Effects of Biochar Production and Application on Greenhouse Gas Emissions: a Meta-Analysis and Life Cycle Carbon Footprint Assessment

Dunxue Yao[1,a], Qingrui Wang[1,b], Chao Liu[2,c], Bo Miao[2,d], Pinglu Chen[3,e], Qing Yang[1,f*]

[1]School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China
[2]Carbon Neutrality Research Center for Power Systems, China Electric Power Research Institute, Beijing, 100192, China
[3]School of Management, Huazhong University of Science and Technology, Wuhan, 430074, China

[a]dxyao125@163.com, [b]wangqr@hust.edu.cn
[c]liuchao@epri.sgcc.com.cn, [d]boycemiao@foxmail.com
[e]chen.pinglu@hust.edu.cn, [f*]qyang@hust.edu.cn

Abstract. This paper evaluates the carbon footprint and emission reduction potential of agricultural straw pyrolysis biochar production and application from a life cycle and meta-analysis perspective. The system includes stages such as straw acquisition (planting, transportation), pyrolysis co-production (construction, operation, wastewater treatment, energy use), biochar transportation, and field application (carbon sequestration, soil GHG reduction). Results show that straw cultivation contributes most to GHG emissions. However, through fossil energy substitution and biochar's carbon sequestration, GHG reductions of 206.62 to 1364.10 kg CO_2-eq per functional unit are achieved. Without considering energy substitution and carbon sequestration, the emission reduction potential of straw biochar is comparable to that of wood residues and sludge. However, when these factors are accounted for, the system's emission reduction potential increases significantly. Biochar application boosts crop yields by 18% to 31%. Substituting excessive nitrogen fertilizer with biochar further enhances emission reduction. Meta-analysis indicates emission reductions of 30.55%, 22.82%, and 21.34% for rice, wheat, and maize straw-derived biochar, respectively. Sensitivity analysis suggests that reducing energy consumption in wastewater treatment and pyrolysis can minimize environmental impact. Central and Eastern China are ideal for rice straw biochar, Northern and Northwestern China for wheat straw, and Northeastern and Northern China for maize straw. Hebei, Shandong, and Henan should be prioritized as pilot provinces for promotion.

Keywords: Meta-analysis, biochar, life cycle, carbon footprint

W. He et al. (eds.), *Proceedings of the 2024 10th International Conference on Advances in Energy Resources and Environment Engineering (ICAESEE 2024)*, Atlantis Highlights in Engineering 36,
https://doi.org/10.2991/978-94-6463-708-3_43

1 Introduction

As a major agricultural country, China produces a significant amount of agricultural straw[1]. Various pyrolysis technologies can convert agricultural straw into biochar, a more stable carbon product, along with other bioenergy products such as bio-oil and pyrolysis gas[2,3]. The gaseous bioenergy products are typically used for electricity generation, while bio-oil can replace diesel as an alternative fuel[4]. Biochar can be returned to the soil to enhance carbon sequestration and significantly reduce greenhouse gas (GHGs) emissions from the soil[5]. The assessment of biochar's emission reduction potential highlights its crucial role as a negative emission technology. However, to fully realize its benefits, a comprehensive evaluation of biochar's negative emission potential at the regional level is essential. Current studies have not provided a detailed assessment of biochar's negative emission potential and often fail to account for the diversity of biomass resources and biochar characteristics[6], resulting in a lack of solid foundation for deployment strategies.

This study employs a life cycle assessment (LCA) approach to evaluate the life cycle carbon footprint of straw-derived biochar. Focusing on the pyrolysis of agricultural straw to produce biochar and its subsequent soil application, the system boundaries are defined, with the functional unit being one ton of biochar output. A detailed inventory collection and analysis are conducted at each stage of the life cycle. Finally, a spatial analysis of the negative emission potential is performed to guide the prioritization of biochar deployment strategies.

2 Meta-analysis and Life Cycle Carbon Footprint

2.1 Meta-analysis

The essence of meta-analysis is the weighted integration of results from different literatures[7]. Meta-analysis first puts forward research questions, conducts literature searches from domestic and foreign websites, determines inclusion and exclusion criteria, and uses software to extract useful data from literature. In meta-analysis, the selection and calculation of effect size is key. In this process, the model is determined as a random effects model, and then the variance between studies is calculated. After that, the influence degree of different factors on the research problem is judged by the size of the effect value, and a forest map is used for visualization. Explanatory variables are introduced through the heterogeneity test, and the effects of the explanatory variables are analyzed. Finally, the model is diagnosed by deviation diagnosis and regression prediction, and the final interpretation result is obtained, as shown in Figure 1.

