A System Dynamics Analysis of Intensive Pig Farming Eco-energy System Based on the Rate Variable Fundamental In-tree Model

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Abstract: Intensive pig farming in Centre China leads to the centralization of excreta .Chinese government has allocated lots of funds to construct biogas engineering for resource utilization of bio-energy in recent years. But investigation shows most of farms in rural areas discharge the residual product of anaerobic digestion directly due to the lack of consumers and funds, which has caused severe environmental pollution, and also endangered the development of farms themselves. In this paper, we have constructed a practical pig farming excreta recycle treatment model via a case study of the Lanpo intensive pig farming ecology system, and have conducted simulations with the corresponding dominant archetype. The results show that policies of encouraging more farmers to utilize biofuel, separating anaerobic digester effluent from irrigating water, developing the winter fallow cropland and the hilly land and governments' fund and technology supporting may help shift the system toward sustainability.

Key words: Intensive pig farming; environmental pollution; Eco-energy System; the SD rate variable fundamental in-tree model; dominant archetype; Center China

Introduction

Since 1980s in Center China, driven by growing demand for livestock products, feedstuff purchase, cost of labor, and epidemic prevention, etc, the scale of pig farms has grown remarkably, many pig farming villages and intensive pig farms have presented over the past decade, It has met the growing demands for pocks, and result in farmers' income increasing. However, the large quantity farming excreta have brought severe environmental damage at the same time. From a systems perspective, the manure and sewage are prone to exceed and consume its environmental carrying capacity, and becoming big pollutant sources. The direct drainage of excreta has inevitably caused serious environmental pollution like malodor, soil contamination, underground water contamination, and river pollution, in turn, it also has endangered the sustainable and healthy development of these farms themselves.

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Chinese government has realized the urgency of better treatment of rural areas pollution caused by scaled livestock farm now, and has made up mind to allocate a great deal of money to equip household biogas pool in rural areas. Many local governments have also invested greatly to constructing biogas engineering for developing and recycle utilization of bio-energy in livestock residue. A number of regions in China has shaped the farming excreta integrated treatment model with the characteristics of the region, such as the eco-agricultural model of 'four in one', which combines the solar energy, pig farming and vegetable planting in canopy with the linkage of biogas digester in North China (Wang Chunxiang, *et al*, 1998), the 'Livestock-biogas-fruit' Circular Economy model in South China (Rongjun Chen, 1997).

But date shows that the rate of the integrated utilization facility constructed is less than 10 percent, and the utilizing ratio is even lower(Su Yang, 2006), the increasingly severe pollution caused by livestock production indicate it must have a good many of obstacles in the way of integrated utilization extended. By investigating in the rural areas in Center China, we found the small and mid-sized scale pig production industry is developing rapidly over past decade. But because of the laggard consciousness of the disposal and recycle utilization of the breeding residue and the financing reason, Lots of breeding farms have built Anaerobic lagoon according to government regulation, but the output of Anaerobic digestion is untreated, most of biogas and Anaerobic digester effluent are discharged directly to circumstance, causes serious environmental pollution like entrophication, river pollution, and underground water contamination, in turn, it also has threatened the sustainable and healthy development of these farms themselves.

In the course of investigation, we ask ourselves how to dissolve the contravention between the development of scale pig production and the serious pollution caused by pig excreta in rural area? How to develop a doable breeding residue treatment method, which can bring farmers advantages and accepted by them of their own accord?

From a system dynamics perspective, the behavior of a system is mostly decided by its inner structure and mechanism. This paper describes a system dynamics model developed to depict the main contradiction of the intensive pig farming eco-energy system in Center China, examine the underlying cause of its occurring and development and to aid in policy design for improved sustainability. The development of the model was guided by a case study of the Lanpo intensive pig farming ecology system in Jiangxi province, Center China. The case is chosen because it has achieved great beneficial results in energy and ecology systems. Our research in Lanpo is supported by National Natural Science Foundation of China, China Specialized Research Fund for the Doctoral Program of Higher Education, and the Big-Scale Biogas Engineering Supporting Foundation of Jiangxi government. The model is based on the rate variable fundamental in-tree modeling approach (Jia Ren-an *et al.*1998) and is general enough to be applicable to the intensive pig farming in other rural areas in Centre China. It is hoped that this study will contribute to the environmental sustainability of the livestock farming industry and agricultural eco-energy Systems.

Methodology

System dynamics modeling is a structural approach, building a feedback model based on causal diagrams and flow diagrams. The change of feedback loops in a model is of great importance to system analyzing, model debugging and simulation output analyzing. Without a normal method, however, it is difficult to obtain all feedback loops in a complex system dynamics flow diagram. During the past two decades, researchers at Nanchang University have developed an approach named the SD rate variable fundamental in-tree modeling approach (Jia Ren-an*et al.*1998) to build models normally while simultaneously analyze feedback loops explicitly. The approach is based on the spanning tree theory of graph theory, focuses on the fundamental rate variables of every subsystem. The approach has been used successfully to build SD model in areas as diverse as human resource management in an organization (Jia Xiaojing, 20 05), enhancing scientific research capacity management at China's university (Lu Weifeng, 2005), sustainable development of agro-ecosystem(JiaRen-an,1998, Wang Cuixia, 2006),and development of software industry in Jiangxi province, China.(Jia Ren-an *et al*, 2002),etc. The group has also developed approaches to complex system feedback analysis based on its rate variable fundamental in-tree model, such as branch-vector determinant algorithm to feedback loops calculation(Jia Ren-an *et al.*2000), branch-vector matrix algorithm to feedback loops calculation(Jia Ren-an *et al.*2001). The archetype generating set modeling approach (Jia Ren-an *et al.*2005), and Vertex Weighted Causal Loop Diagram Analysis Approach (Wang Cuixia *et al.*, 2006) is developed recently during research process. We named these series approaches of SD modeling and analysis as the SD analysis approach based on rate variable fundamental in-tree model .build upon the knowledge of two main threads of knowledge decision conferencing and system dynamics practice, and have formed a complete regular and pragmatic methodology of SD modeling and analysis.

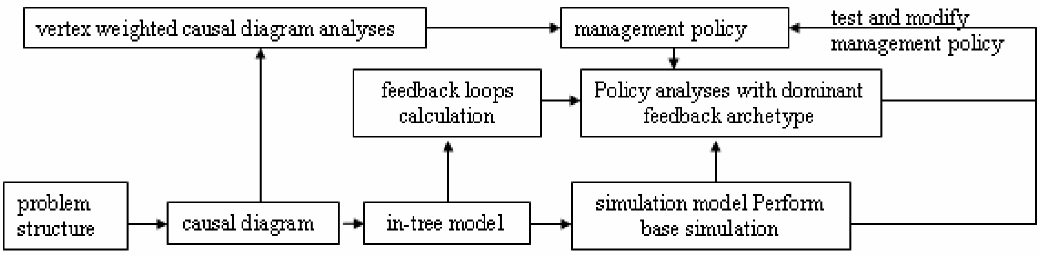


Fig. 1. Flow chart of SD analysis approach based on rate variable fundamental in-tree model

From a methodological point of view, the relevant portion of the modeling and analysis approaches we mentioned is the step-by-step approach shown in Fig. 1.

