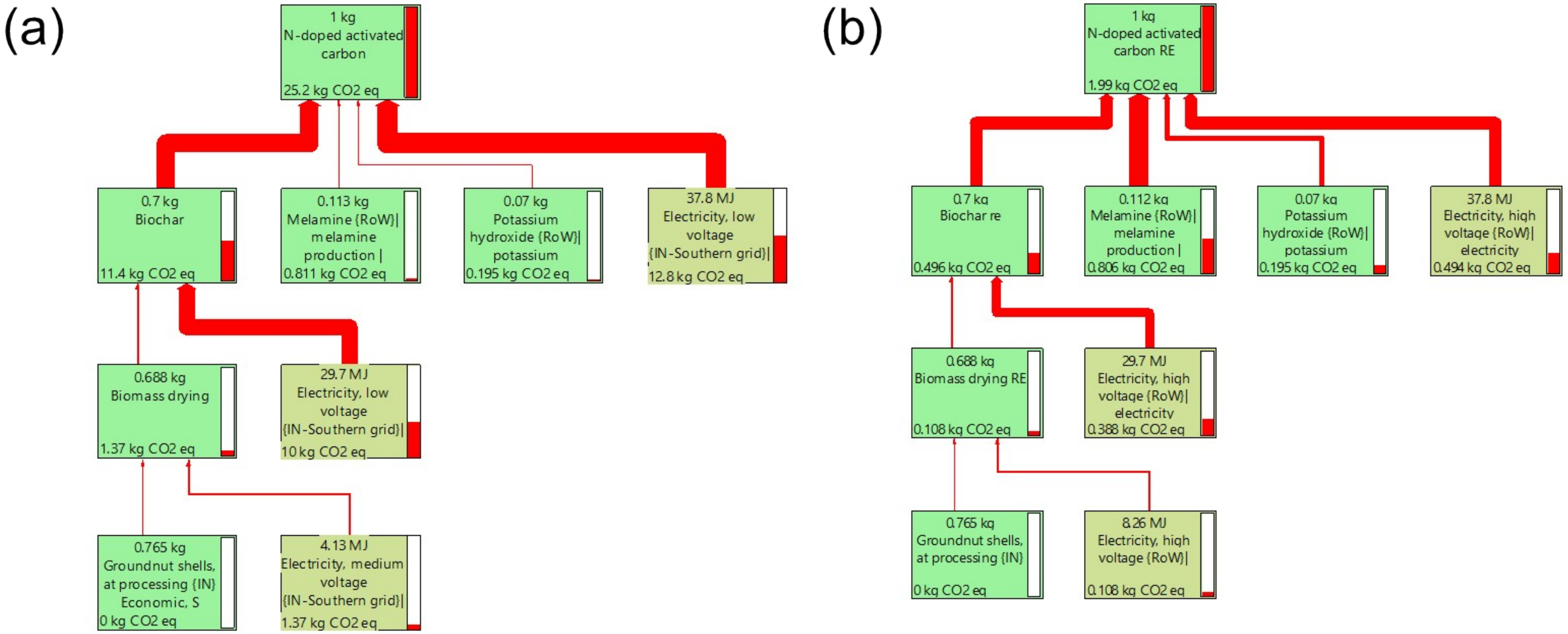


Fig. S18 Sankey representation of GWP emissions for 1 kg PSNAC synthesis and Carbon capture with NRE and RE conditions: (a) PSNAC synthesis in NRE condition, and (b) PSNAC synthesis in RE condition.

