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The Evolution of Policies for the Resource Utilization of Livestock Manure in China

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Abstract: With the continuous development of animal husbandry, the harmless handling and resource utilization of livestock manure has gradually become a bottleneck problem in sustainable agriculture and livestock production in China. This study evaluates the policies related to manure handling and utilization in different economic development periods in China. The decreased pollutant discharge from livestock manure indicates the effectiveness of the strategy aiming to encourage the construction of manure treatment facilities and resource utilization in cropland and to establish a sound legal system for pollutant discharge. New policies and measures should be introduced to promote the coupling of intensive livestock breeding and crop planting, with the direction of nutrient management planning and the incorporation of a service platform for the resource utilization of manure. Technological innovation in green livestock breeding should be supported by policies to achieve source reduction in pollutants in breeding waste.

Keywords: China; animal husbandry; manure; environmental pollution; policy

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1. Introduction

Livestock husbandry is the mainstay of the rural economy in China, as well as in many other countries. Livestock husbandry provides meat, egg, and milk to satisfy the increasing demands for animal protein in the world. It has been estimated that, by 2050, global farm animal production will double, with a faster growing rate than any other agricultural subsector, especially in the developing world [1]. On the other hand, in livestock production, an integral part of the traditional farming system, it is crucial to maintain the sustainability of agricultural systems by utilizing crop residues and other feeds and providing manure as a soil amendment [2]. The global N intake by animals is estimated to be 110 million tons per year, while the global N excretion by animals is estimated to be 100 million tons, implying a 10% efficiency in N use [3]. Livestock production is important in full-chain nutrient use efficiency [4].

The livestock industry produces a large amount of manure. It is estimated that agricultural animals can produce 20 million tons of dry matter and 10 million tons of organic matter through their manure daily [5]. In the European Union (EU), livestock produces about 1.3–1.8 billion tons of manure per year [4]. In China, around 3.8 billion tons of livestock and poultry manure are generated each year, with a less than 60% comprehensive utilization rate [6]. Driven by market demand and policy encouragement, the intensive

livestock and poultry industry has developed rapidly in China and across the world. Large industrial farms were responsible for about 39% of all meat production and 50% of all egg production worldwide [7]. The fast development of the intensive livestock and poultry industry has resulted in the separation of livestock production from the traditional farming system. Large-scale livestock farms normally have insufficient cropland, leading to significant environmental and resource issues for the surrounding ecosystem. The agglomeration of intensive and large animal production systems has resulted in regional surpluses of animal manure, which, in turn, causes pollution in the surrounding areas [8]. In Flanders, Belgium, the high population density alongside intensive industry and livestock production make it a nutrient-rich region. The large fraction of animal manure, which is applied on arable land in Flanders, directly contributes to high nutrient losses to the environment [9]. Livestock and poultry production in China presents a significant environmental threat, particularly in southwest, central, and eastern China [10]. In contrast, the spatial distribution of the manure proportion of total inputs is lower in eastern China and higher in western China [11].

The negative influence of manure discharge includes increased greenhouse gas emissions, greater than emissions produced by the whole transport industry, as well as land degradation, water pollution, and increased health problems [12]. Aside from the environmental issues, pathogenic microorganisms in livestock manure are a source of hazards to human health. Inappropriate manure management causes significant pollution of the local environment and may be a source of disease [8]. Moreover, animal husbandry operations result in groundwater contamination with antimicrobial-resistant bacteria (ARBs) and antimicrobial-resistant genes (ARGs) [13].

In China, the increasing environmental pressure caused by the rapid growth of livestock manure has promoted the enactment of policies, legislations, and regulations related to sustainable manure management and resource utilization. In 1997, the 15th National Congress of the Communist Party of China (CPC) officially proposed the implementation of the sustainable development strategy. In 2015, the United Nations put forward the Sustainable Development Goals to ensure sustainable consumption and production patterns [14]. The present study summarizes the developmental process of policies and legislation systems for livestock manure management to address the fast growth of the livestock industry in China over the past 40 years. The policies and measures aiming to encourage the combination of intensive livestock production and farming from the perspective of sustainable livestock manure management are discussed.

2. Materials and Methods

This study focuses on four main areas: (1) livestock production in China since the reform and opening-up; (2) the legal framework supporting pollution control in China; (3) the laws and policies on manure resource utilization and pollution control in China; (4) policy suggestions for the future.

The main approaches employed consist of the following: (1) The identification of policy and regulation documents on the relevant national governmental sites in China. In this study, the control of pollution from manure was analyzed at the national level. The policies related to livestock and poultry manure treatment, resource utilization, and pollution control since the reform and opening-up were included. (2) A review of scientific publications regarding the technology and policies on the reduction in pollutants from livestock production. The suggested policies based on technological applications were emphasized. The review involved searching for scientific articles published in international journals with the main key words including ‘livestock’, ‘manure’, and ‘resource utilization’, using Baidu Scholar and PubMed, focusing on the international research that offered

a comparative analysis with China. The biases in document selection and gaps in the available literature may lead to a narrow scope of research. Moreover, the policies and regulations in China were reviewed at the national level; the provincial disparities were not considered, which may affect the conclusions drawn this the study.

3. Results and Discussion

3.1. Livestock Production in China

Since the reform and opening-up, China's livestock production has experienced three main stages: rapid growth in output, synchronous growth in output and product quality, and high-quality development.

3.1.1. The Quantitative Development Stage (From 1978 to 2000)

Before 1978, China's livestock production was at a low level. Since the beginning of the reform and opening-up, the consumption of livestock products has entered a stage of rapid growth. In 1978, China's per capita meat consumption was 8.86 kg and reached 20.91 kg in 2000, with an annual increase of about 0.55 kg per capita. Strong demand drives the rapid development of livestock husbandry, and China's meat output increased from 8.56 million tons (mainly pigs, cattle, and sheep) in 1978 to 61.25 million tons in 2000, rising at a double-digit growth rate. The main characteristic of the livestock production sector during this stage was the fast growth in the output of animal products, which basically met the growing demand for animal product consumption (Figures 1 and 2) [15,16].

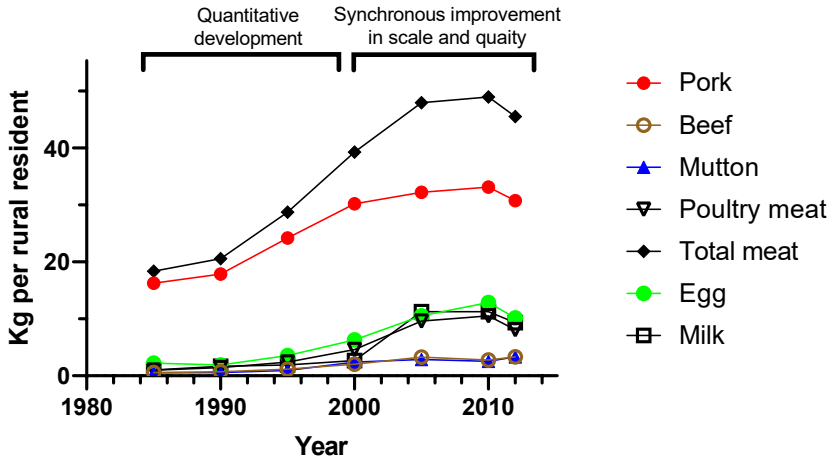

Figure 1. The meat, egg, and milk production per rural resident in China from 1985 to 2012.

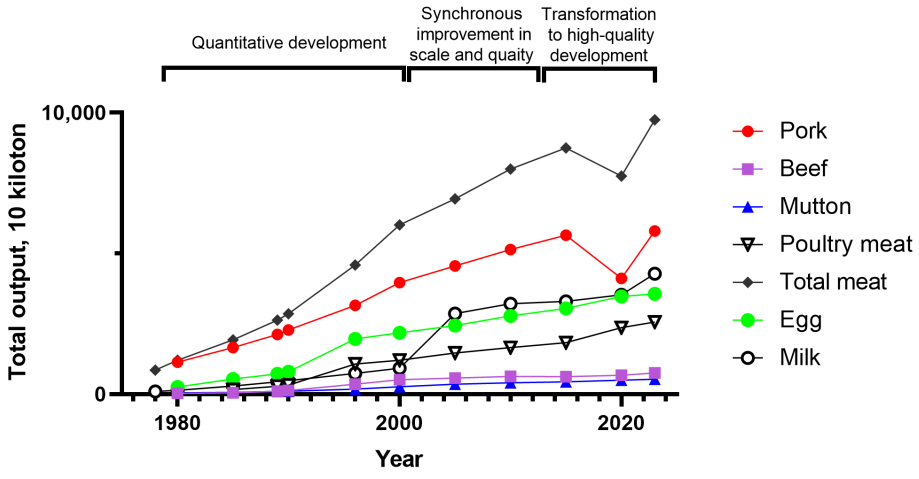

Figure 2. The meat, egg, and milk production in China from 1978 to 2023.

