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Low-carbon development and planning of pig industry using system dynamic and random multi-objective optimization*

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Abstract. We selected a city that is recognized as the World Nature and Culture Heritage and analysed the prospective development of the pig industry in this region. We explored the SD-RMOP model using the system dynamics as a technical platform and a combination of random multi-objective optimization model. Based on that, we explored the relationship among the data in the model and debuged the correlative parameters with random multi-objective optimization. In order to meet the requirement of the orientation that the region has been the leading area for low-carbon development, we studied the livestock industry which plays a dominant role in the primary industry and built the typical pig industrial chain of the livestock industry. Through the analysis of model simulation, the solution on how to develop the animal husbandry industry of this area under the background of low-carbon in the period of the twelfth five-year plan was presented. This study provided important scientific political implication and experimental calibrating approach for some areas on developing the animal husbandry under low-carbon environment.

Keywords: system dynamics, system simulation, industry, energy consumption, carbon intensity, RMOP

1 Introduction

Under the background of low-carbon development, it has been becoming a hot issue to combine the economic effect and environmental effect together in the livestock industry. As for livestock industry, the majority of the researches focused on only one aspect of the price, consumption, scale and so on from the Microcosmic perspective[1–3]. And from the macrocosmic, they concentrate on the internal of the livestock industry. Only a small body of documents analyzed the industry overall[4]. Let alone considering the consumption and with the background of low carbon. This paper discusses the development of the region livestock industry chain at the background of our low carbon and points out the direction of the its future so as to make up the research gaps.

The region we have chosen is one of the most representative livestock industry in Southwest China. As one of the World Nature and Culture Heritage areas, low-carbon development is the inevitable choice, but the present condition of developing the livestock industry in the region is so unreasonable that hinder the orientation of the area as the low-carbon going-first area . Therefore, studying the livestock industry in the region is of great significance.

In this paper, due to the uncertainty of parameters, we will use random right modulus method to transform the multi-objective optimization problem into single objective problem, and sequential quadratic programming method to get the optimal solution of multi-objective problem. Compared with the fixed weights, this method can find all the Pareto optimal solution in nonconvex balanced surface. Random multi-objective optimization can effectively describe the random external factors which affect pig industry[5, 6].

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When we study the industry chain we can make use of the system dynamics, (SD) which is a kind of methodology, which is based on feedback control theory, with the computer simulation technology as the means, and with the comprehensive utilization of qualitative and quantitative analysis to explore the operation law of complex systems[7–9].

2 Livestock industry chain

the reason we choose the pig industry as the starting point to study the low-carbon development of livestock industry is that, in the World Nature and Culture Heritage area we selected, livestock industry is the leading factor of primary industry, while the pig industry plays the dominant role in livestock industry, as well as the region is the low-carbon going-first area.

2.1 Problems

Currently the pig industry in certain region is mainly in the form of small-scale backyard, which at the start of pig breeding and with the end of pork sales. Every link of the chain are connected. At last a network formed with the main line of pig production which the production, finance, information, technology and other cardinal elements run through[10]. Pig breeding industry has a relationship of forward relevance with the feed industry and a connection of backward relevance with the Meat processing industry[11, 12]. With the consideration of the forward relevance, the consumption of the feed, swine, and veterinary drugs affect the relevant industry actively. One is selling them to the market directly, another one is processing them and selling them in the form of pork product, the third one is developing the by-product of the pig[13]. Pig industry structure of the system flow diagram.

The pure pig industry has already developed quite well in the region, but the industry chain construction needs to be improved. On the other hand, the most important thing is that, we must make animal husbandry develop with low-carbon, because of the recent requirement to reduce carbon emissions intensity, this puts forward new demands and new development direction for pig industry. In study we found the key point of the research was that, how to select the appropriate parameters to adjust in the extension links of the industrial chain, and achieve the optimal economic benefits in the premise of low-carbon development, while reduce the carbon intensity.

2.2 Hypothesis

There are two assumptions for the model in the article to analyze the Inter-industry resources:
(1)The resources in the study are abstract to some extent and with the attribute of basic form. No matter what kind of processing to the pork, it is impossible to change its basic form but physical or chemical form;
(2) The amount of the rescouses during the whole process mean the quantity of the core resource of the raw materials, Intermediate products, and final products.

2.3 Symbol

In the study, we present the parameters with specific symbols to facilitate model calculations. The symbols of main related parameters are listed in Tab.1 .

3 Sd-rmop modeling

Now we make the SD-RMOP modeling on the pig industry chain. First, analyze the system, and then optimize the parameters under the dual constraints of ecological and economic benefits.

