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OPINION
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Viewpoints on Net-Zero Emissions of Agricultural Energy Internet

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INTRODUCTION

With the increased concerns about carbon dioxide emissions reduction, China puts forward carbon peak and neutrality goals. In February 2021, State Grid Corporation of China created action plans for carbon dioxide emissions reduction targets. The purpose of the action plans is to promote the upgrading of China's energy system structures to energy Internet, which is an ideal platform for optimal allocation of clean energy. Energy Internet supports the integration of large-scale renewable power generation, energy storage and diversified loads (Zhang, 2022). Accelerated rural electrification project is an effective way to reduce carbon dioxide emissions. Another important way is to develop integrated management system for energy efficiency and carbon reduction. At present, one of the most concerned renew energies is photovoltaic (PV) power generation (Fu, 2022a). Solar PV grid integration has a significant impact on reducing carbon dioxide emissions from burning fossil fuels and other sources, but it also brings power flow uncertainties in modern power systems (Fu et al., 2020). The iron and steel industry is one of the top pillar industries for China's economy but is responsible for the majority of carbon dioxide emissions. Gan et al. carried out several studies which have demonstrated that steel mills can significantly reduce carbon emissions by participating in the demand-side response program without affecting productivity (Gan et al., 2022). From the experiment, Zhang et al. came to realize that wind energy penetration can affect the carbon dioxide emissions reduced by integrating hydrogen-energy storages (Zhang and Yu, 2022). Yadav et al. intended to outline the framework of a market-to-market coordination, which offered a low-carbon trade agreement for PV producers (Yadav et al., 2021). Akbari-Dibavar et al. presented an optimization dispatch framework of power systems with renewable-energy power plants and coal power plants, and the simulation results indicated that carbon capturing and storing systems can significantly reduce carbon dioxide emissions (Akbari-Dibavar et al., 2021). An agricultural energy internet (AEI) can be identified as a smart renewables-dominated power system, and it has been revealed that an AEI has great potential for emission reduction (Fu and Yang, 2022). The preliminary results in (Huang et al., 2020) throw light on the nature of photovoltaic AEI, which provided reliable and affordable energy to agricultural production with PV power generation. Fu initiated experimental investigation to establish a fishery energy internet, which provided a broad space for the installation of PV systems, consisting of modules, inverter, converters, energy storages (Fu, 2022b). Compared with the study on carbon emissions in the field of energy systems, the study on carbon cycle in the field of agriculture is earlier and paid more attention. Agroecosystem has many ways to sequester carbon in soil, and agricultural sequestration has a significant effect on atmospheric net carbon flux (West and Marland, 2002). There are two main differences between AEI and traditional agricultural energy system. The first difference is the physical system. The primary power supply of an AEI is renewable energy, and the agricultural load is electrified. The traditional

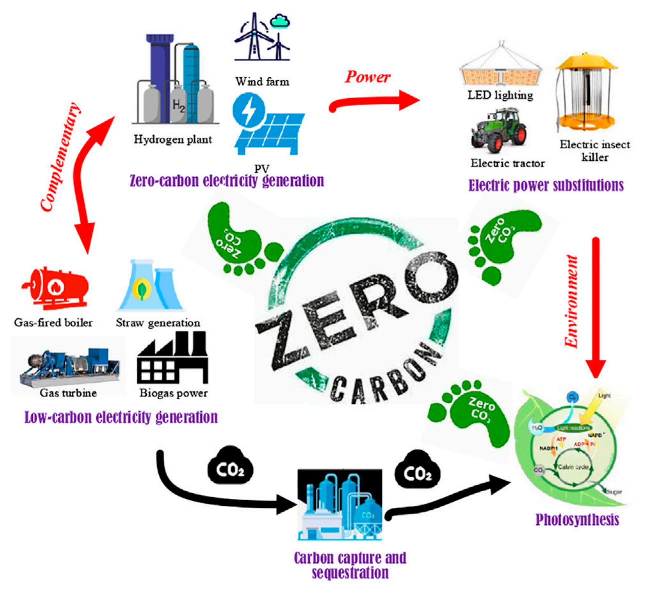

FIGURE 1 | A prosperous net-zero-emissions economy in the AEI.

rural energy system is supplied by the power grid, and the level of agricultural electrification is low. The second difference is the information system. The AEI is based on the combination of smart grid and smart agriculture, while the traditional rural energy system doesn't take full advantage of the Internet of things in agriculture. The research of AEI is still in the primary stage, and renewable energy, agricultural electrification and multi energy complementary technologies have been applied in practical application. However, the carbon cycle between agriculture and energy system is still blank.