3.1.2. The Stage of Synchronous Improvement in Scale and Quality (2001–2013)

In the period from 2001 to 2013, the total output of meat, eggs, and milk in China increased from 63.34, 23.37, and 11.23 million tons in 2001 to 85.35, 28.76, and 36.49 million tons in 2013, respectively, and the per capita consumption of meat, eggs, and milk increased from 49.6, 18.3, and 8.8 kg in 2001 to 62.7 kg, 21.1 kg, and 26.8 kg in 2013, respectively (Figures 1 and 2). Accompanied by the fast growth in livestock production, the large amount of livestock manure with a low level of resource utilization has resulted in serious environmental pollution. According to the data of the Communiqué of the First National Pollution Survey in 2007 [17], the livestock industry produced 243 million tons of manure and 163 million tons of urine. The main water pollutant emissions from livestock production were 12.68 million tons of chemical oxygen demand (COD), 1.02 million tons of total nitrogen (TN), and 0.16 million tons of total phosphorus (TP), accounting for 95.8%, 37.9%, and 56.3% of the total agricultural pollution, respectively, and 41.9%, 21.7%, and 37.9% of the total national emissions, respectively (Table 1). The extensive development of the animal husbandry sector has brought about food safety risks and ecological environment challenges. In order to strengthen safety management and risk monitoring, the Ministry of Agriculture launched the "Action Plan for Pollution-free Food" in April 2001, which enforced the shift of livestock production from quantitative expansion to qualitative development. After the infant milk powder incidents, the Food Safety Law of the People's Republic of China was promulgated and implemented in 2009. In the livestock production sector, breeding inputs such as veterinary drugs, feed, and feed additives have been controlled, and the quality and safety of livestock products have been fundamentally improved. Meanwhile, the environmental challenge from breeding waste has become a problem to be solved.

Table 1. The pollutant emissions produced by livestock production, 10× million Kg.

	National Emissions	Agricultural Emissions	Livestock Emissions	Intensive Livestock Farms [3]	% National Emissions [4]	% Agricultural Emissions [5]	% Livestock Emissions [6]
2007 [1]							
COD	3028.96	1324.09	1268.26	-	41.87	95.78	
NH_3-N	172.91	-	-	-	-	-	
TN	472.89	270.46	102.48	-	21.67	37.89	
TP	42.32	28.47	16.04	-	37.90	56.34	
2017 [2]							
COD	2143.98	1067.13	1000.53	604.83	46.67	93.76	60.45
NH_3-N	96.34	21.62	11.09	7.50	11.51	51.29	67.63
TN	304.14	141.49	59.63	37.00	19.61	42.14	62.05
TP	31.54	21.20	11.97	8.04	37.95	56.46	67.17

COD, chemical oxygen demand; TN, total nitrogen; TP, total phosphorus. [1] Data from the Communiqué of the First National Pollution Survey. [2] Data from the Communiqué of the Second National Pollution Survey. [3] Intensive livestock farms. [4] The percentage of pollutant emissions from livestock production in total national emissions. [5] The percentage of pollutant emissions from livestock production in agricultural emissions. [6] The percentage of pollutant emissions from intensive livestock farm in total livestock production emissions.

3.1.3. Transformation Stage to High-Quality Development (Since 2014)

The increasing severity of the environmental challenge of livestock production waste resulted in the promulgation and implementation of "The Regulation on the Prevention and Control of Pollution from Large-scale Livestock and Poultry Operations" in 2014. It marked the beginning of moving China's livestock production toward green development. The regulation promoted manure resource recycling and use and achieved positive results in decreasing manure pollution. According to the data of the Communiqué of

the Second National Pollution Survey [18], the discharge of water pollutants in livestock production in 2017 was 10.00 million tons of COD, 110,900 tons of ammonia nitrogen (NH_3-N), 596,300 tons of TN, and 119,700 tons of TP. Among them, the discharge of water pollutants from large-scale farms was 6.05 million tons of COD, 75,000 tons of NH_3-N, 370,000 tons of TN, and 80,400 tons of TP, accounting for 60.5%, 67.6%, 62.0%, and 67.2% of total livestock production, respectively (Table 1). Although the absolute emission of pollutants from livestock production has been dramatically decreased, the proportions of livestock production in the total national emissions and agricultural emissions remain at high levels, meaning that manure resource utilization and pollution control remains an arduous task in China. In this period, a series of policies have been implemented to promote the development of agricultural production toward high production efficiency, food safety, resource saving, and environmentally friendliness. The marked feature of animal husbandry in this period is to strengthen pollution prevention by reducing waste and to promote sustainable and green development.

3.2. The Roll-Out of the System of Law on Pollution Control in China

3.2.1. The Initial Establishment Stage (From 1973 to 1991)

In 1972, the United Nations Conference on the Human Environment was held in Stockholm and the attending nations signed the "Declaration of the United Nations Conference on the Human Environment". After the meeting, in 1973, the State Council convened the first national conference on environmental protection. In this meeting, it issued the first environmental protection legal document of China, "A Number of Provisions on Protecting and Improving the Environment". The issued working policy on environmental protection was as follows: comprehensive planning, rational distribution, comprehensive utilization, turning pollution to resource, relying on the masses, everyone being hands-on, protecting the environment, and benefiting the people.

Along with the reform and opening-up, increasing attention has been paid to environmental protection. In 1979, the "Law of the People's Republic of China on Environmental Protection (Trial)" was issued for trial implementation, which, for the first time, established the basic principles, tasks, and policies of environmental protection in China in legal form. After 10 years of development, the "Environmental Protection Law of the People's Republic of China" was promulgated and implemented in 1989. On this basis, China has successively promulgated and implemented several specific regulations on environmental protection, such as the "Law on Water Pollution Prevention and Control" (implemented in 1984), the "Law on Air Pollution Prevention and Control" (implemented in 1988), and the "Law on Solid Waste Pollution Prevention and Control" (implemented in 1996), which enriches the environmental protection legal system in China.

3.2.2. The Transition Stage (1992–2010)

It is well known that the increase in economic growth and production has caused environmental risks, whereas environmental pollution is one of the vital risk factors for sustainable growth. There is an inverted U-shaped relationship between the environmental pollution index and the per capita income [19]. Therefore, sustainable development was proposed in the late 1980s to address the challenges of environmental deterioration and resource scarcity, emphasizing the coordinated development of the economy, society, and environment [20]. The Chinese government began to change from a focus on pollution control to an equal focus on pollution control and ecological conservation.

In 1992, after the United Nations Conference on Environment and Development (Rio), the government published "China's Ten Strategic Policies on Environment and Development" and established the implementation of sustainable development as a national

strategy. Thereafter, "China's Agenda 21, China's White Paper on Population, Environment and Development of 21st Century" (China's Agenda 21) was formulated and implemented in 1994, which is the overall strategy for China's sustainable development. To ensure the implementation of sustainable development, the "Decision of the State Council on Several Issues Concerning Environmental Protection" was issued in 1996. The Decision established a system of maximum quantity control and the verification procedure for control over the discharge of major pollutants. In 2000, the "National Guidelines of Ecological Environmental Conservation" was issued to fully implement the sustainable development strategy and the basic national policy for environmental protection. Thereafter, the "Law on Promoting Cleaner Production" was promulgated in 2003 (revised in 2012) to improve resource utilization efficiency, reduce the generation of pollutants, protect and improve the environment, and promote sustainable economic and social development. By taking a reduction in the major pollutants as the obligatory target for economic growth, there was a shift in the focus on pollution control from end-of-pipe treatment to source control by adjusting economic structures [21].

3.2.3. The Gradually Improving Stage (2010–Present)

In the 18th National Congress of the Communist Party of China (CPC), the construction of ecological civilization was included in the overall layout of the "Five in One" with economic construction, political construction, cultural construction, and social construction. Ecological civilization, a new form of civilization after primitive civilization, agricultural civilization, and industrial civilization, is the new stage in the development of human civilization. Thereafter, the new development concept of "innovation, coordination, green, openness, and sharing" was established in 2015. In 2017, "Enhancing the awareness that lucid waters and lush mountains are invaluable assets" was officially written into the Party Constitution of the CPC. New development concepts, ecological civilization, and building a beautiful China were written into the Constitution of China in 2018. The strategic position of ecological civilization has been significantly elevated, and the construction of ecological civilization and the protection of the ecological environment have become important components of high-quality development. China has been prioritizing eco-environmental progress and pursuing green development under the guidance of ecological civilization. In this period, a series of new policies, laws, and regulations have been made and enacted and the existing laws have been revised accordingly (Table 2). The legal system for environmental protection is gradually improving.

Table 2. The laws, regulations, policies, and actions relevant to livestock manure management and resource utilization in China from 2010 to 2020.

