

List of nomenclature

1. Mapping sets

$R(i)$ — Routes connected to source i .

$R(j)$ — Routes delivering CO₂ to storage sink j .

$I(k)$ — Sources located in country k .

$J(k)$ — Storage sinks located in country k .

A_{ij} — Binary source–sink mapping equal to 1 if CO₂ from source i can be allocated or credited when stored in sink j , and 0 otherwise.

$source(r)$ — Source associated with transport route r .

$sink(r)$ — Storage sink associated with transport route r .

$mode(r)$ — Transport mode associated with route r .

$hub(r)$ — Import hub associated with route r , where applicable.

$country(i)$ — Country where source i is located.

$country(j)$ — Country where storage sink j is located.

$\delta_{i,k}^{src}$ — Binary indicator equal to 1 if source i is located in country k , and 0 otherwise.

$\delta_{j,k}^{host}$ — Binary indicator equal to 1 if sink j is located in host country k , and 0 otherwise.

2. Source parameters

$E_{i,t}$ — Gross CO₂ emissions at source i in period t ($tCO_2/period$).

η_i — Maximum capture fraction at source i ($fraction$).

$\bar{X}_{i,t}$ — Maximum capture capacity at source i in period t ($tCO_2/period$).

c_i^{cap} — Capture cost at source i (USD/tCO_2).

a_i^{cap} — Capture-energy coefficient at source i (MWh/tCO_2).

3. Storage-sink parameters

$\bar{Q}_{j,s}$ — Maximum injection rate at sink j under scenario s ($tCO_2/period$).

$\bar{Q}_{j,s}^{avail}$ — Available injection capacity at sink j under scenario s ($tCO_2/period$).

$\bar{S}_j$ — Cumulative geological storage capacity of sink j (tCO_2).

c_j^{stor} — Storage cost at sink j (USD/tCO_2).

c_j^{inj} — Injection cost at sink j (USD/tCO_2).

λ_j^{pipe} — Offshore-pipeline or sink-delivery loss factor for sink j ($fraction$).

$Fee_{i,s}^{stor}$ — Scenario-specific storage-service fee for sink j (USD/tCO_2).

4. Route, transport, and infrastructure parameters

$\bar{F}_{r,t}$ — Maximum transport capacity of route r in period t ($tCO_2/period$).

D_r^{ship} — Shipping distance of route r (km).

D_j^{pipe} — Offshore-pipeline distance from the import hub to sink j (km).

c_r^{ship} — Variable shipping or route-transport cost (USD/tCO_2).

c_j^{pipe} — Variable offshore-pipeline transport cost for sink j (USD/tCO_2).

λ_r^{ship} — Shipping loss factor on route r ($fraction$).

a_r^{ship} — Shipping-emissions coefficient on route r ($tCO_2\ emitted/tCO_2\ transported$).

a_j^{pipe} — Offshore-pipeline energy coefficient for sink j ($MWh/(tCO_2 \cdot km)$).

a_j^{inj} — Injection-energy coefficient for sink j (MWh/tCO_2).

$\bar{P}_d$ — Capacity of offshore-pipeline diameter option d ($tCO_2/period$).

$\bar{N}_d$ — Maximum allowable number of parallel pipelines for diameter option d ($number\ of\ pipelines$).

5. Country, policy, and accounting parameters

c_k^{elec} — Electricity cost in country k (USD/MWh).

γ_k — Grid-emission factor in country k (tCO_2/MWh).

$P_{k,s}^{pen}$ — Carbon penalty or carbon tax in country k under scenario s (USD/tCO_2).

$P_{k,s}^{cred}$ — Country-specific carbon-credit or avoided-compliance value (USD/tCO_2).

α_s^{src} — Share of verified storage credit allocated to the source country ($fraction$).

α_s^{host} — Share of verified storage credit allocated to the host country ($fraction$).

$\bar{M}_s^{import}$ — Host-country annual CO_2 import cap under scenario s ($tCO_2/year\ or\ MtCO_2/year$).

M_s^{min} — Minimum cross-border export requirement under scenario s ($tCO_2/year\ or\ MtCO_2/year$).

$\bar{I}_{k,s}$ — Maximum annual CO_2 import allowance for country k under scenario s ($tCO_2/year\ or\ MtCO_2/year$).

O_s — Minimum capture or storage share under scenario s ($fraction$).

H^r — Horizon-to-year scaling factor ($multiplier$).

6. Continuous decision variables

$x_{i,t}$ — CO_2 captured at source i in period t ($tCO_2/period$).

$u_{i,t}$ — Uncaptured CO_2 at source i in period t ($tCO_2/period$).

$f_{r,t}$ — CO₂ exported or transported through route r in period t ($tCO_2/period$).
 $d_{i,t}^{dom}$ — Captured CO₂ from source i assigned to domestic storage in period t ($tCO_2/period$).
 $h_{j,t}$ — CO₂ arriving at the host-country import hub serving sink j ($tCO_2/period$).
 $z_{j,t}$ — CO₂ injected and stored at sink j in period t ($tCO_2/period$).
 $z_{i,j,t}$ — Verified CO₂ originating from source i and stored at sink j ($tCO_2/period$).
 $E_{i,t}^{cap}$ — Capture-energy use at source i in period t ($MWh/period$).
 $E_{j,t}^{pipe}$ — Offshore-pipeline energy use for sink j in period t ($MWh/period$).
 $E_{j,t}^{inj}$ — Injection-energy use at sink j in period t ($MWh/period$).
 SE_t — Shipping-related CO₂ emissions in period t ($tCO_2/period$).
 $PE_{k,t}$ — Physical emissions allocated to country k in period t ($tCO_2/period$).
 $UE_{k,t}$ — Uncaptured source emissions allocated to country k in period t ($tCO_2/period$).
 $EE_{k,t}$ — Energy-related emissions allocated to country k in period t ($tCO_2/period$).
 $Cr_{k,t,s}$ — CO₂ storage credit allocated to country k in period t under scenario s ($tCO_2/period$).
 $NE_{k,t,s}$ — Net accounting-emission balance for country k under scenario s ($tCO_2/period$).
 Z — Total annual objective cost ($USD/year$).

7. Binary and integer decision variables

y_r — Binary variable equal to 1 if route r is activated, and 0 otherwise (*binary*).
 w_j — Binary variable equal to 1 if storage sink j is activated, and 0 otherwise (*binary*).
 $b_{j,d}$ — Binary variable equal to 1 if infrastructure option d is selected for sink j , and 0 otherwise (*binary*).
 $n_{j,d}$ — Integer number of pipelines of diameter option d installed for sink j (*integer*).