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Circular Agriculture for Sustainable and Low-Carbon Development in the People's Republic of China

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KEY POINTS

- The People's Republic of China achieved remarkable growth in agricultural production, but this has also led to declining quality of arable lands, soil degradation, eutrophication of surface water, and excessive nitrate in groundwater, amongst other problems that threaten long-term food security.
- The transformation to sustainable and low-carbon agriculture is one of the top priorities of the People's Republic of China. In pursuit of its 2060 carbon neutrality target, greenhouse gas emissions from chemical fertilizer, paddy fields, and the livestock sector are being reduced.
- Asian Development Bank field studies indicate that circular agriculture models can reduce environmental pressures and greenhouse gas emissions from agriculture and bring additional economic opportunities to rural areas. Greater institutional and regulatory capacity, development of market-based mechanisms, development of bio-based value chains, technological innovation, and increased public–private partnerships can help scale up circular agriculture models.

CHALLENGES TO SUSTAINABLE AND LOW-CARBON AGRICULTURE DEVELOPMENT

Over the past 4 decades, grain production in the People's Republic of China (PRC) has increased nearly 2.5 times. Its primary meat production has increased about 5.4 times while per capita consumption of meat has increased 3.9 times; milk, 10.6 times; and eggs, 6.9 times.[1] Despite a remarkable expansion of agricultural production, the country has witnessed declining quality in its arable lands, soil degradation, eutrophication of surface water, excessive nitrate in groundwater, and other emerging environmental issues.[2] Agriculture and livestock produce a large amount of waste and are highly dependent on imported inputs, such as concentrated feeds, and chemical fertilizers. Increasing the use of residual products in one sector as feedstocks for another sector can improve the efficiency of resource use and reduce the environmental pressure as well as the greenhouse gas (GHG) emissions from agriculture.

Note: ADB recognizes "China" as the People's Republic of China.

1 National Bureau of Statistics of China. National Summary Data Page/Special Data Dissemination Standard. https://data.stats.gov.cn/ (accessed on 12 September 2022).

2 Eutrophication is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis, causing impairment of freshwater ecosystems.

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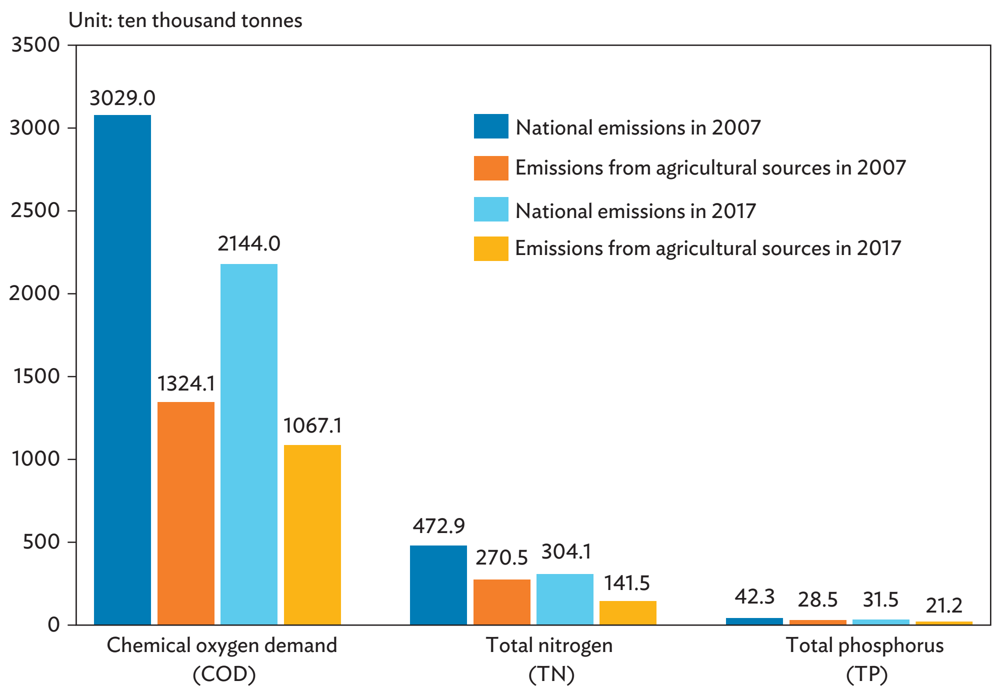
Nonpoint source pollution from agriculture. The intensification of agriculture to boost production has become unsustainable in the PRC. Five primary sources of agricultural and ultimately water pollution are (i) intensive livestock farming, (ii) aquaculture, (iii) excessive use of chemicals, (iv) environmental pollution from indiscriminate burning or disposal of crop residues, and (v) soil pollution from improperly recycled waste plastic films.[3] These nonpoint sources of pollution from agriculture are major challenges,[4] given that they initially pollute water bodies and then progressively widely spread to pollute soil, air, and other channels.[5] The level of emissions remains high in many locations even as nonpoint source pollution from agriculture has decreased. The 2020 Bulletin of the Second National Survey of Pollution Sources shows that chemical oxygen demand has decreased by 19%, total nitrogen by 48%, and total phosphorus by 26% between 2007 and 2017 (Figure 1).