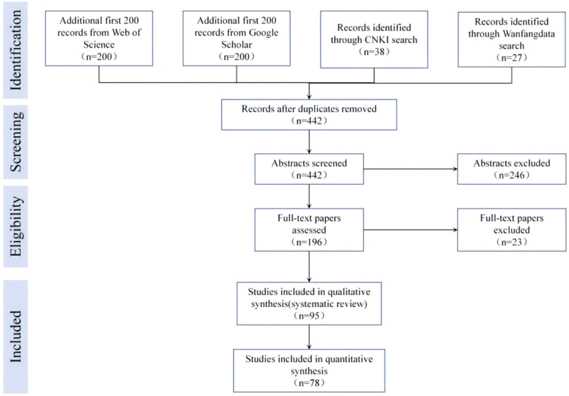

Fig. 1. PRISMA flow diagram of Meta-analysis.

2.2 Research Objectives and Scope

This research aims to evaluate the life cycle carbon footprint of biochar produced from agricultural straw via pyrolysis and its subsequent field application. To clearly present the LCA evaluation results, the system's functional unit is defined as the production of 1 ton of biochar in the pyrolysis co-production process. Using this functional unit as a baseline, the life cycle inventory is systematically organized. The LCA method is then employed to assess carbon emissions across the stages of straw collection, pyrolysis co-production, biochar transportation, and field application.

The system boundary scope for the agricultural straw pyrolysis biochar production and field application system is shown in Figure 2. Based on the "cradle-to-grave" principle, it includes straw acquisition, pyrolysis co-production, biochar transportation, and field application. This study accounts for indirect emissions from resource and energy use, direct emissions from cultivation and operation, and the carbon sequestration benefits of biochar. Emissions from electricity and labor during system construction are excluded due to their negligible impact.

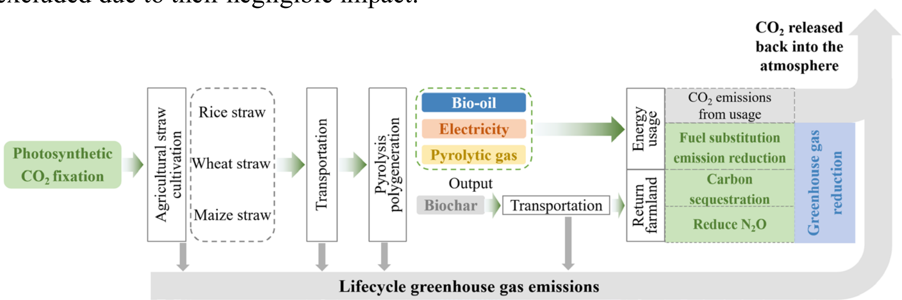

Fig. 2. System boundary diagram of the agricultural straw pyrolysis biochar production and biochar application system.

2.3 Life Cycle Inventory Analysis

Agricultural straw is a by-product of crop cultivation, and this study requires a distribution analysis of its acquisition process. Multi-product allocation methods include economic, mass, and energy-based approaches. The market value allocation method assigns resource and environmental burdens based on the economic value or market price of each product. Based on an analysis of various allocation methods, the market value allocation method is selected for analyzing the environmental load distribution of agricultural straw during crop cultivation.

The straw-to-grain ratio represents the yield of agricultural straw, a by-product with potential value, relative to the yield of the main product. For rice, wheat, and maize, the ratios are 1, 1.17, and 1.04, respectively[8]. Using the market value allocation method, the allocation coefficient of agricultural straw during the acquisition process is calculated as shown in equation (1) below:

$$Allocationrate_i = P_{bypro-i} \times RG_i / \left(P_{bypro-i} \times RG_i + P_{pro-i}\right) \tag{1}$$

In the formula, Allocationratei represents the allocation coefficient for the i type of agricultural straw; Pbypro-i is the price of the i straw type; Ppro-i is the price of the i crop product; and RGi is the straw-to-grain ratio for the i crop.

2.3.1 Agricultural Straw Acquisition Stage.

The agricultural straw acquisition stage consists of two processes: cultivation and transportation. Indirect emissions mainly stem from the use of pesticides, fertilizers (nitrogen, phosphorus, and potassium), machinery, and diesel in agriculture. While the production stage also includes labor and tool/material use for maintenance, these factors are not considered due to challenges in accurate measurement and lack of detailed data.