The approach begins with confirming problems or issues of the system, identifying main variables, and developing a casual diagram, then collecting preliminary information and data, by equations of the correlated arcs or tested results, calculating the value of every vertex in the casual diagram at given time, by putting the value of each vertex into the casual diagram, we can generate a corresponding vertex weighted causal diagram.

The next step is to analyze the value of the vertex weighted causal diagram, identify key leverage points and design intervention policys.

The third step is to define variable types, determine the level and rate series of the system, for each rate variable $\boldsymbol{R_i(t),(i=1,2,\cdots,n)}$, construct a rate variable fundamental in-tree $T_i(t)$, with $\boldsymbol{R_i(t)}$ being its tree root and level variables or rate variables, which affect directly or indirectly through auxiliary variables, being its tree leaves. All of these in-trees construct the SD rate variables fundamental in-tree model of the system.

The forth step of the approach is to collect detailed information and data, construct equations of every variables in the in-tree model, develop a simulation in-tree model.

The fifth step is to conduct base simulate to show the behavior of system under current tendency.

The sixth step is to calculate the numbers of feedback loops of the system based on the in-tree model, then according to the objective of the model, generate a dominant archetype model.

The seventh step is to do policy analysis with the dominant archetype model, to test and modify the policy by simulation scenarios.

A case of LanPo intensive pig farming eco-energy system

The existing structure of the LanPo intensive pig farming eco-energy system.

LanPo is a natural village of Jiangxi Province, it locates in a typical upland small watershed in Center China, and the annual average temperature there is 17.3℃. The work of the farmers in LanPo mainly includes pig farming, paddy planting, and a small quantity of greenstuffs planting for themselves. The pig farming here is concentrated in TaiHua pig farm, owned by Peng Yuquan. The farm is located in a sloping field of LanPo, 3000 heads of commercial pigs' outputs yearly from the farm over the past 4 years. The pigsty of TaiHua is about 2.1ha, in the north of the piggery is about 17 ha undeveloped upland, and there is a small pond (about 0.4 ha) in the south of the piggery, there are about 14 ha paddy field under the sloping field, a canal from the pond flows across paddy field, farmers use water from this canal to irrigate their paddy field. There lived 38 household farmers near the pig farm; there is some scattered vegetable terra around their house. All of these constructed the LanPo intensive pig farming eco-energy system.

The LanPo farm has built three small anaerobic digesters to dispose of the pig production excreta. The total volume of the three digesters is 270m^3, which have greatly solved the pollution from excreta discharge. Unfortunately, the residual product of anaerobic digestion, biogas is let directly into atmosphere due to the lack of consumers and funds. The main components of the biogas released are CH_4 and CO_2 that are two kinds of greenhouse gas. Additionally, abundance of organic wastes in the effluent after digestion supplies the paddy land with a nutrient surplus, which greatly reduced the outputs of paddy land. Even more, nearly 7 months of the land being left fallow, all of the effluent after digestion flow freely into backward water area thus polluting water areas on the way, potable water, agricultural ecology, and living environment severely(Fig.2.).

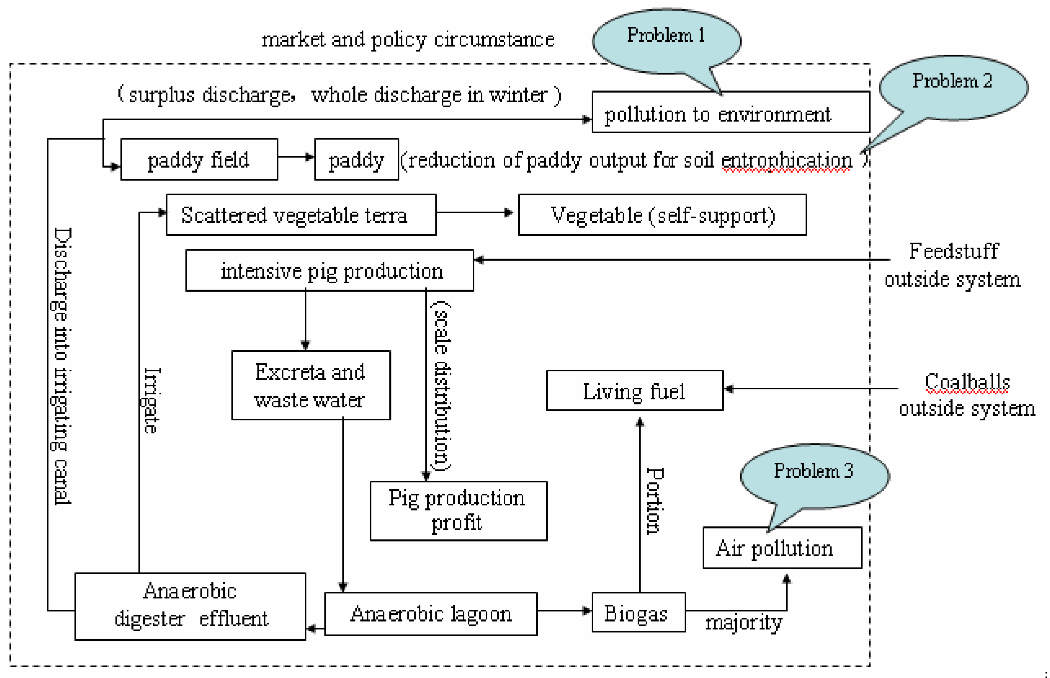


Fig.2. Sketch map for the LanPo intensive pig farming eco-energy system

According to the analysis above, we come to a conclusion, which is

conclusion 1 The LanPo intensive pig farming eco-energy system is a complex system, comprised of pig production, paddy and vegetable planting, energy, environment, and management.

The main existing problems in the course of the system operation are as follows.

Problem 1. Due to the shortage of storage and supply facilities, and unrecognizing biomass energy derived from livestock residue as an important source of renewable energy , the main parts of biogas produced everyday are emitted into atmosphere, and add the amounts of greenhouse gas.

Problem 2. The mixed irrigation of water and digester effluent makes the paddy seeding over flourish, causes paddy reduction of outputs.

Problem3. For lack of loading land, and 7months of fallow, the residual digester effluent causes water and environmental pollution.

We call the pollution caused by the residual products of anaerobic digestion, such as biogas and the liquid after digestion as the second pollution of pig farming. Obviously, the second pollution of pig farming in LanPo intensive pig farming eco-energy system is quite severely.

Vertex weighted causal diagram of LanPo intensive pig farming eco-energy system.

Based on problems mentioned above, we develop a casual diagram comprised of 14 vertexes, and the vertex $v_2(t)$ (pig population) is a key point of the casual diagram, its value varies between 3000 heads/year to 10000 heads/year, and the value of other vertexes change after the value of $v_2(t)$'s change in the interval [3000,10000], Firstly we set the time t= 2005, in year2005, the farming scale of the LanPo farm is 3000heads, so the value of key variable $v_2(t)\big|_{t=2005}$ is 3000 heads, the left point of the interval. Then with this initial value, by equations of the correlated arcs or tested results of these 14 vertexes, calculate the value of every vertex in year 2005. After the value of every vertex is put into the casual diagram, we generate the corresponding vertex weighted causal diagram of the LanPo intensive pig farming eco-energy system. in 2005(Fig.3.).

