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Study on the Relationship between Low-Carbon Circular Farming and Animal Husbandry Models and Human Well-Being: A Case Study of Yongchang County, Gansu Province

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Abstract: The detrimental effects of climate change require countries and regions to use green and low-carbon strategies as the basis for economic development. Agriculture and livestock industry have become among the main industries that emit greenhouse gases. Yongchang County is suitable for the development of large-scale livestock operations due to its unique geographical advantages. However, the potential effects of the carbon dioxide emissions and the environmental impact potential of various farming and animal husbandry farming models on human well-being need to be considered. The purpose of this paper is to use life cycle assessment (LCA) to comprehensively assess the carbon emissions and environmental impact of circular agriculture and livestock industry and to provide important decision support for the establishment of a low-carbon circular agriculture and animal husbandry model. It uses a 75 kg dairy sheep as a functional unit to combine a noncircular farming model (S1) and a circular farming model (S2). The degree of carbon emissions, environmental impact potential and human well-being environmental effects are compared. The results show that the carbon dioxide emission of S1 is 891.3 kg, while the emission of S2 is 647.3 kg, and the difference between the two is 244 kg. S2 has a lower global warming potential than the S1 model; hence, the S2 model, which uses biogas for power, has lower carbon emission than the S1 model. From the perspective of human well-being and environmental benefits, the S2 model of biogas power generation is a low carbon emission and high-benefit model. The biogas power generation model lays the foundation for the realization of the "peak carbon dioxide emissions" and "carbon neutralization" goal, strengthens ecological protection on the north side of the Qilian Mountains and improves human well-being in the region.

Keywords: low-carbon circular agriculture and animal husbandry; life cycle assessment; carbon emissions; environmental impact; human well-being

1. Introduction

Global warming due to excessive emissions of greenhouse gases has become a hot issue of concern to politicians and scholars worldwide [1,2]. The livestock industry has become an important industry in which greenhouse gases are emitted, mainly from the processes of intestinal fermentation and manure decomposition [3]. According to a 2013 report of the Food and Agriculture Organization of the United Nations, the total greenhouse gas emissions from the livestock industry accounted for 14.5% of the total global greenhouse gas emissions [4]. The sheep farming industry also produces many greenhouse gases, such as carbon dioxide and methane, which has caused the government paying more attention to the environmental benefits of sheep products [5]. The dairy sheep industry is an important part of the sheep farming industry, and it is showing a rapid growth trend in various countries around the world. In 2019, the total number of sheep was 1.24 billion, and sheep accounted for 53.1% [6]. Europe, New Zealand and Australia are relatively developed in terms of milk and sheep industrialization and have formed a relatively complete industrial system in terms of yield for sheep milk production and deep processing [7]. Studies from Spain, Chile, New Zealand and other countries have researched the carbon emissions of dairy sheep breeding by using the carbon footprint method to calculate the carbon emissions for producing 1 kg of sheep milk [8–10]. The total number of sheep in China in 2019 was 164 million, which accounted for 13.2% of the world's sheep production [6]. However, the level of industrialization of dairy sheep farming in China is low, and most dairy sheep are produced by traditional breeding. Therefore, studying the carbon emissions of dairy sheep farming in China is of great significance for reducing the world's greenhouse gas emissions.

The traditional livestock industry utilizes a single, linear, noncircular industrial chain distribution process, namely, "resources-products-waste", while circular agriculture is a process of "resources-products-waste-resources" [11]. In recent years, China has vigorously developed circular agriculture, in which the use of biogas projects to treat livestock waste can greatly reduce energy consumption and carbon emissions [12]. Therefore, circular agriculture is an important strategy for realizing low carbon emissions in the agriculture and livestock industries [13]. The circular agriculture model includes the planting industry, animal husbandry industry, waste treatment industry and other industries, along with the subsystems of agricultural product processing service extension [14]. Many methods have been used to study circular agriculture, which are mainly divided into three categories. The first method is the key factor model method, which is based on a mathematical model [15,16]. The second consists of methods that evaluate the structure and changes of circular agriculture patterns, such as analytical hierarchy process (AHP) and driver-pressure-state-impact-response (DPSIR) model methods [17,18]. The third consists of methods that evaluate the sustainability of circular agriculture through systematic processes [19,20]. However, none of these methods can reflect the environmental effects of contaminants on circular agriculture [21]. The life cycle assessment (LCA) method is a common method for evaluating enterprise environmental, social and economic benefits [22]. It has been applied in large-scale biogas centralized gas supply projects, circular agriculture and livestock and poultry breeding [14,23]. Therefore, the adoption of the LCA method has become an important approach in current research on products, corporate greenhouse gas emissions and environmental impact potential [24–27]. However, little research has been conducted on the low-carbonization treatment of milk sheep waste, and domestic research on the milk sheep breeding process and waste treatment is minimal.

Human well-being is a valuable activity or state that people develop based on experience and various factors, including sufficient income, food, water and shelter to maintain a high quality of life; healthy and good social relationships; safety; freedom and choice [28]. There have always been complex relationships between human well-being and greenhouse gas emissions [29]. As the economy grows, human well-being increases and carbon emissions also increase [29]. However, many studies have proven that some developed countries can achieve the win–win scenario of low carbon emissions and high human well-being [30–33]. At present, research focuses mainly on the relation between human well-being and carbon emissions in various countries and regions, such as carbon emission performance and the carbon intensity of human well-being [31,32,34–37]. In addition, research has been conducted on the relationships between employee well-being and corporate carbon emissions and environmental impacts. As a small unit of social and economic development, its production and operation model affects changes in human well-being in all aspects. Although macro research is beneficial for the establishment of policies, micro studies can better promote the transformation of society to a low-carbon lifestyle by estimating the energy consumption and greenhouse gas emissions that correspond to human needs [30]. In September 2020, China proposed plans to reach a carbon peak by 2030 and achieve carbon neutrality by 2060. The "double carbon" goal ("peak carbon dioxide emissions" and "carbon neutralization") requires China to reduce carbon emissions in various fields, but at present, China's major industries rely too much on high energy consumption and high-emission energy sources such as coal and oil, and the industrial structure is in a critical period of transformation. Therefore, studying the relationship between enterprise carbon emissions and human well-being is of great significance not only for China to achieve the "double carbon" goal but also for residents to realize a sense of gain, happiness and security.

