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Research Article

On a Novel Energy Engineering Model from China's Rural Areas

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Abstract: The aim of this study is to provide a comprehensive investigation of the ecological agriculture of quaternity, an innovative mode of energy engineering emerging in North China's rural areas. A delineation and analysis of the composition, functions and principles for designing and working concerning this energy model is conducted. The input, output and input-output ratio with reference to energy in this system and its three subsystems is estimated, compared and discussed, based on the data from a trial sample. The study finds that this quaternity energy mode fulfills an organic integration of the planting industry and the breeding industry and also integration of production and life, affording self-sufficient materials for biogas fermentation and generating abundant organic fertilizers, thus to achieve benign circulation of energy and material flows and ultimately accomplish a high unification of energy, ecology, economic and social utilities. On the empirical evidence, the study exhibits that this model of energy engineering operates well and is energy-concentrated, with rationality in the agro-production structure and considerable comprehensive efficiency. Nevertheless, its energy productivity is merely at a middling level and the area and variety of crops is minor. The study concludes with pointing out proposals of improving and popularizing this energy engineering pattern.

Keywords: Energy engineering, quaternity model, rural area, sustainability

INTRODUCTION

Since the 20th century, the human being has created unprecedented material wealth, pushing forward the progress of social civilization. Yet, notwithstanding enjoying a tremendous rise in science and technology and productivity, the human being suffers painful problems like resource squandering, environmental exacerbation and ecological disruption, which have posed a severe threat to the man's survival and development. Agriculture, which is universally documented as the cornerstone of bolstering national economy, regardless of based on practical demand or with an eye to demand for futuristic development, is supposed to live up to rationality in development of natural resources, effectiveness in maintenance of ecological surroundings and sustainability in extractive industry operations.

China's rapid economic growth is bringing wealth and prosperity, but the Chinese environment and society are struggling to keep pace (Liu *et al*., 2003; Liu and Diamond, 2005; Meng *et al*., 2005; Ravallion and Chen, 2007). Recently, the nation has undergone a profound transformation from a centrally planned toward a market-oriented economy and a shift from a rural agriculturally based to an urban industrially based society (Guan and Hubacek, 2007). It has become one of the fastest growing economies in the world with an average annual GDP growth rate of 9.7% for the past decades. The economic success has resulted in considerable improvements in people's quality of life with large sections of the population experiencing a transition out of poverty and toward consumerist lifestyles. However, the economic achievements have required significant natural resources inputs. Since the year of 1990, China's total energy consumption has grown 5.0% annually from 18 EJ (1018 J) and CO_2 emissions grew by 4.8% per year from 1446 Million Metric Tons (MMT) (Zhang, 2010). Now, the second largest economy is the biggest contributing nation to global emissions of carbonaceous aerosols, with its emissions continuing rising rapidly in line with its industrialization and urbanization and the household (or residential) sector acting as the largest contributor. Thus, household energy use is fairly significant for determining regional and global concentrations of carbonaceous aerosols, changes in net radioactive forcing and the potential for regional modification of climate. Because of the high population exposure levels of fine particles from household fuel combustion, human health effects are also heavily implicated. Especially in an expansion of rural areas in which there is a population totaling to 64 million and most of them are engaged in agriculture production activities, biomass energy has suffered rapacious consumption

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due to unavailability of more effective energy supply, along with excessive felling of energy woods and exterminating of faggot straws. The poor areas substantially resort to energy woods, charcoal and straws to meet basic energy demand, thereby provoking a heavy damage to their ecological environment. It is estimated that 23% of straw resources across China conflagate on fields or are stacked to induce a squandering of this resource and a rise of emissions of harmful gases related to straws (Wang, 1994; Han *et al*., 2002). So, energy utilization models in China's rural regions and low taste thereof have dented sustainability of development in the largest developing country's ecology, economy and society.

This alarming position has triggered attention and interest from the academics to develop a reasonable use of natural resources, shield and polish up ecological environment, preserve the balance of agricultural ecology, steadily run and expand farming production, turn out green food in favorable health and promote sustainable development for agriculture in China. Abroad and domestic practices have attested ecological geoponics is an exactitude way to fulfill argo-sustainable development rather than the traditional agriculture model (Bian, 2000; Ding *et al*., 2003; Qiu *et al*., 2005), which is universally acknowledged a well-organized artificial system of ecology and meanwhile a highly efficient agriculture with a harmonious relationship between structure and function. Usually, diverse regions all over the world bear dissimilar ecological agriculture modes corresponding to their own natural endowments.