Increasing greenhouse gas emissions from agriculture. Agriculture is one of the main sectors responsible for climate change. From 2007 to 2018, global GHG emissions from agri-food systems comprised 21%–37% of total GHG emissions.[6] The Intergovernmental Panel on Climate Change estimates that the global technical mitigation potential from agriculture

Figure 1: Total Water Pollutant Emissions and Agricultural Nonpoint Source Pollution, 2007 and 2017



Sources: Government of the People's Republic of China, Ministry of Agriculture and Rural Affairs, Ministry of Ecology and Environment, and National Bureau of Statistics (2020); Government of the People's Republic of China, Ministry of Environmental Protection, State Statistics Bureau, and Ministry of Agriculture (2010).

3 Government of the People's Republic of China, Ministry of Agriculture. 2017. *Construction Plan of Demonstration Project for Comprehensive Treatment of Agricultural Nonpoint Source Pollution in Key Watersheds (2016–2020)*. Beijing.

4 B. Gong et al. 2021. Nonpoint Source Pollution Control and Greening of China's Agri-food Systems. In *2021 China and Global Food Policy Report: Rethinking Agri-food Systems for the Post-COVID World*. Beijing: Academy of Global Food Economics and Policy, China Agricultural University.

5 In March 2021, the Ministry of Ecology and Environment issued the Trial Implementation Plan for Agricultural Nonpoint Source Pollution Control, Supervision, and Guidance to develop measures to control agricultural nonpoint source pollution, with focus on reducing chemical fertilizers and pesticides and regulating pollution from livestock operations. The aim is to decrease the impact of agricultural nonpoint source pollution on water and soil.

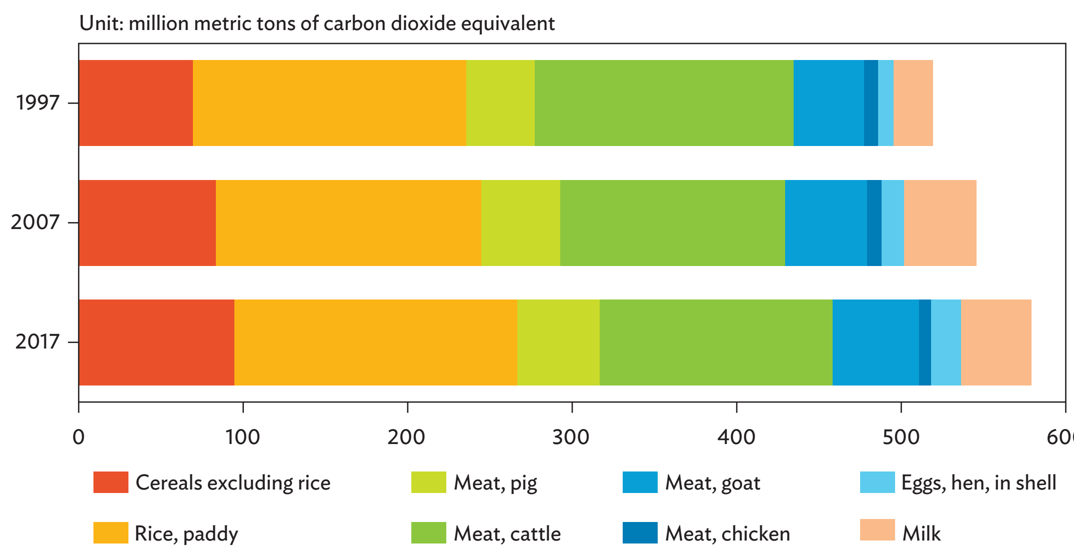
6 C. Rosenzweig et al. 2020. Climate Change Responses Benefit from a Global Food System Approach. *Nature Food*. 1 (2). pp. 94–97. https://doi.org/10.1038/s43016-020-0031-z.