In northeastern China's Qinghai–Tibet Plateau, human activities are intensive, and production is realized mainly by traditional breeding. Improper treatment of aquaculture waste will cause environmental pollution, ecological safety hazards and other problems; hence, it is not conducive to reducing carbon emissions or improving human well-being in the region [38]. Yongchang County, Gansu Province, is located on the internationally recognized north latitude 40-degree gold milk source belt. It is cold in winter and moderate in summer, with sufficient light and dry air. It has the advantages of an industrial foundation and ecological environment for the development of the dairy sheep industry. The aim of this paper is to explore a breeding model with low carbon emissions and high well-being to provide theoretical support and policy suggestions for the low-carbon development of livestock industry and the improvement of human well-being. Therefore, this article considers a cyclic farming enterprise that produces mainly dairy sheep in Yongchang County as an example and compares the noncircular farming and circular farming model. Meanwhile, the LCA method is used to calculate and analyze the carbon emissions and environmental impact potential under the two models. The well-being of company employees and herdsmen was analyzed through a questionnaire survey and comprehensive evaluation and analysis method. Finally, we study the relationship between human well-being and environmental impact under the two scenarios.

2. Methodology

2.1. Overview of the Study Area

Yongchang County is affiliated with Jinchang City, Gansu Province, which is located on northwest Gansu Province, east of the Hexi Corridor, in the northern foot of the Qilian Mountains and at the southern edge of the Alxa Platform, at east longitude 101°04′—102°43′ and north latitude 37°47′–38°39′. The total population is 224,500, which includes 114,500 urban people. [39]. In 2020, the total number of livestock and poultry that were raised in the county reached 2.05 million, which represented a year-on-year decrease of 1.5% and included 1.13 million sheep, which corresponded to an increase of 2.4% [40]. In 2020, the county produced 3 million tons of baby vegetables, of which 750,000 tons of discarded vegetables were processed and fermented into biogas by Gansu Yuansheng Agriculture and Animal Husbandry Technology Co., Ltd, Jinchang, China. The enterprise that is studied in this paper is located on the Luoluowan area of Yongchang Industrial Park. It is an enterprise that vigorously promotes the industrial and agricultural circular economy. It is committed to promoting the comprehensive utilization of agricultural waste feed, fertilizer and biogas, especially in the treatment of crop straw and tail vegetables. The company began to implement the agricultural compound circular economy industrialization project in September 2015 and built a circular agriculture model that integrates "straw feed processing—livestock and poultry breeding—organic fertilizer production—centralized gas supply—tail vegetable processing and processing" (Figure 1) [41].

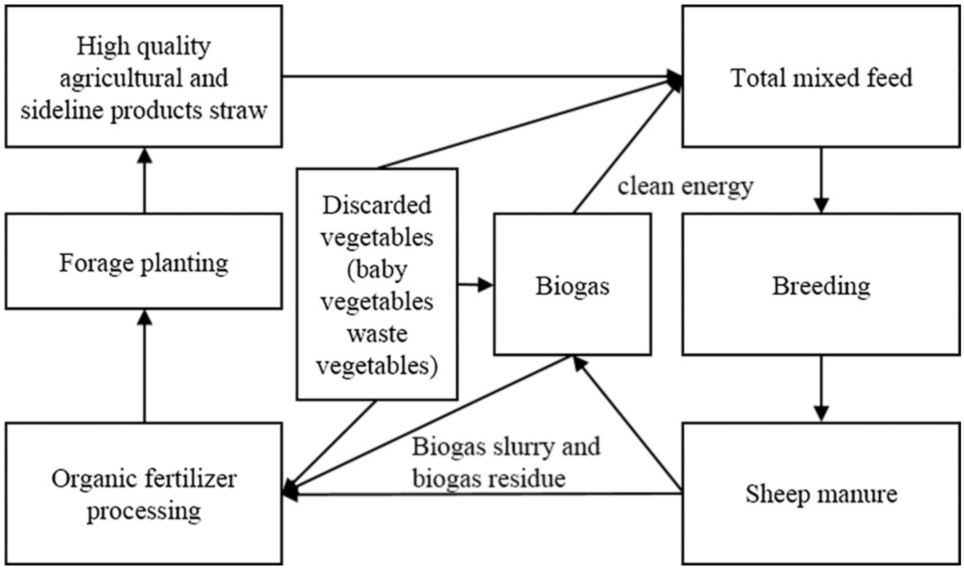

Figure 1. Circular agriculture and animal husbandry model of the enterprise.

The company's large-scale biogas project is divided into three phases. The designed production capacity is 11,000 m^3/day, which is an important link in the industrial and agricultural compound circular economy industrial chain. The biogas project uses the livestock and poultry manure of the Yuansheng company's sheep breeding farm and surrounding farmers, along with crop straw, discarded vegetables and other wastes, to reduce environmental pollution. It also provides clean energy for feed production, organic fertilizer, discarded vegetable processing, domestic cooking and heating, among other applications. At present, the company focuses on dairy sheep breeding. The ecological pasture of 10,000 dairy sheep covers an area of 34.8 km^2, with a total investment of CNY 270 million. Therefore, the company is suitable for comprehensive analysis of the low-carbon level of circular agriculture and livestock industry model.

2.2. Research Method

First, life cycle assessment is used to assess the environmental impacts of products from "cradle" to "grave", namely, from initial raw material collection, production and processing to use, maintenance, scrapping and waste treatment. In recent years, LCA has been widely used to evaluate carbon emissions, with a main focus on carbon footprint research [3,24,42]. The steps of the life cycle assessment method are as follows: research object and scope definition, list analysis, impact assessment and result interpretation. This study mainly analyzes part of the life cycle process, namely, from sheep entering the market to sheep exiting the market, and does not consider the process of product transportation.

2.2.1. Functional Unit

One adult ewe with a weight of 75 kg is set as the functional unit (functional unit, Fu). The dairy sheep breeding industry is the pillar industry of the company. The breeding scale has reached 10,000. The dairy sheep are all hybrids of East Friensian milk sheep that were imported from New Zealand and Germany and local Husheep. The East Friensian milk sheep have good adaptability in the Jinchang area and show excellent lactation and growth performance.

2.2.2. System Boundary Diagram

Figure 2 shows the system boundary of the life cycle assessment in this paper, which is divided into five systems, namely, a breeding system, tail vegetable treatment system, biogas system, organic fertilizer processing system and raw material system.

