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An integrated, bottom-up approach to evaluate the role of bioenergy with carbon capture and storage (BECCS) in achieving net-zero energy systems

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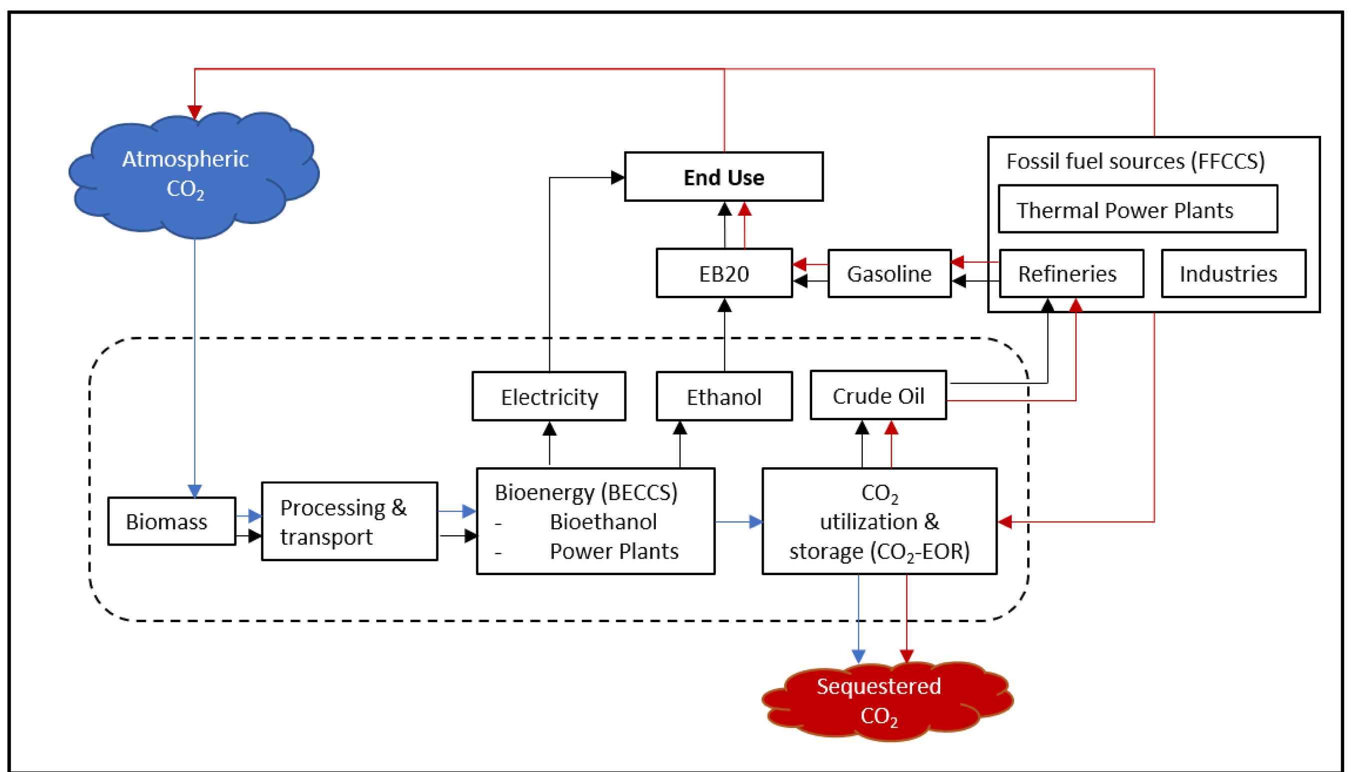
Early-stage deployment of BECCS, supported by integrated policies and financing mechanisms to suit the socio-economic and environmental context, could help achieve net-zero energy systems at small scales and further evaluate their feasibility in the long run.

Background and Motivation

- Deep decarbonization of energy systems is key to achieving Paris climate goals
- Emission scenarios emphasize on the large-scale deployment of Carbon dioxide removal (CDR) technologies like BECCS
- But on-ground deployment of BECCS is still at a nascent stage, its feasibility and realistic potential needs further investigation
- Early integration of CDRs like BECCS in energy systems could offer valuable insights about their impacts on society and the larger environment

Approach

We propose an integrated bottom-up optimization approach to study the role of BECCS in net-zero energy transitions using the case of Ankeshwar Enhanced Oil Recovery (EOR) project in Gujarat, India. Focus on crop residue biomass, existing policies and technologies.