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2010	Guiding Opinions of Ministry of Agriculture on Accelerating the Standardization of Intensive Livestock and Poultry Farm	Livestock farms should strictly adhere to the laws and regulations on standardized production and manure treatment.	https://www.moa.gov.cn/gk/tzgg_1/tz/201003/t20100329_1456886.htm (accessed on 29 March 2010).
2010	Work Plan for Creation of Standardized Demonstration of Intensive Livestock and Poultry Farm	Standardized livestock farms should handle manure harmlessly by using the proper method and the necessary facilities, achieving resource utilization or meeting the national discharge standard.	https://www.moa.gov.cn/nybgb/2010/dwq/201805/t20180531_6150772.htm (accessed on 20 May 2010)

Table 2. *Cont.*

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2014	The Regulation on the Prevention and Control of Pollution from Large-scale Livestock and Poultry Operations	Governments at all levels should clarify the goals and tasks of pollution prevention and control in livestock and poultry breeding and specify the construction of key pollution control facilities and the reduction in waste from breeding production and discharge into environment, thus encouraging and supporting manure use for fertilizer and for energy.	https://www.gov.cn/flfg/2013-11/26/content_2535095.htm (accessed on 26 November 2013)
2015	Guiding Opinions on Promoting the Adjustment and Optimization of Pig Farming Layout in Southern Water Network Areas	By 2020, the proportion of large-scale pig farming with an annual output of over 500 heads should have reached over 70%, the proportion of large-scale pig farms with supporting facilities should have reached over 85%, and the comprehensive utilization rate of pig manure should have reached over 75% in the southern water network region.	https://www.moa.gov.cn/govpublic/XMYS/201511/t20151127_4917216.htm (accessed on 27 November 2015)
2015	Environmental Protection Law of the People's Republic of China	Governments at or above the county level should incorporate environmental protection into their local economic and social development plan. All of the units and individuals engaged in livestock and poultry breeding and slaughtering should take measures to scientifically dispose of breeding waste such as manure, dead animals, and sewage to prevent environmental pollution.	https://www.mee.gov.cn/ywgz/fgbz/fl/201404/t20140425_271040.shtml (accessed on 25 April 2014)
2015	Action Plan for Water Pollution Prevention and Control	This plan scientifically delimited the areas prohibited for livestock and poultry breeding. Intensive livestock and poultry farms should coordinate to construct facilities for the storage, handling, and utilization of manure and wastewater. In the dense region of small-scale livestock and poultry farms, manure and wastewater should be collected and centrally treated for resource utilization. Newly built, reconstructed, and expanded livestock and poultry farms should have a system of rainwater and sewage division from 2016.	https://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm (accessed on 16 April 2014)
2016	Action Plan for Soil Pollution Prevention and Control	This plan promoted source reduction by strictly regulating the production and reasonable use of veterinary drugs and feed additives. It encouraged the integration of crop and pig production for circular development. The proportion of intensive livestock and poultry farms with manure treatment facilities and equipment should have reached over 75% by 2020.	https://www.gov.cn/zhengce/content/2016-05/31/content_5078377.htm (accessed on 31 May 2016)
2016	National Development Plan for Pig Production (2016–2020)	The comprehensive utilization rate should have reached over 75% by 2020.	https://www.moa.gov.cn/govpublic/XMYS/201604/t20160420_5101912.htm (accessed on 20 April 2016)

Table 2. *Cont.*

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2017	Guidelines on Promoting Agricultural Supply-side Structural Reform	These guidelines aimed to promote the carrying out of pilot projects for the county-wide promotion of an integrated crop–livestock system, to accelerate the centralized treatment of livestock and poultry manure, and to promote technical models for the comprehensive utilization of manure, such as "fruit livestock", "vegetable livestock", "tea livestock", etc.	https://www.gov.cn/zhengce/202203/content_3635258.htm (accessed on 5 February 2017)
2017	Opinions of the General Office of the State Council on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste	By 2020, a scientific and standardized system for the resource utilization of livestock and poultry manure with clear rights and responsibilities and strong constraints should have been established and performed in a crop–livestock integrated manner. The comprehensive utilization rate of livestock and poultry manure should have reached over 75%. The farms equipped with manure treatment facilities and equipment should have reached over 95% for intensive farms and 100% for large-scale breeding farms one year ahead of schedule.	https://www.gov.cn/zhengce/content/2017-06/12/content_5201790.htm (accessed on 12 June 2017)
2017	Action Plan for Resource Utilization of Livestock and Poultry Manure (2017–2020)	The comprehensive utilization rate of manure should have reached over 75%, and the construction rate of manure treatment facilities and equipment should have reached over 95% in intensive farms and 100% in large-scale breeding farms one year ahead of schedule.	https://www.moa.gov.cn/govpublic/XMYS/201707/t20170710_5742847.htm (accessed on 10 July 2017)
2017	Opinions on Innovating Systems and Mechanisms to Promote Green Agricultural Development	This measure establishes a comprehensive system guided by green ecology to improve the resource utilization of livestock manure. It clarified the territorial responsibilities of local governments and the main responsibilities of the farms.	https://www.gov.cn/zhengce/2017-09/30/content_5228960.htm (accessed on 30 September 2017)
2018	Law of the People's Republic of China on Environmental Protection Tax	The emissions equivalent of atmospheric pollutants, solid waste, and water pollutant emissions from livestock and poultry manure and waste was specified.	https://www.gov.cn/zhengce/content/2017-12/30/content_5251797.htm (accessed on 30 December 2017)
2018	Law of the People's Republic of China on the Prevention and Control of Water Pollution (Amended)	This measure added the requirements for the collection and treatment of sewage by small-scale livestock farms and clarified the responsibilities of local governments.	https://www.mee.gov.cn/ywgz/fgbz/fl/200802/t20080229_118802.shtml (accessed on 1 January 2018)
2018	Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution (Amended)	Livestock and poultry farms should collect, store, transport, and harmlessly treat sewage and livestock and poultry manure in a timely manner to prevent the emission of odorous gases.	https://www.mee.gov.cn/ywgz/fgbz/fl/201811/t20181113_673567.shtml (accessed on 13 November 2018)
2018	Opinions of Central Committee of CPC and State Council on Comprehensively Enhancing Ecological and Environmental Protection and Resolutely Fighting the Tough Battle of Pollution Prevention and Control	Farms should adhere to the integration of crop planting and livestock breeding, and locally dispose of and utilize livestock and poultry breeding waste. By 2020, the comprehensive utilization rate of livestock and poultry manure should have reached over 75%, and large-scale breeding farms equipped with manure treatment facilities should have reached over 95%.	https://www.gov.cn/zhengce/202203/content_3635309.htm (accessed on 24 June 2018)

Table 2. *Cont.*

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2020	Notification on Further Clarifying the Requirements for Resource Utilization of Livestock and Poultry Manure to the Field and Strengthening the Supervision of Livestock and Poultry Farm Pollution	This measure encouraged the resource utilization of livestock and poultry manure in cropland, established the standards and regulations for the use of manure as fertilizer in cropland, and strengthened technical and equipment support. It also strengthened the in-process and post-event supervision of manure resource utilization in farm fields.	https://www.gov.cn/zhengce/zhengceku/2020-06/17/content_5520019.htm (accessed on 4 June 2020)
2020	Law of the People's Republic of China on the Prevention and Control of Solid Waste Pollution	To avoid environmental pollution, intensive livestock and poultry farms should collect, store, and utilize or dispose of solid waste generated from the animal breeding procession in a timely manner.	https://www.mee.gov.cn/ywgz/fgbz/fl/202004/t20200430_777580.shtml (accessed on 30 April 2020)
2020	Opinions on Promoting High Quality Development of Animal Husbandry	The development of animal husbandry should stay market-driven, eco-friendly, and policy-led. The comprehensive utilization rate of breeding waste in large-scale livestock and poultry farms should reach more than 80% by 2025 and 85% by 2030.	https://www.gov.cn/zhengce/content/2020-09/27/content_5547612.htm (accessed on 27 September 2020)
2021	Opinions on Promoting the Sustainable and Healthy Development of the Pig Industry	This measure aimed to accelerate resource utilization by promoting the integration of planting and breeding, to promote a management system for nutrient balance, and to accelerate the cultivation of socialized service organizations.	https://www.gov.cn/zhengce/zhengceku/2021-08/07/content_5629987.htm (accessed on 5 August 2021)
2021	Opinions on Comprehensively Promoting Rural Revitalization and Accelerating Agricultural and Rural Modernization	This measure aimed to build a number of demonstration counties of agricultural non-point source pollution comprehensive control in the Yangtze River Economic Belt and Yellow River Basin.	http://cpc.people.com.cn/n1/2021/0222/c64387-32033326.html (accessed on 22 February 2021)
2021	Guiding Opinions on Accelerating the Establishment and Improvement of a Green and Low-Carbon Circular Development Economic System	This measure aimed to accelerate the green development of agriculture, improve the level of resource utilization of livestock and poultry manure, and promote the comprehensive utilization of crop straw.	https://www.gov.cn/zhengce/content/2021-02/22/content_5588274.htm?5xyFrom=site-NT (accessed on 22 February 2021)
2021	Notices of the Ministry of Natural Resources and Ministry of Agriculture and Rural Affairs on Land Management for Facility Agriculture	This measure aimed to integrate land for livestock and poultry breeding, including land for manure treatment, as agricultural production land.	https://gk.mnr.gov.cn/zc/zxgfxwj/202102/t20210202_2609527.html (accessed on 2 February 2021)
2021	Regulations on the Management of Pollutant Discharge Permits	All of the units are subjected to the classified management of pollutant discharge permits according to the amount of pollutants generated, pollutant emissions, and the degree of impact on the environment.	https://www.mee.gov.cn/ywgz/fgbz/xzfg/20210/t20210129_819519.shtml (accessed on 29 January 2021)
2021	Law of the People's Republic of China on Rural Revitalization Promotion	This measure encouraged and supported agricultural producers to adopt advanced breeding technologies in water saving and energy saving, promoted the integration of planting and breeding, and prioritized the development of ecological circular agriculture.	https://www.gov.cn/xinwen/2021-04/30/content_5604050.htm (accessed on 29 April 2021)