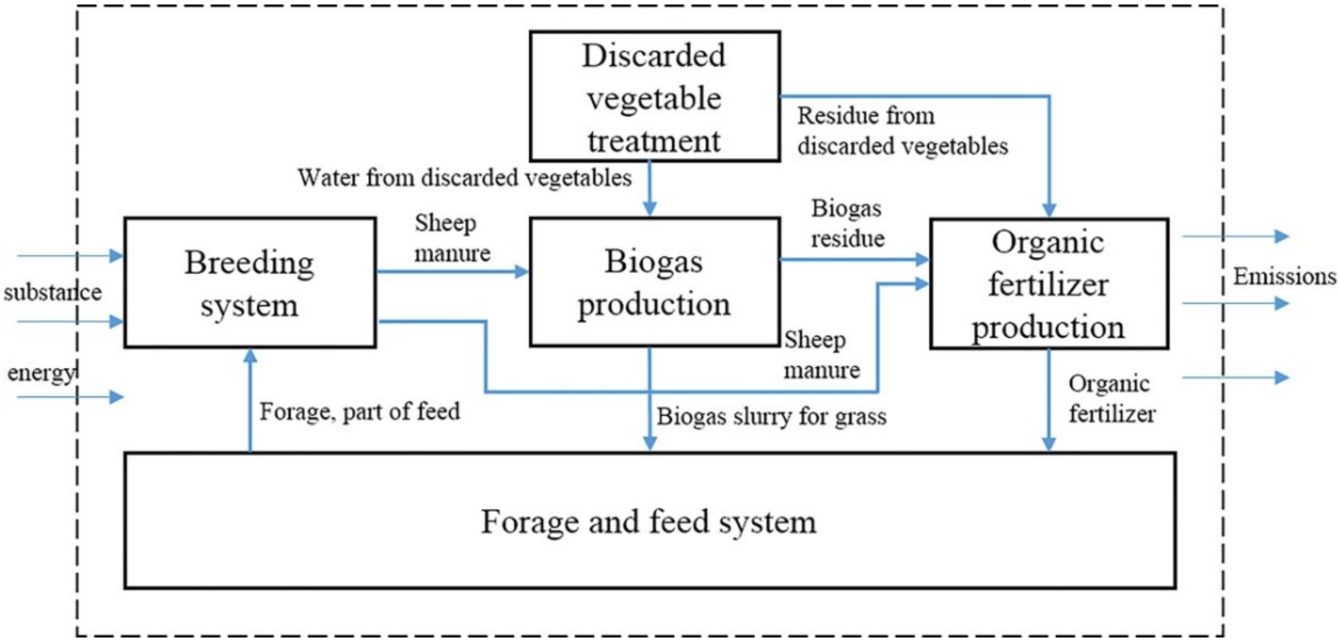

Figure 2. Boundary diagram of the circular agriculture and livestock breeding system of the enterprise.

The research object of this paper is the low-carbon circular agriculture and animal husbandry model of the Yongchang dairy sheep farm, and "feed processing—dairy sheep breeding—discarded vegetable processing—comprehensive utilization of biogas—organic fertilizer processing" is selected as a typical case. The core element of the low-carbon agriculture and animal husbandry model is the treatment of agricultural and animal husbandry waste, and this model organically combines the planting industry, aquaculture industry and feed processing industry. In the utility model, the sheep dung from the dairy sheep farm and the discarded baby vegetables of the farmers are mechanically pressed into a biogas fermentation tank to produce biogas for heating, cooking and feeding steam. Then, the biogas liquid is returned to the field to form organic fertilizer, and the biogas residue is used for the processing of organic fertilizer granules. The research objective is to study the input–output of the dairy sheep breeding process, biogas production, waste treatment and raw material system, analyze the process emission list of each link, and evaluate the environmental impact.

The life cycle analysis of this study makes the following assumptions for the low-carbon circular agriculture and animal husbandry model: Since the biogas fermentation process is anaerobic fermentation and the system is closed, pollutant emissions during biogas fermentation are not considered. Generally, the service life of a biogas digester is 20 years; hence, the emissions and environmental impact of the waste of biogas digesters are not considered in this paper. All data are derived from the relevant data and literature of the company, and other emission coefficients are obtained from the relevant literature, books and databases of life cycle assessment.

2.3. Data Source

According to the production and operation of the company in 2020, in this paper, the consumptions of forage, electric energy, diesel, water and other substances and the energy input of an adult diary sheep in one year are calculated, along with the discharged amounts of sheep manure, sewage, waste heat and waste. The values for each subsystem are presented in Table 1.

Table 1. Input–output analysis of each subsystem.

Subsystem	Input	Units	Quantity	Source of Standard	Output	Units	Quantity
the forage and feed system	Biogas slurry for grass	kg	1310	Biomass processing and production	alfalfa	kg	51
	Diesel	kg	752.3	China(CN)	silage corn	kg	216
	Electricity	MJ	626.4	China(CN)			
	Ground water	kg	10,700	EU-28			
	Organic fertilizer	kg	1014	Organic fertilizer processing			
	Pesticides	kg	3.05	GLO			
	Corn seed	kg	0.87	EU-28			
dairy sheep farming	alfalfa	kg	51	forage systems	Manure	kg	1310
	concentrated feed	kg	21	Compete feed	sheep	kg	75
	Diesel	kg	1.42	China (CN)	Waste water	kg	214
	Electricity	MJ	257.1	China (CN)	Sheep milk	kg	75
	Grassland	m^2	133.3	Grassland			
	silage corn	kg	216	forage systems			
	water	kg	857.1	EU-28			
discarded vegetable processing	Discarded vegetables	kg	1379	forage systems	Water from discarded vegetables	kg	1103.2
	water	kg	1103	Compete feed	Residue from discarded vegetables	kg	165.5
	Diesel	kg	350	China (CN)			
	Electricity	MJ	55	China (CN)			
Biogas project	water from discarded vegetables	kg	1103.2	Discarded vegetables processing	Biogas	kg	51.4
	Electricity	MJ	118.8	China(CN)	Biogas residue	kg	1051
	Manure	kg	1310	Dairy sheep breeding	Biogas slurry for grass	kg	1310
					Thermal energy from biogas	MJ	850.1
Biogas power generation	water from discarded vegetables	kg	1103.2	Discarded vegetables processing	Biogas residue	kg	1051
	Electricity	MJ	118.8	China(CN)	Biogas slurry for grass	kg	1310
	Manure	kg	1310	Dairy sheep breeding	Electricity for Biogas	MJ	9.8
					Electricity for feed	MJ	100.8
					Electricity for Sheep milk	MJ	100.8
					Electricity for organic fertilizer processing	MJ	91
organic fertilizer processing	Biogas residue	kg	1051	Biomass processing and production	Organic fertilizer	kg	1014
	Residue from discarded vegetables	kg	165.48	discarded vegetables processing	Water vapour	kg	1622
	Electricity	MJ	91	China(CN)			
	Humic acid	kg	276.3	soil			
	Manure	kg	259	Dairy sheep breeding			
	Mineral waste	kg	39.47	Dairy sheep breeding			
	Sludge	kg	788.3	soil			
	Water	kg	788.3	EU-28			

Note: 1 cubic meter of biogas = 1.215 kg; 1 KWh = 0.28 MJ.

2.3.1. Forage and Feed System

The food of the company's dairy sheep is composed of pasture (alfalfa), concentrated feed and corn silage. The total arable land area is 5,000,250 m^2, of which 533,360 m^2 is planted with alfalfa, 2,866,810 m^2 with silage corn and 1,600,080 m^2 with vegetables. Pasture and corn are grown using organic fertilizers that are produced by the company. Using organic fertilizers can promote the sequestration of carbon in the soil by the application of specific agricultural practices that can improve the reduction of the release of carbon and consequently the reduction of its emission. The company's dairy sheep consume green organic food, and the goat milk that is produced is of good quality [43]. Table 1 is the input–output table of the raw material system. The left half of the table presents the material quality and energy consumption input of the system, and the right side of the table presents the feed products that are produced. The specific data of Forage and Feed system is based on the data provided by the enterprise, and according to the input and output for 75 kg of adult ewe converted proportionally.