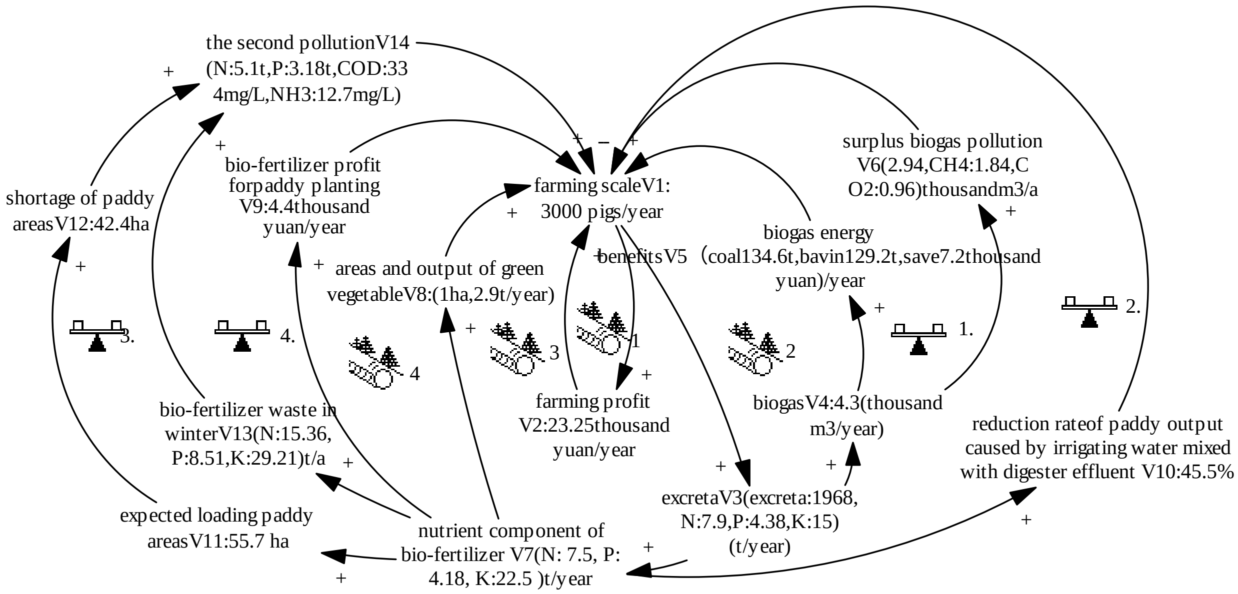


Fig.3. vertex weighted causal diagram of the LanPo intensive pig farming eco-energy system. in 2005

Similarly, by set pig population(key variable) to be other value, such as 1000 heads, or 5000 heads, 10000heads, we can also generate the correspond vertex weighted causal diagram of The LanPo intensive pig farming eco-energy system. at that farming scale.

The dynamic variety of values of vertexes in different farming scale shows the law of feedback effect of each positive and negative feedback loops of the system, we tried to identify key leverage points and to design intervention strategies.

Policy development

For the limits to growth, the management principle is: Don’t push the reinforcing(growing)process, remove (or weaken) the source of limitation(Peter M. Senge,1993). Use it for reference, based on the objective of LanPo intensive pig farming eco-energy engineering, we have designed the management strategies to ensure and facilitate the development of the LanPo intensive pig farming eco-energy system as follows.

Policy 1. Add investment, establish biogas storage, extend the biogas deliver pipe, transport biogas to other farmers, encourage them to use biogas as fuel. Develop biogas generating electricity engineering, utilize bio-energy of biogas, to save the cost of fuel and reduce the livestock pollution simultaneously.

Policy 2. Implement diffluence and sedimentation engineering, to separate anaerobic digester effluent from irrigating water, to restrain the reduction of paddy output for soil entrophication

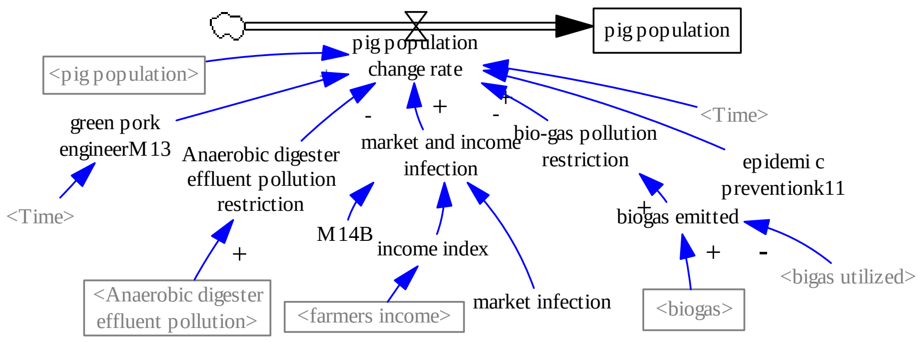
Policy 3. Enhance the using efficiency of land in the system, implement an eco-energy system engineering, to combine the pig production with paddy planting, wintertime fallow cropland and dry land vegetable planting，to integrate development of breeding and planting industry.

Policy 4 Government and institutions devote to the breeding residue recycle utilization plan, to support farmers in money and technology. At present, farmers in China are still poor, the scale breeding of livestock is a main approach for their incomes growth, so it will harm them if Chinese government establishes strict legislations to control the pollution by the pure cost process as the developed countries encouraged. Further more, in China's countryside, any technology will not be widely accepted, unless it can provide farmers with multi-benefits. So the spread of biogas engineering in China should be well designed after a systematic analysis and aim at the harmonious integrity of three kinds of benefit, i.e., economic benefit, ecological benefit, and social benefit.

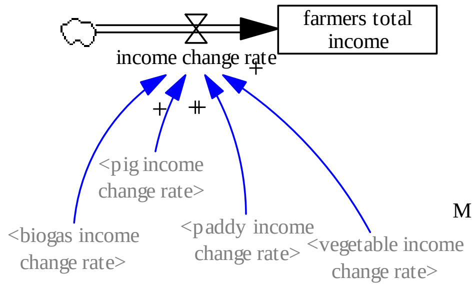
Rate variable fundamental in-tree model of LanPo intensive pig farming eco-energy system

In order to test the result by policy implementation and make peasant understand the scheme, it is necessary to expound the quantitative simulation results with SD diagrams and to make specific feedback analysis. Therefore, in accordance with system qualitative analysis, we divided the system into six subsystems; which are intensive pig farming subsystem, farmers' total income from the system subsystem, anaerobic digester effluent subsystem, paddy planting subsystem, vegetable planting subsystem, and biogas subsystem. For each subsystem, there is a corresponding in-tree; the total in-trees construct the rate variable fundamental in-tree model of the LanPo intensive pig farming eco-energy system.

