Hindawi Publishing Corporation
Abstract and Applied Analysis
Volume 2013, Article ID 303854, 13 pages
http://dx.doi.org/10.1155/2013/303854

Research Article

Simulation and Optimization of One Live Pig Low-Carbon Industry Chain Using SD-RCCM

Jiuping Xu,[1,2] Jie Yan,[2,3] and Liming Yao[1,2]

[1] *Low-Carbon Technology and Economy Research Center, Sichuan University, Chengdu 610064, China*
[2] *Uncertainty Decision-Making Laboratory, Sichuan University, Chengdu 610064, China*
[3] *School of Management, Northwest University for Nationalities, Lanzhou 730124, China*

Correspondence should be addressed to Jiuping Xu; xujiuping@scu.edu.cn

Received 2 July 2013; Accepted 3 August 2013

Academic Editor: Massimiliano Ferrara

The destruction of the natural environment has been drawing more and more attention. Developing low-carbon industry chains is an effective solution to the conflict between rapid economic growth and high CO_2 emissions. Summarizing various traditional and new industry chain sustainable development, live pig industry was chosen as a typical industry chain to study low-carbon development using a system dynamics and random chance-constrained model (SD-RCCM). Leshan, a world natural and cultural heritage area in China, was selected as a typical city to analyze the low-carbon pig industry. Three different programs based on distribution ratios were selected to study this industry. The results showed that program 1, which considers both environmental and economic benefits, realizes sustainable development. In order to extend the pig industry chain and fully utilize pig ordure and other waste, introducing a Clean Development Mechanism (CDM) and household biogas exploitation program is recommended.

1. Introduction

With economic development, greenhouse gas (GHG) emissions have increased greatly in China. In 1990, the per-capita emission in China was half the global average value, but the current amount has reached 4.3t CO_2, equal to the global average level [1]. The Chinese government has announced a reduction in carbon intensity per unit of GDP by 40–45% by 2020, based on 2005 levels. The low-carbon economy refers to an economy with "three lows and one high" (low energy consumption, low pollution, low emission, and high-performance) as its basic features [2]. Today, the low-carbon economy is considered to be both an economic transformation direction and an inevitable choice for enterprise development. Enterprises need to develop low-carbon products to rely on independent innovation, develop a low-carbon industry chain, and present a new low-carbon society.

Numerous studies describing various low-carbon industry chains are available from the open literature. A preliminary bottom-up analysis of the energy use in the chemical industry has been performed, the results of which show that there is significant room for more selective processes and further energy saving [3]. Ren and Wang have investigated the development status of the iron and steel industry using a carbon emission coefficients method. They concluded that laying a theoretical foundation for realizing the target of sustainable and low-carbon economic development in iron and steel industry is essential [4]. Rehan discussed the implications of actions for mitigating global warming in the cement industry [5]. Low-carbon electricity development in China has been studied from the integrated resource strategy planning perspective based on the Super Smart Grid [6]. Low-carbon food which is manufactured by less simple carbohydrates and more advanced low-carbon technology with the characteristics of low pollution, low emission, low power, low calorie, and low fat during the production, transportation, and consumption has been analyzed systematically [7]. For the food industry, it is essential to complete the energy conservation, emission reduction and safety management system in the whole process from farmland to the table, including chopsticks. Duan and Huang briefly introduced the basic conditions for energy saving and emission reduction in the Chinese tobacco industry, proposing that, to realize low-carbon development in tobacco industry energy saving and emission reduction need to be promoted from five perspectives [8]. Based on the existing problems in the transportation system, Lai and Ren analyzed the low-carbon sustainable development of the transportation industry [9]. Tang and Shi analyzed the fundamental concept of low-carbon tourism and discussed some countermeasures for the sustainable development of tourist administrations, enterprises, attractions, and tourists [10].

Agriculture is the second major source of GHG, in which the GHG emissions of animal husbandry account for 18% of global gross emissions, even more than traffic and transportation. The live pig industry chain from breeding to selling, as a vital component of animal husbandry, also generates a great deal of CO_2, especially in intensive pork processing. Pig ordure also creates significant environmental pollution. The development of the pig industry places a high burden on resource use and environmental quality. The welfare, health, and management of pigs as well as environmental concerns are relevant issues that impact the success of the producer in the market and need to be considered to increase public and consumer acceptance of pig production [11].

Extensive studies have been conducted on the pig industry. These studies include information about pig breeding, price, scale, consumption, disease prevention, and even waste disposal. Maria Nöremark investigated Swedish pig farmers' disease awareness, information retrieval, and biosecurity routines during an outbreak of an exotic infectious disease, using as a basis experience from the first outbreak of PRRS in Sweden in 2007 [12]. Ngapo focused on consumers from pig markets in France, England, Sweden, and Denmark to obtain insights into the decision making involved in the choice of fresh pork and attitudes towards pig production systems [13]. Elzen investigated a system innovation in pig husbandry which concerned sustainability and animal welfare [14]. Yang developed a multi activity DEA to simultaneously measure productive efficiency and environmental efficiency in farrow-to-finish pig production in Taiwan [15]. Using methodology from the Intergovernmental Panel on Climate Change (IPCC), Verge calculated the GHG emissions from the Canadian pork industry [16]. Lemke analyzed developmental trends and the driving forces in smallholder pig production systems in the marginalized mountainous areas of North west Vietnam [17]. Green, using novel algorithms for the accumulation of protein and lipid, applied a mechanistic model to study pig growth and composition [18]. A nonparametric data envelopment analysis (DEA) technique was used to investigate the degree of technical and scale efficiency of commercial pig farming in Greece [19]. Several data sets were used to test the proposition that feed intakes can be predicted from knowledge of simple measurements of pig live weight and fatness [20]. These papers mostly concentrated on one or two aspects of pig industry chain from a microcosmic angle or focused inward on the industry. Research studying the overall pig industry chain using system dynamics (SD) is, to date, limited.

SD methods, a simulation technology that studies complex systems based on the foundation of feedback control theory and the measurement of computer imitation technology, are well acknowledged for modeling the behavior of a complex system [21]. SD is widely used to dynamically capture the complex relationship of society, economy, resource, and environment. For example, Wang presented an SD approach to analyze an urban transportation system [22]. Ferrara et al. applied the philosophy of system control to find some useful laws of the macroeconomic system [23–25]. Benjamin used SD as a decision-making tool in building design [26].

Due to the uncertainty of the parameters, relevant quantitative data fluctuate randomly within a certain range thus, a stochastic process is used. In order to reach a balance amongst multiple objectives, a random chance-constrained model (RCCM) is introduced. Cao and Gu [27] researched a crude oil scheduling problem using stochastic chance-constrained mixed-integer nonlinear programming models. Bhattacharya designed a chance-constrained goal programming model for an advertising planning problem [28]. In this paper, two models are combined, and an integrated model, SD-RCCM, is developed.

This paper is organized as follows. In Section 2, a pig industry chain for low-carbon development is introduced, and the problem is presented. In Section 3, the modelings of the SD and the RCCM are established. Taking economic output and emission reduction into consideration, the total output value, total energy consumption, and carbon intensity over the next 10 years are examined. Section 4 applies the SD-RCCM model to Leshan's pig industry, presents the simulation, and analyzes three different optimization programs. Section 5 puts forward suggestions for the sustainable development of the region's pig industry. In the last section, conclusions are made, and recommendations are proposed.

2. Statement of the Problem

In this part, the pig industry chain is described. The assumptions are outlined, and corresponding variables are clarified.