2.3.2. Breeding System

According to the data in Table 1, the specific data of the breeding system is based on the data provided by the enterprise, and according to the input and output for 75 kg of adult ewe converted proportionally. The manure that is produced in the breeding stage in the S2 model is treated by the biogas project, and the manure from the farming system in the S1 model is not treated but decomposed in its natural state. According to the IPCC 2006 report, the methane emission coefficient of sheep is 5 kg/head/a, and the nitric oxide emission coefficient is 0.16 kg/head/a [1].

2.3.3. Stage of Discarded Vegetable Processing

The main source of discarded vegetables is vegetables that are discarded after transport from cold storage to the processing site. The ratio of the actual product to the baby cabbage is 1:1. Water from the discarded vegetables is used to produce biogas, and vegetable residue is used to produce organic fertilizer. Table 1 is the input–output table of discarded vegetable processing in the S2 model. The discarded vegetables in the S1 model represent only the process from baby cabbage production to discarded cabbage production, and discarded cabbage is not processed into biogas. Therefore, the processing input of the discarded vegetables in the S1 model is 2758 kg, and the amount of produced tail vegetables is 1379 kg.

2.3.4. Biogas Project

A biogas project is added to the S1 model. The specific data of biogas project is based on the data provided by the enterprise, and according to the input and output for 75 kg of adult ewe converted proportionally (Table 1).

2.3.5. Biogas Power Generation

A biogas generation system is added to the S2 model. The material input in the biogas power generation model is the same as that in the biogas production stage, but in terms of output, the biogas is converted into electricity, which is distributed to various subsystems. In general, 1 m^3 of biogas can generate 2 kWh. According to Table 1, the biogas production is 51.4 kg, and the total power generation is 84 kWh, which is equal to 302.4 MJ. The electric energy for biogas production is 9.8 MJ, the electric energy for raw material production is 100.8 MJ, the electric energy for dairy sheep breeding is 100.8 MJ, and the electric energy for organic fertilizer processing is 91 MJ.

2.3.6. Organic Fertilizer Production

According to the data in Table 1, the specific data of organic fertilizer production is based on the data provided by the enterprise, and according to the input and output for 75 kg of adult ewe converted proportionally. The difference between the S1 mode and the S2 mode is that the sheep manure of the S1 mode is not treated and the S2 mode has treated discarded vegetable.

2.4. Scenario Settings

This paper mainly discusses the environmental impact and carbon emissions under noncircular agriculture and animal husbandry and biogas power generation farming models to find a low-carbon model with low environmental impact and low carbon emissions. Therefore, two models are designed in this paper (Table 2). S2 is a circular agriculture and animal husbandry model that is applied after biogas is used for power generation. Biogas power generation provides part of the power for forage and feed systems, dairy sheep breeding, biogas production and organic fertilizer processing. The input–output data of S1 and S2 are presented in Table 1. The byproducts that are not involved in the cycle are regarded as wastes, and the corresponding environmental load is shared according to the principle of quality distribution.

Table 2. Settings of two scenarios.

Scenarios	Description
S1	Single Forage and Feed system, single dairy sheep breeding, untreated discarded vegetables, single biogas production and single organic fertilizer processing
S2	Forage and Feed system + dairy sheep breeding + discarded vegetable treatment + biogas power generation + organic fertilizer processing

2.5. Environmental Impact Category and Assessment Method

At present, various LCA evaluation methods are used to evaluate the impacts of products and production processes on the environment, such as the environmental impact assessment method for chemical reduction (TRACI) and the environmental design method for industrial products (EDIP) [43]. In this paper, CENTUM voor Milieuwetenschappen (CML) was used to evaluate the environmental impacts of the two milk sheep breeding models. CML is a problem-oriented LCA method that was developed by the Environmental Science Center of Leiden University. It aims to design the best environmental indicators based on the International Organization for Standardization (ISO) 14,040 series.

According to the evaluation object, this paper selects three types of indicators to evaluate the environmental load that is caused by the circulation of the agricultural industrial chain. The first category of indicators consists of the total consumptions of raw materials or resources, including abiotic depleting elements (ADP elements) and abiotic depletion fossils (ADP fossils). The second category of indicators includes the impacts on the atmosphere and water resources, such as the acidification potential (AP), global warming potential (GWP), photochemical ozone generation potential (POCP), ozone layer depletion potential (ODP) and eutrophication potential (EP). The last category of indicators consists of toxicity indicators, including the freshwater aquatic ecotoxicity (FAETP), human toxicity potential (HTP), marine aquatic ecotoxicity (MAETP) and terrestrial ecotoxicity potential (TETP).

2.6. Comprehensive Evaluation and Analysis Method for Human Well-Being of Employees and Herdsmen

Based on the division of human well-being elements in MA, this paper combines the definitions of human well-being indicators by experts and scholars, as well as the analysis of the socio-economic system in the research area, and selects a variety of characterization indicators to establish the evaluation system of human well-being indicators for employees and herdsmen, using multiple indicators. We used comprehensive evaluation method to evaluate the well-being of employees and herdsmen. The principle is:

$$F = \sum_{\mathrm{i}=1}^{n} \mathrm{W_i f_i} \tag{1}$$

In the formula: F is the comprehensive index of human well-being; i is the individual index of human well-being; n is the number of index; $\mathrm{f_i}$ is the standardized score of index i; $\mathrm{W_i}$ is the weight value of indexi. The larger the value of F the higher the human well-being.

3. Result Analysis

3.1. Main Emission Results of LCA under the Two Scenarios

Environmental Emission Inventories under the Two Scenarios

Based on Gabi9.2, the LCA method is used to calculate the main pollutants that are emitted into the air under the two scenarios, as presented in Table 3. The table is divided into the emissions into the air of inorganic substances and organic substances, atmospheric particles, pesticide pollutants and radiation. The global CML2001-Jan. 2016, World, year 2000, Excel biogenic carbon data (global equivalents) are used as the standard to calculate the standardized value of main atmospheric emissions of each system of S1 and S2, as presented in Table 3.

Table 3. Main atmospheric emissions under the two scenarios (unit: kg).