The rest of the paper contains three main parts. First, we outline the carbon cycles through energy and agriculture in *Carbon Cycles Through Energy and Agriculture*. Second, we give the paths to net-zero emissions in *Paths to Net-Zero Emissions*. Then, we list math formulas including the formulas related to carbon footprint in energy and agriculture in *Carbon Footprint Calculation Formulas*. Finally, the discussion is presented in *Discussion*, along with the accompanying conclusion section in *Conclusion*.

CARBON CYCLES THROUGH ENERGY AND AGRICULTURE

Agricultural carbon emissions include the following four aspects. 1) Animal husbandry and fisheries produce methane, which accounts for more than a quarter of greenhouse gas emissions from the agricultural sector. 2) Nitrous oxide released in grain production, which involves the production and use of chemical fertilizers, organic fertilizers and pesticides. 3) Agricultural land use reduces the absorption of carbon dioxide. Grassland and forest are transformed into agricultural land, and the annual harvesting activities reduce the absorption of carbon dioxide. 4) Energy consumption in the food supply chain leads to carbon emissions, and the carbon footprint covers food processing, transportation, packaging and retail.

AEI is the best experimental object to realize carbon cycle and net-zero carbon emissions, as shown in **Figure 1**. The carbon footprint forms a closed loop between the energy system and the agricultural system. Whether on the source side or the demand side, the AEI can always find a feasible way to achieve net-zero carbon emissions. In terms of power sources, we develop renewable energies to reduce the carbon emissions from generation. Specifically, we replace coal-fired generation with natural gas-fired power generation and a straw power plant. The main difference between biomass fuel and mineral fuel is that it contains less carbon and can realize low-carbon power generation. We use carbon capture and storage technologies to collect carbon dioxide emitted by low-carbon energy, and the carbon is finally absorbed in the form of carbon rich agriculture. In addition, PV power generation, wind power generation and hydrogen energy are largely integrated to the grid in rural areas. These three energy sources are zero-carbon electricity generations and produce no carbon dioxide. In terms of demand side, an electric farm has become an agricultural production mode net-zero emissions. We promote electric energy substitution (EES) in the AEI *via* replacing oil tractors with electric tractors, replacing pesticides control with electric pesticides. EES not only avoids carbon emissions, but also improves the quality of agricultural products. In addition, the development of agricultural electrification based on EES also provides the basis for the agricultural informatization, which is the basis of smart farming.

PATHS TO NET-ZERO EMISSIONS

The upgrading route to net-zero emissions in an AEI includes carbon capture and sequestration (CCS), electric energy substitution and clean energy. Electric energy substitution and clean energy can be regards as carbon emission reduction technologies. In terms of electric energy substitution, LED lighting, plasma agricultural nitrogen fixation, electric insecticidal and electric agricultural machinery have higher product quality and lower carbon dioxide emission than petroleum agricultural technologies, which are represented by petroleum machinery and chemical fertilizer. Electric farms can significantly reduce the intensity of agricultural greenhouse gas emissions. In terms of renewable energy, rooftop PV, bagasse-based power generation, straw -based power generation and biogas energy generated from livestock manure can not only offset the emission of fossil energy used in agricultural production and rural life, but also reduce the electricity expenditure. In terms of CCS, it is worthwhile mentioning the photosynthesis of farmland and grassland. As a result of agricultural electrification, the carbon sequestration of farmland can be improved, and "net-zero" carbon emissions can be achieved in an AEI. AEI has two ways to supply the carbon dioxide for a closed greenhouse. The first way is to transmit carbon dioxide from gas-fired power generation to greenhouses. The second way is to use solar energy to power the distributed carbon dioxide capture device to capture carbon dioxide in the air.

CARBON FOOTPRINT CALCULATION FORMULAS

Considering that the carbon emission of AEI has not yet formed a standard, we introduce several important formulas to support the application of carbon emission calculation in China. At present, most of China's agricultural production still uses electricity from the power grid, whose carbon emissions can be calculated according to the government documents of the Ministry of Ecology and Environment of China[1].

$$E_g = AD_g \times EF_g, \quad (1)$$

where E_g, tCO_2, is the emission from the purchased electricity, AD_g, MWh, is the purchased electricity consumption, and EF_g, tCO_2/MWh, is the grid emission factor. In 2021, the Ministry of Ecology and Environment of China set EF_g to 0.5839 tCO_2/MWh.