2.1. System Description. The pig industry chain is defined as commercial pig breeding, slaughter, processing, and marketing activities; with relationships both forward and backward. Boar breeding, forage planting, and veterinary production drive the pork production development. High revenue from pork production and its by-products also boosts the improvement. From the backward perspective, the slaughtered pigs either enter the market directly or supply other markets with various kinds of processed pork products. Pig bones, blood, and skin are used to manufacture high quality products, such as bone glue and leather; thus, creating more revenue. Pig ordure and urine produce a great deal of CO_2 and other environmental problems. Using anaerobic fermentation biotechnology, this waste can be used to produce biogas, biogas slurry, and biogas residue. By separating the dry ordure and manufacturing organic fertilizer together with biogas slurry and residue, it is recycled back into the pig breeding industry.

In the pig industry chain, there is a positive and a negative circular chain. Firstly, the positive circular chain is "pig breeding $\xrightarrow{+}$ live pig $\xrightarrow{+}$ output value $\xrightarrow{+}$ pig breeding," with

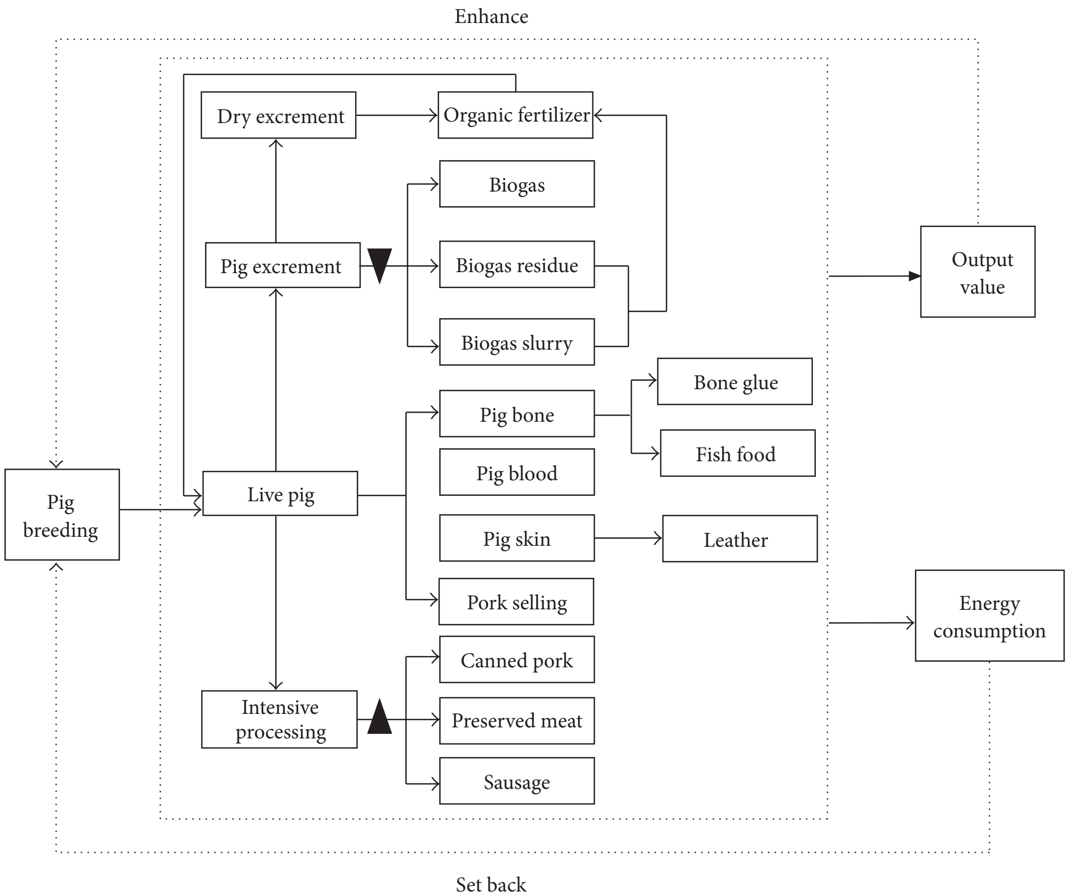

Figure 1: Pig industry chain.

the high output value boosting pig breeding through the enhancement factor of the output value; thus, adding to the total amount of live pigs. On the other hand, "pig breeding $\xrightarrow{+}$ live pig $\xrightarrow{+}$ energy consumption $\xrightarrow{-}$ pig breeding," the amount of live pigs decreases under the influence of increasing energy consumption.

On analyzing the pig industry chain, the ▲ shown in Figure 1 shows that intensive pork processing consumes significant energy, which reaches 0.8725, 0.6852, and 0.6321 Tce/ton respectively, while pig ordure causes the biggest environmental problem, just as the ▼ shows. Balancing economic output and environmental protection is urgent. So, appropriate control parameters need to be selected to adjust the pig industry chain and achieve optimal economic benefits with low-carbon development.

2.2. Hypothesis. There are four assumptions for the model.

(1) The slaughter is well-off, and the market is sufficient. There is no further study on these two elements in our paper.

(2) Pork can be processed into various kinds of products, such as minced pork, but in Leshan sausages and preserved meats are the featured products. Canned pork, preserved meat, and sausages are studied as part of intensive processing.

(3) Pig bristle is ignored.

(4) Because pig blood consumes little energy, it is ignored to simplify the model.

2.3. Notation. In this study, the following specific symbols are used to identify the parameters to facilitate model calculations. The symbols for the main related parameters are listed in Table 1.

3. Modeling

The SD-RCCM is based on the description of pig industry chain. A goal programming method was adopted to solve the problem.

3.1. System Dynamic Model. Besides the two circular chains mentioned previously, there are some small chains inside the industry itself. The main pork intensive processing chain is "live pig → pork → intensive processing of pork → canned pork or preserved meat or sausage." There are also several important ordure disposal chains, ① "pig ordure → dry pig ordure → organic fertilizer," ② "pig ordure → biogas,"

Table 1: Variable symbol of pig industry chain.

Number	The meaning of variables	Variable units	Symbol
1	The output of live pig	Headage	Q
2	The output of pork	Ton	Q_0
3	Sales of pork	Ton	Q_{01}
4	Intensive processing amount of pork	Ton	Q_{02}
5	The output of biogas	ton	Q_1
6	The output of organic fertilizer	Ton	Q_2
7	The output of canned pork	Ton	Q_3
8	The output of preserved meat	Ton	Q_4
9	The output of sausage	Ton	Q_5
10	The output of pig ordure	Ton	Q_e
11	Unit output of pig ordure	Ton	UQ_e
12	Price of pork	Ten thousand yuan/ton	P_0
13	Price of canned pork	Ten thousand yuan/ton	P_3
14	Price of preserved meat	Ten thousand yuan/ton	P_4
15	Price of sausage	Ten thousand yuan/ton	P_5
16	Distribution ratio of intensive processing	NO.	x_1
17	Distribution ratio of canned pork processing	NO.	x_2
18	Distribution ratio of preserved meat processing	NO.	x_3
19	Distribution ratio of sausage processing	NO.	x_4
20	Distribution ratio of pork sales	NO.	x_5
21	Total output value	Ten thousand yuan	TV
22	The output value of pork sales	Ten thousand yuan	V_{01}
23	The output value of intensive processing	Ten thousand yuan	V_{02}
24	The output value of biogas	Ten thousand yuan	V_1
25	The output value of organic fertilizer	Ten thousand yuan	V_2
26	The output value of canned pork	Ten thousand yuan	V_3
27	The output value of preserved meat	Ten thousand yuan	V_4
28	The output value of sausage	Ten thousand yuan	V_5
29	Total energy consumption	Tce	TE
30	Energy production of biogas	Tce	E_1
31	Energy consumption of organic fertilizer	Tce	E_2
32	Energy consumption of canned pork	Tce	E_3
33	Energy consumption of preserved meat	Tce	E_4
34	Energy consumption of sausage	Tce	E_5
35	Energy consumption of bone glue	Tce	E_6
36	Energy consumption of fish food	Tce	E_7
37	Energy consumption of leather	Tce	E_8
38	Unit energy production of biogas	Tce	$\tilde{e}_1$
39	Unit energy consumption of organic fertilizer	Tce	$\tilde{e}_2$
40	Unit energy consumption of canned pork	Tce	$\tilde{e}_3$
41	Unit energy consumption of preserved meat	Tce	$\tilde{e}_4$
42	Unit energy consumption of sausage	Tce	$\tilde{e}_5$
43	Unit energy consumption of bone glue	Tce	$\tilde{e}_6$
44	Unit energy consumption of fish food	Tce	$\tilde{e}_7$
45	Unit energy consumption of leather	Tce	$\tilde{e}_8$