In northern China, a new model termed as quaternity has been spread into popularity for more than two decades. This model is characteristically marked by a combination of courtyard economy and agricultural ecology. For picking up the output and quality of faming products, it plays a surpassing role in how to develop full and rational use of this style with a view to facilitating expansion of courtyard economy and farming production. This study is dedicated to probing into the results arising from this energy model, particularly its energy output to provide a theoretic basis for its improvement and further popularization.

Furthermore, the aim of this study is to contribute to the growing body of literature concerning sustainable development by probing into the consequences of this novel energy form, ecological model of quaternity, which has been spread through rural areas in China for decades and, suggest constructive strategies of improving this model, eventually to enhance rustic power and environment sustainability. We consider four aspects:

- Energy flows
- Ecological benefit
- Social utility
- Input-output efficiency

The four aspects allow us to address many of the economic questions setout in energy sustainability studies and to compare our results with the existing evidence. Another contribution is that we determine and compare production efficiency for the three subsystems in this energy project that has not been addressed in the current literature concerning China's rural energy issue to date. Our empirical analysis thus provides a broad evaluation of comprehensive effects, which the fresh energy engineering exerts upon in the energy industry. Our main findings are:

- The model of quaternity energy engineering plays a significant part in maintaining ecological equilibrium in the countryside for it can generate methane sufficient to satisfy the routine cooking energy demand of peasant households, thus diminishing the volume of coal or faggot consumption and eventually facilitate the improvement of rural ecology: an abatement of forestry and vegetation damage, an easing of environment contamination incurred by fuel wood and coal conflagrating and a waning effect upon water loss and soil erosion.
- Men and livestock excrements are at any time into the tank for yielding biogases so that the courtyard is beyond stink and contamination, basically altering the past countryside's yards plagued by considerable droppings, mosquitoes and flies. Furthermore, this gives rise to cutting off a channel which spreads hurtful bacteria, improving physical health for rural residents.
- There is a middle level of performance for this system, the output-input ratio of 0.115. With regard to the breeding engineering subsystem, swine has a high rate of energy conversion with pork cherishing a massive quantity of heat, thus contributing to a comparatively high output-input proportion within the energy ecological engineering system in North China rural areas.
- The system itself suffers a not very high productivity and dissatisfactory linkage between the planting and breeding subsystems. The input-output ratio is relatively not high, 0.244 in the breeding subsystem and, 0.56 in the case of the biogas tank subsystem mainly as no continuity in batch feeding exerts a negative effect on the output of marsh gas and steady production of methane liquid.

Overview of quaternity mode:

Quaternity mode structure: The ecological agricultural mode of quaternity is an energy engineering ecological system in the condition of closed state, which is theoretically based on ecology, economics and systematic engineering science, with land resource being its foundation, solar energy being its motive power and biogas being its ligament of

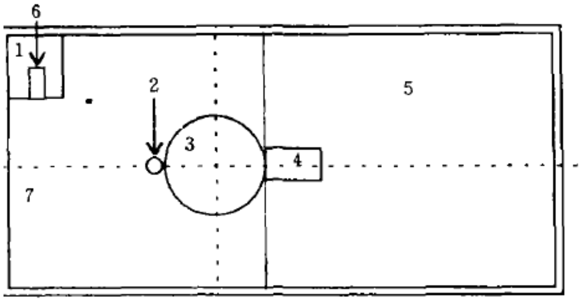

Fig. 1: Sketch map
1: Toilet; 2: Feed inlet; 3: Metahne tank; 4: Discharge hole; 5: Sunshine greenhouse; 6: Toilet pit; 7: Piggery

linking each part. Bonding the planting and breeding industry, this engineering, composes a methane tank, a pig and poultry house, a lavatory and a daylight greenhouse into a whole one to turn out biogas under the completely sealing circumstance via the technique of converting materials into energy (Fig. 1). This style, termed as quaternity meaning four dimensions in one entity, is an embodiment of organic blending of methane technology, breeding technology and planting technology to upgrade agriculture toward high yielding, high efficiency and high grade. Furthermore, this energy engineering constitutes a complete production and circulation system featuring pooling multi-industries and intensive operations. And reinforces full circular use of materials via the rational coalescent of planting, breeding and microbes so as to promote agriculture without pollution and scraps to take shape. More significantly, this engineering system turns to sophisticated production technologies and techniques to develop a full utilization of a limited quantity of resources including land, labor, time, feedstuff and financial fund, translating the bygone extensive farming industry into an intensive-operated one.