Table 2. *Cont.*

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2021	Opinions of the Central Committee of CPC and State Council on Further Fighting the Tough Battle of Pollution Prevention and Control	By 2025, carbon dioxide emissions per unit of the country's GDP should be reduced by 18% from its level in 2020.	https://www.gov.cn/zhengce/2021-11/07/content_5649656.htm (accessed on 7 November 2021)
2021	14th Five Year Plan to Promote Agricultural and Rural Modernization	This plan supported the development of green circular agriculture which combines planting and breeding, continuously carrying out resource utilization of livestock and poultry manure, strengthening the construction of manure treatment facilities in large-scale breeding farms, and promoting the use of manure as fertilizer in cropland.	https://www.gov.cn/zhengce/content/2022-02/11/content_5673082.htm (accessed on 11 February 2022)
2022	Action Plan for the Battle of Agricultural and Rural Pollution Control (2021–2025)	This plan enforced the supervision of pollution prevention and control in livestock and poultry farming. By 2025, the comprehensive use rate of livestock and poultry manure should reach more than 80%.	https://www.mee.gov.cn/xxgk2018/xxgk/xxgk03/202201/t20220129_968575.html (accessed on 25 January 2022)
2022	Self-monitoring Technology Guidelines for Pollution Sources—Livestock and Poultry Breeding	The standard is applicable to the self-monitoring of water and gas pollutants, noise, and their impact on the surrounding environmental quality produced by livestock and poultry farms.	https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/202205/t20220517_982349.shtml (accessed on 1 July 2022)
2022	Technical Guidelines for Construction of Fecal Treatment Facilities in Livestock and Poultry Farms	This measure provided guidelines for reducing water consumption, manure, odor, and greenhouse gas emissions through clean production, the improvement in animal breeding and manure handling facilities, and the comprehensive utilization of manure.	https://www.moa.gov.cn/govpublic/xmsyj/202208/t20220823_6407515.htm (accessed on 12 August 2022)
2023	Guiding Opinions on Promoting the Construction of Standard System for Resource Utilization of Livestock and Poultry Manure	By 2030, this measure aims to set and revise around 100 national and industry standards and a series of local, group, and enterprise standards mainly for manure on-site and nearby utilization for energy and fertilizer, improving the standard system for the resource utilization of livestock and poultry manure. It aims to develop a a basic promotion service system combining public welfare and marketization for the standardization of manure treatment and utilization.	https://www.gov.cn/lianbo/bumen/202308/content_6901183.htm (accessed on 31 August 2023)
2024	Opinions of the Central Committee of CPC and the State Council on Accelerating the Comprehensive Green Transformation of Economic and Social Development	By 2030, this measure aims to achieve remarkable results in the green transition in all areas of economic and social development; and by 2035, a green, low-carbon, and circular development economic system should be basically established.	https://www.gov.cn/zhengce/202408/content_6967663.htm (accessed on 11 August 2024)
2024	Guiding Opinions of the Ministry of Agriculture and Rural Affairs on Accelerating the Comprehensive Green Transformation of Agricultural Development and Promoting Rural Ecological Revitalization	This measure promoted source reduction and the scientific utilization of manure in nearby cropland. By 2030, the comprehensive use rate of livestock and poultry manure should reach more than 85%.	https://www.gov.cn/zhengce/zhengceku/202412/content_6995343.htm (accessed on 26 December 2024)

Table 2. *Cont.*

Year	Name of Laws, Regulations, and Policies	Objective and Main Contents	Source
2024	Opinions of the General Office of the State Council on Accelerating the Construction of Waste Recycling System	This measure aims to establish a sound system for the collection, treatment, and utilization of livestock and poultry manure, and to construct facilities for centralized manure collection, treatment, and storage, as well as facilities for biogas residue and slurry storage and utilization, according to local conditions.	https://www.gov.cn/gongbao/2024/issue_11186/202402/content_6934547.html (accessed on 6 February 2024)

3.3. The Laws and Policies on Manure Resource Utilization and Pollution Control in China

In order to prevent pollution from the livestock sector, many countries have implemented a series of regulations. For example, most European countries have similar regulations regarding livestock farming including licensing required for housing animals, the storage of manure and slurry to enable better agronomic utilization, and prohibited periods for land spreading [22]. The policies and regulations in China also pertain to storage and resource utilization.

3.3.1. Laws on High-Quality Development in Animal Husbandry Industry

To promote the sustainable development of the animal production sector, the relevant content about the handling and utilization of breeding wastes has been included in the laws on agriculture and animal husbandry since 2000. When the "Law of People's Republic of China on Agriculture" was first implemented in 1993, there was no article about the harmless treatment and resource utilization of livestock manure. The revised law in 2003 made clear provisions for the treatment and utilization of livestock and poultry breeding waste. The units and individuals engaged in intensive livestock and poultry breeding should carry out harmless handling or comprehensive utilization of manure, wastewater, and other waste to prevent environmental pollution and ecological damage. Thereafter, for the guidance of modern animal husbandry, the "Law of the People's Republic of China on Animal Husbandry" came into effect in 2006, providing detailed regulations on livestock farms and pollution discharge behavior. There is government support to build facilities for the comprehensive utilization or harmless disposal of breeding waste, while livestock and poultry farms should ensure their normal running. The farms should guarantee that pollutants are discharged in compliance with the relevant standards. When the law was revised again in 2022, content about the resource utilization of manure was added, stating that the breeding waste should be comprehensively utilized. The government encourages the utilization of manure as organic fertilizers and the development of integrated planting and breeding under the guidance of a nutrient balance management plan. In the "Circular Economy Promotion Law of the People's Republic of China", issued in 2009, the state encourages and supports agricultural producers and related enterprises to adopt advanced or applicable technologies for the comprehensive utilization of livestock and poultry manure.

In order to promote the transformation of the growth of the animal production industry from extensive to modern and standardized, the Ministry of Agriculture issued the "Opinions on Accelerating the Promotion of Standardized Scale Breeding of Livestock and Poultry" and the "Work Plan for the Creation of Standardized Demonstration farms for Livestock and Poultry Breeding" in 2010, which regard the prevention and control of livestock and poultry breeding waste as an important part of standardized breeding, highlighting the harmless disposal of livestock and poultry manure. In 2018, the second round of the establishment of standardized demonstration of livestock and poultry breeding

(2018–2025) was carried out to encourage environmentally friendly production methods in livestock breeding.

To further promote the sound development of the animal husbandry industry, the General Office of the State Council issued the "Guideline on Promoting the High-quality Development of the Animal Husbandry Industry" (2020). It has been stressed that the state will continuously promote the green and circular development of animal husbandry in three aspects: promoting the resource utilization of breeding wastes, strengthening circular agriculture by integrated planting and animal breeding, and comprehensively improving the level of green breeding. The guideline set the goal that the comprehensive utilization rate of breeding waste in large-scale livestock and poultry breeding farms should reach more than 80% by 2025 and 85% by 2030. The environmental constraint targets were implemented in the "14th Five Year Plan for National Agricultural Green Development" issued by six departments including the Ministry of Agriculture and Rural Affairs. The issuance of the guidance has significant practical and far-reaching historical significance for ensuring the sustainable and healthy development of the animal husbandry industry.