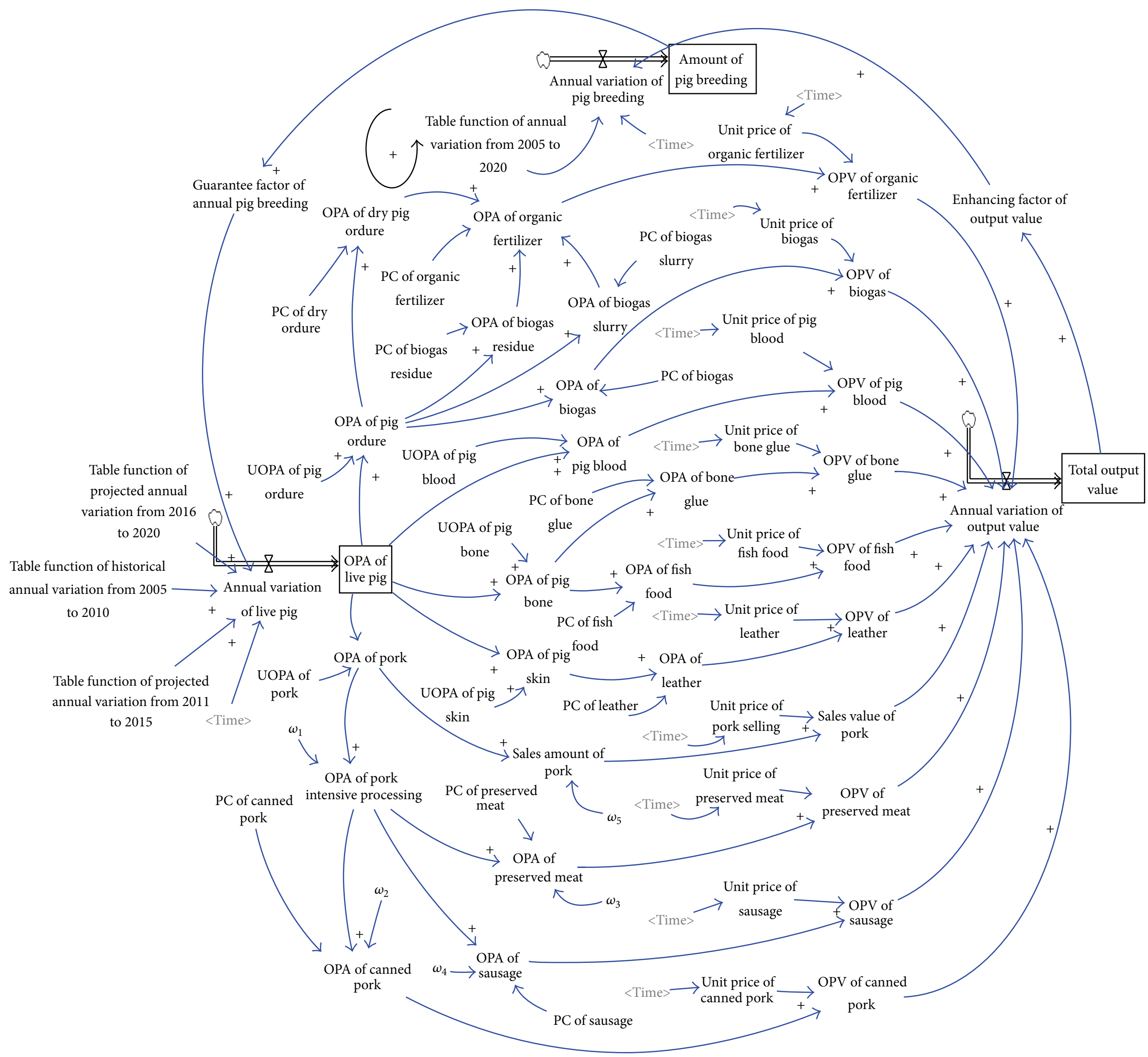

Figure 2: The output value of the pig industry chain.

and ③ "pig ordure → biogas slurry and residue → organic fertilizer."

The SD models are shown in Figures 2 and 3. Some of the system relationships are as follows.

(1) The total output of pig ordure equals the headage of live pigs multiplied by the unit output of pig ordure:

$$Q_e = Q * UQ_e. \quad (1)$$

(2) The sales of pork equal pork production multiplied by the distribution ratio of pork:

$$Q_{01} = Q_0 x_5. \quad (2)$$

(3) The sales value of pork is determined by the sales of pork multiplied by the sales price:

$$V_{01} = Q_{01} P_0. \quad (3)$$

(4) Pork intensive processing produces three kinds of products: canned pork, preserved meat, and sausages. Thus, the output value of intensive processing is the sum of the respective output values:

$$V_{02} = V_3 + V_4 + V_5. \quad (4)$$

(5) The output of pork intensive processing is calculated by pork production volume multiplied by the distribution ratio of intensive processing:

$$Q_{02} = Q_0 x_1. \quad (5)$$

(6) The total output value is the sum of the pork intensive processing value and the output value of biogas and organic fertilizer:

$$\mathrm{TV} = V_{02} + V_1 + V_2. \quad (6)$$

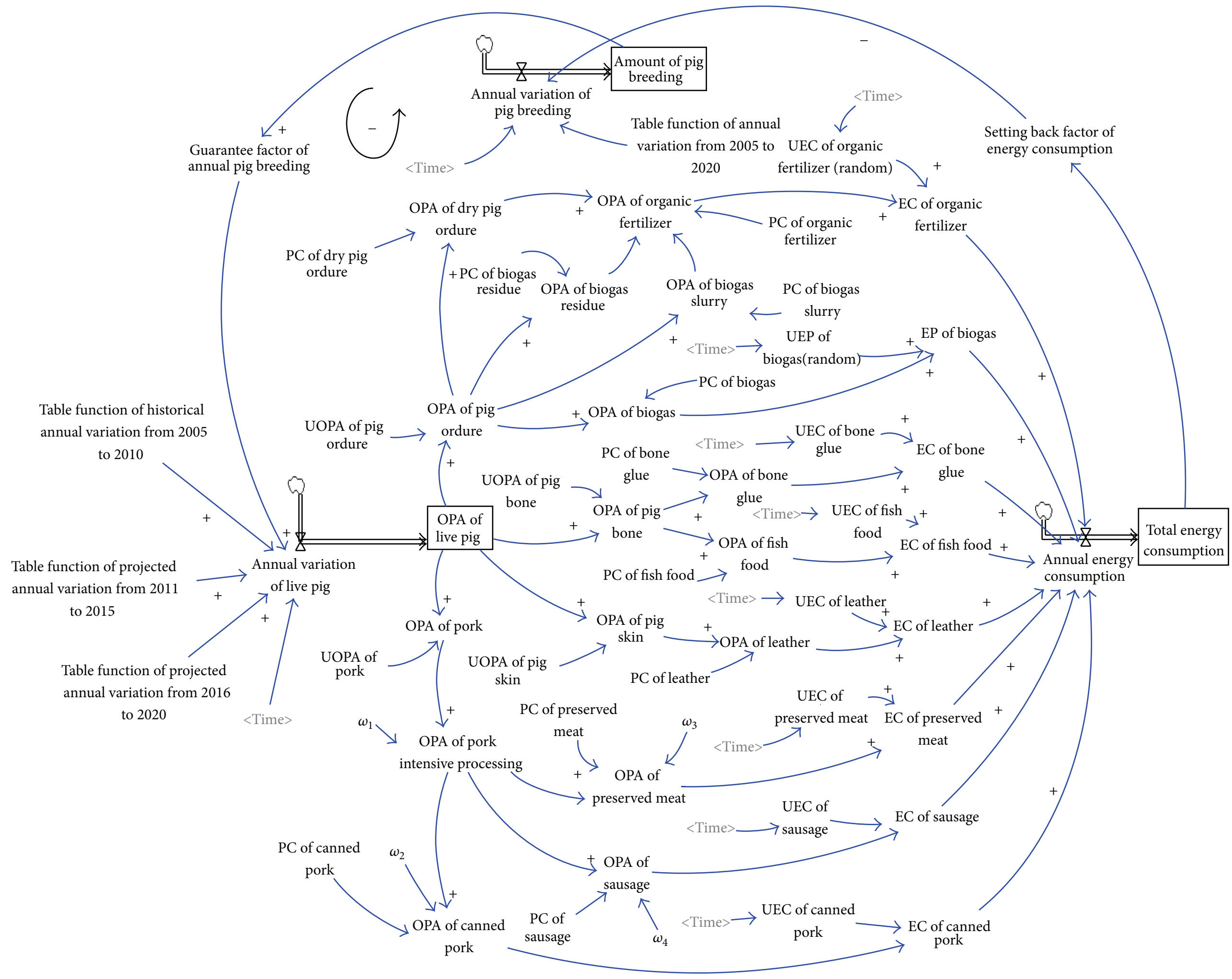

Figure 3: The energy consumption of the pig industry chain.

(7) The energy consumption of organic fertilizer equals the output amount of organic fertilizer multiplied by unit energy consumption:

$$E_2 = Q_2 \tilde{e}_2. \quad (7)$$

(8) The amount of biogas energy production is calculated by biogas volume multiplied by unit energy production:

$$E_1 = Q_1 \tilde{e}_1. \quad (8)$$

(9) The total amount of energy consumption is the sum of energy consumption of organic fertilizer, canned pork, preserved meat, sausages, bone glue, fish food, and leather minus the energy biogas production:

$$\mathrm{TE} = E_2 + E_3 + E_4 + E_5 + E_7 + E_8 + E_9 - E_1. \quad (9)$$

3.2. Random Chance-Constrained Model. To realize maximum output value with a low-carbon focus, a chance-constrained model is established. In practice, the pig production chain has a long history and has developed well in the region, and the unit energy consumption amount of pig-related products from historical records vary within a certain range and tend to obey a uniform distribution. To reduce the uncertainty of the system, a stochastic process is taken into consideration and applied to the RCCM [29].

Pork is sold directly or intensively processed. The latter creates high revenue but consumes significant energy. A distribution ratio for intensive processing, preserved meat processing, canned pork processing, and sausage processing and pork selling is selected as the control parameter. Total output value and energy consumption are simulated by changing control parameters.

3.2.1. Objective Functions. Two objectives are considered—maximum output value and minimum energy consumption.

(1) The Total Output Value of the Pig Industry Chain. As Figure 2 shows, total output value is the sum of the output value of biogas, organic fertilizer, bone glue, fish food, leather, pig blood, canned pork, preserved meat, and sausage:

$$\max \mathrm{TV} = \sum_{i=1}^{9} P_i Q_i + P_0 Q_{01} = \left(P_0 x_5 + P_3 x_1 x_2 + P_4 x_1 x_3 + P_5 x_1 x_4\right) Q_0 + V_0, \tag{10}$$

where V_0 represents the output value of other products.

(2) Total Energy Consumption of the Pig Industry Chain. From Figure 3, every link in the chain consumes energy. As the system generates part of the biogas, that part is deducted when calculating the total energy consumption. Because of technological improvements and other reasons, the unit energy consumption $\tilde{e}$ is considered a stochastic number and varies within a certain range with some fixed possibilities. Minimum energy consumption cannot be determined unless first dealing with the stochastic number.

Energy consumption can be controlled to some degree, and the probability of meeting the condition reaches a given level. So the function is as follows,

$$\min \overline{f}, \tag{11}$$

where meet $\Pr\{(\tilde{e}_3 x_1 x_2 + \tilde{e}_4 x_1 x_3 + \tilde{e}_5 x_1 x_4) Q_0 + \sum_{i=7}^{9} Q_i \tilde{e}_i + \tilde{e}_2 Q_2 - \tilde{e}_1 Q_1\} \geq \theta$, where θ is the given confidence level, and Pr represents the random probability measurement.

3.2.2. Constraint Functions. The constraints are considered as follows.

(1) Fundamental Guarantee of Pork Products. Considering that pork is a daily needed product and the quantity in one area must meet its daily demand, the total amount of all kinds of pork products is supposed to reach a certain level:

$$Q_{01} + Q_3 + Q_4 + Q_5 \geq D_0; \tag{12}$$

that is,

$$x_5 Q_0 + x_1 x_2 Q_0 + x_1 x_3 Q_0 + x_1 x_4 Q_0 \geq D_0, \tag{13}$$

where D_0 stands for the fundamental demand volume for pork in the area.

(2) Constraints on Quantity of Preserved Meat and Sausage. Leshan is a large exporter of preserved meat and sausage. This export brings benefits for local farmers. Thus, the amount of preserved meat and sausage must meet fundamental demand:

$$P_4 x_1 x_3 Q_0 + P_5 x_1 x_4 Q_0 \geq F_0, \tag{14}$$

where F_0 represents the fundamental output value of preserved meat and sausage local farmers expect.

On the other hand, preserved meat and sausages are seasonal consumer products, with sales usually being higher at the end of the year as they are not easily preserved in summer. Thus, the quantity should be controlled to a certain degree:

$$x_1 x_3 Q_0 + x_1 x_4 Q_0 \leq G_0, \tag{15}$$

where G_0 stands for the maximum output amount of preserved meat and sausages.

(3) The Energy Consumption of Canned Pork Constraint. Because canned pork processing consumes a great deal of electricity, while the local resources are quite limited, the energy expense is relatively high. Thus, energy consumption for canned pork processing should be constrained. The unit energy consumption of canned pork processing varies, so it is transformed from a stochastic parameter into a determined one. The probability of meeting the constraint condition is expected to reach a given level:

$$\Pr\left\{\tilde{e}_3 x_1 x_2 Q_0 \leq E_0\right\} \geq \gamma, \tag{16}$$

where E_0 stands for the maximum energy consumption of canned pork intensive processing and γ stands for the probability value given in advance.

(4) Distribution Ratio Constraint. The sum of pork used for various products should be equal to or less than the total pork production volume. The constraint conditions on the distribution ratio are as follows:

$$\begin{aligned} x_1 + x_2 &\leq 1, \\ x_3 + x_4 + x_5 &\leq 1, \\ 0 \leq x_i \leq 1, &\quad i = 1, \ldots, 5, \end{aligned} \tag{17}$$

where x_i stands for the corresponding distribution ratio.