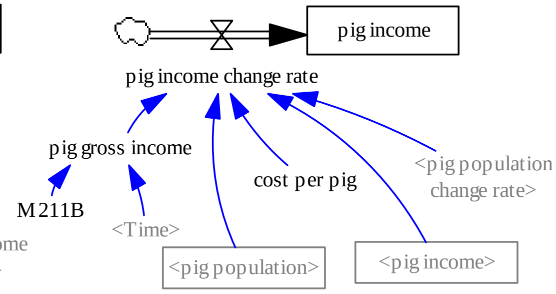
The in-tree model is composed of ten rate variables fundamental in –trees (see fig.4). The root of a rate variable fundamental in-tree is a rate variable, the level variables or other rate variables, external variables, constants (parameters) which control the root only through auxiliary variables is called the leaves of the in-tree.



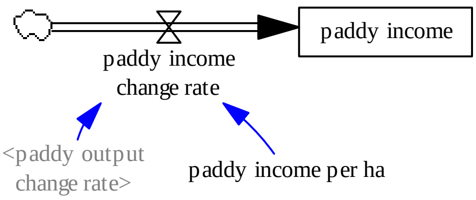
(a)...T1(t)



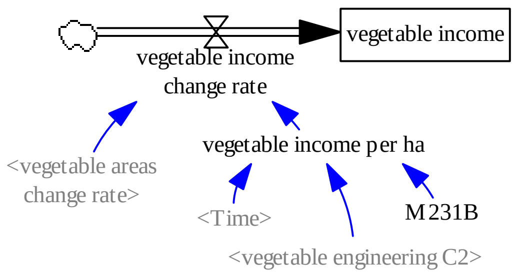
(b)...T2(t)



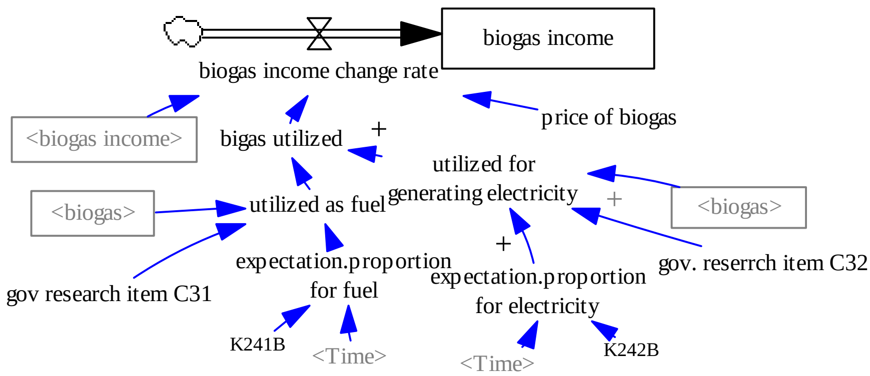
(b1)...T21(t)



(b2)...T22(t)



(b3)...T23(t)



(b4)...T24(t)

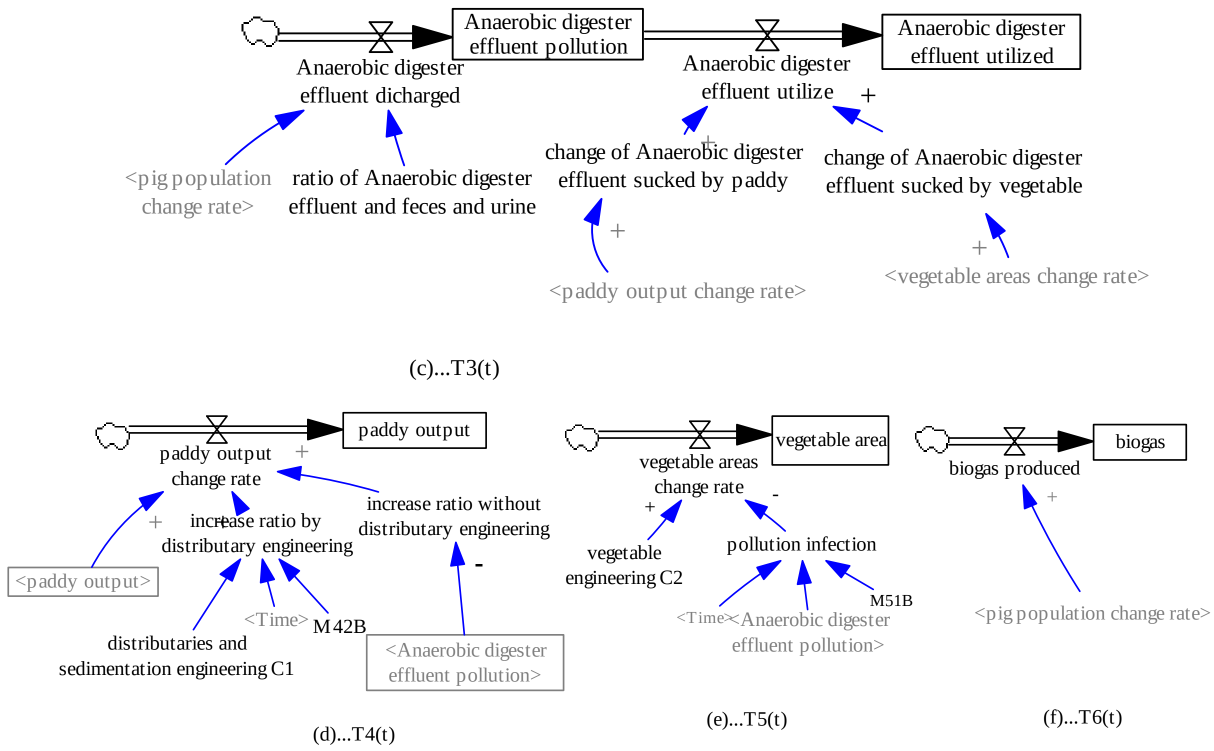


Fig.4. the rate variable fundamental in-tree model of the LanPo intensive pig farming eco-energy system

Base simulation

The simulation time horizon is 14 years. Euler integration was used with DT set to 0.25. The base simulation showed in Figure 5(a) shows the structure of farmers earning in the LanPo intensive pig farming eco-energy system. The variables shown are (1) Farmers earning, (2) pig income, (3) paddy income, (4) biogas income, and (5) vegetable income.

The base simulation of income structure can be described as following:

1. Income from pig production is the main part of farmers' income during the simulation periods, accounts for more than 50% of farmers' income, even reaches nearly 90%some years. So it is obvious that intensive pig farming is a main approach to facilitate farmers' income growth in this region.

2. Implement eco-energy system engineering, ensures the income of paddy and vegetable planting increases steadily, contributes to farmers' income growth.

3. Recycle utilization of biogas and bio-fertilizer, saves living fuel and fertilizer spending for farmers, also contributes to farmers' income growth, moreover, with the development of the eco-energy system engineering, profit created by it will escalate.

