EVALUATING THE USE OF NEGATIVE EMISSION TECHNOLOGIES UNDER CHINA'S CARBON-NEUTRAL TARGET FOR 2060

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Overview

Almost all global scenarios under ambitious climate targets rely on the deployment of negative emission technologies (NETs), including bioenergy with carbon capture and storage (BECCS) and afforestation. However, their roles in most countries' deep decarbonization pathways and the potential economic and environmental implications have not been fully investigated. Besides, broad economic interactions and complex technical information of NETs bring challenges for traditional top-down or bottom-up models. To address the methodological challenges, we integrate energy technology details into a macroeconomic framework and develop a national hybrid computable general equilibrium (CGE) model for China. Based on this, insights are provided into the deployment scale of bioenergy, BECCS, and afforestation in China's mitigation pathways towards carbon neutrality by 2060, as well as the induced macroeconomic and land-use consequences.

The results indicate that BECCS would start to take the market share around 2030 and the share of negative emissions provided by it would reach about 79% in 2060. The carbon removals in 2060 would be 2,118 $MtCO_2yr^{-1}$, 170 $MtCO_2yr^{-1}$, and 617 $MtCO_2yr^{-1}$ from bioelectricity with CCS, biofuel with CCS, and afforestation, respectively. When only BECCS is deployed as NET, more fossil energy would be phased out and renewable energy would take larger market shares. In 2060, most biomass would consist of cellulosic crops (43-47%) and residues (49-52%). Cropland would decrease by 6.9-8.3% due to land competition caused by NET deployment. GDP loss in 2060 under the carbon-neutral target would be 6.4% without NETs and it would be alleviated to 4.8% with NETs. This study supplements the existing global-level knowledge to identify the local feasibility and trade-offs of NET expansion.

Methods

This study builds on a dynamic recursive national CGE model designed for bioenergy-related researches, called China Hybrid Energy and Economic Research model for BioEnergy (CHEER-BE). The core model structure is shown in Fig. 1. Our model contributes to the existing literature by explicitly modeling detailed bioenergy (both 1st and 2nd generation) and biomass sectors under a macroeconomic framework, which breaks the highly aggregated feature of traditional CGE models. Besides, through integrating two key NETs (BECCS and afforestation) simultaneously, their combined effects can be compared with the standalone effects, while most previous studies analyzed BECCS and afforestation separately.

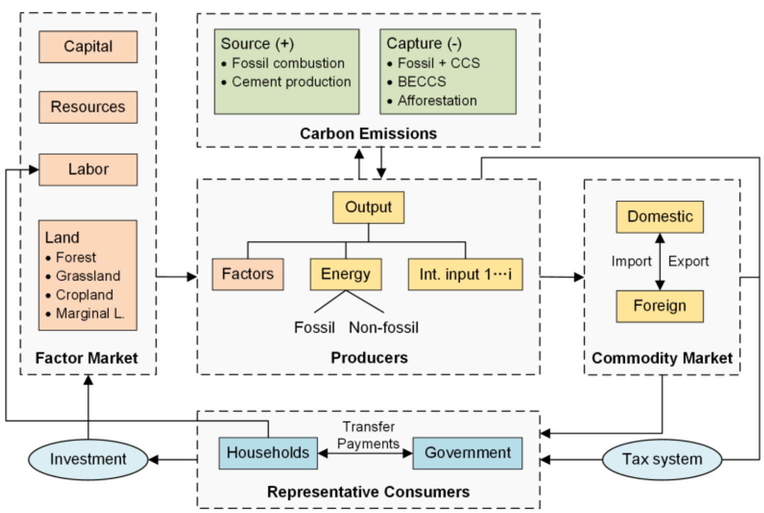

Fig. 1. Core model structure of CHEER-BE.

To evaluate the deployment scale and implications of NETs under China's mitigation pathways towards the carbon-neutral target, one reference scenario and three deep decarbonization scenarios are designed: (1) reference scenario (REF), (2) deep decarbonization without NETs (DP-noNET), (3) reaching carbon-neutral by 2060 with BECCS (Zero-BECCS), and (4) reaching carbon-neutral by 2060 with BECCS and afforestation (Zero-BECCSAff). The hybrid CGE modeling approach and scenario settings in this study can also be applied to other countries and regions.

Results

(1) Deployment scale of negative emission technologies

BECCS would begin to be used around 2030. In the Zero-BECCS scenario, the cumulative CO_2 removal by BECCS from 2018 to 2060 would be about 30.6 Gt. In 2060, bioelectricity with CCS would capture 2,405 $MtCO_2yr^{-1}$ while biofuel with CCS would capture 200 $MtCO_2yr^{-1}$. When afforestation is also adopted as a negative emission source in the Zero-BECCSAff scenario, the cumulative CO_2 removal by NETs from 2018 to 2060 would be about 37.0 Gt, in which 27.8 Gt is from BECCS and 9.2 Gt is from afforestation. In 2060, 21.2-24.5% of the total power generation would come from biomass with CCS and 38.8-47.6% of the refined oil production would come from biofuel with CCS.