The carbon emission of natural gas power generation is calculated by the following formula

$$E_{gas} = AD_{gas} \times EF_{gas,} \quad (2)$$

$$AD_{gas} = FC_{gas} \times NCV_{gas,} \quad (3)$$

$$EF_{gas} = CC_{gas} \times OF_{gas} \times \frac{44}{12}, \quad (4)$$

where E_{gas}, tCO_2, is the carbon emissions from natural gas power generation, AD_{gas}, GJ, is the activity data of natural gas, EF_{gas}, tCO_2/GJ, is the emission factor, FC_{gas}, 10^4Nm^3, is consumption of natural gas, NCV_{gas}, GJ/10^4Nm^3, is the low calorific value of natural gas, CC_{gas}, tC/GJ, is the carbon in per unit calorific, and OF_{gas}, %, is the carbon oxidation rate. In 2021, the Ministry of Ecology and Environment of China set NCV_{gas} to 389.31 GJ/10^4Nm^3 and set CC_{gas} to 0.01532 tC/GJ.

DISCUSSION

Major Sticking Points

Net-Zero Emissions of AEI face many challenges and difficulties. The major sticking points can be concluded as follows. 1) Low carbon of rural energy system faces unprecedented economic challenges. It can significantly reduce the carbon emissions of rural energy systems *via* promoting electric energy substitution and renewable energy power generation. However, electricity substitution and renewable energy power generation will significantly increase the cost of agricultural production and rely too much on government subsidy to survive. Poor economy may hinder the promotion of techniques for carbon sequestration and greenhouse gas emission reduction. In addition, China has experimented with emission reduction technologies, but the energy-related production costs and emission reduction effect, need to be demonstrated and verified in the field of engineering. 2) China lacks special policies and standards for agricultural energy system. China has issued a series of policies and measures for green agriculture and renewable energy, and they play a certain role in carbon sequestration and greenhouse gas emission reduction in agricultural energy systems. However, China's carbon peak and neutrality is still blank for the AEI, and there is no technical standard for net-zero emissions of the AEI, resulting in great obstacles to the promotion of a net-zero emissions energy business. 3) We lack a professional research platform for net-zero emissions energy systems in rural areas. As there are no clear requirements for carbon sequestration and greenhouse gas emission reduction in agriculture, there is not only no clear route to carbon peak and carbon neutralization in agricultural energy systems, but also no specialized agency charging for carbon cycle monitoring of agricultural energy systems. The carbon monitoring of the AEI is scattered in different agriculture and energy sectors, which is unable to form a closed-loop monitoring. To carry out the systematic theory of carbon peak and neutrality for AEI, there is an urgent need to establish a professional research platform for net-zero emissions. 4) At present, the development of renewable energy in rural areas lacks top-level design, and the agriculture and energy sectors are uncoordinated. Rural renewable energy planning is difficult to implement and inefficient. Urban-rural dualization is one of the important reasons for the plight of rural renewable energy. To solve the problem of developing renewable energy in rural areas, we should coordinate the urban and rural energy systems. Rural areas should not only establish a clean energy system to replace coal energy systems, but also provide cities with energy products such as biological natural gas and biomass briquette fuel, so as to give full play to the role of renewable energy in reducing carbon.

Advantages

Building renewable energy in rural areas has outstanding advantages and great potential for carbon emission reduction. The vast countryside provides vast space and cheap land for the construction of wind power, PV generation, geothermal energy, etc. Agricultural waste provides a steady stream of fuel for biomass energy. The development and growth of distributed renewable energy has become an important supplement to the rural low-carbon economy growth. Under the background of the vigorous development of rural renewable energy, the low-carbon process of energy system has accelerated. In contrast, the shortage of land and high cost in cities have seriously limited the development of renewable energy. From the perspective of demand side, agricultural production has the

[1]https://www.mee.gov.cn/xxgk2018/xxgk/xxgk06/202112/t20211202_962776.html.

function of CCS, while industrial and commercial production emits carbon dioxide.

CONCLUSION

The construction of AEI is an effective way to serve rural revitalization. This was demonstrated in a number of studies that AEI can not only significantly improve the reliability of energy supply, but also improve energy efficiency and renewable energy in rural areas. AEI relies on agricultural production, renewable energy and electric energy substitution to achieve the goal of zero carbon emissions. The low-carbon of AEI can improve the income level of farmers and improve the human habitat environment. Technical measures for AEI net-zero emissions include the following two aspects: 1) An energy-crop carbon emission model should be established according to the actual agricultural park. 2) A carbon monitoring platform should be built to realize real-time monitoring of carbon emission, carbon sink and carbon credit.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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