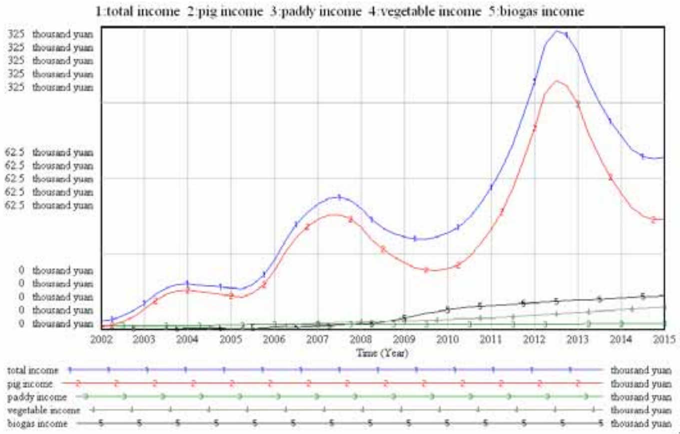


Fig.5.(a) Base simulation showing (1)Farmers income, (2) pig income, (3) paddy income, (4) biogas income, and (5)vegetable income

The base simulation shown in Figure 5(b) indicates the variation of anaerobic digester effluent pollution and paddy output in the LanPo intensive pig farming eco-energy system. The variables shown are (1) Anaerobic digester effluent pollution, (2) paddy output.

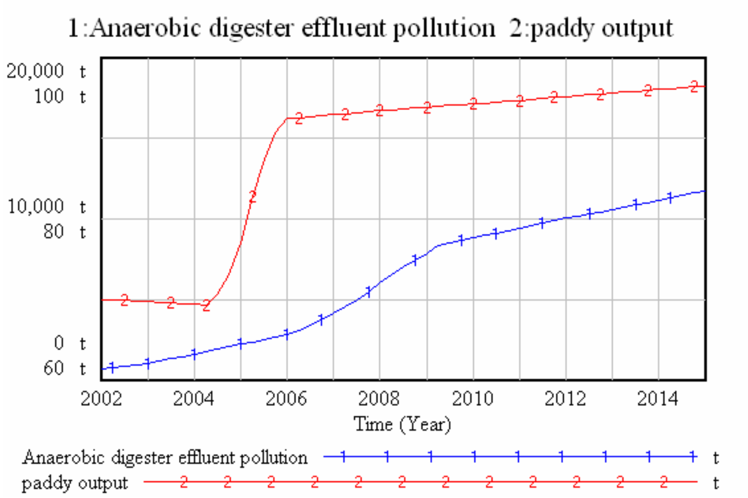


Fig.5.(b) Base simulation showing (1) Anaerobic digester effluent pollution, (2) paddy output

The base simulation of anaerobic digester effluent pollution and paddy output shows that anaerobic digester effluent pollution exists in the LanPo intensive pig farming eco-energy system, but due to implement distributaries of and sedimentation engineering, the output of paddy increases with steady steps.

To understand the simulated behavior of variables of the system, we hope to explain what causes such behavior characteristics, and what is the feedback structure of this complex system?

To answer these questions, the problems barged up against firstly are

1. How many feedback loops are contained in Fig4?
2. How does the feedback loops, especially the dominant, interact each other?

Policy analyses with dominant feedback archetype simulation

To depict structure of a system, feed back loops are used in SD. As we all know that among these feed back loops, it must exit one or even more dominant feed back loops during each developing period of the system. The characteristic of the main feed back loops and the inter-action of them determined the character and diversification of system behavior. We named the dominant feed back loop which has typical actual meanings as a dominant feedback archetype. Based on the in-tree model, with the branch-vector determinant algorithm, we can find that 17 feedback loops, ranging from two-order to six-order, constructing the Lanpo intensive pig farming ecology system. We can simulate the dominant feedback archetypes to analyze the efficiency of policy we suggested after vertex weighted causal diagram analysis.

Lanpo village belong to the main paddy production area of Center China, which is the main paddy production region of China. So our policy objectives are twofold: (i) a sustainable pig farming industry that can provide sizeable benefits for farmers' income and employment; and (ii) conservation of rural environment that are essential to the sustainability of paddy planting.

As mentioned in last section, there are three main contradiction problems in the Lanpo intensive pig farming ecology system, which are the pollution caused by surplus biogas; reduction of paddy output caused by the irrigating water mixed by bio-fertilizer; and the Anaerobic digester effluent pollution due to the shortage of bio-fertilizer loading cropland and unused of bio-fertilizer during the winter. These three problems each corresponds to a subsystem.

1. 'Pig-biogas-income' subsystem. It is a subsystem of intensive pig production and biogas utilized as resource. The objective of this subsystem is to reduce the emission of greenhouse gas in biogas, and save the spending of living fuel of farmers.
2. 'Pig-biogas-paddy-income' subsystem. Here 'pig' denotes intensive pig production, 'biogas' denotes the biogas engineering, and 'paddy' denotes paddy planting .the objective of this subsystem is to ensure the security of paddy planting.
3. 'Pig-biogas-vegetable-income' subsystem. Here 'pig' denotes intensive pig production, 'biogas' denotes the biogas engineering, and 'vegetable' denotes paddy vegetable planting. The objective of this subsystem is to father the pollution caused by excessive anaerobic digester effluent

The feedback structure of these three subsystems is the dominant structure of the Lanpo intensive pig farming ecology system, the feedbacks of it make of three dominant archetypes. Now we use them for policy analysis.

Recycle biogas utilization

Recycle biogas utilization includes increasing biofuel consumers and developing biogas generating electricity engineering to reduce the emission of greenhouse gas. To test the impact of the government investment and institutions technology supporting, we conducted a simulation with dominant archetype 1: Pig-biogas –income.

Feedback analysis of Dominant archetype 1: 'Pig-biogas –income'

The archetype is embedding by five in-trees, which are T_1 (t) (pig population in-tree), T_2 (t) (total income in-tree),

T_6 (t) (biogas in-tree), and its structure flow diagram $\mathbf{G_{126}(t) = T1(t)\vec{\cup}T2(t)\vec{\cup}T21(t)\vec{\cup}T24(t)\vec{\cup}T6(t)}$ is shown in Figure 6(a).

From Figure 6(a) we can see there are 7 feedback loops in archetype 1.

① Two 3-order positive feedback loops(1, 2) on the top left depict the fact that intensive pig farming facilitate farmers' income growth, they are main part of the archetype;

② The middle part are two 4-order positive feedback loops(3, 4), which depict biogas energy used as living fuel ,or for generating electricity, can reduce biogas pollution, save and earn money, the pig farming industry develops at the same time;

③ 5 and 6 are two 2-order positive feedback loops, they depict biogas energy used as living fuel ,or for generating electricity, can reduce biogas pollution, facilitate the pig farming industry develops. The value of Policy parameter $C_{31}$and C_{32} in the archetype reflecting the implement of government research item.

④ The 2-order negative feedback loop underside (1) is a balancing loop depicting the restriction of biogas pollution to pig farming scale.