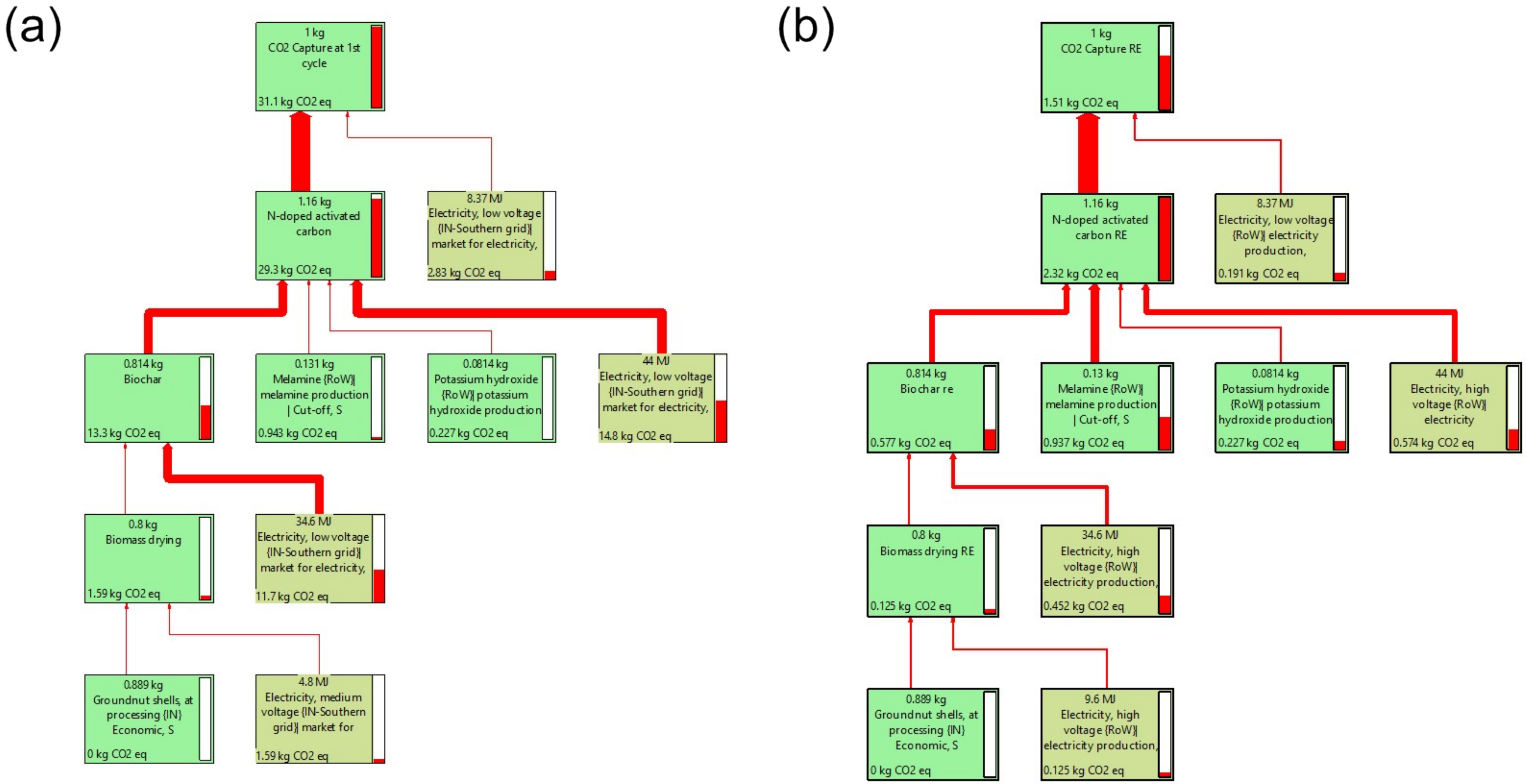


Fig. S19 Sankey representation of GWP emissions for 1 kg PSNAC synthesis and Carbon capture with NRE and RE conditions: (a) Carbon capture with NRE at cycle 1, and (b) Carbon capture with RE at cycle 1.