(2) Feedstock structure for bioenergy production

Comparing the biomass consumption in 2060, the Zero-BECCS scenario would hold the largest consumption amount (115.3 billion dollars, US$2018), followed by the Zero-BECCSAff scenario (98.3 billion dollars) and the DP-noNET scenario (72.5 billion dollars). As for the feedstock structure, the shares of cellulosic crops and residues would grow rapidly, especially after 2030. In 2060, cellulosic crops would take up to 43.1-48.6% of the total biomass consumption, and residues would take up to 43.0-51.8%.

(3) Implications on land use and macroeconomics

Compared with the REF scenario, in 2060, cropland would decrease by 5.5%, 8.3%, and 6.9% in DP-noNET, Zero-BECCS, and Zero-BECCSAff, respectively. In the DP-noNET scenario, the GDP loss would be 6.4% in 2060 to reach near-zero without NETs. However, when BECCS and afforestation are adopted as NETs, the negative impacts on GDP would be alleviated to some extent. For instance, in 2060, the GDP loss rates in Zero-BECCS and Zero-BECCSAff scenarios would be 5.1% and 4.8%, respectively.

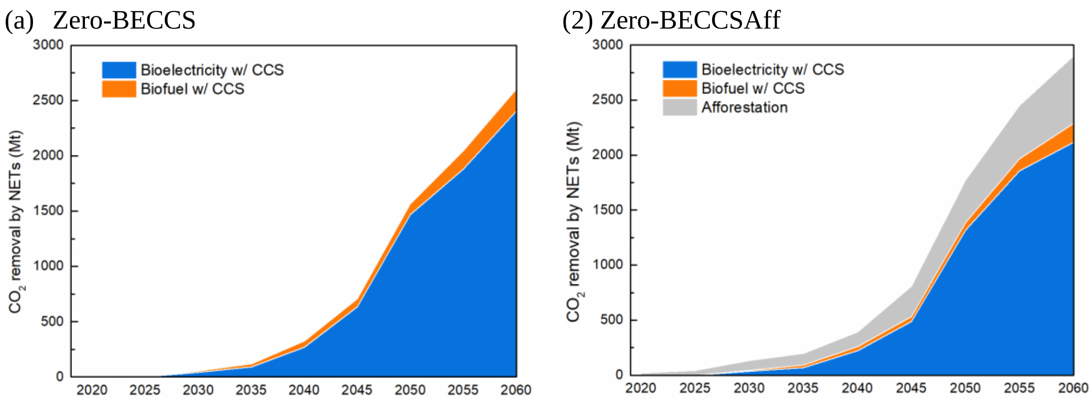

Fig. 2. CO_2 removal by negative emission technologies in two carbon-neutral scenarios.

Conclusions

First, negative emission technologies (NETs) could play significant roles in China's mitigation pathways to realize carbon neutrality. The results show that in 2060, NETs would capture 2.91 $GtCO_2yr^{-1}$ by BECCS and afforestation. Among them, 21.2% of the negative emissions would come from afforestation. When only BECCS is deployed, more fossil-based energy would phase out and renewable energy would take larger market shares. BECCS would start to take the market share around 2030 and it would provide more negative emissions in the electricity sector than that in the refined oil sector. Besides, the adoption of BECCS and afforestation could prolong the use of fossil energy.

Second, expanding the cultivation of dedicated energy crops is essential to meet the biomass demand of BECCS development. The results illustrate that under the carbon-neutral target, the demand for bioenergy after 2040 cannot be satisfied by the technical bioenergy potential. Even under full irrigation conditions, the gaps for bioelectricity and biofuel in 2060 would be 6.88-7.78 EJ and 1.72-2.26 EJ, respectively. Moreover, most biofuel would be second-generation biofuel and nearly half of the feedstock would consist of dedicated cellulosic crops, so that land and water might be the main environmental constraints. In this context, reclaiming marginal land, improving irrigation conditions, and selecting drought-tolerant and high-yield cellulosic crops may be promising options for feedstock expansion.

Third, adopting BECCS and afforestation could reduce the cost of deep decarbonization and alleviate land-use changes. If NET adoption is restricted, the GDP loss would be higher than the scenarios where NETs could be used. To realize carbon neutrality, the mitigation pathway with BECCS and afforestation could reduce the GDP loss by 5.8% and reduce carbon price by 10.9% in 2060 compared with the pathway only BECCS is used. Meanwhile, afforestation could reduce the reliance on BECCS, thereby mitigating land competition between energy crops and food crops and alleviating cropland reduction at about 6.9%.