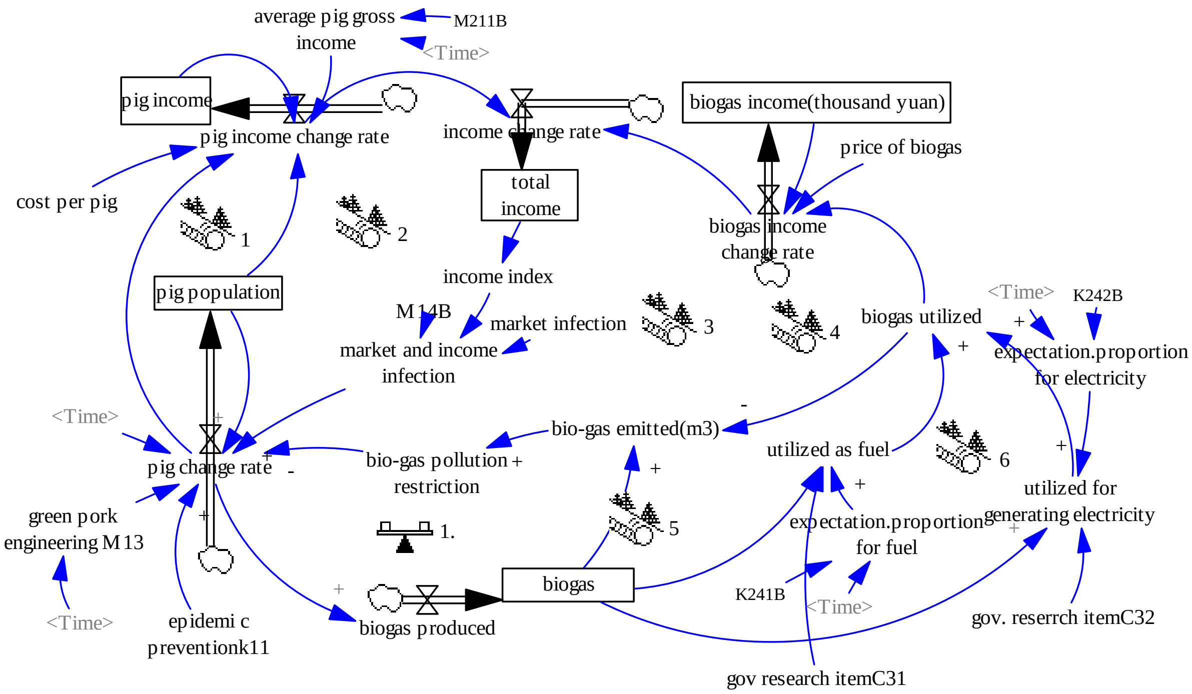


Fig.6 (a).Structure diagram of dominant archetype 1(Pig-biogas- income)

Simulation of policy 1

We conduct the simulation by changing values of policy variables C_{31}, C_{32} respectively, and three scenarios are planned.

Scenario 1：C_{31}=0, C_{32}=0 government and research institute haven't launched into the bio-energy utilization; all of the biogas output are emitted directly.

Scenario 2：C31=1, C32=0, government and research institute get involved in the item of biogas utilized as fuel.

Scenario 3：C_{31}=1, C_{32}=1, government and research institute's item of biogas utilized as fuel and utilized for generating electricity are started.

The results are shown in Fig.6 (b)

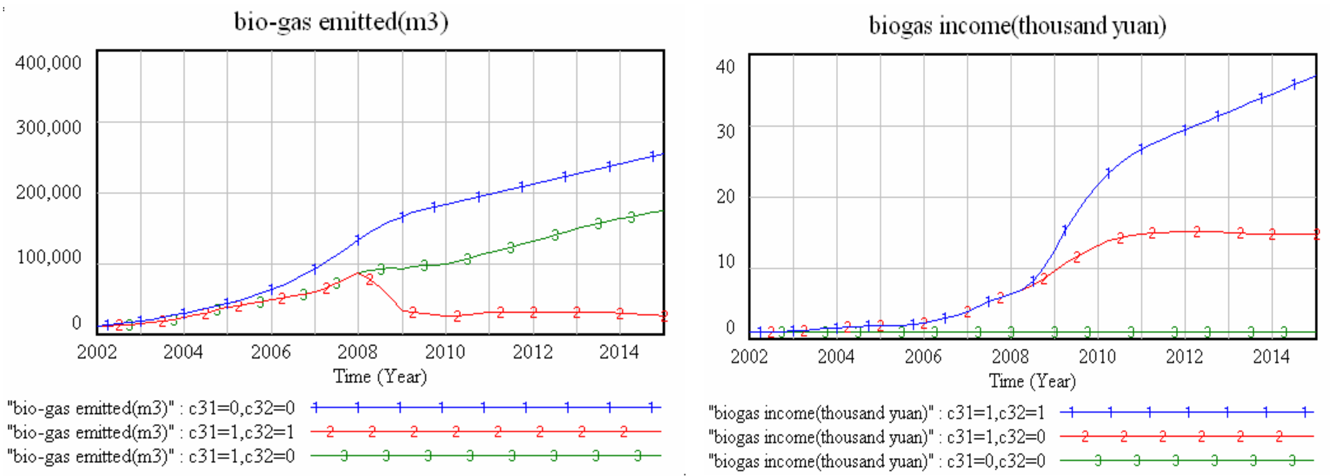


Fig.6 (b) simulation of biogas emitted and biogas income with recycle biogas utilization

For the LanPo farm, if there were no biogas recycle utilization engineering, 13.3 thousand cubic meters biogas should be emitted into the atmosphere per year during year 2002~2015, that is there are 8.32thousand cubic meters CH_4 and 4.32 thousand cubic meters CO_2 should be emitted into the atmosphere per year during year 2002~2015, further more, the emission should increase year after year, by the year 2015, the emission of CH_4 and CO_2 should reach15.9 and 8.25 cubic meters. The fund and technology invested by government and research institutes to construct resource utilization of biogas can reduce the emission of biogas effectively with the reduction ratio of 73.6% per year.

At the same time, 10thousand RMB Yuan fuel cost are saved per year due to the biofuel , in year 2008, the income of biogas reaches to 25 thousand RMB Yuan for the performance of item which generate electricity with biogas

Anaerobic digester effluent and irrigating water diffluence engineering

The purpose of this policy engineering is to prevent the anaerobic digester effluent from flowing excessively into paddy field via the irrigation raceway, which results in the reduction of paddy output. Hereby, we conducted a simulation with dominant archetype 2: Pig-biogas-paddy-income to depict the scenarios of paddy output pre and after the anaerobic digester effluent and irrigating water diffluence engineering.

Feedback analysis of Dominant archetype 2(Pig-biogas-paddy-income)

The archetype is established by embedding operation of six in-trees, which are $T_1(t)$(pig population in-tree), $T_2(t)$(farmers' total income in-tree), $T_{21}(t)$(pig income in-tree), $T_{22}(t)$(paddy income in-tree), $T_3(t)$ (Anaerobic digester effluent in-tree), and $T_4(t)$(paddy output) $\boldsymbol{T1(t)\vec{U}T2(t)\vec{U}T21(t)\vec{U}T22(t)\vec{U}T3(t)\vec{U}T4(t)}$, its structure flow diagram is shown in Figure 7(a).