3.3.2. The Laws and Regulations Specializing in the Resource Utilization and Pollution Control of Livestock and Poultry Breeding Waste

The "Administrative Measures for Pollution Prevention and Control in Livestock and Poultry Farming" regulation, issued by the State Environmental Protection Administration in 2001, firstly governs the layout of livestock breeding sites, facility construction for the prevention and control of pollution from breeding waste, and pollutant discharge. The proposed principles for the treatment of breeding waste are reduction, harmless handling, resource utilization, and the prioritization of comprehensive utilization. To supplement the regulation, the corresponding technical standards were put forward, such as the "Discharge Standard of Pollutants for Livestock and Poultry Breeding (GB 18596-2001)" and the "Technical Standard of Preventing Pollution for Livestock and Poultry Breeding (HJ/T 81-2001)" [23,24]. The regulation and standards provided guidelines for the handling of breeding waste during the fast-growing period of intensive animal husbandry.

Fifteen years later, the "Regulations on the Prevention and Control of Pollution from Large scale Livestock and Poultry Farming" (State Council) came into effect in 2014. The regulation systematically stipulated the requirements for pollution prevention and control in livestock and poultry farming, the comprehensive utilization of manure, and the legal responsibilities. The regulations define the prohibited areas for breeding livestock and poultry. New and expanding livestock and poultry farms are asked to undergo environmental impact assessments, and all farms should be equipped with facilities for manure storage and handling and should ensure their normal operation. The regulations encourage the comprehensive utilization of breeding waste by means of measures such as returning it to cropland, the preparation of biogas, and the manufacture of organic fertilizer. The regulation specifies that breeding farms are the main entities responsible for implementing manure treatment and pollution prevention and control. Based on the regulation, the prevention and control of pollution from livestock and poultry breeding waste has gradually been incorporated into the relevant administrative regulations and policies. Thereafter, the prevention measures, comprehensive utilization, and treatment of breeding waste, incentive measures, and legal responsibilities have gradually improved, forming a distinctive system of regulations and policies for manure treatment in China.

In 2016, the 14th meeting of the Central Leading Group on Financial and Economic Affairs of CPC studied the disposal and recycling utilization of livestock breeding waste. The meeting emphasized that the resource utilization of manure is related to the lives of over 600 million rural residents, in addition to aspects of the rural energy revolution, improvements in soil fertility, and the governance of agricultural non-point source pollution.

It was proposed to solve the problem of resource utilization of breeding waste during the 13th Five Year Plan period. Thereafter, the policy system related to manure management began to transition from directive policies to incentive policies to increase the incentives for the resource utilization of livestock manure [25]. In June 2017, the General Office of the State Council issued the "Opinions on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste". This aims to establish scientific, standardized, and clear rights and responsibilities and strong constraint systems for the resource utilization of breeding waste, forming a circular development mechanism for planting and breeding. By 2020, the comprehensive utilization rate of livestock and poultry manure in China should have reached over 75%, and the matching rate of manure treatment facilities in intensive livestock farms should have reached over 95%. For large-scale livestock farms, the matching rate of manure treatment facilities should have reached 100% by 2019, one year ahead of schedule. Thereafter, the General Office of the Ministry of Agriculture and Rural Affairs and the General Office of the Ministry of Ecology and Environment issued the "Guiding Opinions on Promoting the Returning Utilization of Livestock and Poultry Breeding Wastes to Cropland and Strengthening the Control of Pollution from Livestock Breeding in accordance with the Laws". As a supporting policy, the comprehensive utilization rate of livestock and poultry manure should reach 80% by 2025 and 90% by 2035. The guideline aims to facilitate the full utilization of manure in cropland with low-cost measures, setting up a new pathway for the green development of animal husbandry. For further implementation of the policy, the Office of the Ministry of Agriculture and Rural Affairs and the Office of the Ministry of Ecology and Environment issued a notice "Further Clarifying the Requirements for Returning Livestock and Poultry Manure to Cropland and Strengthening the Supervision of Pollution" (2020). The notice promulgated a series of standards and specifications to guide the utilization of breeding waste in cropland or pollution discharge. For livestock farmers with sufficient supporting cropland, manure utilization in cropland after harmless treatment should comply with the requirements of the "Technical Specifications for Sanitation Treatment of Livestock and Poultry Manure" (GB/T 36195) [26] and the "Technology Code for Land Application Rates of Livestock and Poultry Manure" (GB/T 25246) [27], and the supporting area of cropland should reach the minimum requirement of the "Technical Guidelines for Calculating the Carrying Capacity of Cropland for Livestock and Poultry Breeding Waste" [28]. For livestock farms with insufficient supporting cropland, the discharge of manure into the environment after treatment should comply with the requirement of the "Discharge Standards of Pollutants for Livestock and Poultry Breeding" (GB 18596) and the relevant local discharge standards [23]. The wastewater used for agricultural irrigation should comply with the "Standards for Irrigation Water Quality" (GB 5084) [29]. After the implementation of the regulations, the integrated planting and breeding measures have made significant achievements, and the pollution from manure has been controlled.

3.3.3. The Requirements for Breeding Waste Handling and Resource Utilization Outlined in the Laws and Regulations on the Protection of the Environment and Pollution Control

Since 2004, the laws and regulations on the protection of the environment and pollution control have been progressively revised in accordance with the development of the economy and society. The relevant content about the handling and resource utilization of breeding waste has gradually been included in the revised laws. The territorial management responsibility of local governments and the principal responsibility of breeding farms in the harmless treatment and resource utilization of breeding waste have been strengthened.

The "Law of the People's Republic of China on Prevention and Control of Environmental Pollution by Solid Waste", first revised in 2004 (implemented on 1 April 2005), stipulated that large-scale livestock and poultry farms should collect, store, utilize, or dispose of

manure generated during the breeding process in accordance with the relevant regulations to prevent environmental pollution. In the second revision of the law (implemented on 1 September 2020), the concept of manure was extended to solid wastes, in which livestock and poultry bedding, waste feed, feathers, and so on were included. In the "Action Plan for Soil Pollution Prevention and Control" (2016), more than 75% of large-scale breeding farms should have been equipped with handling facilities for breeding waste by 2020.

In the revised "Law of the People's Republic of China on Prevention and Control of Water Pollution" (implemented on 1 June 2008), the regulation on livestock and poultry manure and wastewater was added. The revised law required the state to support the construction of facilities for the comprehensive utilization or harmless handling of livestock and poultry wastewater, while farms should ensure the normal running of the facilities to prevent pollution in the water environment. In 2015, the "Action Plan for Prevention and Control of Water Pollution" was issued and implemented to set up the system of household collection and centralized treatment and utilization of wastewater in the concentrated area of livestock and poultry breeding. New-built, renovated, and expanded large-scale livestock and poultry farms were required to implement the separation of rainwater and sewage, as well as the resource utilization of manure and sewage, from 2016. In the second revision of the law, implemented on 1 January 2018, the relevant requirement was further refined, stating that the local governments (county and town) in the concentrated area of livestock and poultry breeding are responsible for the household collection and centralized treatment and utilization of wastewater.

The prevention of air pollution from livestock breeding did not receive attention until 2015. In the revision of the "Air Pollution Prevention and Control Law of the People's Republic of China" in 2015 (effective from 1 January 2016), a clear requirement was put forward that livestock and poultry farms should collect, store, transport, and dispose of sewage, manure, and carcasses in a timely manner to prevent the emission of odorous gases. Recently, the "Action Plan for Continuous Improvement of Air Quality" (State Council, 2023) required promoting the application of a low-protein diet for farm animals, encouraged rearing pigs and chickens in closed houses, supported storing, handling, and transporting manure in closed facilities, and strengthened waste gas collection and treatment. By 2025, the total atmospheric ammonia emissions from large-scale livestock and poultry farms in the Beijing, Tianjin, Hebei, and surrounding areas should decrease by 5% compared to 2020.

In 2015, the revised "Environmental Protection Law of the People's Republic of China" (implemented on 1 January 2015) put forward for the first time a requirement for pollution prevention and control in livestock and poultry breeding. It stipulated that farms should take scientific measures to handle manure, carcasses, and wastewater to prevent environmental pollution. The local governments have the responsibility to provide guidelines for the effective handling of livestock manure and wastewater.

To further promote the resource utilization and harmless handling of breeding waste, economic measures have been used in environmental management. The policy of pollution fees is an important financial tool for environmental protection. The environmental fees system has been employed to internalize the external environmental costs of emission units since 1982, according to the "Interim Measures for the Collection of Pollution Charges", which was presented after the "Law of the People's Republic of China on Environmental Protection" (for trial implementation) was published. After more than 30 years, a positive effect has been observed, namely the reduction in SO_2 and COD emissions, achieving the goal of a cleaner environment [30,31]. The drawbacks such as the higher cost of pollution control compared to the pollution levy standard, the inequitable regional expropriation, and the arbitrarily reduced or exempted pollutant fees to attract investment and increase regional GDP, however, have led to major flaws and loopholes in the pollutant emission

fees system [30]. The policy "environmental fees to taxes" could effectively curb the environmental violations of corporations, mainly by increasing the environmental supervision capacity of the government and the environmental endeavors of corporations [31]. The "Environmental Protection Tax Law of the People's Republic of China" (abbreviated as Environmental Taxes), announced on 25 December 2016, was implemented on 1 January 2018. The newly formulated tax law replaced environmental fees with taxes, achieving a smooth transition from the pollution discharge fee system to the environmental protection tax system in accordance with the principle of "tax burden shifting". Based on the ecological footprint accounts of 30 provinces in China from 2010 to 2020, the outcome of Environmental Taxes on restraining ecological footprints obviously surpassed that of the pollution fees [32].