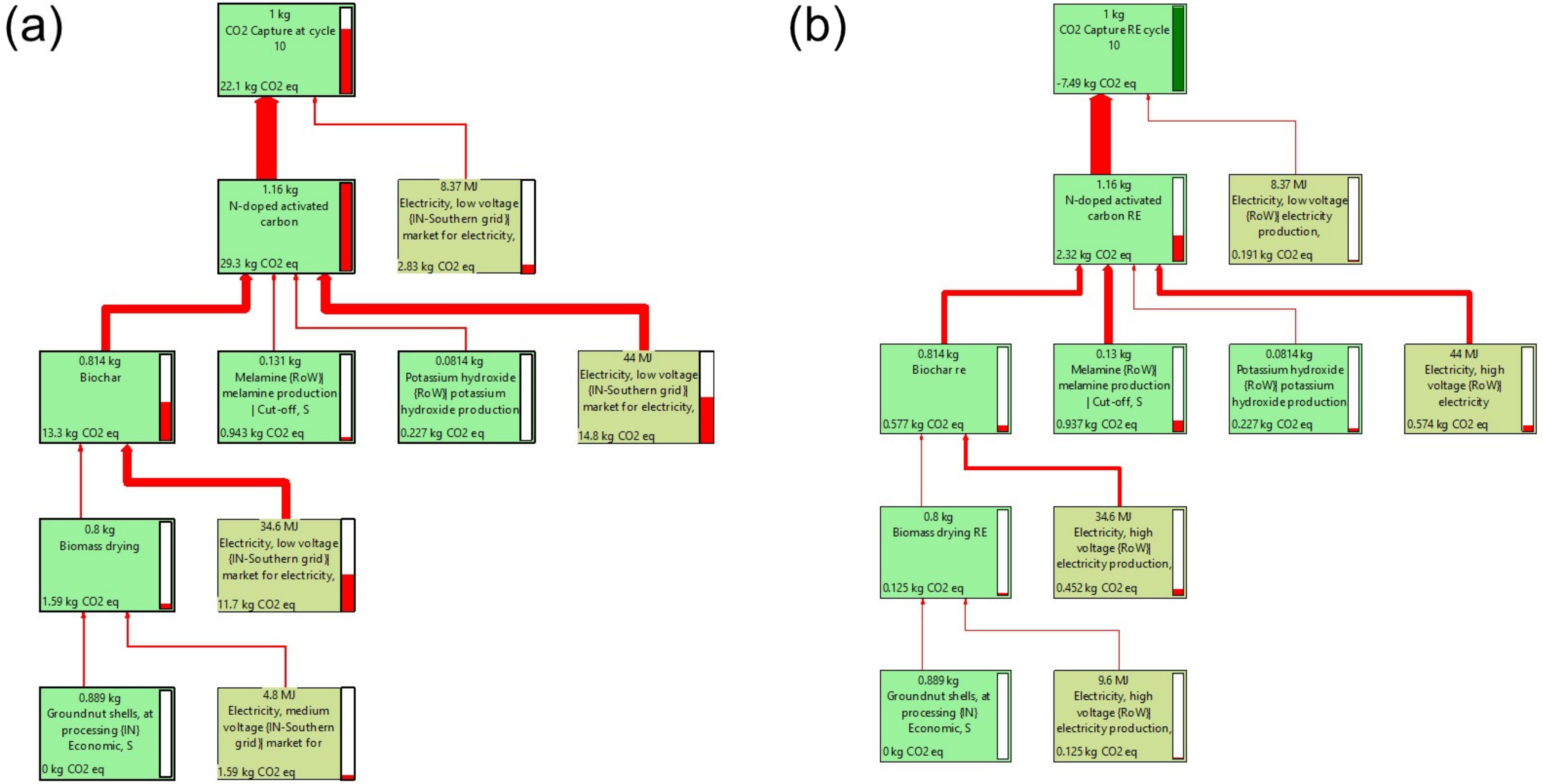


Fig. S20 Sankey representation of GWP emissions for 1 kg PSNAC synthesis and Carbon capture with NRE and RE conditions: (a) Carbon capture with NRE at cycle 10, and (b) Carbon capture with RE at cycle 10.