Summarizing previous, the RCCM is shown as follows:

$$\begin{aligned} &\max \mathrm{TV} = \left(P_0 x_5 + P_3 x_1 x_2 + P_4 x_1 x_3 + P_5 x_1 x_4\right) Q_0 + V_0 \\ &\min \overline{f} \\ &\text{s.t.} \begin{cases} \Pr\left\{ \left(\tilde{e}_3 x_1 x_2 + \tilde{e}_4 x_1 x_3 + \tilde{e}_5 x_1 x_4\right) Q_0 \right. \\ \quad \left. + \sum_{i=7}^{9} Q_i \tilde{e}_i + \tilde{e}_2 Q_2 - \tilde{e}_1 Q_1 \right\} \geq \theta \\ x_5 Q_0 + x_1 x_2 Q_0 + x_1 x_3 Q_0 + x_1 x_4 Q_0 \geq D_0 \\ P_4 x_1 x_3 Q_0 + P_5 x_1 x_4 Q_0 \geq F_0 \\ x_1 x_3 Q_0 + x_1 x_4 Q_0 \leq G_0 \\ \Pr\left\{\tilde{e}_3 x_1 x_2 Q_0 \leq E_0\right\} \geq \gamma \\ x_1 + x_2 \leq 1 \\ x_3 + x_4 + x_5 \leq 1 \\ 0 \leq x_i \leq 1, \quad i = 1, \ldots, 5. \end{cases} \end{aligned} \tag{18}$$

3.3. Goal Programming Method. The goal programming method is initialized by Charnes and Cooper [30, 31] in 1961. After that, Ijiril [32], Kendall and Lee [33], and Ignizio [34] deeply researched and widely developed it. When dealing with many multiobjective decision making problems, it is widely applied since it could provide with a technique which is accepted by many decision makers; that is, it could point out the preference information and harmoniously inosculate it into the model. In our paper, there are two objectives, f_1 represents maximum economic output and f_2 represents minimum energy consumption.

The basic idea of this method is that, for the objective function $\mathbf{f}(\mathbf{x}) = (f_1(\mathbf{x}), f_2(\mathbf{x}))^T$, decision makers give a goal value $\mathbf{f}^o = (f_1^o, f_2^o)^T$ such that every objective function $f_i(\mathbf{x})$ approximates the goal value f_i^o as closely as possible. Let $d_p(\mathbf{f}(\mathbf{x}), \mathbf{f}^o) \in \mathbf{R}^m$ be the deviation between $\mathbf{f}(\mathbf{x})$ and $\mathbf{f}^o$, then consider the following problem:

$$\min_{\mathbf{x}\in X} d_p(\mathbf{f}(\mathbf{x}), \mathbf{f}^o), \tag{19}$$

where the goal value $\mathbf{f}^o$ and the weight vector $\mathbf{w}$ are predetermined by the decision maker. The weight w_i expresses the important factor that the objective function $f_i(\mathbf{x})$ $(i = 1, 2)$ approximates the goal value f_i^o, $1 \le p \le \infty$.

When $p = 1$, the simple goal programming method which is most widely used is recalled. Then we have

$$d_p(\mathbf{f}(\mathbf{x}), \mathbf{f}^o) = \sum_{i=1}^{m} w_i \left|\mathbf{f}(\mathbf{x}) - \mathbf{f}^o\right|. \tag{20}$$

Since there is the notation $|\cdot|$ in $d_p(\mathbf{f}(\mathbf{x}), \mathbf{f}^o)$, it is not a differentiable function any more. Therefore, denote that

$$\begin{aligned} d_i^+ &= \frac{1}{2}\left(\left|f_i(\mathbf{x}) - f_i^o\right| + \left(f_i(\mathbf{x}) - f_i^o\right)\right), \\ d_i^- &= \frac{1}{2}\left(\left|f_i(\mathbf{x}) - f_i^o\right| - \left(f_i(\mathbf{x}) - f_i^o\right)\right), \end{aligned} \tag{21}$$

where d_i^+ expresses the quantity that $f_i(\mathbf{x})$ exceeds f_i^o, and d_i^- expresses the quantity that $f_i(\mathbf{x})$ is less than f_i^o $(i = 1, 2)$;

$$\begin{aligned} d_i^+ + d_i^- &= \left|f_i(\mathbf{x}) - f_i^o\right|, \\ d_i^+ - d_i^- &= f_i(\mathbf{x}) - f_i^o, \\ d_i^+ d_i^- &= 0, \quad d_i^+, d_i^- \ge 0. \end{aligned} \tag{22}$$

In order to easily solve the problem (22), abandon the constraint $d_i^+ d_i^- = 0$ $(i = 1, 2)$; and we have

$$\begin{aligned} &\min \sum_{i=1}^{m} w_i \left(d_i^+ + d_i^-\right) \\ &\text{s.t.} \begin{cases} f_i(\mathbf{x}) + d_i^+ - d_i^- = f_i^o, & i = 1, 2 \\ d_i^+, d_i^- \ge 0, & i = 1, 2 \\ \mathbf{x} \in X \end{cases} \end{aligned} \tag{23}$$

where $\omega_1 = 0, \omega_2 = 1$ that is to indicate attention while be paid to environmental protection sacrificing economic benefits. $\omega_1 = 1, \omega_2 = 0$ means that output value can be increased despite harming the environment. Finally $\omega_1 = 0.5, \omega_2 = 0.5$, state that environmental protection and economic output are of equal importance in the development process. The SD model is optimized according to the previous three, cases and a satisfactory scheme to achieve sustainable development is determined.

Table 2: The historical record of live pig from 2005 to 2009 (ten thousand headage).

Year	2005	2006	2007	2008	2009
Annual variation of live pig	20.87	18.33	−47.63	13.56	14.68
Amount of live pig	360.85	379.18	331.55	345.11	359.79

4. Simulation and Optimization

Leshan in Sichuan province, China, is a typical example to stimulate the pig industry chain. Sichuan Province is one of the biggest pork production and selling bases in China, with the amount of live pig and pork production ranking first nationwide. Leshan is a pork production and intensive processing leader in Sichuan Province with a production volume of 510,364 tons of pork annually and a revenue of nearly 2987.1 million's. Leshan is also the location of the world natural and cultural heritage—Leshan Giant Buddha, which means that achieving sustainable development is of paramount importance.

The parameter values were inserted into the SD model simulation software VENSIM to perform the simulation. Data from 2011 were marked as the initial conditions time = 0. The simulation spans 10 years, from 2011 to 2020.

4.1. Data Sources. The amounts of live pigs from 2005 to 2009 are shown in Table 2. According to government planning documents, the amount of live pigs is expected to reach 605.8 thousands of headage in 2015 and 880.7, thousands headage in 2020. The fluctuating boar price tends to vary in a five year cycle, that is, low-rise-rise-fall-fall, as shown in Table 3.

The guarantee annual amount pig breeding factor equal the amount of live pig/the pig breeding amount. The pig breeding information is shown in Table 4, and the average value of the guarantee factor is 0.89. The enhancing output value factor is IF THEN ELSE ("Total output value" $> -1, 1, 0.99$). The energy consumption setting back factor is IF THEN ELSE ("Total energy consumption" $> -1, 1, 0.73$).

Information for the parameters was obtained from various sources. For example, reference to the twelfth five-year national economic and social development plan and other administrative reports in this region, local pork processing factories and other related enterprises, and an Internet and field investigation to determine market information.

Triangular random numbers were selected with 0.8 as the measure for this model. The random variables in the pig production chain data are shown in Table 5.

4.2. Simulation Results. Typical weights were chosen to form three different programs. In program 1, $\omega_1 = 0.5$, $\omega_2 = 0.5$, both environmental protection and economic benefit are considered. In program 2, $\omega_1 = 1$, $\omega_2 = 0$, only economic benefit was considered. In program 3, $\omega_1 = 0$, $\omega_2 = 1$, only environmental protection was considred. Using RCCM, the optimal solutions are shown in Table 6. Inserting these optimizing values into the SD model the results are shown

Table 3: The projected amount of live pig from 2010 to 2015 (ten thousand headage).

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual variation of live pig	13.12	17.53	21.68	−16.74	−3.23	15.61	17.32	19.55	−13.71	−5.02	11.76
Amount of live pig	372.91	390.44	412.12	395.38	392.15	407.76	425.08	444.63	430.92	425.90	437.66

Table 4: The amount of pig breeding from 2005 to 2020 (ten thousand headage).

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual variation	11.28	20.59	−53.51	15.23	16.51	14.76	19.67	24.37	−18.82	−3.62	17.54	19.46	21.96	−15.41	−5.64	13.21
Total amount	405.45	426.04	372.53	387.76	404.26	419.02	438.69	463.06	444.24	440.62	458.16	477.62	499.58	484.18	478.54	491.75

Table 5: Data of the random variables.