In 2018, the Central Committee of the CPC and the State Council issued the "Opinions on Comprehensively Enhancing Ecological and Environmental Protection and Resolutely Winning the Tough Battle for Prevention and Control of Pollution", requesting the combination of planting and livestock breeding and the local disposal and utilization of breeding waste. By 2020, the comprehensive utilization rate of livestock and poultry breeding waste should have reached over 75%, and over 95% of large-scale breeding farms should have been equipped with manure treatment facilities. In 2021, the "Opinions of the Central Committee of the CPC and the State Council on Further Promoting the Battle of Pollution Prevention and Control" detailed major targets for improving the country's ecological environment, with the total discharge of major pollutants continuously declining by 2025 and 2035. By 2025, the comprehensive utilization rate of livestock and poultry manure in the country should reach over 80%, and a green way of life and production should be formed by 2035. As a result of the series of policies and measures to encourage an improvement in the manure resource utilization rate, the comprehensive utilization rate of manure increased gradually from 60% in 2016 to 78% in 2023 (Figure 3). This result indicated the effectiveness of the series of policies. In future, more relevant economic policies and technological innovation will be continuously carried out to support the comprehensive utilization of livestock manure.

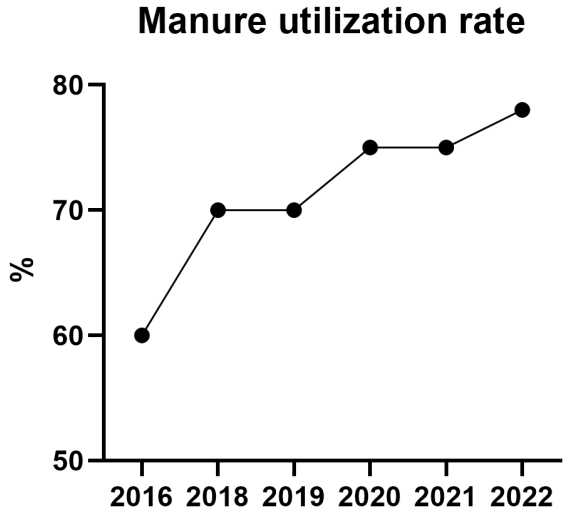

Figure 3. The comprehensive utilization rate of manure in China from 2016 to 2023.

3.3.4. Special Policies Regarding Pig Breeding

Pig production is important in the world's food supply chain. The global pork sector provided approximately 34% of the global meat supply in 2022 [33]. China is the world's largest producer and consumer of pork. The FAO forecasts global pig meat output to reach 124.6 million tons in 2022, up 1.8% from 2021, and a likely expansion in China's production

to account for around 46% of the global pig meat output [34]. In 2022, the production and consumption of pork in China were 55.41 million tons and 57.17 million tons, respectively [35]. The pig industry sector is therefore a main contributor to manure production. In 2015, the total amount of manure including fresh feces, urine, and flush wastewater generated from pigs, cows, beef cattle, poultry, and sheep in China was estimated to be 5.687 billion tons [36]. The total amount of pig, cattle, sheep, and poultry manure was estimated to be 4.37, 0.97, 0.25, and 0.096 billion tons, representing 76.8%, 17.1%, 4.4%, and 1.7% of total manure production, respectively [30]. In the EU, as well as in China, pig farms usually have insufficient agricultural areas to spread their manure in an environmentally feasible way [37]. Hence, pig farming has attracted great attention in China. In 2015, the "Guiding Opinions on Promoting the Adjustment and Optimization of Pig Farming Layout in Southern Water Network Areas" were introduced. It was proposed that by 2020, the proportion of large-scale pig farming with an annual output of over 500 pigs in the southern water network areas should reach over 70%, the proportion of supporting facilities for manure treatment in large-scale pig farms should reach over 85%, and the comprehensive utilization rate of pig manure should reach over 75%, achieving basic pollution control in pig farming and basic stability in pig production. In the "National Development Plan for Pig Production (2016–2020)", the ecological goal was set to significantly improve the comprehensive utilization rate of manure (>75%) and promote the coordinated development between pig production and environment protection. According to the "Opinions on Accelerating the Resource Utilization of Livestock and Poultry Breeding Waste" issued by the General Office of the State Council, the MOA issued the "Action Plan for Resource Utilization of Livestock and Poultry Manure 2017–2020". It strengthened the promotion of manure resource utilization by focusing on large-scale breeding farms and highlighting pig, cow, and beef cattle farms. Based on the "Opinions on Promoting the Sustainable and Healthy Development of the Pig Industry" issued in 2021, the overall promotion of manure utilization is being carried out throughout the major counties for pig production. Moreover, the measure encourages the construction of pig breeding farms (households) around large-scale planting bases, facilitating the integration of planting and pig breeding.

3.3.5. Methods of Manure Management and Utilization

Many papers have reviewed the methods and technologies for manure management and utilization such as composting, anaerobic fermentation, and so on [38–42]. In China, the technical solution advised by the government focuses on source reduction, generation control during the rearing process, and resource utilization.

For source reduction, it is recommended to minimize pollutant emissions from excreta by scientifically reducing the nutritional level of the diet and improving feed conversion efficiency. The recommendations include feeding livestock with diets of low nitrogen, low phosphorus, and low minerals, supplemented with microbial and enzyme additives. Secondly, they suggest performing standardized renovation and equipment updates in large-scale livestock farms to improve the zootechnical performance and decrease the mortality. The use of water-saving drinkers and the implementation of rain and sewage division systems are encouraged to reduce wastewater generation. Large-scale pig and dairy farms are encouraged to replace a water flushing system with a dry cleaning system and to reuse sewage for manure cleaning. Moreover, large-scale breeding farms should determine the breeding scale based on the available cropland and construct the necessary supporting facilities for manure treatment and resource utilization. To promote resource utilization, the manure produced in beef cattle, sheep, and poultry farms should be composted and used as organic fertilizers. Pig and cow farms are encouraged to conduct solid–liquid

separation. Solid manure should be composted, while sewage should be subjected to anaerobic fermentation for integrated use in irrigation and fertilization in cropland.

3.3.6. The Effectiveness of Policies on Pollution in the Livestock Production Sector

With the combination of the relevant regulations and supporting policies, the pollutants from the livestock production sector have decreased dramatically. According to the "Annual Report on Ecological Environment Statistics in China" [43], the chemical oxygen demand (COD) and ammonia nitrogen (NH_3-N) production of wastewater in China decreased gradually from 2011 to 2015 in both the total discharge and the agricultural source (Figures 4 and 5). This result indicates that the pollution from the agriculture and livestock production sector has decreased year by year. In this period, the data on the outputs of COD and NH_3-N from agricultural sources were obtained from the key investigation on an average of 136,088 large-scale livestock and poultry farms and 9062 raising zones and calculations for planting, aquaculture, and other livestock farming households, based on their production and discharge intensity.

