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• **Editorial Notes** •

Preface to the Special Issue on Carbon Neutrality: Important Roles of Renewable Energies, Carbon Sinks, NETs, and non-CO_2 GHGs※

Junji CAO[1], Ning ZENG[2,3], Yi LIU[4], Bengang LI[5], and Pengfei HAN[3,4]

[1]*Institute of Atmospheric Physics*, *Chinese Academy of Sciences*, *Beijing* 100029, *China*

[2]*Department of Atmospheric and Oceanic Science*, *and Earth System Science Interdisciplinary Center*, *University of Maryland*, *College Park* 20742, *Maryland*, *USA*

[3]*State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics*, *Institute of Atmospheric Physics*, *Chinese Academy of Sciences*, *Beijing* 100029, *China*

[4]*Carbon Neutrality Research Center*, *Institute of Atmospheric Physics*, *Chinese Academy of Sciences*, *Beijing*100029, *China*

[5]*Sino-French Institute for Earth System Science*, *Laboratory for Earth Surface Processes*, *College of Urban and Environmental Sciences*, *Peking University*, *Beijing* 100871, *China*

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The year 2020 witnessed milestone commitments to carbon neutrality with the EU, China, USA, Japan, South Korea, Canada, and South Africa, each pledging to reach net-zero carbon emissions. Countries that have adopted or have considered net-zero targets now represent 63% of the total contributions to global greenhouse gas (GHG) emissions. With the efforts of all parties, the 26th Conference of the Parties (COP26) achieved a package of outcomes in the Glasgow Climate Pact. Here, a breakthrough consensus was reached on reducing coal, controlling methane, and halting deforestation (Wang et al., 2022, Page 1209). To achieve net-zero carbon, we need to take action to implement the Paris Agreement and the Glasgow Climate Pact Since the global temperature slowdown of the nationally determined contributions (NDC) scenario is only 0.6°C, all countries need to pursue stricter carbon reduction policies for a more sustainable world. (Fu et al, 2022, Page 1209).

China strives to reach peak carbon emissions before 2030 and achieve carbon neutrality before 2060. Achieving carbon neutrality is a great challenge for China as there are only 30 years from projected peak emissions to reach neutrality. However, great opportunities will arise once neutrality is reached.

To support the neutrality target, both decreasing carbon emissions and increasing the capacity of carbon sinks are vital. Power and industries are anticipated to substantially ramp up renewable energies (e.g., wind, solar, etc.), and carbon sinks will increase throughout the next few decades. A large-scale land greening campaign, ocean negative emission technology, and reductions of non-CO_2 GHGs will play a critical role.

Thus, we have organized a special issue: "Carbon Neutrality: Important Roles of Renewable Energies, Carbon Sinks, NETs, and non-CO_2 GHGs" to compile the scientific questions, technical requirements, and achievements in these fields. These efforts will provide accurate and updated scientific understanding, technical support, and possible solutions for power, industries and nations to reach carbon neutrality.

This special issue provides highlights from carbon neutrality research. The papers are categorized into four groups as follows.

(1) **Important roles of renewable energies in decreasing CO_2 emissions:** A perspective paper to show the Yin-Yang transformation from fossil fuel to renewable energies is given by Zeng et al. (2022, Page 1229), which pointed out that solar energy is a key unlimited resource while other energy resources (e.g., hydro, wind, and nuclear fission) are expected to reach their upper limits in a carbon-neutral scenario. While Yang et al. (2022, Page 1239) presented a review of solar

※ This paper is a contribution to the special issue on Carbon Neutrality: Important Roles of Renewable Energies, Carbon Sinks, NETs, and non-CO_2 GHGs.

resource assessment and forecasting and pointed out that a bridge between atmospheric sciences and solar energy engineering is needed. Furthermore, Huang et al. (2022, Page 1316) developed a solar nowcasting system based on the Fengyun-4 Geostationary Satellite, which performed well in the North China Plain. Moreover, accurate estimates of CO_2 emissions are important. By investigating regional combustion efficiency using $\Delta XCO:\Delta XCO_2$ observed by a portable Fourier-transform spectrometer in Beijing, Che et al. (2022, Page 1299) showed that the MEIC (Multi-resolution Emission Inventory for China) dataset underestimates CO_2 emissions by about 11%, and the PKU (Peking University emission inventories) dataset underestimates CO_2 emissions by 49%. These papers showcase how complex and interdisciplinary research related to carbon neutrality is.

(2) **Terrestrial carbon sinks will play an important role in offsetting the anthropogenic CO_2 in achieving a carbon-neutral goal:** Global vegetation coverage and carbon fluxes (GPP, NPP, and Ra) show an overall increase in a warmer scenario compared with the 1980–2000 period. Gao et al. (2022, Page 1285) applied the CAS-ESM2 model to investigate the response of terrestrial ecosystems to climate warming, while Ying et al. (2022, Page 1329) showed that ocean–atmosphere teleconnections mostly affect GPP over eastern China, which dominates the interannual GPP variability for China as a whole. Furthermore, Li et al. (2022, Page 1271) showed that the variability of air-sea O_2 flux in CMIP6 provides a valuable complement for estimating terrestrial and oceanic carbon sinks.

(3) **NETs (Negative Emissions Technologies) will absorb CO_2 emissions that are very difficult to reduce:** Carbon dioxide Capture and Utilization (CCU) will play an important role in the carbon-neutral goal. Zhang et al. (2022, Page 1252) summarized the frontiers of CCU, which is a new "atmosphere-to-atmosphere" carbon cycle, thus offering a huge potential for the indirect reduction of carbon. Potential cutting-edge CCU technologies during the decarbonization of energy and industrial systems include direct air capture (DAC), flexible metal-framework materials (MOFs) for CO_2 capture, integrated CO_2 capture and conversion (ICCC), and electrocatalytic CO_2 reduction (ECR).

(4) **Non-CO_2 GHGs face great challenges in emissions reductions:** Methane (CH_4) is the second most important greenhouse gas, following CO_2. Yang et al. (2022, Page 1360) showed that grassland and shrubbery are ideal vegetation types to reduce CH_4 emissions in the Loess Hilly Region. Considering that wetland ecosystems are the most important natural CH_4 sources, Wang et al. (2022, Page 1375) showed that CH_4 emissions were highest in summer and lowest in spring in the Dajiuhu subalpine peatland, which can be explained by seasonal variations of the interactions between methanogens and methanotrophs, soil temperature, and nitrogen. Furthermore, Zhu et al. (2022, Page 1343) showed two parallel GOSAT XCH4 retrievals that inverted global methane emissions from 2010 to 2019 and concluded that accelerated atmospheric methane increases over the second half of the 2010s were mainly driven by Eurasian Boreal and Tropical South American emissions.

China's carbon neutrality goal requires technological, socio-political, and economic initiatives toward clean energy to run smoothly over a short amount of time. International collaboration on scientific and technical innovation, as well as effective deployment, is essential to building a safe, fair, common, and more resilient global future. Underinternational frameworks such as the Paris Agreement, the 2030 Agenda for Sustainable Development, and the Belt and Road Initiative, China should vigorously export its renewable energy technologies and products and provide domestic and international support in achieving carbon-neutral goals.