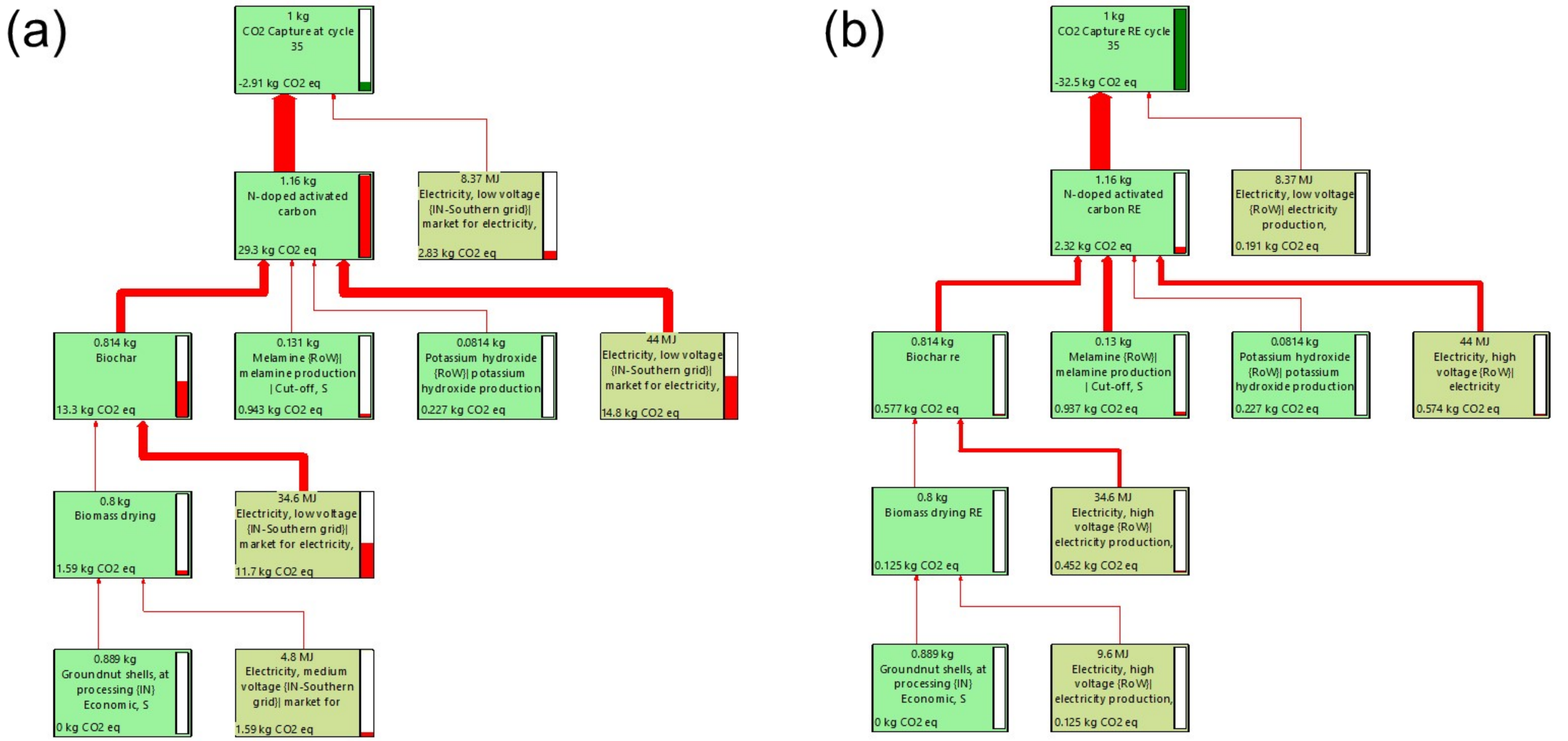


Fig. S21 Sankey representation of GWP emissions for 1 kg PSNAC synthesis and Carbon capture with NRE and RE conditions: (a) Carbon capture with NRE at cycle 35, and (b) Carbon capture with RE at cycle 35.