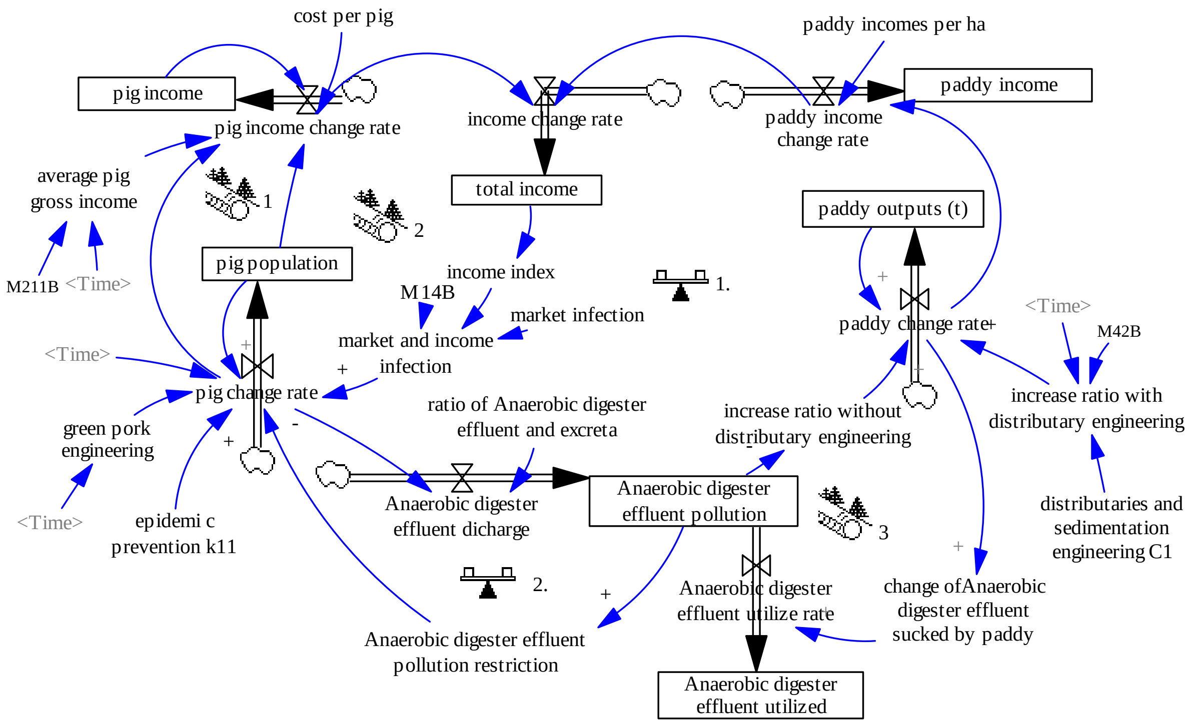


Fig.7 (a). Structure diagram of dominant archetype 2(Pig-biogas-paddy-income)

Feedback analysis of Dominant archetype 2:'Pig-biogas-paddy-income'

Figure 7(a) shows that there are 5 feedback loops in archetype 2.

① Two 3-order positive feedback loops on the top left (1, 2) depict the fact that intensive pig farming facilitate farmers' income growth, they are main part of the archetype;

② The middle part is a 5-order negative feedback loop(1), which depict the structure of severe reduction of paddy output due to pig production effluent adding too many nutrients to the paddy field;

③ At the bottom of the archetype is a 2-order negative feedback loop (2), which depicts the restriction of digester effluent pollution to pig farming scale.

④ The right corner of the archetype is a 2-order positive feedback loop (3), it depicts the cycle of digester effluent pollution increase and the reduction of paddy output.

Simulation of policy 2

We conduct the simulation by changing values of policy variables C_1, and two simulation scenarios are planned.

Scenario 1 : $C_1=0$, diffluence engineering has not been brought into effect, anaerobic digester effluent is discharged into irrigating water channel.

Scenario 1 :$C_1=1$, diffluence engineering is brought into effect, anaerobic digester effluent and irrigating water flowing separately. Simulation result is shown in Fig. 7(b).

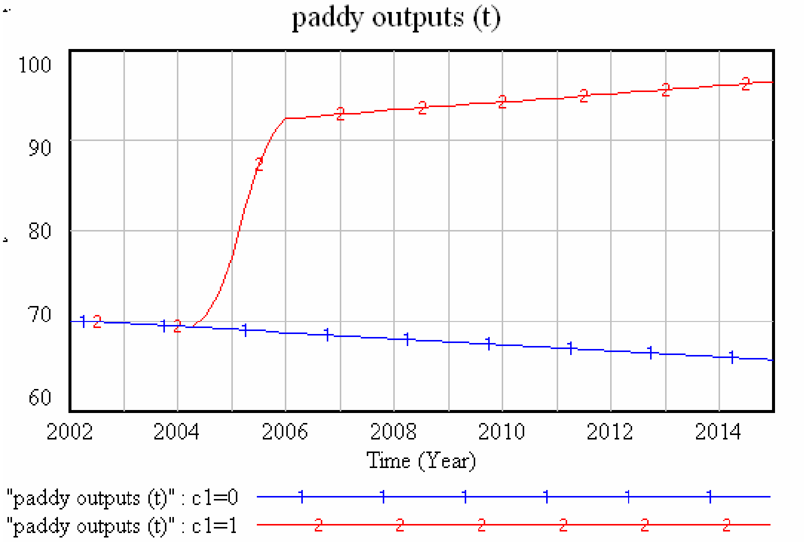


Fig. 7(b) Comparative simulation of paddy outputs

The paddy outputs reduce year after year without the diffluence engineering, which shows the pollution of intensive pig production endangering the security of paddy planting; the tendency of line 2 proves that the policy engineering is guarantee to ‘Pig-biogas-paddy-income’ ecological agricultural model.

Wintertime fallow cropland and dry land vegetable planting engineering

The purpose of this policy engineering is to solve the problem of the anaerobic digester effluent pollution to water areas on the way, potable water, agricultural ecology, and living environment due to scarcity of loaded land and the season limitation of manure application. Hereby, we conducted a simulation with dominant archetype 3: Pig-biogas-vegetable-income to depict anaerobic digester effluent pollution pre and after the wintertime fallow cropland and dry land vegetable planting engineering.

Feedback analysis of Dominant archetype 3(Pig-biogas-vegetable-income)

The archetype is made up of six in-trees, which are $T_1(t)$(pig population in-tree), $T_2(t)$(farmers’ total income in-tree), $T_{21}(t)$(pig income in-tree), $T_{23}(t)$(vegetable income in-tree), T3(t) (Anaerobic digester effluent in-tree), and $T_5(t)$ (vegetable areas) by embedding operation, its structure flow diagram is shown in Figure8(a).