Table 1. Pig industry chain parameters of symbol tables

Symbol	The meaning of variables	Variable units
P	Ten thousand	Price
MP	Kg	Amount of manure produced per pig
PM	Kg	Total amount of pig manure
Q_{01}	Ton	The amount of pork sales
PO	Ton	Total pork
PR	Ton	Pork processing capacity
SEP	tce/t	Sale Price
PDM	Ton	Total amount of dry manure
X_1	No.	Sales coefficient
Q_2	Ton	Organic fertilizer production
PS	No.	Output of pig skin
P_2	Ten thousand	The price of organic fertilizer
e	tce/t	Unit production energy consumption
E_2	Tce	The energy production of organic fertilizer
Q_{02}	Ton	Number of further processing of pork
E_1	Tce	Biogas energy production
COV	Ten thousand	Canned pork revenue
E_3	Tce	Glue consumption of energy production
Q_1	Ton	Biogas production
Q_3	Ton	Glue production
TP	Ten thousand	Total revenue
E_4	Tce	The energy production of fish feed
P_1	dollar/Cubic meter	Gas prices
E_5	Tce	The energy production of leather
E_6	Tce	Bacon consumption of energy production
E_7	Tce	The energy consumption of sausage production
PDC	No.	Production coefficient
E_8	Tce	The energy consumption of canned pork production
E	Tce	Total energy consumption
X_2	No.	Further processing coefficient
CI	tce/Ten thousand	Carbon intensity
CIC	No.	Coefficient of carbon intensity
X_4	No.	The coefficient of production bacon
BGC	No.	Glue the coefficient production
SL	No.	Pig herds
RI	No.	Rate of increase
RR	No.	Reduce the rate of
UV	Tce	The number of recycling
TPQ	Ton	The total amount of processing
EOV	Ten thousand	Net output
TI	Ten thousand	Total investment
X_3	No.	Coefficient of production of canned
CIN	Ten thousand	Cash income

3.1 Model description

Through the research of pig industry, under the principle of low-carbon economy, through the analysis of the pig breeding, processing, and the use of related energy, as well as the analysis of processing condition of pig farming by-products, from the point of view of industrial output and energy consumption and drew a pig industrial chain chart. Feces were fermented into energy and supply the energy consumption needed in processing or household. This kind of deal meets the realistic requirements, but also fit in with the development requirements of low-carbon economy[14].

3.2 Pig system

After the front analysis of system, now we can build a general model of pig industry chain. See Fig. 1.

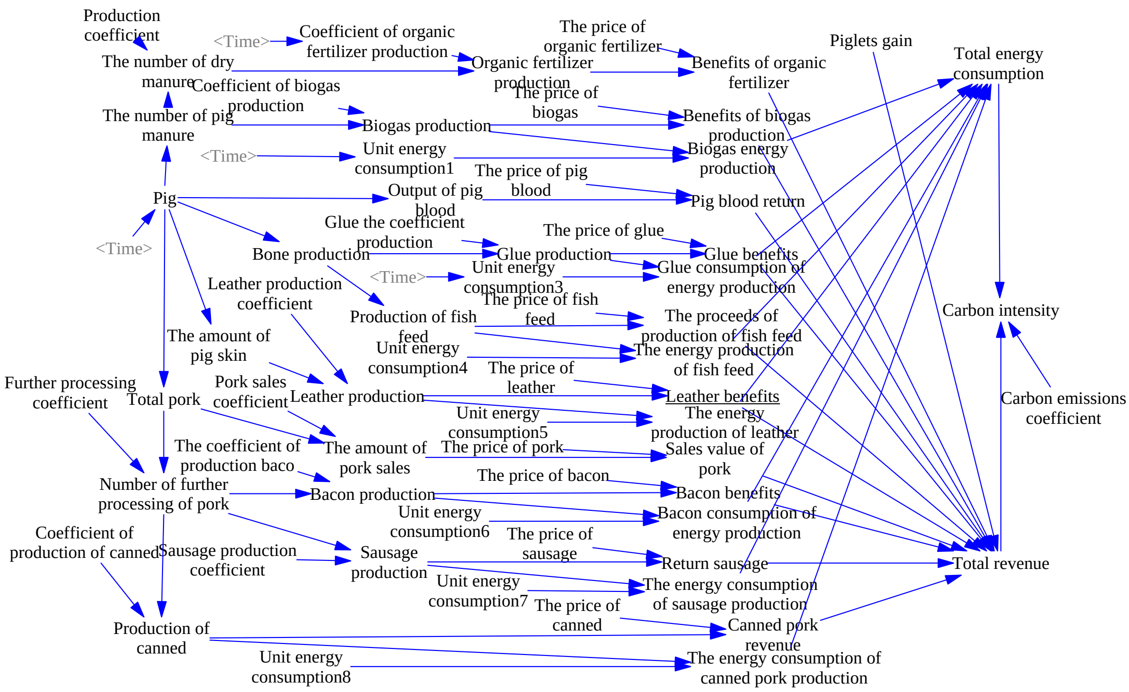

Fig. 1. Structure map of live pigs

A part of the relationship in the system:

$$PM = P \times MP, \quad Q_{01} = Q \times X_2, \quad P_{01}Q_{01} = P_{01} \times Q_{01},$$
$$\text{PCOV} = P_6Q_6 + P_7Q_7 + P_8Q_8, \quad PR = Q \times Q_2, \quad TR = P_1Q_1 + R_1 + P_2Q_2 + \text{PCOV},$$
$$E_1 = e \times Q_1, \quad E = E_3 + E_4 + E_5 + E_6 + E_7 + E_8 - E_1, \quad CI = E/TR \times \text{CIC}.$$

3.3 Model optimization

According to the determination principles and relevant constraints of the control parameters, we chose the sales factor, deep processing factors, Can processing factor and bacon processing factor as control parameters. By changing the value of control parameters, we can simulate the total output and the total energy consumption situation of the. industrial chain.

$$\max \sum_{i=1}^{9} \tilde{P}_i Q_i + P_{01}Q_{01} + P_1 \tag{1}$$

$$\min \ e\left(\sum_{i=2}^{8} Q_i - Q_1\right) \tag{2}$$

$$\text{s.t.} \begin{cases} X_1 + X_2 \leq 1 \\ X_3 + X_4 \leq 1 \\ c_1 \leq X_1 Q \leq d_1 \\ c_2 \leq X_2 Q \leq d_2 \\ c_3 \leq X_3 Q_{02} \leq d_3 \\ c_4 \leq X_4 Q_{02} \leq d_4 \\ 0 \leq X_1, X_2, X_3, X_4 \leq 1 \end{cases} \tag{3}$$

$\tilde{P}_i \sim U(a_i, b_i)$ is a random variable in uniform distribution[15]. The objectives of the model above-mentioned with random variable in it, we can not directly get solution, so we use the probability measure to transform it into deterministic objectives.

$$\max\ \bar{f} \tag{4}$$

$$\min\ g(x) = e\left(\sum_{i=2}^{8} Q_i - Q_1\right) \tag{5}$$

$$\text{s.t.} \begin{cases} \Pr\{f(x) \geq \bar{f}\} \geq \theta \\ X_1 + X_2 \leq 1 \\ X_3 + X_4 \leq 1 \\ c_1 \leq X_1 Q_1 \leq d_1 \\ c_2 \leq X_2 Q_2 \leq d_2 \\ c_3 \leq X_3 Q_{02} \leq d_3 \\ c_4 \leq X_4 Q_{02} \leq d_4 \\ 0 \leq X_1, X_2, X_3, X_4 \leq 1 \end{cases} \tag{6}$$

where θ is risk parameter$\tilde{P}_i \sim U(a_i, b_i), (i = 1, 2, 3, 4, 5, 6, 7, 8, 9)$ are random variables.

Theorem 1. *Assume that $\tilde{P}_i \sim U(a_i, b_i)$ are all uniformly distributed random variables and they are independent with each other. Then we have the following equivalent relation,*

$$\Pr\{f(x) \geq \bar{f}\} \geq \theta \Longleftrightarrow \bar{f} \leq B - \theta(B - A). \tag{7}$$

Proof. Since $\tilde{P}_i \sim U(a_i, b_i)(i = 1, 2, 3, 4, 5, 6, 7, 8, 9)$ are uniformly distributed random variables and are independent with each other, it follows that

$$\sum_{i=1}^{9} \tilde{P}_i \sim U(A, B) \tag{8}$$

is also a uniformly distributed random variable, where $A = \min(R_1 + P_{01}Q_{01} + \sum_{i=1}^{9} P_i Q_i)$, $B = \max(R_1 + P_{01}Q_{01} + \sum_{i=1}^{9} P_i Q_i)$. According to the density function of uniformly distributed variable, we have the following distributed function,

$$Pr\{f(x) \geq \bar{f}\} \geq \theta \Longleftrightarrow \begin{cases} 0, & \text{if } \bar{f} > B \\ \frac{B-\bar{f}}{B-A}, & \text{if } A \leq \bar{f} \leq B \\ 1, & \text{if } \bar{f} < A \end{cases}$$

Since it holds that $0 \leq \theta \leq 1$ in the real-world environmentwe have the following three cases:
(1) If $\bar{f} > B$, it does not obviously satisfy the conditions;
(2) If $\bar{f} \leq A$, $Pr\{f(x) \geq \bar{f}\} \geq \theta$ must hold;
(3) If $A \leq \bar{f} \leq B$, it follows that $Pr\{f(x) \geq \bar{f}\} \geq \theta \Longleftrightarrow \bar{f} \leq B - \theta(B - A)$.