Heading	Categories	S1	S2
Inorganic emissions	Total	1.12×10^4	7.47×10^3
	CO_2	8.91×10^2	6.47×10^2
	CO_2(aviation)	1.66×10^{-3}	1.63×10^{-3}
	CO_2(biotic)	2.26×10	1.70×10
	CO_2(land use change)	4.55×10^{-1}	4.20×10^{-1}
	CO_2(peat oxidation)	4.38×10^{-6}	5.79×10^{-6}
	Fluoride	2.52×10^{-5}	2.35×10^{-5}
	NO_2	9.57×10^{-2}	5.48×10^{-3}
	N_2O	3.46×10^{-1}	1.47×10^{-2}
	SO_2	2.78	2.50
Organic emissions	Total	7.03	6.52
	Methane	5.67	5.27
	Methane(biotic)	5.55×10^{-3}	1.58×10^{-2}
Paticles	Total	1.12	8.97×10^{-1}
	PM10	5.21×10^{-4}	4.63×10^{-4}
	PM2.5	2.77×10^{-1}	2.06×10^{-1}
Pesticides	Total	1.03×10^{-6}	4.74×10^{-7}
Radioactive emissions	Total	-8.60×10^{-11}	-8.77×10^{-11}

Since there is no comparability, we cannot judge the degrees of environmental impact under the two scenarios based only on the air pollution emissions in Table 3. However, in terms of quality alone, the emissions of carbon dioxide, which is an important greenhouse gas, merit comparison. According to Table 3, the air emission under S1 is higher than that under S2. Considering carbon dioxide as an example, the emission under S1 is 891.3 kg, while that under S2 is 647.3 kg, which is a difference of 244 kg. Among the organic emissions, the methane emission under S1 is 5.67 kg, and that under S2 dairy sheep farming is 5.27 kg. Therefore, compared with the S1 noncircular model, the biogas power generation model can reduce the carbon dioxide emissions of the dairy sheep breeding process and is a more energy-saving and low-carbon model.

3.2. Results of LCA Analysis

According to the calculation results that are presented above, 3 categories and 11 environmental effects in the two models were calculated based on LCA. The results are presented in Table 3, where Sb denotes antimony, R11 denotes trichlorofluoromethane, P denotes phosphate, and DCB denotes dichlorobenzene. The global CML2001-Jan. 2016, World, year 2000, Excel biogenic carbon data (global equivalents) are used as the standard to calculate the standardized value of the environmental impact potential of each system of S1 and S2, as presented in Table 4.

Table 4. Life Cycle Assessment analysis results based on the CML2001-Jan. 2016 method.

Result Type	Category	S1	S2	Units
Eigenvalue analysis	GWP 100 years	1.14×10^{3}	7.87×10^{2}	kg CO_2eq.
	AP	5.54	4.14	kg SO_2eq.
	EP	6.60×10^{-1}	3.25×10^{-1}	kg P eq.
	ODP, steady state	1.65×10^{-12}	2.15×10^{-12}	kg R11 eq.
	POCP	1.42×10^{-2}	4.65×10^{-2}	kg Ethene eq.
	ADP elements	1.02×10^{-3}	1.16×10^{-3}	kg Sb eq.
	ADP fossil	6.17×10^{4}	5.82×10^{4}	MJ
	FAETP	40.4	55.2	kg DCB eq.
	HTP	2.40×10^{2}	3.87×10^{2}	kg DCB eq.
	MAETP	1.41×10^{5}	1.52×10^{5}	kg DCB eq.
	TETP	3.67	3.49	kg DCB eq.
standardized value results	GWP 100 years	2.52×10^{-10}	1.95×10^{-10}	kg CO_2eq
	AP	1.41×10^{-10}	1.06×10^{-10}	kg SO_2eq.
	EP	2.93×10^{-11}	1.91×10^{-11}	kg Phoshate eq.
	ODP, steady state	4.50×10^{-20}	5.88×10^{-20}	kg R11 eq.
	POCP	2.52×10^{-12}	8.21×10^{-11}	kg Ethene eq.
	ADP elements	1.82×10^{-11}	2.06×10^{-11}	kg Sb eq.
	ADP fossil	1.14×10^{-9}	1.07×10^{-9}	MJ
	FAETP	1.16×10^{-10}	1.59×10^{-10}	kg DCB eq.
	HTP	6.61×10^{-10}	1.07×10^{-9}	kg DCB eq.
	MAETP	4.92×10^{-9}	5.31×10^{-9}	kg DCB eq.
	TETP	2.29×10^{-11}	2.18×10^{-11}	kg DCB eq.

As presented in Table 4, the GWP index of the S1 model is higher than that of the S2 model, and the difference between the two is 357.5 kg CO_2eq, which is mainly because biogas power generation offsets part of the greenhouse gas emissions that are generated by electricity consumption. The AP, EP, ADP fossil and TETP indices of the S1 model are also higher than those of the S2 model, which indicates that the S2 model has lower eutrophication, acidification potential, fossil fuel consumption potential and terrestrial ecotoxicity than the S1 noncircular model. In the S2 model, the photochemical ozone production potential (POCP), ozone depletion potential (ODP), human potential toxicity (HTP), aquatic ecotoxicity indicators (FAETP, MAETP) and nonbiological depleting elements (ADP elements) are higher than those in the S1 model, which may be due to the large amount of diesel that is used in the feedstock system. Overall, the S2 model has less impact on global warming, but the toxicity index is slightly higher than that of the S1 model.

The standardized value results of LCA show that the GWP index of S2 is lower than that of S1, thereby indicating that the dairy sheep breeding system under the biogas power generation model has less influence on the global warming potential than that under the noncyclic S1 model.

The global warming potential characterizes the emission potential of greenhouse gases. Higher values of GWP indicate higher greenhouse gas emission potential. Figure 3 shows that the GWP value of the S1 model is higher than that of the S2 model. From the perspective of the discharge of each subsystem, the raw material system of S1 is 26.5 kg CO_2eq higher than that of S2, and the breeding system of S1 is 131.76 kg CO_2eq higher than that of S2. The discarded vegetable processing system of S1 is 40.8 kg CO_2eq higher than that of S2, while the biogas project and organic fertilizer processing system are 70.1 kg CO_2eq and 88.5 kg CO_2eq higher, respectively. The significantly difference here is the breeding system. The value of S1 is 169 kg CO_2eq, while the value of S2 is 37.2 kg CO_2eq, the difference between the two is 131.76 kg CO_2eq. The main reason is that the noncircular model S1 does not process the sheep manure into biogas, and more methane is emitted than in the S2 model. The main difference between the remaining subsystems of S1 and S2 is that the S2 model uses biogas. Biogas power generation is used to supply forage and feed systems, breeding systems, biogas projections, and organic fertilizer processing systems. The use of clean energy can reduce carbon dioxide emissions.