At a pyrolysis temperature of 550°C, the biochar yield stabilizes. The biochar yields for rice, wheat, and maize straw are 36.25%, 28.61%, and 28.67%, respectively[9]. Therefore, this section assumes a pyrolysis temperature of 550°C for the co-production process to calculate the material and energy consumption required to produce 1 ton of straw-derived biochar. The GHGs from pesticide use, fertilizers, machinery, and diesel during straw cultivation are shown in Figure 3 for each province in China. GHGs from rice, wheat, and maize cultivation in Yunnan Province are the highest, at 58.73, 107.08, and 113.38 kg CO_2-eq per functional unit, respectively. In comparison, crop cultivation in Sichuan Province generates significantly lower emissions.

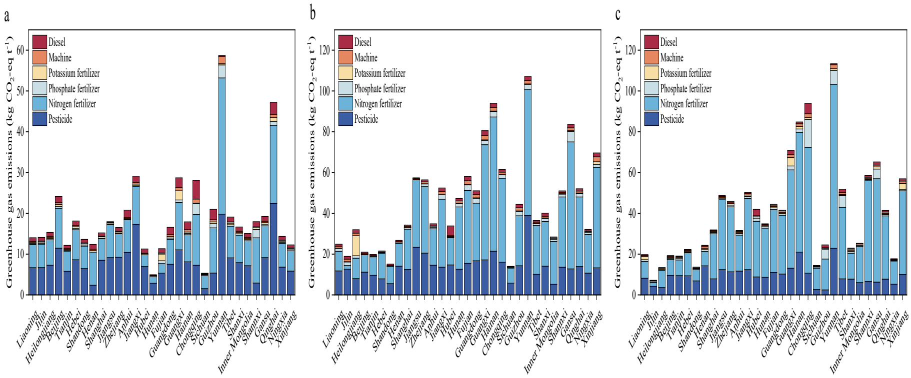

Fig. 3. Indirect greenhouse gas emissions from straw cultivation across different provinces in China. Rice straw (a), Wheat straw (b), and Maize straw (c).

This study considers only the direct GHGs of CO_2, N_2O, and CH_4 during agricultural production. CO_2 emissions result from the loss of soil organic carbon (SOC), N_2O emissions from nitrogen fertilizer application, and CH4 emissions from anaerobic respiration in rice paddy fields. CH_4 emissions are relevant only to rice cultivation, while for wheat and maize, only CO_2 and N_2O emissions are considered. According to the IPCC report, over a 100-year period, the global warming potentials of CH_4 and N_2O are equivalent to 25g and 298g of CO_2, respectively.

The CO_2 emissions from straw during cultivation are normalized to the functional unit, as shown in Figure 4a. The study shows significant regional and crop-specific variations in CO_2 emissions. Nationwide, CO_2 emissions from rice straw cultivation are 1282.65 kg CO_2-eq per functional unit, while wheat straw has the highest emissions at 3745.17 kg CO_2-eq, followed by maize straw at 3251.26 kg CO_2-eq. N_2O emissions from agricultural straw during cultivation vary significantly by region and crop, as shown in Figure 4b. Nationwide, N_2O emissions from rice, wheat, and maize cultivation are 45.01, 451.48, and 323.91 kg CO_2-eq per functional unit, respectively. Nationwide, the CH_4 emissions from rice straw cultivation amount to 3457.09 kg CO_2-eq per functional unit, as shown in Figure 4c.

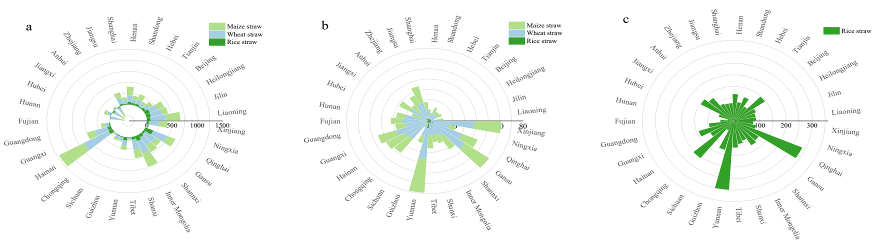

Fig. 4. Direct emissions during the agricultural straw cultivation process (kg CO_2-eq t^{-1}). CO_2 emissions (a), N_2O emissions (b), and CH_4 emissions (c).