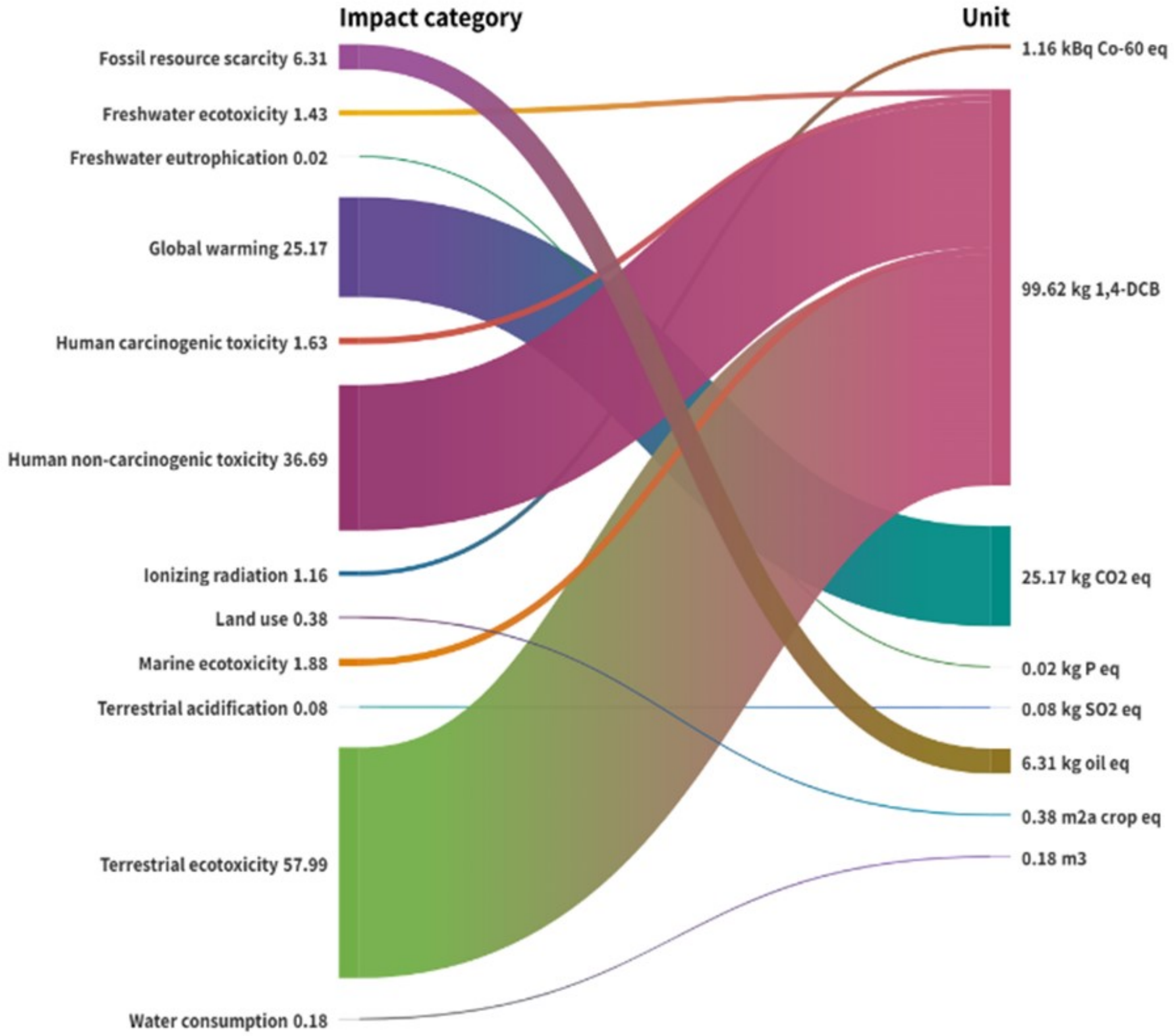


Fig. S22 Sankey representation of the impact categories for adsorbent synthesis under NRE grid.