It is obvious that $B - \theta(B - A) \leq B$ holds, so we have $A \leq \bar{f} \leq B - \theta(B - A)$. Above all, we know that $Pr\{f(x) \geq \bar{f}\} \geq \theta \Longleftrightarrow \bar{f} \leq B - \theta(B - A)$. □

4 Application

We included the actual value of the parameter region into the model and then used a simulation modeling.

4.1 Paraments

Fixed variableAmount of manure produced per pig (330 Kg), Coefficient of biogas production (350 Milliliter/Kg), Coefficient of carbon intensity (2.66 Tce/Ten thousand).

The number of live pigs to slaughter: Set up to 45.82 ten thousand in 2008, According to the analysis of the selected regional trends and relevant planning policy to forecast results. Set up to 53.80 ten thousand in 2012 , Set up to 60 ten thousand in 2015 .

The constant variables above are the average prices for the surrounding areas, but not only limited to the local prices.

After adjusted the control parameters of the situation as shown in Tab. 2.

Table 2. Pig industry chain control parameters

Program	Currently	Adjusted
Sales coefficient	0.7	0.2
Further processing coefficient	0.25	0.75
Coefficient of production of canned	0.17	0.5
The coefficient of production sausage	0.2	0.3

4.2 Simulation with pig industry

Based on previous studies, the parameters of the selected region of the actual values are exerted into the pig industry chain dynamic and a systematic simulation software VENSIM is used to simulate the model.

Part of the simulation results.

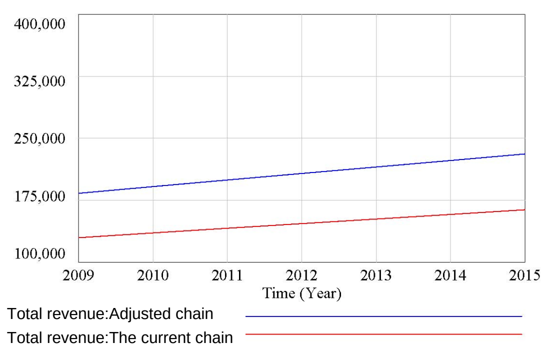

Fig. 2. The total energy consumption

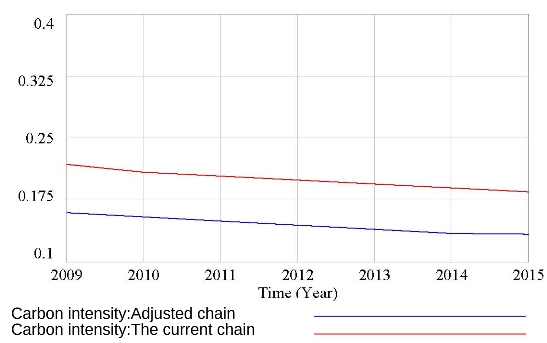

Fig. 3. Carbon intensity

According to the simulation results, we can see that:

(1) *Economic benefits:* Through the optimization of control parameters, the pig industry chain extends, increases the investment on the bone glue which is blank in the area of basic industries; increase the proportion of deep processing of pig. in the process of extending pig industry chain, the carbon emissions intensity in the region can be reduced, and the output will increase remarkably.

(2) *The ecological benefits:* On the part of ecological benefits, the application rate of fertilizer and pesticides get reduced, and produce pollution-free green food, improve the quality of agricultural products; promote the use and conversion of rural waste and improve utilization of energy in rural areas, in addition, under the requirements of development in low-carbon, the total energy consumption in the region increase to some extent, However, the growth of economic output is far greater than the addition of energy consumption, so the carbon emission intensity show the trend of rapid decline.

4.3 Conclusions

The method we used in the establishment of the livestock industrial chain of the World Nature and Culture Heritage area under the ground of low-carbon development Is as follows, first we established the SD-RMOP model, and took SD as a platform to build the industrial chain, then made random multi-objective optimization in allusion to the parameter values of key nodes in the system .and using the method, we analyzed the way of how to develop the live stock industry with low-carbon and forecasted the development prospect, and it is worth to be drawn on in this region.

The study of this paper was based on the industrial chain, and considered the influence of uncertainties in the microscopic, to explore the SD-RMOP model in microscopic and our further study will focus on more subtle livestock industry.

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