This study assumes the use of agricultural diesel trucks for straw transport, with an average distance of 30 km from the farmland to the pyrolysis plant. In the pyrolysis multi-product system, transporting the straw required to produce 1 ton of rice, wheat, and maize straw-derived biochar generates GHGs of 19.64, 24.55, and 24.55 kg CO_2-eq, respectively.

2.3.2 Pyrolysis Multi-product Stage.

The pyrolysis multi-product system's GHG emissions include indirect emissions from material and energy inputs during construction and operation, as well as direct emissions from wastewater treatment. Based on the feasibility report for the Hubei Ezhou project, emissions from construction-related equipment are evenly distributed over the system's operational lifespan. Life cycle GHG emissions from equipment total 1406.86 t CO_2-eq/yr, with the thermodynamic system accounting for the largest share at 648.41 t CO_2-eq/yr. GHG emissions for producing 1 ton of rice, wheat, and maize straw-derived biochar are 68.31, 86.56, and 86.38 kg CO_2-eq, respectively, during operation and maintenance. CH_4 emissions from wastewater treatment for producing 1 ton of rice, wheat, and maize straw-derived biochar are 72.40, 91.74, and 91.55 kg CO_2-eq, respectively.

In the life cycle assessment of agricultural straw-derived biochar, the GHGs reduction potential during the pyrolysis stage mainly arises from the substitution of fossil energy. Energy products from the pyrolysis system-biochar, pyrolysis gas, and bio-oil are analyzed. Using the relationship between pyrolysis temperature and the lower heating values (LHV) of these products as established by Deng et al.[9], the LHV of straw pyrolysis products at 550°C was calculated, as shown in Table 1.

Table 1. Lower Heating Values of Pyrolysis Products (Unit: GJ t^{-1} biomass).

	Rice straw	Wheat straw	Maize straw
Biochar	7.26	6.53	6.76
Pyrolysis gas	0.41	1.70	2.11
Bio-oil	2.13	2.13	2.13

The pyrolysis gas replaces coal-fired power generation and coal gas heating, bio-oil substitutes coal tar, and biochar is directly applied to the soil. The GHGs emission factors for supercritical coal-fired power, coke oven gas, and coal tar are 207.78, 48.52, and 48.35 g CO_2-eq/MJ, respectively[10]. Using 80% of the pyrolysis gas to replace supercritical coal-fired power generation results in emission reductions of 186.35, 989.39, and 1226.19 kg CO_2-eq per functional unit, respectively. Using 20% of the pyrolysis gas for coal gas heating leads to reductions of 10.88, 57.76, and 71.58 kg CO_2-eq per functional unit. Additionally, substituting bio-oil for coal tar results in emission reductions of 284.10, 359.96, and 359.21 kg CO_2-eq per functional unit, respectively.

2.3.3 Biochar Transportation Stage.

GHGs during biochar transportation are mainly influenced by transportation volume and distance. Assuming the use of agricultural diesel trucks for road transport, with an average distance of 30 km from the pyrolysis plant to the farmland. The diesel consumption coefficient is 0.05 L/(t·km) and the diesel density is 0.83 kg/L. Based on diesel consumption, density, and market price, the annual cost is calculated. The GHGs for transporting 1 ton of biochar are 7.14 kg CO_2-eq.

2.3.4 Biochar Application Stage.

This study assumes that the positive effects of biochar application on soil are reflected in the reduction of N_2O emissions. A meta-analysis revealed that the emission reduction factors for rice, wheat, and maize straw-derived biochar are 30.55%, 22.82%, and 21.34%, respectively, as shown in Figure 5. The N_2O reduction potentials differ when these biochars are applied to agricultural soils, with reductions of 11.38, 8.50, and 7.95 kg CO_2-eq per functional unit for rice, wheat, and maize straw-derived biochar, respectively.