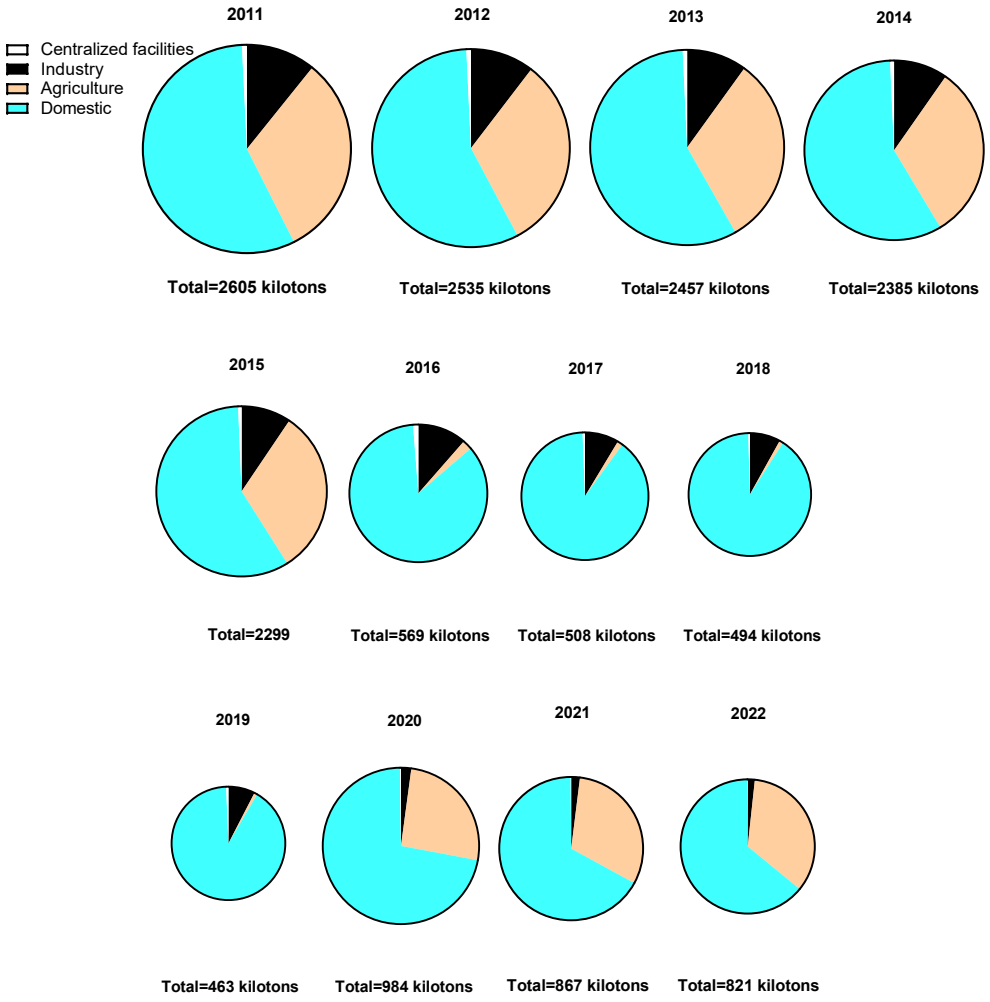

Figure 4. The chemical oxygen demand (COD) production in China from 2011 to 2022, million tons (mts).

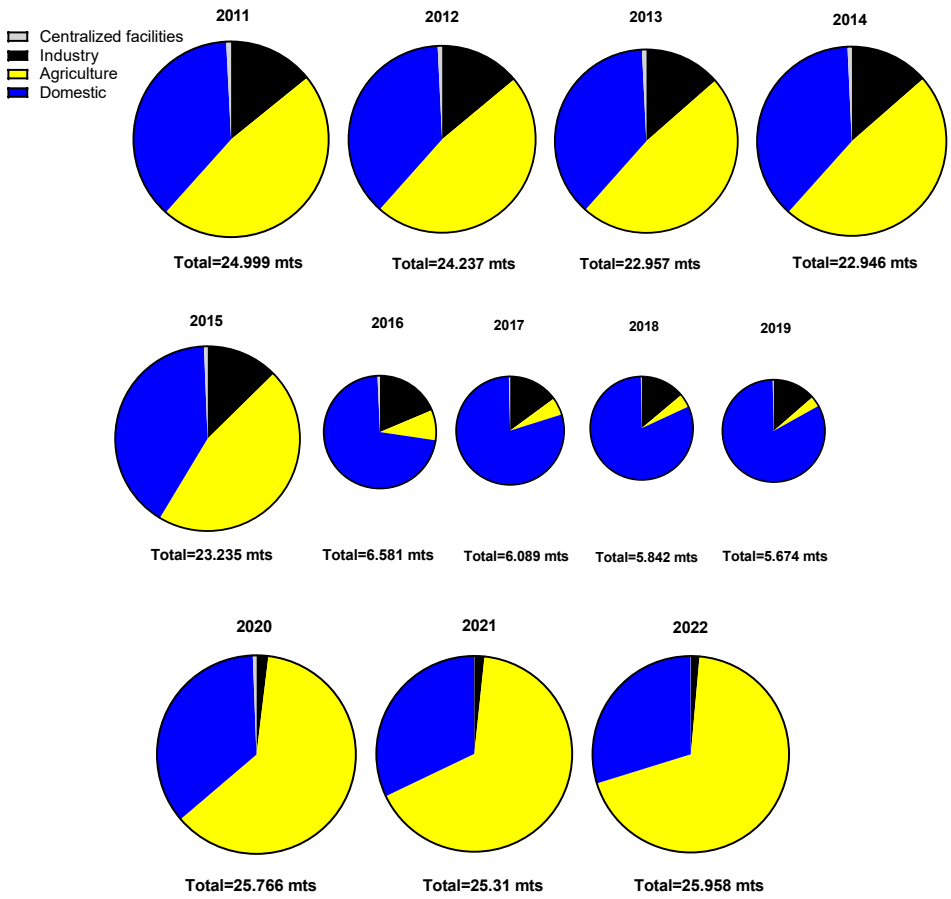

Figure 5. The ammonia nitrogen (NH_3-N) production in China from 2011 to 2022, kilotons.

From 2016 to 2019, however, there was a marked drop in the total and agricultural source emissions of COD and NH_3-N. The sharp fall was related to the changed statistical caliber in the livestock production sector, which was mainly based on large-scale livestock and poultry farms (an average of 11,168 farms). The result further indicates that pollution control in large-scale livestock and poultry farms made great progress in this period. The scope of the survey on pollution emissions from livestock production included large-scale livestock and poultry farms (with a designed annual output of $\geq$5000 pigs, 500 cows, 1000 beef cattle, 150,000 laying hens, and 300,000 broiler chickens).

In 2020, the pollutant discharge in wastewater from agricultural sources was statistically investigated based on each province. Compared with 2019, the scope of the agricultural source investigation since 2020 has expanded to include large-scale breeding farms (with $\geq$500 live pigs (slaughtered), $\geq$100 dairy cows (in stock), $\geq$50 beef cattle (slaughtered), $\geq$2000 laying hens (in stock), and $\geq$10,000 broiler chickens (slaughtered)). The expanded investigation scope is comparable to integrated pollution prevention and control (IPPC), which covers intensive animal rearing for farms with a capacity of greater than 40,000 animal places for poultry, 2000 for fattening pigs, and 750 for sows [22]. Consequently, there was a marked increase in the total and agricultural emissions of both COD and NH_3-N. Although the total emissions of COD and NH_3-N in wastewater decreased continuously from 2020 to 2022, the emissions from agricultural sources showed an expanding trend in both the absolute amount and the proportion in total emissions. The result suggests that new technologies and policies need to be updated to help livestock farms reduce and reuse livestock waste.

3.4. Policy Suggestions for the Resource Utilization of Livestock and Poultry Manure and Pollution Control in the Future

The livestock sector will maintain sustained growth in China in response to the increasing demand for animal-sourced foods in the future, leading to manure management remaining a major challenge. There are still many bottlenecks in effective manure utilization [44]. The existing study and practice, however, show that the impact of waste from the animal production industry could be controlled and mitigated with the application of appropriate measures regarding efficient manure management and resource utilization, feeding regimens, and emissions control [45]. The effectiveness of these measures depends on governmental intervention via policies and measures. The implementation of subsidies and governmental support to facilitate the adoption and installation of advanced technologies and manure management practice on farms has proven to be imperative in the U.S.A., for example, the California Dairy Digester Research and Development Program (DDRDP), which provides grants to support the development and installation of dairy digesters, and the California Alternative Manure Management Program (AMMP), which offers financial incentives for the adoption of manure management practices that reduce methane emissions [46]. Effective environmental policies combined with increased public awareness of food safety and ecological environment protection will lead to a more fundamental change in breeding waste handling and resource utilization.

3.4.1. Supporting Third-Party Manure Resource Utilization and Integrated Planting and Breeding

According to the spatial dataset on intensive and extensive livestock production in China in 2017, there was a different structure of livestock production systems in urban (less livestock), peri-urban (intensive production dominated), and rural areas (mixed system) [47]. In the intensive livestock production system, the separation of animal production from agriculture results in livestock and poultry farms lacking enough cropland for manure resource utilization, and the planting industry relies on chemical fertilizers, which leads to soil degradation. An integrated and balanced planting and breeding system is a fundamental way to eliminate the environmental threat from breeding wastes. The integrated breeding and planting system, however, needs a bridge to connect livestock and poultry farms from the supply side to the agricultural planting industry on the demand side. According to a desk study in France, it is estimated that manure treatment is considerably underused, and the development or creation of collective processing platforms (composting, drying, etc.) is highly recommended to produce organic amendments and fertilizers in an easy marketable form [48].

The service platform for resource utilization of manure (SPRUM) for the planting and breeding industry chain, provided by a socialized service organization or a third-party service company, is helpful for not only large-scale livestock farms but also small and medium-sized planting farms. The SPRUM could provide professional guidance and services throughout the entire industry chain, including manure storage, transportation, fertilizer recommendation based on soil testing, and manure mechanical application. Small and medium-sized livestock farmers who do not have the relevant handling capabilities can entrust the SPRUM to handle their breeding waste, and the SPRUM will take on the responsibility of the farms in terms of the harmless treatment of manure.