is equivalent to three-quarters of the sector's emissions mostly through carbon sequestration.[7] Agriculture also offers climate change mitigation opportunities through methane reduction investments such as lowering emission intensity of livestock, adopting low-carbon rice cultivation practices, and minimizing waste. Achieving the PRC's goal of carbon neutrality by 2060 requires GHG emission reductions as well as carbon sequestration in agriculture.

Greenhouse gas emissions of carbon dioxide (CO_2) equivalent in the PRC increased 2.4 times between 1990 and 2018, raising the PRC's world share of GHG emissions from 9.5% to 23.0%.[8] In the same period, GHG emissions from agriculture—primarily from croplands, rice farming, livestock enteric fermentation, manure management, and field residues—increased by 18%.[9] In 2017, the primary sources of GHG emissions from agricultural activities in the PRC were rice production at 27% and beef production at 17% (Figure 2).

Inefficient utilization of agriculture organic waste. The PRC is the world's largest producer of crop straw, with 0.81 billion tons in 2017. According to the Ministry of Agriculture and Rural Affairs, the country's comprehensive utilization rate of crop straw reached 86%, and 70% for livestock and poultry manure in 2019.[10] Nitrogen management practices on the PRC's farmland are relatively poor, and only one-third of manure nitrogen is utilized, while the rest is released into the air as pollution.[11] Crop straw and livestock manure are the main available organic waste, which can be used for biomass energy in rural areas. However, bulk coal is still the leading heating and cooking fuel in most rural areas, with high CO_2 emissions, causing air pollution issues. According to the *China Energy Statistical Yearbook 2019*, total domestic energy consumption of rural residents in 2019 was 245 million tons of standard coal, of which coal consumption accounted for about 40%, while renewable energy utilization accounted for only 12%. Increasing biomass energy in rural areas can effectively reduce the emission of major conventional pollutants.

Figure 2: Greenhouse Gas Emissions from Agricultural Activities in the People's Republic of China by Subsector, 1997–2017



Source: Food and Agriculture Organization of the United Nations (FAO). Emissions Totals. FAO Database. https://www.fao.org/faostat/en/#data/GT (accessed 20 March 2021).

7 P. Smith et al. 2007. Agriculture. In B. Metz et al., eds., *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York: Cambridge University Press.
8 Food and Agriculture Organization of the United Nations (FAO). 2021. Emissions Totals. FAO Database. https://www.fao.org/faostat/en/#data/GT (accessed 20 March 2021).
9 Enteric fermentation is fermentation that takes place in the digestive process in ruminant animals such as cattle, sheep, goat, and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product, which is a major source of GHG emission in agriculture.
10 Animal Husbandry and Veterinary Service. 2020. Reply to Recommendation No. 1817 of the Third Session of the Thirteenth National People's Congress. *Agriculture Office Notice*. No. 294. Beijing: Ministry of Agriculture and Rural Affairs. http://www.moa.gov.cn/govpublic/xmsyj/202010/t20201014_6354202.htm.
11 Z. Bai et al. 2016. Nitrogen, Phosphorus, and Potassium Flows through the Manure Management Chain in China. *Environmental Science and Technology*. 50 (24). pp. 13409–13418.