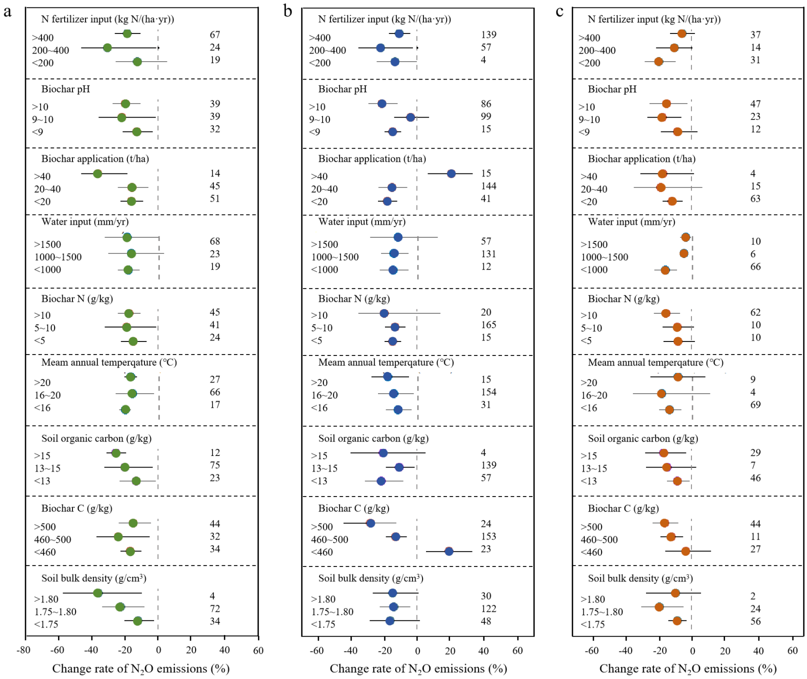

Fig. 5. Biochar-induced relative changes in N_2O emissions based on a meta-analysis. Rice straw (a), Wheat straw (b), and Maize straw (c).

In meta-analysis, the degree of variation in effect sizes is referred to as heterogeneity. The Baujat plot is used to detect studies that contribute to heterogeneity, illustrating each study's contribution to overall heterogeneity and its impact on the effect size along the Y-axis, as shown in Figure 6a. Subsequent influence diagnostics are performed, where studies with significant influence are marked in red in the aforementioned analysis, indicating the presence of inter-study heterogeneity without affecting the overall trend, as depicted in Figure 6b. The Q-Q plot is utilized to test whether the regressionfitted residuals follow a normal distribution. If they conform to a normal distribution, the points on the Q-Q plot will closely adhere to the line y = x. The results illustrated in Figure 6c suggest that the residuals from the regression fit approximately follow a normal distribution. Standardized residuals, obtained by dividing the residuals by their estimated standard deviation, can assess the model's appropriateness. Points with standardized residuals greater than 2 or less than -2 may be outliers; however, the number of outliers in all studies is minimal and does not affect the final results, as shown in Figure 6d.

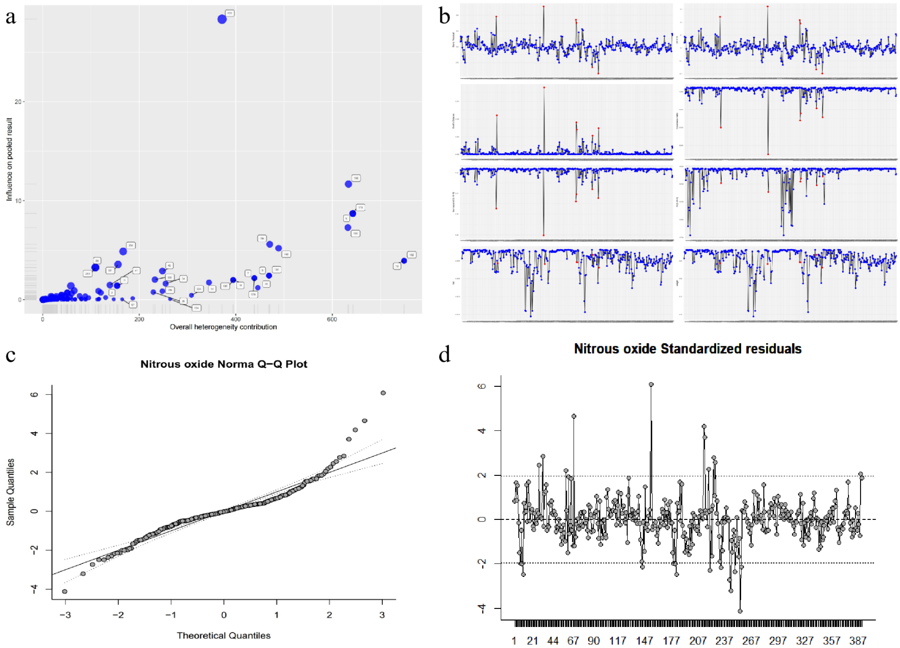

Fig. 6. Heterogeneity test of meta-analysis and regression fitting test. Baujat plot (a), Influence diagnosis (b), Normal Quantile-Quantile plot (c), and Standardized residuals plot (d).