Notes: Blue and red arrows indicate the flow of atmospheric and fossil CO_2. Black arrows indicate the flow of commodities. EB20: 20% ethanol blended gasoline as per India's 2018 Biofuels Policy

Mathematical set-up

Objective function

$$minimize\ TotalCost = (Cost_{bio} + Cost_{be} + Cost_{cap} + Cost_{ctr} + Cost_{oil}) - RE_{be}$$

The mixed integer linear programming model minimizes the total cost of the biomass-CO_2-EOR system. The total annualized cost is the sum of investment and variable costs of biomass processing and transport ($Cost_{bio}$), bioenergy conversion ($Cost_{be}$), CO_2 capture, compression and transport ($Cost_{cap} + Cost_{ctr}$) and oil extraction ($Cost_{oil}$) minus the revenue generated from the sale of bioenergy products like bioethanol and electricity (RE_{be}).

Constraints

Biomass supply and demand: The sum of all the biomass supplied from any selected location (i) to BECCS plants (j) should be less than or equal to the available biomass at i. The biomass supplied to any selected BECCS plant (j) from all the biomass supply locations (i) should be less than or equal to the maximum demand for biomass at j.

$$\sum_j X_{ij} \leq SB_i * Y_i \quad \forall i \qquad\qquad \sum_i X_{ij} \leq DBM_j * U_j \quad \forall j$$

CO_2 supply and demand: The CO_2 supplied from any BECCS (j) or fossil fuel with CCS (FFCCS) (s) locations should be less than or equal to the CO_2 available for capture at these locations. The total supply of CO_2 to a sink (k), for all BECCS and FFCCS plants, should be enough to satisfy the demand at the sink.

$$\sum_k W_{jk} \leq \sum_i (X_{ij} * \varphi_j * \varepsilon_j * CR) \quad \forall j \qquad\qquad \sum_k Z_{sk} \leq \sum_j (PR_s * \varepsilon_s * CR) \quad \forall s$$

$$\sum_j W_{jk} + \sum_s Z_{sk} \geq DSINK_k \ \forall k$$

Other: Allocation only to open facilities, integer and non-negative constraints

Parameters: SB_i is biomass supply capacity at i, DBM_j is maximum demand at j, φ_j is bioenergy conversion factors, ε_j is bioenergy emission factors, ε_s fossil fuel plant emission factors, PR_s is production at FFCCS plant, CR is CO_2 capture rate, $DSINK_k$ is CO_2 demand at sink k. ***Variables:*** X_{ij}: Processed biomass supplied from i to j, W_{jk}: CO_2 supplied from BECCS plant j to EOR site k, Z_{sk}: CO_2 supplied from FFCCS plant s to EOR site k, Y_i = 1 if biomass supplied from i, else 0, U_j = 1 if BECCS plant set up at j, else 0, V_s = 1 if FFCCS plant set up at s, else 0