EVOLUTION OF CIRCULAR AGRICULTURE MODELS IN THE PEOPLE'S REPUBLIC OF CHINA AND LESSONS LEARNED FROM THE FIELD STUDIES

Circular Agriculture as a Key Solution for Sustainable and Low-Carbon Economy in the People's Republic of China

In September 2020, President Xi Jinping pledged that the PRC will strive to reach carbon peaking before 2030 and achieve carbon neutrality before 2060. The PRC has been increasing policy efforts for sustainable and low-carbon transformation of agriculture, introducing a series of policies on resource use, nonpoint source pollution, ecological protection, and supply of high-quality agricultural products. In February 2021, the State Council promulgated the Guidance on Accelerating the Establishment of a Green Low-Carbon Circular Economic System, which encourages the development of ecological farming and breeding and strengthens the certification and management of green food and organic agricultural products. It puts forward four key contents of the strategy: (i) developing eco-circular agriculture, (ii) increasing the utilization of livestock and poultry waste as resources, (iii) promoting the comprehensive use of crop straws, and (iv) strengthening the control of agricultural film pollution.

In August 2021, the PRC issued the 14th Five-Year National Agricultural Green Development Plan, 2021–2025 as the special plan for agricultural green development. The plan mandates the government to promote green and low-carbon circular development in agriculture and rural areas through building green and low-carbon supply chains. Five qualitative targets and 11 quantitative indicators for green agricultural development by 2025 have been set. The five qualitative targets comprise (i) improvement in resource utilization, (ii) improvement of agriculture production environment, (iii) improvement in agro-ecosystems, (iv) increased supply of green agriculture products, and (v) enhanced ability for carbon emission reduction and carbon sequestration.

Circular agriculture strengthens the protection and utilization of agricultural biological resources by gradually reducing the intensity of resource utilization. It enables the multilevel recycling of physical energy in the agricultural system to maximize the use of the various biological components of the ecosystem. Circular agriculture can reduce the use of chemical fertilizers, pesticides, and livestock manure emission, contributing to climate change mitigation and reducing environmental pressure from agriculture as a result of more efficient use of these environmentally sensitive production inputs. The application of organic fertilizer can restore degraded soil quality and improve agriculture productivity. Therefore, it can be a key solution to achieve sustainable and low-carbon agriculture development and bring more economic opportunities to rural areas.[12] For example, circular bioeconomy initiated by the European Union (EU) provides a chance to promote the use of renewable biological resources that can convert waste streams into useful products and support the conversion of natural resources (see Box).

Circular Bioeconomy Model in the European Union

The concept of circular economy highlights the importance of resource efficiency and resilience. It aims to preserve the value of resources by recycling them at the end of their use, thereby minimizing waste production. In 2018, the European Union updated its Bioeconomy Strategy with the following goals:

(i) ensure food security and nutrition;
(ii) sustainably manage natural resources;
(iii) reduce dependence on unsustainable and nonrenewable resources, from both local and international sources;
(iv) support climate change mitigation and adaptation; and
(v) strengthen European competitiveness and job creation.

Each goal promotes the establishment of a local bioeconomy and stimulates investments of public stakeholders as well as the private sector. The action plan, which covers 14 tangible actions, introduced a European Circular Bioeconomy Fund. It is a proposed 250 million euro (€) venture fund, wherein the European Investment Bank has committed €100 million. Food and farming systems are key parts of the circular bioeconomy, accounting for about three-quarters of the overall bioeconomy employment and about two-thirds of bioeconomy turnover. The strategy is accelerating the transformation toward sustainable, healthy, nutrition-sensitive, resource-efficient, resilient, circular, and inclusive food and farming systems.

As a part of its due diligence with respect to the bioeconomy fund, the European Investment Bank acknowledged some financial access issues—particularly on how to scale up bioeconomy-related investments from pilot and/or demonstration projects to flagship and industrial-scale plants. It also identified demand and market risks as the highest investment risk factor. Filling the financial gap requires an effective regulatory framework (including biomass certification), complemented by several public and private sector interventions.

Sources: European Commission, Directorate-General for Research and Innovation. 2018. *A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment—Updated Bioeconomy Strategy*. Brussels; and Food and Agriculture Organization of the United Nations. Circular Economy: Waste-to-Resource & COVID-19. https://www.fao.org/land-water/overview/covid19/circular/en/.