The SPRUM is relatively weak and in a state of disorderly development, needing policy support. One area is to open and share the data of the governmental supervision platform for livestock and poultry breeding wastes, which will assist in the construction of the manure production information sharing system and facilitate the resource utilization of manure. The second route is to introduce financial subsidy policies for third-party manure service companies, including subsidies for the purchase of manure treatment facilities and

equipment, transportation vehicles, and fertilization machinery, as well as subsidies for the use of manure fertilizers. The third route is to establish a cooperative relationship between the government and the SPRUM, introducing performance evaluation for the supervision of third-party manure utilization service organizations and establishing a long-term operational guarantee mechanism.

3.4.2. Encouraging Technological Innovation in Green Animal Husbandry

At present, the policies focus on promoting the resource utilization of breeding waste to prevent the pollution caused by the indiscriminate discharge of breeding waste. Excessive nitrogen and phosphorus from manure returned to cropland have not received adequate attention. In the EU, the Nitrate Directive (91/676/EC), approved in 1991 and implemented at the latest by 2003, regulates the use of N in agriculture, especially through its mandatory measures to designate areas vulnerable to nitrate leaching and to establish action programs and codes of good agricultural practice for these areas [49]. This directive has exerted a strongest influence on intensive livestock production systems by limiting the amounts of animal manure and fertilizers applied to land to ensure that the amount of N applied via animal manure (including that deposited by grazing animals) does not exceed 170 kg/ha/y for each farm in vulnerable areas. Hence, we not only need to pay attention to the total amount of manure emissions, but also need to further focus on nitrogen and phosphorus emissions from manure.

It is well known that source reduction to decrease nitrogen and phosphorus excretion by feeding livestock a low-protein and low-mineral-phosphorus diet is a powerful, cost-effective approach. By feeding livestock a low-protein diet, N excretion will be decreased. In heavy growing–finishing pigs from 35 to 180 kg BW, the dietary CP concentration can be effectively decreased by approximately 3% units on a DM basis by supplementing their diet with synthetic Lys, without adversely affecting their growth performance and carcass characteristics, while the reduction in the dietary protein concentration by 3% units can also decrease N excretion by an average of 24.5% [50]. In broilers fed a low-protein diet (Day 0 to Day 14, 18% CP; Day 15 to Day 35, 17% CP) supplemented with synthetic key essential amino acids, N excretion was reduced by 46.3% during the 35-day rearing period compared to the controls (Day 0 to Day 14, 23.5% CP; Day 15 to Day 35, 20.5% CP) [51].

Precision feeding is a feeding practice that aims to precisely match the nutrient supply with the dynamic requirements of farm animals, without exceeding or falling short, based on the real-time collection of data for zootechnical performance and feed ingredients. The benefits of precision feeding include higher economic returns, reduced excretion to the environment, and improved efficiency in resource utilization [52]. Precision feeding is an effective approach to make livestock production more sustainable without compromising growth performance. For example, feeding pigs individually with diets tailored to match 100% of their nutrient requirements made it possible to reduce digestible lysine intake by 26%, estimated N excretion by 30%, and feeding costs by USD 7.60/pig (−10%) relative to group feeding [53]. Feeding each pig according to its individual nutrient requirements may reduce the potential climate change impact by up to 6% and the potential eutrophication and acidification impacts by up to 5% compared with the normal group feeding system [54]. Excessive phosphorus excretion in manure increases the amount of land required to dispose of the manure and has a detrimental effect on the economy in areas of intensive animal agriculture. Strategies such as precision feeding and the application of phytase or low-phytic acid grains in monogastric diets may decrease the P content in manure by 40 to 60% in swine and poultry and by 25 to 40% in ruminants [55]. The introduction of precision livestock feeding can lead to a reduction in greenhouse gases and ammonia emissions in air, nitrates and antibiotics pollution in water bodies, and phosphorus, antibiotics, and heavy

metals in the soil [56]. In the future, it is necessary to develop more sound environmental policies and measures to promote innovation in green animal husbandry and to encourage the updating of equipment and the reforming of technologies such as genetic selection for the feed conversion ratio, precision feeding, and the national biosecurity system.

3.4.3. Introduction and Implementation of Nutrient Management Planning

The maximum amount of nutrients that can be carried by the soil defines the upper limit of manure that can be returned to the soil, whereas overfertilization exceeds the requirement of the soil and will result in nutrient overload. Nutrient management planning (NMP) is concerned not only with optimizing the economic return from nutrients used for crop production but also with the potential impact of these nutrients on the environment. The key concept of the plan allocates the available manure nutrients in a way that maximizes the economic benefit of the nutrients while minimizing the environmental impact [57]. In an integrated planting and breeding system, livestock manure is the major source of nutrients used for the fertilization of cropland and grassland. Accurate estimates of the amounts of nutrients in livestock manure are required for nutrient management planning and also for estimating N budgets and emissions to the environment [58].

Successful NMP is a complex process, and the key point is to identify the stakeholders involved in NMP, which are critical for the establishment of an accurately matched NMP. The stakeholders include the breeding farms, crop planting farmers, local government, MRUSP, and so on. Within the framework, the breeding farms provide the manure, while the planting farms supply the cropland. The MRUSP provides a platform for the successful operation of NMP, including accurate accounts of the nutrient input from manure and the nutrient output of cropland, education and training, and technical or even financial assistance for the farmers. The local government should serve as a regulator to ensure the mandatory implementation of NMP and guarantee the achievement of a nutrient balance within a specific region. Therefore, policies to promote the implementation of NMP and the running of the MRUSP should be introduced. In the U.S.A., "concentrated animal feeding operations" (CAFOs) are required to have a pollution discharge permit under the Clean Water Act, and those operations must implement a nutrient management plan (NMP) as part of their National Pollution Discharge System (NPDES) permit. By 2004–2006, 62% of U.S.A. hogs, 60% of broilers, and 49% of dairy cows were in operations that had NMP [59]. The expanded environmental regulations through NMP should be developed to improve the supervision system for manure utilized as fertilizer in cropland. Effective manure nutrient management should consider the structural shifts in livestock farming and the changes in animal species that affect the distribution, storage, and application of manure [60]. A long-term county-level manure nutrient dataset will be helpful for the successful application of NMP, which could provide improved spatial and temporal information on manure nutrients [60]. Moreover, advanced manure processing facilities will further guarantee nutrient recycling to increase nutrient use efficiencies and reduce the dependency on inorganic fertilizers [9].

3.4.4. Building an Ecological Compensation Policy System for Major Livestock and Poultry Breeding Areas

The development of animal husbandry in China is unbalanced in different provinces. Taking the total meat production as an example, in 2020, China's total meat production was 77.484 million tons, of which 10 provinces including Shandong, Sichuan, Henan, Hunan, Hebei, Yunnan, Guangdong, Anhui, Guangxi, and Liaoning had a total meat production of 47.162 million tons, accounting for more than 60% of the country's total production [15,16]. The cultivated land area of these 10 provinces, however, is 50.5 million hectares, accounting for approximately 39.5% of the total national area, and the pressure of

returning manure to the field is higher than in the other provinces. Animal husbandry is unmatched with the agricultural planting area and land-carrying capacity, which threatens the agricultural environment.

The 20th National Congress Report of the CCP pointed out that it is necessary to establish a mechanism to realize the value of ecological products and improve the compensation system for ecological protection. Reasonable ecological compensation is the key to incentivizing green production behavior. At present, China has explored the establishment of ecological compensation mechanisms in natural reserves, important ecological functional areas, mineral resource development, and watershed water environment protection, and has achieved good results. In the agriculture sector, there is ecological compensation. Agricultural ecological compensation includes compensation for the protection of agricultural resource assets and compensation for green agricultural production behavior [61]. Therefore, it is necessary to establish an ecological compensation mechanism that calculates the ecological environment beneficiaries between provinces and cities based on the consumption of livestock products and an ecological compensation mechanism that compensates for damages within the province. The compensation fund will support livestock farms and the MRUSP in effectively handling and utilizing breeding manure, forming an integrated planting and breeding system.

4. Conclusions

In conclusion, the livestock sector in China is increasingly regularized by policies and measures, through which pollutant discharge from farm animal production has been effectively decreased. The comprehensive utilization rate of manure increased from 60% in 2016 to 78% in 2022. The results of this study demonstrate the effectiveness of introducing measures to encourage the construction of manure handling facilities, supporting manure utilization in cropland, and establishing a sound legal system to regulate pollutant discharge. The concurrent environmental policies and measures for the management of livestock manure and waste still have some imperfections, such as regional disparities, insufficient local supporting funds, insufficient supervision, and so on. These imperfections lead to the limited effectiveness of the policies and measures and a high economic cost during their implementation. To further prevent environmental pollution associated with livestock manure, the regulations and policies need to constantly be updated in terms of source reduction and resource utilization, especially regarding the construction of socialized service platforms and supervision networks. Technological innovation in precising feeding, manure composting, and wastewater anaerobic treatment should be further encouraged by policies.

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