Symbol	Value	Unit
$\tilde{e}_1$	$U(0.6239, 0.7325)$	Tce
$\tilde{e}_2$	$U(0.1795, 0.2005)$	Tce
$\tilde{e}_3$	$U(0.3020, 0.3352)$	Tce
$\tilde{e}_4$	$U(0.1252, 0.1455)$	Tce
$\tilde{e}_5$	$U(0.3115, 0.3335)$	Tce
$\tilde{e}_7$	$U(0.3735, 0.4023)$	Tce
$\tilde{e}_8$	$U(0.2663, 0.2911)$	Tce
$\tilde{e}_9$	$U(0.2693, 0.2808)$	Tce

Table 6: Data of the control variables.

	Current program	Optimization program 1	Optimization program 2	Optimization program 3
w_1	0.32	0.6543	0.8725	0.4033
w_2	0.39	0.3524	0.4369	0.2185
w_3	0.31	0.3288	0.3543	0.3853
w_4	0.32	0.3333	0.2181	0.4215
w_5	0.65	0.3523	0.1277	0.6124

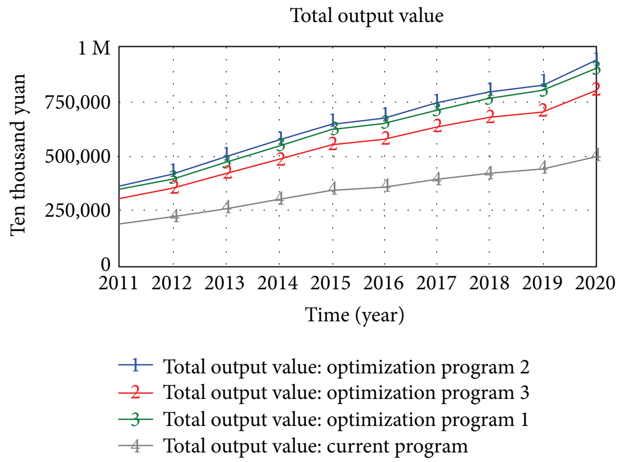

Figure 4: Total output value.

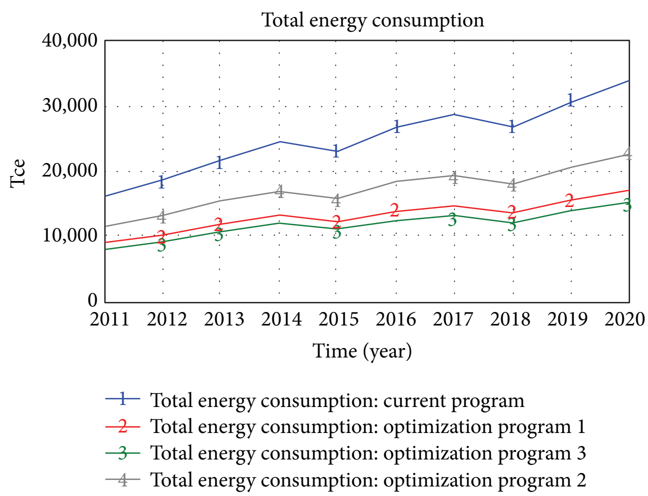

Figure 5: Total energy consumption.

in Figures from 4 to 11. Now a brief analysis based on these figures is disscussed.

From Figure 4 to Figure 6, the total output value of the current program is the lowest, less than 2500 million yuan, while the total energy consumption is the highest, nearly 17,000 Tce. Thus, the carbon intensity is also the largest, though this trend may be due to technical innovation and management improvement. Thus, we can conclude that the optimization is necessary and useful.

Comparing the three optimization programs, from Figure 4, program 2 reaches the highest output value, nearly 6500 million yuan in 2015 and not far from 1 billion till 2020. Program 1 is just a little lower than program 2, while program 3 has an output value of 8000 million yuan in 2020.

From Figure 5, the energy consumption trend is upward because of production scale expansion. The energy consumption of program 2 which only considers economic benefit, is the highest among the three optimization programs, reaching nearly 23,000 Tce in 2020, yet still significantly lower than the current program. Program 1 is only 18,000 Tce, almost the same as program 3 which is only concerned with environmental protection.

From Figure 6, carbon intensity decreases year by year and reaches 0.13 in 2020 with program 1, the lowest among the four programs. The value is 0.14 in program 3 and 0.16 in program 2. The distribution ratio is shown from Figure 7 to Figure 11.

From Figures 7, 8, and 9, the output value of preserved meat grows the fastest compared with canned pork and

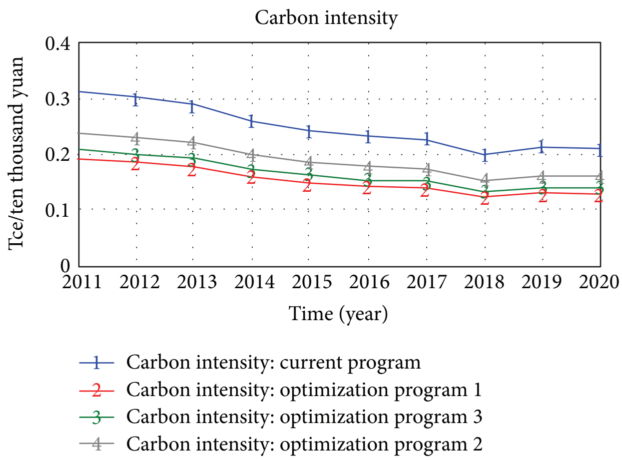

Figure 6: Carbon intensity.

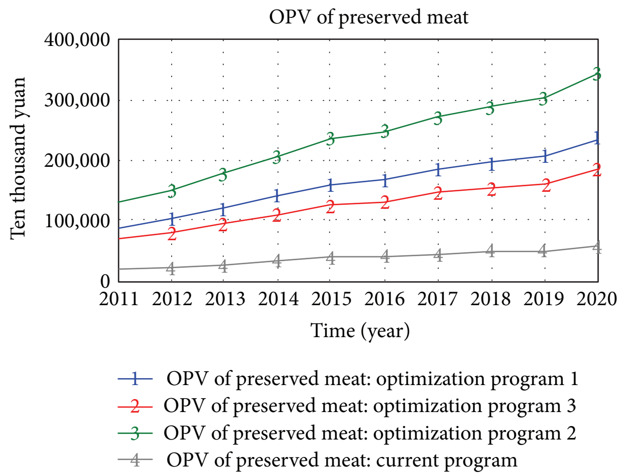

Figure 8: The output amount of preserved meat.

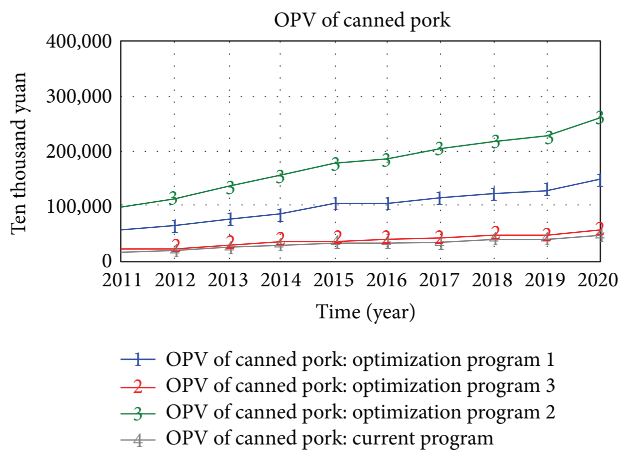

Figure 7: The output value of canned pork.