The carbon sequestration potential of biochar is influenced by its fixed carbon content and stability. At a pyrolysis temperature of 550°C, the fixed carbon contents of rice, wheat, and maize straw-derived biochar are 52.87 wt.%, 63.05 wt.%, and 65.15 wt.%, respectively, with a stability of 75.08%[9]. Using Chen et al.'s soil carbon sequestration formula[11], the annual sequestration potentials per functional unit are 145.55 kg CO_2-eq for rice, 173.57 kg CO_2-eq for wheat, and 179.35 kg CO_2-eq for maize straw-derived biochar.

2.4 Carbon Footprint Results

Figure 7 presents the proportional GHGs emissions of each subprocess within the system's life cycle. The carbon emissions for the agricultural straw cultivation stage are based on national averages. The analysis reveals that the cultivation stage contributes the largest share of GHG emissions in the pyrolysis poly-generation system integrated with biochar application, accounting for 40.16%, 39.13%, and 32.43% for rice, wheat, and corn straw, respectively. The contributions from straw and biochar transportation are relatively negligible. The emissions during the cultivation stage are primarily driven by the use of raw materials and related reactions, with fertilizer application being the dominant factor due to its high energy consumption and significant emissions.

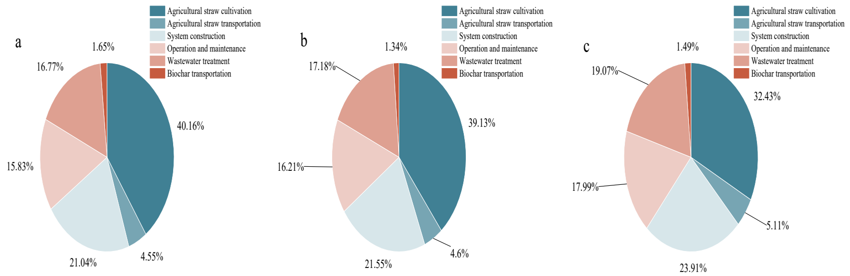

Fig. 7. The composition of greenhouse gas emissions in the system. Rice straw (a), Wheat straw (b), and Maize straw (c).

The net GHGs of the system are shown in Figure 8. The findings reveal that in scenarios excluding energy substitution and biochar carbon sequestration, the system emits between 431.64 and 533.95 kg CO_2-eq per functional unit. In contrast, when energy substitution and biochar carbon sequestration are accounted for, the system can reduce GHGs by 206.62 to 1364.10 kg CO_2-eq per functional unit. For comparison, biochar production systems using wood residues and sludge as feedstocks exhibit emission factors ranging from -1100 to 680 kg CO_2-eq per ton of biochar[12]. Thus, without considering energy substitution and carbon sequestration, the emission reduction potential of straw biochar is comparable to that of wood residues and sludge. However, when these factors are included, the system's emission reduction potential is significantly enhanced.

Based on the relationship between pyrolysis temperature and straw biochar carbon content proposed by Deng et al.[9], this study calculates the C content of rice, wheat, and maize straw-derived biochar at the optimal pyrolysis temperature. Additionally, using the relationship between biochar C content and crop yield, it estimates the nationwide impact of straw biochar on crop yields. The biochar application rate increases crop yields by 18%~31%. Consequently, by leveraging biochar's role in improving crop yields, substituting excessive nitrogen fertilizer inputs with biochar can achieve even greater emission reduction benefits.

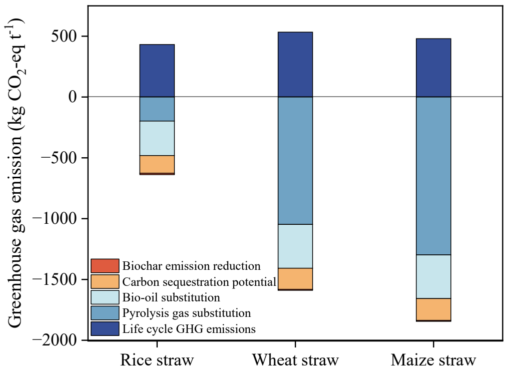

Fig. 8. The greenhouse gas emissions of the agricultural straw pyrolysis biochar production and application system.