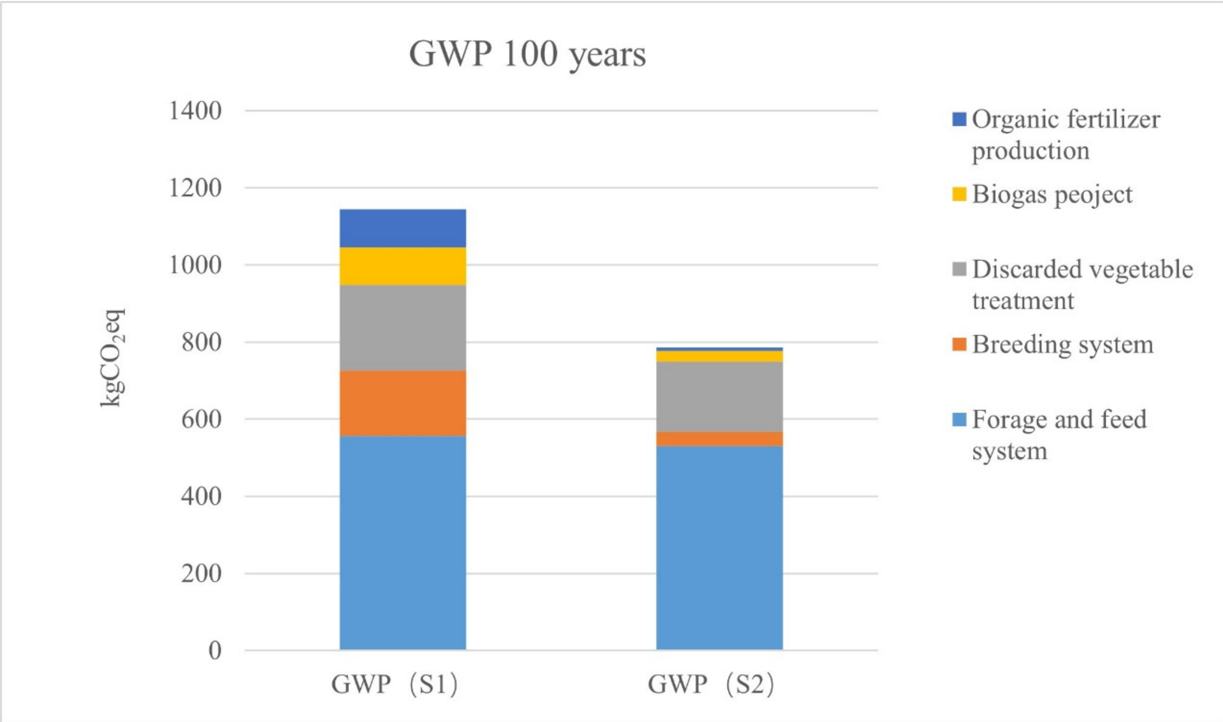

Figure 3. Comparative analysis of the global warming potential (GWP) under the two scenarios.

3.3. Comparative Study on the Well-Being of Enterprise Employees and the Well-Being of Herdsmen

This study uses a multi-index comprehensive evaluation method to estimate the level of human well-being [44]. Human well-being questionnaires are randomly distributed to 50 employees of the company and to 32 local herdsmen. The average values of human well-being indicators in 2020 are calculated (Table 5). This paper uses 13 indicators in four categories to assess the level of human well-being. This study uses the well-being of local herdsmen to characterize the past well-being of employees. As presented in Table 5, the per capita net income of company employees is CNY 4500, while the income of herdsmen is CNY 1842. The energy usages of employees and herdsmen differ: Employees use 516 kg of coal/year, whereas herdsmen use 2991 kg, and employees use 812 kWh/year, whereas herdsmen consume 1054 kWh/year. However, the per capita housing area of employees is smaller than that of herdsmen. From the perspective of health, employees and herdsmen differ in terms of their satisfaction with vegetables and meat. Employees are more satisfied with vegetables and meat than herdsmen, who report average satisfaction. The main reason is that herders believe that there are more pesticide residues in vegetables. However, the proportion of employees who purchase the "five social insurances and one housing fund" is higher than that of herdsmen. This is because the company buys the "five insurances and one housing fund" for employees. From a safety point of view, employees and herdsmen are both satisfied with ecological safety, and work safety is a greater risk for employees. From the perspective of social relations, the proportion of employees with a high school education or above is higher than that of herdsmen, the family sizes of employees and herdsmen are both 3, and both are satisfied with their family status.

Table 5. Comparison of human well-being indicators of the company's employees and herdsmen.

Target Layer	Standard Layer	Index Layer	Employee	Herdsmen	Source
The basic conditions needed to maintain a high-quality life	Economic living standard	Per capita monthly net income (yuan)	4500	1842	Questionnaire
	Energy consumption	Per capita energy consumption (structure)	Coal: 516 kg Electricity:812 KWh	Coal: 2991 kg Electricity:1054 kWh	Questionnaire
	Housing conditions	Per capita energy consumption (structure)	29 m^2	37.8 m^2	Questionnaire
Health	Vegetable satisfaction	Vegetable satisfaction	Quite satisfied	general	Questionnaire
	Meat satisfaction	Meat satisfaction	Quite satisfied	general	Questionnaire
	Physical health satisfaction	Physical health satisfaction	Quite satisfied	Quite satisfied	Questionnaire
	Medical insurance	The proportion of the number of people participating in medical insurance in the total number	54%	100%	Relevant personnel of the company/Questionnaire
	Proportion of purchasing "five insurances and one housing fund"	The proportion of the number of people participating in the five social insurances and one housing fund to the total number	58%	10%	Relevant personnel of the company/Questionnaire
Security	Ecological safety satisfaction	Ecological safety satisfaction	Relatively safe	Relatively safe	Questionnaire
	work safety	Number of work-related injuries	2	None	Company management
Good social relations	Education level	Percentage of people with high school degree or above in total	16%	3.3%	Questionnaire
	Family burden	Total number of family dependents	3	3	Questionnaire
	Family status	Family status satisfaction	Quite satisfied	Quite satisfied	Questionnaire

The results show that there are differences between the level of human well-being of employees and that of herdsmen, which are mainly concentrated in the per capita income, energy structure, and housing area that maintain the basic standard of living. Firstly, from a health point of view, the satisfaction with vegetables and meat is similar, whereas there are significant differences in the number of people who participate in medical insurance and in the proportion who purchase the "five social insurances and one housing fund". Secondly, from the perspective of safety, employees and herdsmen differ mainly in terms of work safety. Finally, from the perspective of social relations, there are significant differences in education levels.

This paper uses the Analytic Hierarchy Process (AHP) to determine the weight of each index in the comprehensive evaluation index system of employee and herdsmen's well-being, and uses the range normalization method to standardize the specific data of each index. The results are shown in Table 6. From Table 6 we can see the total score of the basic conditions needed to maintain a high-quality life. Health of employees is higher than that of herdsmen, and the economic living standard energy of employees is higher than that of herdsmen, but the score of the health for employees is less than that of herdsmen. The security and the good social relationship of employees is higher than that of herdsmen. In general, the overall human well-being score of employees is higher than that of herdsmen.

Table 6. The overall level of well-being of employees and herdsmen.