[12] Q. Zhu, R. Jia, and X. Lin. 2019. Building Sustainable Circular Agriculture in China: Economic Viability and Entrepreneurship. *Management Decision*. 57 (4). pp. 1108–1122.

Since 2019, the Asian Development Bank (ADB), in partnership with the PRC's Ministry of Agriculture and Rural Affairs (MARA), has been providing technical assistance to study circular agriculture models in key agriculture provinces.[13] The project assessed crop–livestock partnership models in Shandong and Heilongjiang provinces and comprehensive utilization models of crop straw in Gansu, Heilongjiang, and Hubei provinces, and identified the constraints and policy implications to scale up circular agriculture models in the country.

Circular Crop–Livestock Model

Circular crop–livestock model requires partnerships between crop cultivation and livestock breeding, in which crop and livestock producers exchange crop residues for livestock feeds and livestock manure for fertilizer. This circular model is an important measure to improve the efficiency of agricultural resource utilization and to promote environmentally sustainable and climate-resilient agriculture. The use of biomass organic fertilizer from livestock manure also has additional benefits of productivity improvement by improving soil quality. Although livestock manure is the main source of organic fertilizer, most manure resources are not used effectively in the PRC because of seasonal restrictions, lack of rural labor, and high cost of transportation. As a result, returning straw in the field is still the dominant form of use rather than using it for feed.

Policy developments. In 2017, the MARA formulated the Action Plan for Replacing Chemical Fertilizer with Organic Fertilizer in Fruit, Vegetable, and Tea. Under this plan, selected key cities and districts cultivating fruits, vegetables, and tea were given subsidies and technical training to undertake demonstration projects for substituting chemical fertilizer with organic fertilizer.

In 2017, the General Office of the State Council issued the Opinions on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste. It proposed (i) establishment of a resource utilization system of waste from livestock and poultry breeding, (ii) creation of a breeding cycle development mechanism, and (iii) achievement of more than 75% comprehensive utilization rate of livestock and poultry manure nationwide by 2020.

Lessons from the field study. A study on an integrated model of the circular crop–livestock model was carried out in Tailai County, Heilongjiang Province, and Yucheng City, Shandong Province with ADB technical assistance. Both are key agriculture regions facing the typical problems of the agriculture sector in the PRC: low productivity of crop sector, soil degradation, pollution from the livestock sector, nonpoint source pollution, and low quality of agricultural products. These regions have diverse types of agriculture production dominated by small-scale farms.

In Yucheng's circular crop–livestock model, soil organic matter increased by more than 20%, leading to a 5% higher grain yield. The use of organic fertilizer reduced the chemical fertilizer application in greenhouse vegetable farms by more than 30%. However, due to limited crop area, livestock manure cannot be fully used in the crop sector, and the amount of crop straw is not sufficient to provide sufficient feed for livestock sector.

Tailai County faces a major issue of decreasing soil's organic matter content, causing lower crop yields. The annual carbon emissions from Tailai's soil respiration from planting were about 393,000 tons. Assuming that 50% of the straw is returned to the field, it can provide the soil with 131,800 tons of carbon. Fully returning livestock manure to the field can provide additional 102,100 tons of carbon to the soil per year. However, utilization of crop straw and livestock manure as organic fertilizer remains low due to lack of collection and storage facilities. The scale of the livestock sector is much smaller than the crop sector, which is limiting the supply of livestock manure to the crop sector.

The field study indicated that the development of circular crop–livestock agriculture requires a well-designed land use and industry development plan at the county level, which considers the carrying capacity of the local environment and adjusts the agricultural planting and breeding structure. In replicating the model across the PRC, it is important to establish technical standards for crop–livestock circulation, design standards on industrial space layout, and quality standards for waste processing products.[14] Establishing a mechanism to mutually benefit crop, livestock, and waste processing enterprises is also critical for sustainability of the circular model. The field study highlighted the significance of developing the following institutions:

(i) development of green agricultural products market, where participants in the circular agriculture model can cover the additional cost of participating in a circular agriculture model;
(ii) evaluation of the environmental benefit and GHG reduction potential of different entities participating in a circular agriculture model; and
(iii) enforcement of the polluter pays principle and strengthening of the penalties for environmental damages to increase the private cost of pollution.