Model parameters and data

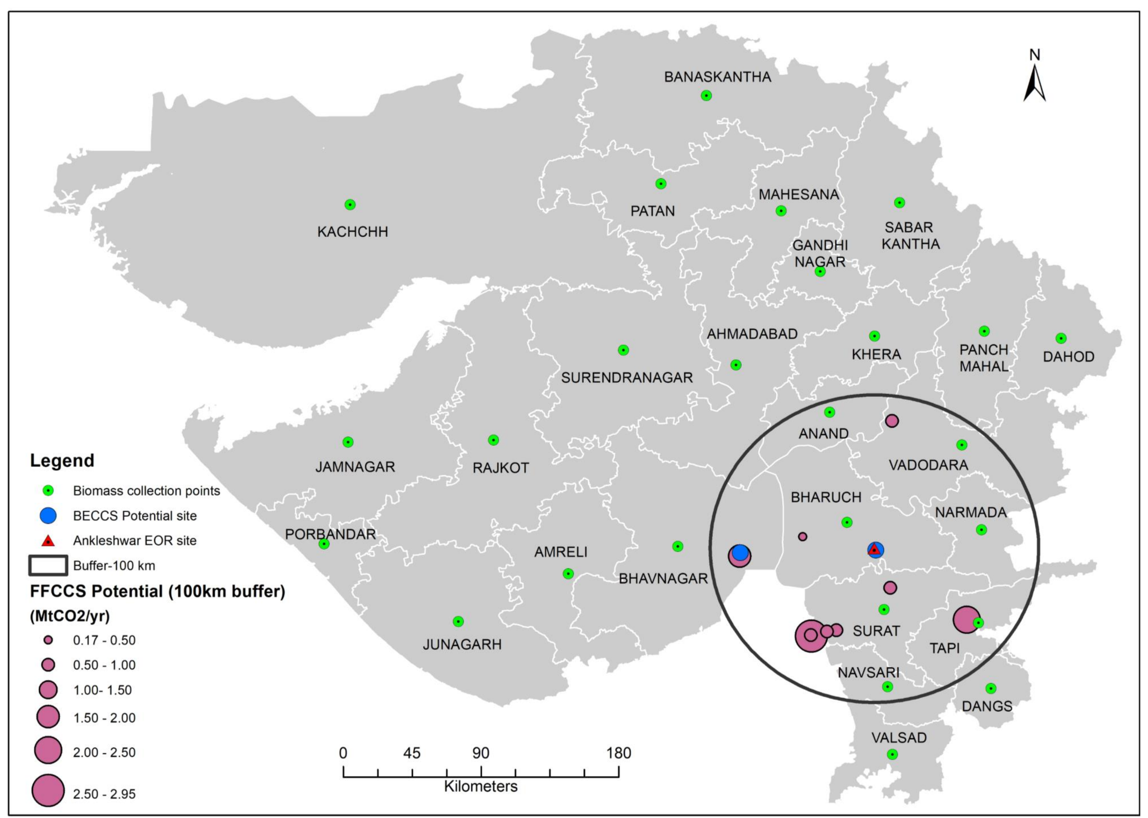
- CO_2 demand at EOR/other sinks
- Sources and potential of biogenic CO_2 (BECCS), fossil CO_2 (FFCCS)
- Cost of biomass, bioenergy production, carbon capture & storage

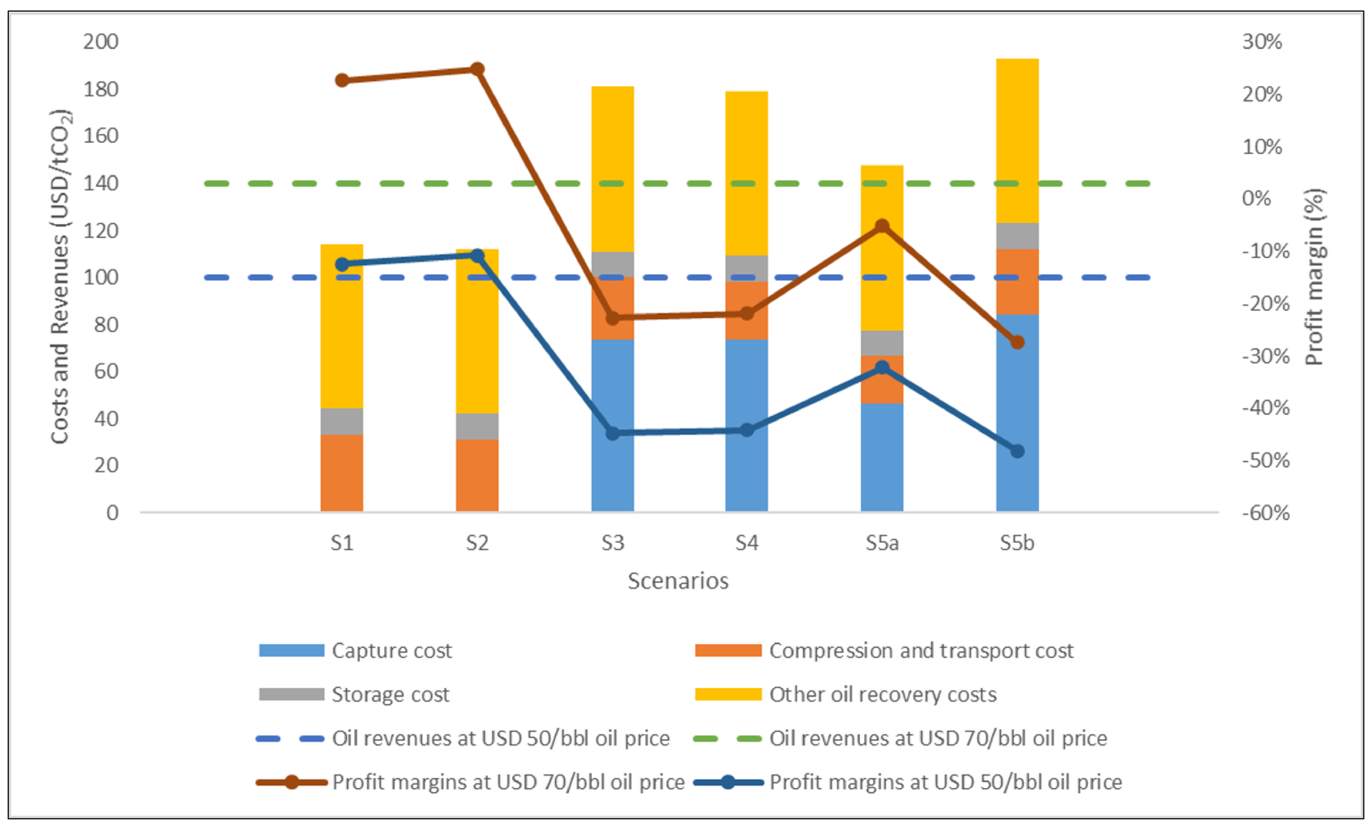
Scenarios:

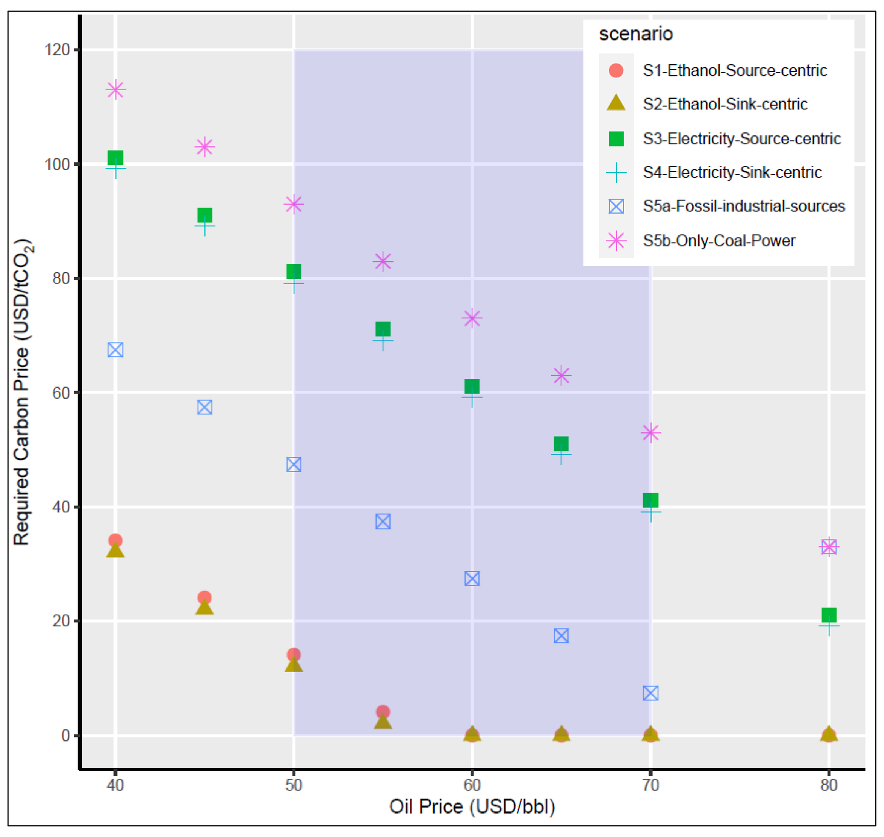
S1: Ethanol (source-centric); S2: Ethanol (sink-centric); S3: Bioelectricity (source-centric); S4: Bioelectricity (sink-centric); S5a: All fossil industrial FFCCS plants; S5b: Only coal power plants

Results

- The proposed system could become profitable and meet near-term demand if the oil prices are above USD 56/barrel (bbl)
- For low oil prices, carbon prices below USD 40 per tCO_2 could make CO_2-EOR profitable for ethanol and industrial processes (S1, S2, S5a)







Policy Implications: **Energy Security | Livelihood Opportunities | Local Environment | Research and Development into CCS**

Source: Patange, O. S., Garg, A., & Jayaswal, S. (2022). An integrated bottom-up optimization to investigate the role of BECCS in transitioning towards a net-zero energy system: A case study from Gujarat, India. *Energy*, *255*, 124508. Contact: patange@iiasa.ac.at

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