2.5 Sensitivity Analysis

Sensitivity analysis is primarily conducted to evaluate how changes in key factors within a system impact critical indicators. Fertilizer application rates during crop cultivation (Scenario A, B), electricity consumption during the pyrolysis process (Scenario C, D), energy consumption during the wastewater treatment (Scenario E, F), and fuel consumption for biochar transportation (Scenario G, H) are selected as sensitivity variables. These variables are adjusted within a range of ±10%. Using the baseline scenario, defined by the established system parameters and environmental impact assessment results. The impact of different values of sensitivity variables on GWP is examined, and the sensitivity analysis of the system's carbon footprint is shown in Figure 9. The variation in energy consumption for wastewater treatment has the most significant impact on the carbon footprint. Compared to the baseline scenario, the GWP potential of rice straw, wheat straw, and corn straw changes by 1.68%, 1.72%, and 1.91%, respectively. The sensitivity analysis results suggest that reducing energy consumption in wastewater treatment and electricity usage during the pyrolysis stage can effectively minimize the environmental impact.

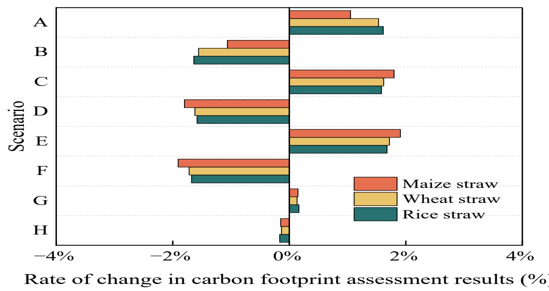

Fig. 9. Sensitivity analysis of carbon footprint in system.

2.6 Spatial Distribution of the Carbon Reduction Potential

The nationwide deployment of system offers substantial GHGs reduction potential. Data on the annual production of major cereal crops in China for 2022, were sourced from the China Statistical Yearbook. This study assumes that 20.4% of the total straw is used for biomass pyrolysis. By assessing the available biomass, the potential number of biomass pyrolysis plants in each province can be estimated.

The GHGs reduction potential for each province was calculated based on the number of potential biomass pyrolysis plants and the varying direct and indirect emissions from different processes. Overall, deploying rice, wheat, and maize straw pyrolysis for biochar production and biochar application could reduce national GHGs by 3.71×10^6, 7.53×10^6, and 1.85×10^7 t CO_2-eq/yr, respectively, as shown in Figure 10. Integrating pyrolysis co-production systems with biochar applications for the processing of agricultural straw in various provinces can create systems with significant GHGs reduction potential. Specifically, Central and Eastern China are suitable for producing and applying rice straw biochar, Northern and Northwestern China for wheat straw biochar, and Northeastern and Northern China for corn straw biochar. Among these regions, Hebei, Shandong, and Henan can be prioritized as pilot provinces for promotion and application.

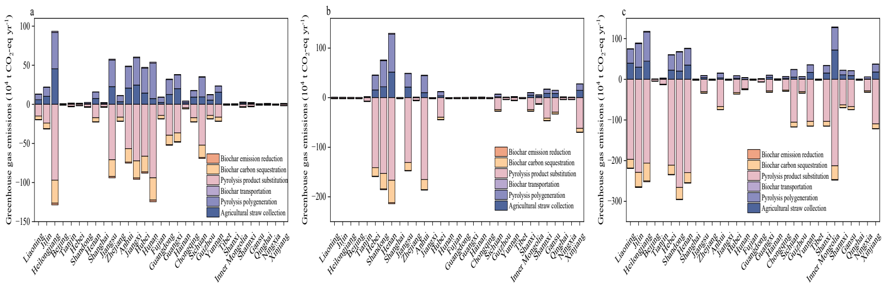

Fig. 10. The spatial distribution map of the system's carbon reduction potential. Rice straw (a), Wheat straw (b), and Maize straw (c).

3 Conclusion

The agricultural straw cultivation stage is the largest source of GHGs emissions in life cycle, with rice, wheat, and maize straw cultivation contributing 40.16%, 39.13%, and 32.43%, respectively. The meta-analysis reveals that the emission reduction factors for rice, wheat, and maize straw-derived biochar are 30.55%, 22.82%, and 21.34%, respectively. The system achieves GHGs reductions of 206.62 to 1364.10 kg CO_2-eq per functional unit, driven by the substitution effect of fossil energy and the carbon sequestration of biochar. Without energy substitution and carbon sequestration, straw biochar's emission reduction potential is similar to wood residues and sludge. However, including these factors significantly increases the potential. Biochar application boosts crop yields by 18% to 31%, and replacing excess nitrogen fertilizer with biochar further enhances emission reductions. The sensitivity analysis suggests that reducing energy consumption in wastewater treatment and electricity use during the pyrolysis stage can effectively minimize environmental impact. The national GHGs reductions from deploying rice, wheat, and maize straw pyrolysis biochar production and application systems can reach 3.71×10^6, 7.53×10^6, and 1.85×10^7 t CO_2-eq/yr, respectively.