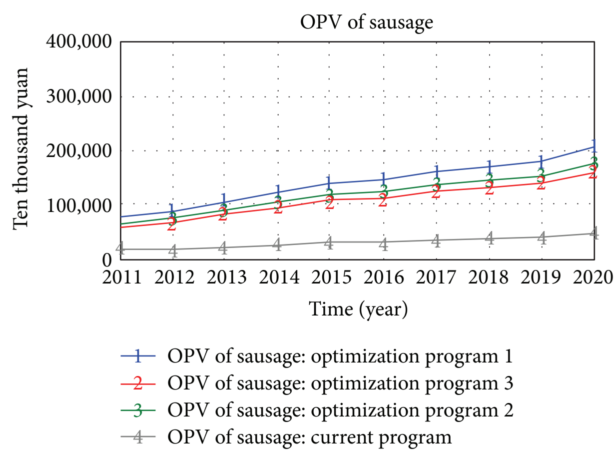

Figure 9: The output value of sausage.

sausage. Program 1 reaches 2300 million in 2020, even higher than the current sales value. From Figure 7, the canned pork output value reaches 1500 million in program 1, which is lower than preserved meat, because canned pork processing consumes more energy, and output needs to be constrained. From Figure 9, the sausage output value is nearly 2000 million in program 1 in 2020.

From Figure 10, the sales value also grows yearly but not as rapidly as with intensive processing. The current program has a high sales value of 1800 million in 2020, but program 1 only reaches 900 million.

From Figure 11, the intensive processing output amount increases year on year because of the increasing revenue. Program 1 reaches nearly 70,000 tons of intensive processing, much higher than the current 25,000 tons.

Summarizing the previous, the optimization programs are better than the current program. Optimization program 1 is the optimum; program 2 realizes the largest output value but with high energy consumption and high carbon intensity. Program 3 consumes the lowest energy, but the output value is also low, with carbon intensity a little high. The distribution ratio for intensive processing is higher than pork sales, because intensive processing produces greater returns. Even though it also consumes more energy, if the distribution ratio is optimized, economic benefit and environmental protection can be balanced. Analyzing program 1, the intensive processing distribution ratio is a little more than 50%. The pork selling ratio is a little more than 30%. Other ratios are almost the same, but the ratio of canned pork processing is a little lower because of its high energy consumption.

4.3. Policy Proposals. The pig industry has an important position in Leshan's agriculture. Therefore, it needs to set a good example and realize the transformation from traditional agriculture to low-carbon agriculture with high efficiency, low emission, low pollution, and low energy consumption.

4.3.1. Economic Benefit

(1) Strive to develop intensive pork processing, and especially increase the proportion of preserved meat and sausage processing, but the canned pork processing

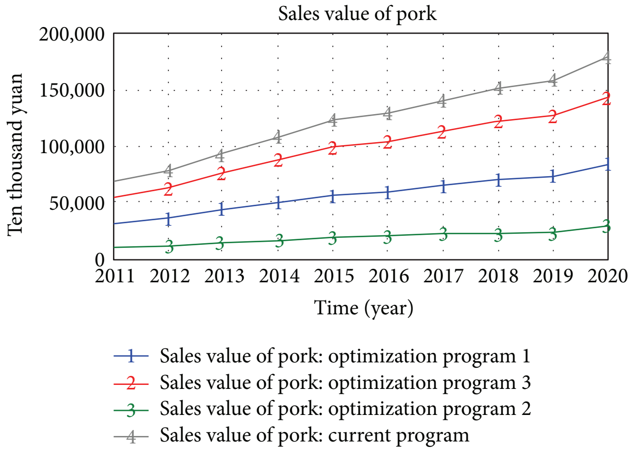

FIGURE 10: The sales value of pork.

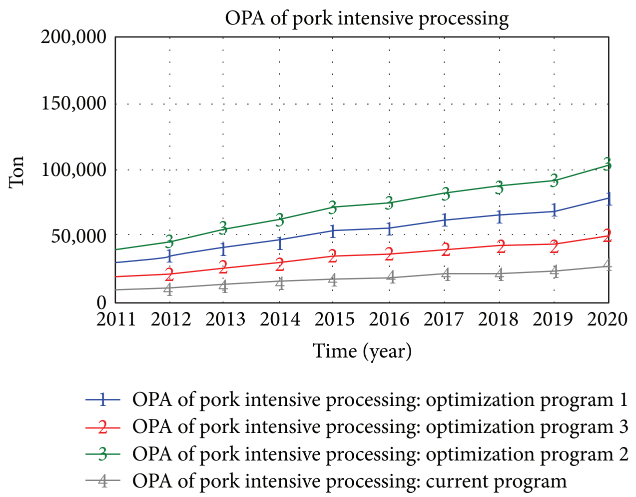

FIGURE 11: The output amount of intensive processing.

proportion should be constrained to reduce the high energy consumption.

(2) Try to develop high-end products in the pig industry chain. Increase the input of bone glue and leather productions as LanYan corporation is featured for its bone glue products. Research the technology of SOD extraction from pig's blood. These high-tech products would help to extend the pig industry and bring about higher returns.

(3) Implement brand strategy. Leshan is famous for its intensive pork processing products, especially sausages, preserved meat, and canned pork, so government and enterprises should cooperate to enhance the whole industry chain's competitiveness and influence. All government departments should work together and offer financial and political support for this development. The intensive processing products are expected to rank first nationwide through expert assistance, government's service, and the enterprises' own endeavors. LanYan corporation's continued development is of significant importance; LanYan needs to develop to scale, standardize and modernize and create a platform for the cooperation of enterprises, colleges, and financial department; thus, boosting the transformation from scientific technology to productivity and leading the development of the live pig industry in Leshan, even in China.

(4) Comprehensive utilization of pig ordure, urine, and other waste. To reduce energy consumption and CO_2 emissions, it is suggested that ecological pig breeding farms should be developed, to fully exploit and utilize the biogas energy produced by pig ordure and urine. Construct an underground biogas production pool and research and develop biogas power generation. Implement a household biogas pool project to assist in solving the cooking fuel problem for local farmers, and save household energy costs.

(5) Construct three-level delay filtration ponds of biogas slurry using distributary irrigation engineering technology. Develop "breeding – planting" biologic chain production engineering technology, to realize resource recycling of biogas slurry in cultural zones. Exploit the engineering technology of "pig – biogas slurry – paddy rice," "pig – biogas slurry – fruit," and "pig – biogas slurry – fish food planting." Also, establish a circulation chain of "pig – biogas slurry – upland sweet potato – organic fertilizer," which replaces industry forage to feed the pigs, thus eliminating the heavy metal pollution of pigs and producing pollution-free pig food.

4.3.2. Ecological Benefit. The Clean Development Mechanism (CDM) is one of the "flexibility" mechanisms defined in the Kyoto Protocol [35]. It is intended to meet two objectives: ① to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), which is to prevent dangerous climate change; and ② to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments (GHG emission caps) [36]. Programmatic Clean Development Mechanism (PCDM) is the development and completion of CDM; it aims to exploit clean technology of low profit and small potential, such as rural household small biogas technology. As a world natural and cultural heritage area and a large pork production base, Leshan is expected to be a leader in the performance of CDM in the pig industry, promoting the application and popularization of clean technology in the overall pig industry chain. Of important significance to the sustainable development of agriculture in Leshan is the introduction of CDM/PCDM to Leshan's biogas construction and the development of rural biogas CDM/PCDM programs. Through these efforts, the low-carbon pig industry chain can realize sustainable development in Leshan.

5. Conclusion

In this paper, the sustainable development of low-carbon industry chains is summarized. The low-carbon pig industry in Leshan was selected as a case study using SD-RCCM. It is one of the biggest pig breeding bases in Sichuan province and also a world natural and cultural heritage area, so the balance between economic and environmental benefit is critical. Distribution ratios were taken as control variables, and three different weights for the economy and the environment were selected. The corresponding optimal distribution ratio using RCCM-calculated. The values were inserted into an SD model and a comparison was made. From the results, we conclude that program 1 which seeks to balance both the economy and environment was the best optimization. To realize the extension of the pig industry, CDM should be introduced into production. A further extension would be to establish a rural household biogas program and "breeding – planting" biologic chain engineering technology.