		Employees Well-Being				Herdsmen Well-Being			
Target Layer	**Standard Layer**	**Normalized Value**	**Weights**	**Single Score**	**Total Score**	**Normalized Value**	**Weights**	**Single Score**	**Total Score**
The basic conditions needed to maintain a high-quality life	Economic living standard	0.840	0.295	0.248	0.264	0.537	0.343	0.184	0.258
	Energy consumption	0.185	0.064	0.012		0.615	0.095	0.058	
	Housing conditions	0.052	0.090	0.005		0.154	0.104	0.016	
Health	Vegetable satisfaction	0.490	0.029	0.014	0.108	0.523	0.030	0.016	0.125
	Meat satisfaction	0.490	0.025	0.012		0.523	0.027	0.014	
	Physical health satisfaction	0.530	0.097	0.052		0.719	0.083	0.060	
	Medical insurance	0.460	0.038	0.017		1.000	0.033	0.033	
	Proportion of purchasing "five insurances and one housing fund"	0.460	0.027	0.012		0.091	0.027	0.002	
Security	Ecological safety satisfaction	0.607	0.086	0.052	0.052	0.573	0.086	0.049	0.049
	work safety	0.010	0.076	0.001		0	0.064	0	
Good social relations	Education level	0.607	0.075	0.046	0.103	0.297	0.022	0.006	0.061
	Family burden	0.520	0.032	0.017		0.456	0.033	0.015	
	Family status	0.610	0.067	0.041		0.813	0.049	0.040	
Overall Human Well-Being Score					0.527				0.494

The main social and economic characteristics of enterprise employees and herdsmen are presented in Table 7. Among them, 42 employees, namely, 84%, have a monthly income of CNY 3000–6000, whereas the number of herdsmen with a monthly income of CNY 3000–6000 is at most 13, which accounts for 43%. However, 10% of herdsmen have a monthly income of less than CNY 1000. There are 29 employees in the company who have the "five social insurances and one housing fund", which accounts for 58%, while only 3 herdsmen have the "five social insurances and one housing fund", which accounts for 10% of the total. There is little difference in household size. Employees with households of 4–5 persons account for 54%, while 63% of herdsmen have households of 4–5 persons. The education levels of employees and herdsmen are quite different. Forty-four percent of the employees have a bachelor's or college education, while the number of herders with a junior high school education is at most 17, which accounts for 57%, and the number of people with an undergraduate or college education is zero.

3.4. Research on the Relationship between Low-Carbon Farming and Animal Husbandry Models and Human Well-Being

To better compare the relationship between environmental impact potential and per capita income (income), we use per capita income–environmental benefits to analyze the dual effects of human well-being and the environment in various models (Table 8). Therefore, we use per capita income divided by the LCA indicator to express the relationship between human well-being and environmental impact. We use income–acidification potential (IAP), income–global warming potential (IGWP), income–photochemical ozone generation potential (IPOCP), income–ozone layer depletion potential (IODP) and income–eutrophication potential (IEP) to explain the income's impacts on the atmosphere and water resources. The high IGWP value of that model indicates that it has low carbon emission and high well-being. Meanwhile, we use income–freshwater aquatic ecotoxicity (IFAETP), income–human toxicity potential (IHTP), income–marine aquatic ecotoxicity (IMAETP) and income–terrestrial ecotoxicity potential (ITETP) to explain the income's impacts on toxicity indicators. The per capita income–environmental benefit values under the two models are obtained, as presented in Table 8.

Table 7. Socioeconomic characteristics of employees and herdsmen.

Type	Feature	Category	Frequency	Percentage/%
Socio-economic characteristics of employees	monthly income	<1000 yuan	0	0%
		1000–3000 yuan	8	16%
		3000–6000 yuan	42	84%
		>6000 yuan	0	0%
	Is there a "five social insurance and one housing fund"	yes	29	58%
		no	21	42%
	How many people in the family	≤3 people	19	38%
		4–5 people	27	54%
		≥6 people	4	8%
	education level	primary school	0	0%
		junior high school	11	22%
		High school or technical secondary school	17	34%
		Bachelor or college	22	44%
		Postgraduate	0	0%
Socio-economic characteristics of herders	monthly income	<1000 yuan	3	10%
		1000–3000 yuan	9	30%
		3000–6000 yuan	13	43%
		>6000 yuan	5	17%
	Is there a "five social insurance and one housing fund"	yes	3	10%
		no	27	90%
	How many people in the family	≤3 people	11	37%
		4–5 people	19	63%
		≥6 people	2	7%
	education level	primary school	14	47%
		junior high school	17	57%
		High school or technical secondary school	1	3%
		Bachelor or college	0	0%
		Postgraduate	0	0%

Table 8. Per capita income–environmental benefits under the two scenarios.

Per Capita Income–Environment Ratio	S1	S2	Units
IAP	3.18×10^{13}	4.25×10^{13}	CNY/kg SO_2-Equiv.
IGWP	1.79×10^{13}	2.30×10^{13}	CNY/kg CO_2-Equiv.
IPOCP	1.79×10^{15}	5.48×10^{13}	CNY/kg R11-Equiv.
IODP	1.00×10^{23}	7.65×10^{22}	CNY/kg Ethene-Equiv.
IEP	1.54×10^{14}	2.36×10^{14}	CNY/kg R11-Equiv.
IFAETP	3.87×10^{13}	2.83×10^{13}	CNY/kg P-Equiv.
IHTP	6.80×10^{12}	4.22×10^{12}	CNY/kg DCB-Equiv.
IMAETP	9.14×10^{11}	8.47×10^{11}	CNY/kg DCB-Equiv.
ITETP	1.97×10^{14}	2.07×10^{14}	CNY/kg DCB-Equiv.

As presented in Table 8, the indicators of IAP, IGWP and IEP of S2 are all higher than those of S1, thereby indicating that the biogas power generation model not only reduces the greenhouse gas emissions potential but also improves human well-being. The toxicity and other indicators of the S1 model are higher than those of the S2 model, thereby indicating that the S1 model has a higher income–toxic environment index.

4. Discussion

4.1. Discussion on Low-Carbon Cycle Agriculture and Animal Husbandry Research

Studies have shown that reasonable breeding of cattle, sheep and other animals can not only reduce carbon emissions but also increase soil carbon sequestration and help slow climate warming [9]. In addition, a carbon footprint study of Spanish dairy sheep farming that was based on the LCA method showed that the greenhouse gas emissions of sheep milk ranged from 1.77–4.09 kg CO_2eq/kg, with the lowest value corresponding to the most intensive farm and the highest value corresponding to the most extensive and least productive farms [10]. This shows that intensive farming can reduce greenhouse gas emissions from dairy sheep. The farming method that is considered in this article is a large-scale intensive farming method, which can also effectively reduce carbon emissions.