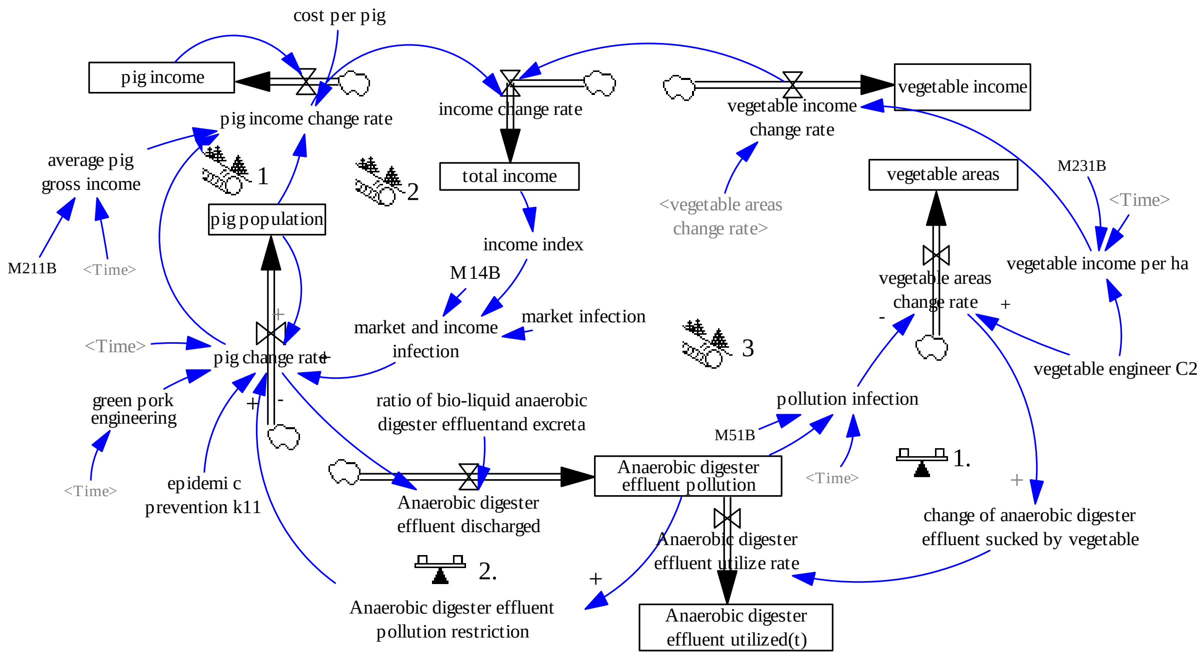


Fig.8 (a). Structure diagram of dominant archetype 3(Pig-biogas-vegetable-income)

As is shown in Fig.8 (a), there are 5 feedback loops in the structure of archetype 3.

① Two 3-order positive feedback loops on the top left (1, 2) depict the fact that intensive pig farming facilitate farmers' income growth, they are main part of the archetype;

② The middle part is a 5-order positive feedback loop(3), which depict farmers total income increased by resource utilization of anaerobic digester effluent to vegetable planting, which in turn enlarges the scale of pig farming. The value of Policy parameter C2 in Fig. 7(a) set for the vegetable engineering. If the engineering is actualized, C2=1, otherwise C2=0.

③ At the bottom of the archetype is a 2-order negative feedback loop (1), which depicts the restriction of digester effluent pollution to pig farming scale.

④ The right bottom of the archetype is a 2-order negative feedback loop (2), it depicts the vegetable engineering's effect on digester effluent pollution.

Simulation of policy 3

We conduct the simulation by changing values of policy variables C_2 and two simulation scenarios are planned.

Scenario 1：C_2=0, vegetable engineering has not been brought into effect.

Scenario 2：C_2=1, vegetable engineering is brought into effect.

The simulation results are shown in Fig.8 (b).

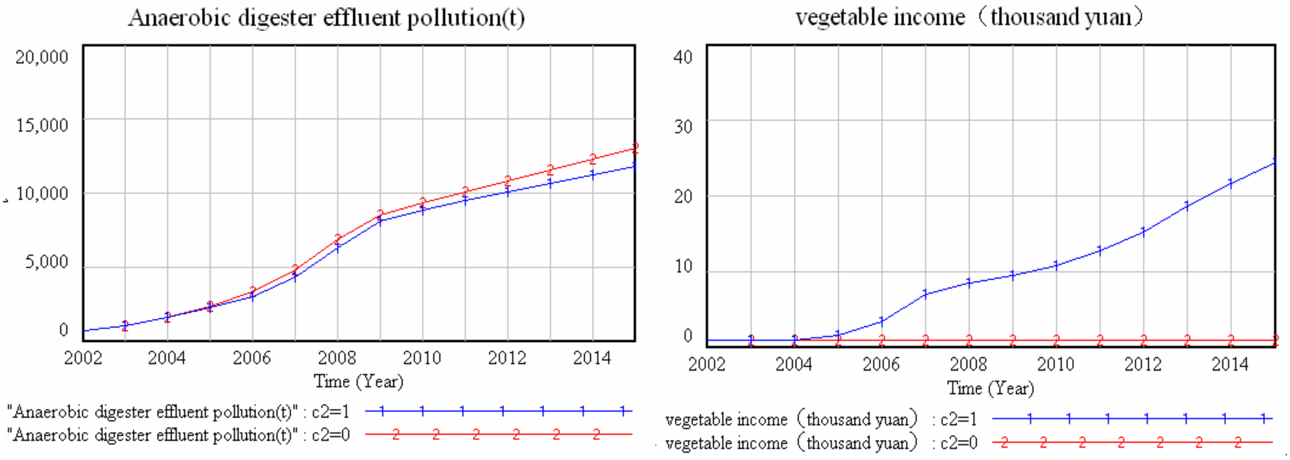


Fig.8 (b) simulation of digester effluent pollution and vegetable income under the policy engineering

The scenarios of anaerobic behavior of the Lanpo intensive pig farming ecology system shows the vegetable engineering has some distribution to digester effluent pollution treatment, but as for the output of digester effluent, the effect is limited. So to insure the sustainable development of agricultural ecosystem, we suggest increase investment on digester effluent resource utilization, enlarge the vegetable planting areas, and at the same time emphasize the moderation of pig farming scale, confirm the farming scale by the land area.

From the simulation result of vegetable income, we can see after vegetable engineering being brought into effect，farmers earn quite a lot by selling green vegetable. The income of it will amount to nearly 30thousand Yuan in the year 2015.

Summary

We have constructed a practical pig farming excreta resource utilization model via a case study of the Lanpo intensive pig farming ecology system, and have conducted simulations during years 2002 to 2015of the system with the corresponding dominant archetype, The results show that policies of encouraging more farmers to utilize biofuel, separating anaerobic digester effluent from irrigating water, developing the winter fallow cropland and the hilly land and governments' fund and technology supporting may help shift the system toward sustainability. However the simulation results have also opened out the capacity limitation of the recycle utilization in breeding residues treatment, because of the physics resource limitation. So we suggest the rural intensive livestock production should calculate the carrying capacity of its soil, control the scale of breeding, to retain the sustainable development of its eco-energy System.

We have demonstrated the SD analysis approach based on the rate variable fundamental in-tree model in this paper, which is giving the preparatory management policy by vertex weighted causal loop diagram analysis approach, then contrast system's developing tendency of implementing and not implementing management strategy to demonstrate、amend and confirm it, the approach has embodied the micro world function of system dynamics, and is especially useful for establishing the management policy of complexity systems.

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