Acknowledgments

The authors wish to thank the anonymous referees for their helpful and constructive comments and suggestions. The work is supported by the Key Program of National Natural Science Foundation of China (Grant no. 70831005), the 985 Program of Sichuan University (Innovative Research Base for Economic Development and Management), the Western and Frontier Region Project of Humanity and Social Sciences Research, Ministry of Education of China (Grant no. 13XJC630018), the National Natural Science Foundation of China (Grant no. 71301109), the Philosophy and Social Sciences Planning Project of Sichuan province (Grant no. SC12BJ05), and the Initial Funding for Young Teachers of Sichuan University (Grant no. 2013SCU11014).

References

[1] IEA, *World Outlook 2008*, IEA Publications, 2008.

[2] UK Energy White Paper, *Our Energy Future—Creating a Low Carbon Economy*, UK Department of Trade and Industry, 2003.

[3] M. Neelis, M. Patel, P. Bach, and K. Blok, "Analysis of energy use and carbon losses in the chemical industry," *Applied Energy*, vol. 84, no. 7-8, pp. 853–862, 2007.

[4] L. Ren and W. Wang, "Analysis of existing problems and carbon emission reduction in Shandong's iron and steel industry," *Energy Procedia*, vol. 5, pp. 1636–1641, 2011.

[5] R. Rehan and M. Nehdi, "Carbon dioxide emissions and climate change: policy implications for the cement industry," *Environmental Science & Policy*, vol. 8, no. 2, pp. 105–114, 2005.

[6] J. Yuan and Z. Hu, "Low carbon electricity development in China—an IRSP perspective based on super smart grid," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 2707–2713, 2011.

[7] X. Yang and X. Jia, "Low-carbon economy and low-carbon food," *Energy Procedia*, vol. 5, pp. 1099–1103, 2011.

[8] N. Duan and Y. Huang, "Measures for energy saving and emission reduction in Chinese tobacco industry," *Energy Procedia*, vol. 5, pp. 818–823, 2011.

[9] F. Lai and J. Ren, "On the necessity and governance model of the construction of China's low-carbon transportation system," *Energy Procedia*, vol. 5, pp. 1502–1507, 2011.

[10] Z. Tang, C. Shi, and Z. Liu, "Sustainable development of tourism industry in China under the low-carbon economy," *Energy Procedia*, vol. 5, pp. 1303–1307, 2011.

[11] T. L. T. Nguyen, J. E. Hermansen, and L. Mogensen, "Fossil energy and GHG saving potentials of pig farming in the EU," *Energy Policy*, vol. 38, no. 5, pp. 2561–2571, 2010.

[12] M. Nöremark, A. Lindberg, I. Vågsholm, and S. S. Lewerin, "Disease awareness, information retrieval and change in biosecurity routines among pig farmers in association with the first PRRS outbreak in Sweden," *Preventive Veterinary Medicine*, vol. 90, no. 1-2, pp. 1–9, 2009.

[13] T. M. Ngapo, E. Dransfield, J.-F. Martin, M. Magnusson, L. Bredahl, and G. R. Nute, "Consumer perceptions: pork and pig production. Insights from France, England, Sweden and Denmark," *Meat Science*, vol. 66, no. 1, pp. 125–134, 2004.

[14] B. Elzen, F. W. Geels, C. Leeuwis, and B. van Mierlo, "Normative contestation in transitions 'in the making': animal welfare concerns and system innovation in pig husbandry," *Research Policy*, vol. 40, no. 2, pp. 263–275, 2011.

[15] C.-C. Yang, "Productive efficiency, environmental efficiency and their determinants in farrow-to-finish pig farming in Taiwan," *Livestock Science*, vol. 126, no. 1–3, pp. 195–205, 2009.

[16] X. P. C. Vergé, J. A. Dyer, R. L. Desjardins, and D. Worth, "Greenhouse gas emissions from the Canadian pork industry," *Livestock Science*, vol. 121, no. 1, pp. 92–101, 2009.

[17] U. Lemke and A. Valle Zárate, "Dynamics and developmental trends of smallholder pig production systems in North Vietnam," *Agricultural Systems*, vol. 96, no. 1–3, pp. 207–223, 2008.

[18] D. M. Green and C. T. Whittemore, "Calibration and sensitivity analysis of a model of the growing pig for weight gain and composition," *Agricultural Systems*, vol. 84, no. 3, pp. 279–295, 2005.

[19] K. Galanopoulos, S. Aggelopoulos, I. Kamenidou, and K. Mattas, "Assessing the effects of managerial and production practices on the efficiency of commercial pig farming," *Agricultural Systems*, vol. 88, no. 2-3, pp. 125–141, 2006.

[20] C. T. Whittemore, J. C. Kerr, and N. D. Cameron, "An approach to prediction of feed intake in growing pigs using simple body measurements," *Agricultural Systems*, vol. 47, no. 2, pp. 235–244, 1995.

[21] K. M. Kang and M. Jae, "A quantitative assessment of LCOs for operations using system dynamics," *Reliability Engineering and System Safety*, vol. 87, no. 2, pp. 211–222, 2005.

[22] J.-F. Wang, H.-P. Lu, and H. Peng, "System dynamics model of urban transportation system and its application," *Journal of Transportation Systems Engineering and Information Technology*, vol. 8, no. 3, pp. 83–89, 2008.

[23] C. Udrişte, M. Ferrara, D. Zugravescu, and F. Munteanu, "Controllability of a nonholonomicmacroeconomic system," *Journal of Optimization Theory and Applications*, vol. 154, pp. 1036–1054, 2012.

[24] M. Ferrara, "An AK Solow model with a non-positive rate of population growth," *Applied Mathematical Sciences*, vol. 5, no. 25–28, pp. 1241–1244, 2011.

[25] M. Ferrara and L. Guerrini, "More on the green Solow model with logistic population change," *WSEAS Transactions on Mathematics*, vol. 1, no. 8, pp. 41–50, 2009.

[26] B. P. Thompson and L. C. Bank, "Use of system dynamics as a decision-making tool in building design and operation," *Building and Environment*, vol. 45, no. 4, pp. 1006–1015, 2010.

[27] C. Cao, X. Gu, and Z. Xin, "Stochastic chance constrained mixed-integer nonlinear programming models and the solution approaches for refinery short-term crude oil scheduling problem," *Applied Mathematical Modelling*, vol. 34, no. 11, pp. 3231–3243, 2010.

[28] U. K. Bhattacharya, "A chance constraints goal programming model for the advertising planning problem," *European Journal of Operational Research*, vol. 192, no. 2, pp. 382–395, 2009.

[29] J. Xu and L. Yao, *Random-Like Multiple Objective Decision Making*, vol. 647 of *Lecture Notes in Economics and Mathematical Systems*, Springer, 2011.

[30] A. Charnes and W. Cooper, *Management Models and IndustrialApplications of Linear Programming*, vol. 1, 1961.

[31] A. Charnes and W. Cooper, *Management Models and Industrial Applications of Linear Programming*, vol. 2, 1961.

[32] Y. Ijiril, *Management Goals and Accounting for Control*, North-Holland, Amsterdam,Netherlands, 1965.

[33] K. Kendall and S. Lee, "Formulating blood rotation policies with multiple objectives," *Management Science*, vol. 26, no. 11, pp. 1145–1157, 1980.

[34] J. Ignizio, *Goal Programming and Extensions*, Lexington Books, Lexington, Mass, USA, 1976.

[35] B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer, "Climate change 2007: mitigation," Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 2007.

[36] M. Grubb, "The economics of the kyoto protocol," *World Economics*, vol. 4, no. 3, pp. 143–189, 2003.