Low-carbon research on circular agriculture has focused mostly on the pig industry and other industries [14,23,45]. Numerous studies have shown that processing and fermenting agricultural and livestock wastes into biogas is an important strategy for reducing carbon emissions and environmental pollution [46,47]. In addition, biogas can be used not only for heating and cooking but also for power generation. The use of biogas for power generation has significant effects in slowing climate warming and reducing carbon emissions [23,48–50]. For example, in Hebei Jing an, China, the impact of biogas power generation on the environment is lower than that of coal-fired power generation at 6264.17 per capita equivalent standard load [48]. The results of this paper showed that, compared with the noncircular biogas power generation model, the carbon emission reduction effect was significant, with a total reduction of 357.5 kg CO_2eq (Table 4). At present, the company has 7000 dairy sheep; hence, the biogas power generation model will have a reduction of 2502.5 t CO_2eq a year compared with the noncircular model. Therefore, the biogas power generation model is a low-carbon circular farming and animal husbandry model.

Faced with the demand to achieve the "dual-carbon goal", the aquaculture industry needs to vigorously promote low-carbon circular agriculture and animal husbandry models. In this article, the low-carbon circular agriculture model that is based on biogas engineering is a new low-carbon model for the aquaculture industry. It can not only grow grass and raise sheep and return sheep manure to the field but also make sheep farms achieve zero emissions of manure and improve the soil structure so that the water body is not polluted, thereby realizing a virtuous circle and ecological efficiency. At present, this company has suitable conditions for biogas power generation. If biogas power generation is used in the stages of dairy sheep breeding, organic fertilizer processing, and raw material production in the future, the carbon emissions and energy consumption of the entire company will be significantly reduced. At present, the company focuses mainly on dairy sheep breeding. After 5 years, the stock of dairy sheep will reach 50,000. The annual production of dairy sheep is 35,000, and the annual production of mutton sheep is 65,000. The annual production of sheep milk is 23,000 tons. The sales revenue is CNY 552 million. The company has planned a "company + herdsman" breeding model [41]. This model can not only reduce the company's breeding costs and expand the scale of breeding but also reduce energy consumption and carbon emissions, provide a way to achieve carbon neutrality, and improve the income and well-being of herders.

The LCA method can be used to comprehensively evaluate the environmental impact potential of recycling agricultural and animal husbandry enterprises and to analyze the emission of pollutants in a system [14,46]. In this study, the LCA method demonstrated performance advantages in terms of environmental indicators, but these advantages were less reflected in the internal connections of the research system, especially socioeconomic indicators.

4.2. Complex Relationship between Low-Carbon Farming and Animal Husbandry Models and Human Well-Being

The results of this paper show that the circular agricultural production model of biogas power generation can reduce carbon emissions and improve economic well-being. The level of economic well-being of farm employees is higher than that of ordinary herders, but the total amount of coal and electricity that is used per capita is lower than that of ordinary herders. The research of Cai Guoying and others on human well-being in Qinghai Lake shows that increasing the level of human well-being in the region corresponds mainly to increasing the per capita net income and adjusting the industrial structure to create more employment opportunities [51]. The research results of this paper also prove that the income of employees and herdsmen is an important factor that affects the level of well-being. Other research discussed the working environment has an impact on the employees' well-being. The result showed the better the working environment, the higher the well-being of employees [52], and the study of this paper shows that the value of the composite index of human well-being is higher under the low-carbon model (Table 6).

There are differences in the LCA results and human well-being among various scenarios, which indicate that the relationships between models and human well-being are complex [31]. Studies have analyzed the relationship between ecosystem services and human well-being in the Manas River Basin in Xinjiang through the carbon flow method. The results showed that, to alleviate the contradiction between economic development and ecological protection in the basin, it is necessary to effectively maintain the stability of carbon flow in natural ecosystems during economic growth. This maintenance will further improve the level of human well-being and maintain the sustainable development of the region [53]. Therefore, changes in human well-being are closely related to the carbon flow in the ecosystem. This article used per capita income–environmental benefits to study the relationship between environmental impacts and human well-being. The results showed that the income–global warming benefits of circular models are higher than those of the noncircular models, thereby indicating that circular models with biogas power generation is a low carbon emission and high-benefit model. This is closely related to the use of a biogas power supply instead of a coal-fired power supply. Although this approach can reflect the coupling relationship between carbon emissions and economic well-being, it is not comprehensive and does not systematically explain the relationships between other well-being elements and carbon emissions. Therefore, it is necessary to establish a more detailed, more complete, and more systematic carbon emission-welfare indicator system. In addition, we need to give attention to the link between subjective well-being and carbon emissions.

5. Conclusions

This paper considered recycling agricultural and animal husbandry enterprises as the research objects, compared corporate carbon emissions and the environmental impact potential under two scenarios, compared the average well-being of local herders with that of corporate employees, and quantitatively analyzed the relationship between environmental impact potential and economic well-being. In the final comprehensive evaluation, a low-carbon farming and animal husbandry business model that is more suitable for local development was obtained. The conclusions are as follows:

1. In the two scenarios, the carbon dioxide emissions of the noncircular model are higher than those of the circular agriculture and animal husbandry model. The main reason is that the sheep manure is not treated in the noncircular model. The circular agriculture and animal husbandry model uses biogas power generation to replace the traditional coal-fired power supply, thereby reducing greenhouse gas emissions; thus, the circular agriculture and animal husbandry model is conducive to greenhouse gas emission reduction. Overall, compared to the noncircular model, the cyclic agriculture and animal husbandry model has lower global warming potential, acidification potential and eutrophication potential, but the toxicity index is slightly higher.
2. The levels of well-being of enterprise employees and herdsmen differ, which is reflected mainly in income level, residential area and satisfaction with vegetables and meat. The average income of employees is higher than that of herdsmen, the average residential area is smaller, and the consumption of coal and electricity is lower; employees are more satisfied with meat and vegetables, while herdsmen report average satisfaction. In terms of education level, the average education level of employees is higher than that of herdsmen. Comparing the per capita income–environmental benefit values under the two scenarios, it is found that the IAP, IGWP and IEP indicators are higher in the circular model than in the noncircular model of agriculture and animal husbandry, thereby indicating that the biogas power generation model not only reduces the greenhouse gas emission potential but also improves human well-being.
3. In the development of low-carbon industries, the combined effects of carbon emissions and environmental impacts must be considered. The biogas power generation model

that is considered in this article realizes low carbon emission and high human well-being. Therefore, it is recommended that Yongchang County vigorously develop green and low-carbon circular agriculture on the basis of a reasonable analysis of the carbon emission reduction and environmental impact potential of various models. It is necessary to promote low-carbon recycling agriculture and animal husbandry models that are based on biogas power generation and strengthen the resource utilization of discarded vegetables, straw, livestock and poultry manure to achieve the "double carbon" goal and a win–win situation for human well-being.

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