Comprehensive Utilization of Crop Straw

Expansion of grain production has led to a growing amount of straw in the PRC, whose burning during the harvest season has been causing seasonal air pollution. In 1998, an administrative regulation on the prohibition of straw burning was issued, followed by a succession of 24 policies and regulations since the late 1990s banning straw burning. These have curbed straw burning out in the open. Data show that the annual average remote sensing fire

[13] ADB. 2019. *People's Republic of China: Agriculture Green Production and Waste Management*. Manila.

[14] Examples of these standards are as follows: (i) standards on livestock raising by enforcing strict feed additive standards, reducing inputs of heavy metals, antibiotics, and controlling environmental risks of manure utilization from the source; (ii) quality inspection standards on arable land and a long-term mechanism for soil testing and formula fertilization to guide farmers to return livestock manure to the field scientifically to maintain soil nutrient balance; and (iii) accounting methods for livestock manure emissions.

points of straw burning at the national level has decreased by 58% between 2003–2005 and 2014–2016.

Policy developments. There are five major technologies for the comprehensive utilization of crop straw: (i) feed use, (ii) fertilizer use, (iii) energy use, (ii) straw substrate such as cultivation substrate for edible mushrooms production, and (v) industrial raw materials such as for building supplies and papermaking. The PRC government and major ministries and commissions have issued more than 20 financial support policies to promote the comprehensive utilization of straw using subsidies and rewards. Since 2016, 2.5 billion yuan (CNY) has been invested in pilot projects to fully utilize crop residues through innovative technologies and developing the service system for collection, storage, and transportation. In 2017, CNY457 million in subsidies was allocated to procure crushing and returning machines for crop residues, and picking and baling machines to help return crop residues to the field. At the same time, the Ministry of Finance, National Development and Reform Commission, and State Administration of Taxation issued preferential tax policies for the comprehensive utilization of straw, such as the catalogue of preferential income tax for enterprises with comprehensive utilization of resources. The government also issued relevant market regulation policies, and incentive and supportive policies to further ensure the implementation of comprehensive utilization of crop straw.

Lessons from the field study. ADB's technical assistance included a field study on existing crop straw utilization models in Gansu, Heilongjiang, and Hubei provinces. The study found that these models can contribute to (i) improving environmental quality and human health through the reduction of air pollutant emissions, such as nitrogen oxide, sulfur dioxide, particulate matter, and carbon monoxide; (ii) reducing CO_2 emissions through carbon sequestration and emission reduction; (iii) reducing the use of chemical fertilizer and improving soil fertility; and (iv) producing industrial raw materials. For example, the field study indicates that the use of straw as a fertilizer can eliminate 90% of emissions of air pollutants (soot, sulfur dioxide, nitrogen oxide, and carbon monoxide) compared to straw combustion.

The field study identified four technical models of crop straw utilization for replication, based on the characteristics of regional resources, the environment, and the economy of agricultural production: (i) central heating model, based on centralized straw collection and straw bundling direct combustion in the northeastern region of the PRC; (ii) feed use of crop straw in plain areas where livestock breeding is dominant; (iii) direct fertilizer utilization in mountainous areas; and (iv) combination of feed and fertilizer use in the northwestern region of the PRC, where straw is mainly used as feed and the remainder as fertilizer.

The field study suggested preferential policies for land use and transportation such as straw collection, storage, transportation, and straw processing, and for implementing a renewable energy quota system. Currently, only straw power generation is eligible for subsidy for biomass on-grid electricity pricing. The potential policy options include renewable energy quota system, which sets a mandatory market share of regional renewable energy in power generation, and renewable power certificate system, which certifies the use of renewable power.

RECOMMENDATIONS TO PROMOTE CIRCULAR AGRICULTURE FOR SUSTAINABLE AND LOW-CARBON RURAL DEVELOPMENT

Incorporate circular agriculture models in regional development plans. Although the livestock sector is increasingly dominated by large-scale producers, small-scale farmers still dominate the PRC's crop sector. This structural gap between large-scale livestock producers and small-scale crop producers increases transaction costs in establishing a circular crop–livestock model. Recognizing the economic and environmental advantage of circular agriculture model, the regional development plan should diversify the industrial structure between livestock and crop sectors and optimize the use of local biological resources through increasing industrial linkages. The cost–benefit analysis performed in ADB's technical assistance project indicates that the circular crop–livestock model can be a sustainable solution on a local scale.