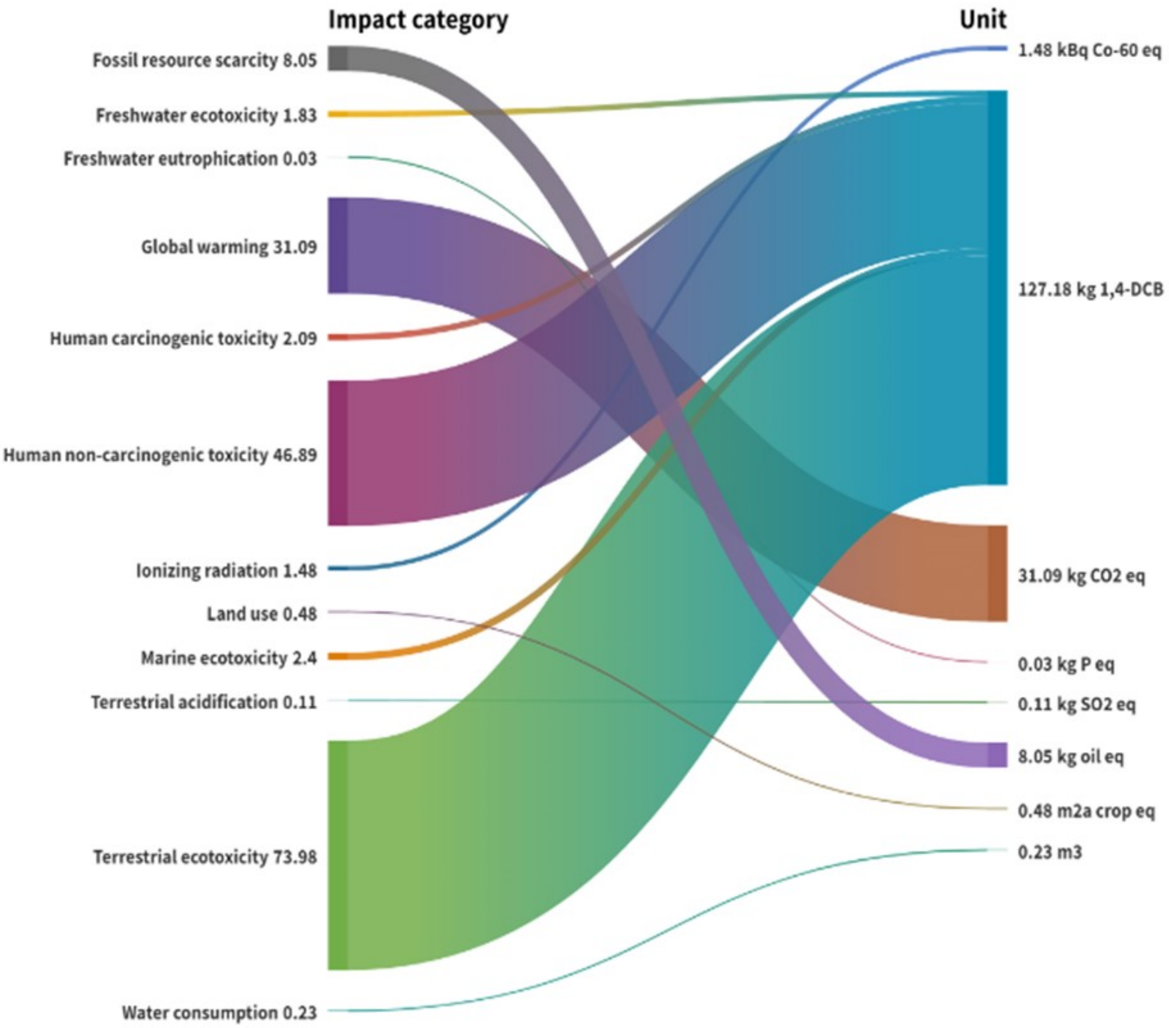


Fig. S23 Sankey representation of the impact categories for carbon capture under NRE grid.

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