Acknowledgments

This work was financially supported by the National Natural Science Foundation of China (Grant No. 52076099), the National Natural Science Foundation of China (Grant No. 42201315), and the Smart Gird-National Science and Technology Major Project (2024ZD0800500).

References

1. Xin Zhao, Ruochen Li, Wenxuan Liu, Wensheng Liu, Yinghao Xue, Renhua Sun, Yuxuan Wei, Zhe Chen, Rattan Lal, Y. Dang, Zhi-Yu Xu, and Hailin Zhang. 2024. Estimation of crop residue production and its contribution to carbon neutrality in China. Resour Conserv Recycl 203 (April 2024), 107450.
2. Xiong Zhang, Huanhuan Zheng, Jing Wu, Wei Chen, Yingquan Chen, Xuezhi Gao, Haiping Yang, and Hanping Chen. 2021. Physicochemical and adsorption properties of biochar from biomass-based pyrolytic polygeneration: effects of biomass species and temperature. Biochar 3 (July 2021), 657–670.
3. Li Liu, Peng Jiang, Hongliang Qian, Liwen Mu, Xiaohua Lu, and Jiahua Zhu. 2022. CO_2-negative biomass conversion: An economic route with co-production of green hydrogen and highly porous carbon. Appl. Energy 311 (April 2022), 118685.
4. Douglas C. Elliott. 2007. Historical Developments in Hydroprocessing Bio-oils. Energy Fuels 21, 3 (May 2007), 1792–1815.
5. Johannes Lehmann, Annette Cowie, Caroline A. Masiello, Claudia Kammann, Dominic Woolf, James E. Amonette, Maria L. Cayuela, Marta Camps-Arbestain, and Thea Whitman. 2021. Biochar in climate change mitigation. Nat. Geosci 14 (December 2021), 883–892.
6. James A. Ippolito, Liqiang Cui, Claudia Kammann, Nicole Wrage-Mönnig, Jose M. Estavillo, Teresa Fuertes-Mendizabal, Maria Luz Cayuela, Gilbert Sigua, Jeff Novak, Kurt Spokas, and Nils Borchard. 2020. Feedstock choice, pyrolysis temperature and type influence biochar characteristics: a comprehensive meta-data analysis review. Biochar 2 (September 2020), 421–438.
7. Xuanchen Meng, Ennan Zheng, Dingmu Hou, Mengting Qin, Fanxiang Meng, Peng Chen, and Zhijuan Qi. 2024. The effect of biochar types on carbon cycles in farmland soils: A meta analysis. Sci. Total Environ 930 (June 2024), 172623.
8. Jianchun Zhu, Ronghua Li, Xiangyun Yang, Zengqiang Zhang, and Zhimin Fan. 2012. Spatial and temporal distribution of crop straw resources in 30 years in China. J. Northwest A&F Univ 40 (March 2012), 139–145.
9. Xu Deng, Fei Teng, Minpeng Chen, Zhangliu Du, Bin Wang, Renqiang Li, and Pan Wang. 2024. Exploring negative emission potential of biochar to achieve carbon neutrality goal in China. Nat. Commun 15, 1 (February 2024), 1085.

10. Qing Yang, Hewen Zhou, Xiaoyan Zhang, Chris P. Nielsen, Jiashuo Li, Xi Lu, Haiping Yang, and Hanping Chen. 2018. Hybrid life-cycle assessment for energy consumption and greenhouse gas emissions of a typical biomass gasification power plant in China. J. Clean. Prod 205 (December 2018), 661–671.
11. Wei Chen, Xueyu Hu, Yangyang Zhang, Di Zhang, and Jinzhan Song. 2015. Estimation of carbon sequestration potential of rice straw pyrolyzing to biochar. Environ. Sci. Technol 38, 11 (November 2015), 265–270.
12. Kavindi Gajasinghe Arachchige Ganga, Longlong Tang, Sasaki Yuma. 2024. Assessing GHG emission reduction in biomass-derived biochar productionvia slow pyrolysis: A cradle-to-gate LCA approach. RESOUR CONSERV RECY 212 (January 2024), 107900.