Develop technical standards, and monitoring and evaluation capacity for the circular agriculture model. The government should further clarify the transportation and marketing standard of agricultural wastes, and prepare guidelines on form, technical specification, and quality. The government should also enhance the monitoring and evaluation capacity to accurately collect, release, and use the data on agricultural nonpoint source pollution emission, as well as the performance of circular agriculture models through the interactive verification of multichannel and multisource data. For example, local governments can establish an arable land quality inspection standard system and improve soil testing and formula fertilization.

Reform agricultural subsidies and introduce innovative policy support. Environmental benefits resulting from agricultural conservation practices (such as improving water quality, reducing GHG emissions, and protecting biodiversity) are unpriced externalities. Policy institutions and regulations can provide incentives (e.g., cash payments, reduced levies) to private resource users for the enhancement of ecosystem services—or alternatively, impose charges for the degradation of these services. For example, subsidies for mechanical facilities for returning straw to the field and leaving straw from the field can be effective, especially in the northeastern part of the PRC. Other measures include imposing taxes on polluting and unsustainable production, and using funds from fiscal stimulus policies to support the adaptation of circular agriculture models.

Develop circular agricultural value chains. Farmers have little incentive to participate in circular agriculture models, unless they can recover additional costs from markets or via public support.

Developing markets for ecological agricultural products enhances incentives for farmers to participate in circular agriculture models. Resolute government support is needed to address the information asymmetry between consumers and producers, and to transform the food supply chain. For example, introducing the certification system of ecological agricultural products can generate a price premium for ecological or green agricultural products. Lishui City in Zhejiang Province increased the premium for ecological agricultural products and mobilized its market forces to build a regional agricultural brand.[15]

Enhance private sector investment in circular agriculture. Private sector participation in circular agriculture models plays an important role in scaling up circular agriculture models by developing circular technology and its applications. For example, the field study performed by ADB's technical assistance in Yucheng City, Shandong Province assessed the financial return to investment on the crop straw utilization for 10 main enterprises and found that they all are financially viable. For the private sector to accurately assess risks and adopt appropriate risk-mitigating mechanisms, it is essential to develop an enabling environment for risk assessment and management. The government can promote a public–private partnership mode of financing through a preferential tax system. The study found that tax credit system to reduce or exempt some taxes for straw comprehensive utilization enterprises for a certain period can be a useful policy tool to allow small and micro enterprises to participate in circular agriculture.

Promote research and development for circular agriculture. The allocation of public research and development funds should be further oriented to transition to resource-conserving agriculture, raise awareness of researchers, and guide them to carry out research on agriculture waste recycling technology. It is therefore vital to actively support and strengthen the development and application of recycling technology, such as the efficient use of fertilizer and pesticides, reprocessing of aquaculture waste and crop residues, and decontaminating heavy metal pollution in cultivated lands.

Establish more intersectoral circular bioeconomy models for sustainable and low-carbon rural development. Currently, the PRC's efforts to establish circular agriculture models concentrate on the comprehensive use of crop straw and manure resources. In many regions, waste treatment is highlighted rather than waste recycling. However, other biomass resources are underexploited as many waste streams (such as forestry and fisheries residues, food wastes, sewage residues) are not used in an optimal way and more materials and energy extracted from them. Going forward, the PRC should explore further opportunities to establish more intersectoral circular bioeconomy models to make use of biomass resources in rural areas for a wider range of value-added products, including energy, materials (wood, plastics, and clothing), biochemicals, and biopharmaceutical products. Promoting a circular bioeconomy can be a key rural initiative to address multiple societal challenges under the PRC's rural vitalization strategy, including food security, climate change adaptation, environmental sustainability, and rural prosperity.

15 National Development and Reform Commission. 2021. Lishui Shangeng: An Effective Mechanism under Brand Premium. https://www.ndrc.gov.cn/xwdt/ztzl/jljqstcpjzsxjz/jdal/202108/t20210827_1294852.html?code=&state=123.

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