Overall design and construction technique: Doing the overall designing and construction of the quaternity energy model complies with principles as follows:

- **Comprehensiveness:** Meaning that this structure will be prohibited from variation and modification upon being launched with falling into the permanent project category so that it is necessary and imperative for this engineering to be operated under total planning and arrangement in an effort to fulfill a complement of multi functions, namely courtyard, water, forest and road enjoy comprehensive governance.
- **Economy of scale:** Casting a light that this mode can organize thousands of households within an area to uniformly develop farming activity and send small family courtyards into a large-scale commodity-produced base so as to integrate into markets.
- **Suiting the measure to local conditions:** Voicing that market investigation, persuading and teaching the mass of rural inhabitants, scientific-technological consultation, analysis of feasibility ought to be well performed ahead of time to pursue interests and avoid risks.
- **Synthesizing of production:** Characterized by a high level of production, developing producing potential and various resources, intensive technology, virtuous cycle and ecological balance. So, the engineering is constructed as per the following measures:
  - **Site:** Which had better be leeward located in front of household houses, face the sun and south, extend along the east-west direction and may westing-extend (or easting) to an angle less than 15°, shaded light by trees and higher buildings.
  - **Aggregate planning:** Commanding that a piggery covering 15-20 m^2 and a toilet with an 1 m^2 area should be built at one end, below which is a methane tank with an 8-10 m^3 set up and with an range of less 15 m to the peasant's kitchen. Specifically, a small yard can establish the piggery to the north of the greenhouse (Fig. 1).

Variety of fermented-metabolic products within the methane tank: On the heel of primary materials being processed through zymosis inside the biogas pool, two types of outcomes are generated. One takes the form of gas, mainly methane and the other one exists in the form of methane liquids and residues. These substances can be divided into three varieties: the first is nitrogen, phosphor and kalium, which are directly absorbed and used by crops; ions such as Ca, P, Fe, Cu, Zn and Mn, taking shape from fermentation, belongs to the second category, which can penetrate into seed cells to stimulate seeds to germinate and crops to grow up (Yin *et al*., 2007); and macromolecule matters can be seen as the last type, to name but few, aminophenol, auxin, red enzyme, humus acid and antibiotic, which play an important regulating role in crop growth (Song *et al*., 2001). Additionally, in methane microorganism bacterial is highly valuable protein, which can be utilized as kind of high grade forage for animals (Sun and Gao, 2004). These bacterial can lead to a rise of semi-rugged protein content in biogas fermentation material liquids.

Usages regarding fermented-metabolic products within the methane tank: Fermentation residues refer to the part of primarily fermenting materials, which have failed to be digested by microorganisms following the aftermath of zymolysis and whose ingredients are related to fermenting materials so these solid-shaped sediments can be used as a feedstuff or a fertilizer.

Table 1: Size of system and subsystem

Piggery area (m^2)	Greenhouse area (m^2)	Toilet area (m^2)	Methane tank cubage (m^3)	Whole system area (m^2)
16	145	1	8	190

Methane functions in this energy engineering mode: In the greenhouse, biogas is mainly utilized for increasing temperature and CO_2 density. Combustion of 1 m^3 methane can cause a release of KJ 23000 calories, thus improving 2-3°C for the canopy's inner. Generally, a greenhouse awning with an area of 100 m^2 is allocated a biogas lamp so that three lamps igniting from 5.30 to 8.30 in the morning can trigger a temperature rise of a 350 m^2 greenhouse. One cubic meter biogas may produce 0.98 m^3 in CO_2 (Dong, 2000). Within a certain level, veggie photosynthesis can improve output and increase its density.

Uses concerning liquids of biogas: Biogas liquid embraces abundant proteins, amino acids and microelements like N, P and K, in which there are plenty of physiological active materials mattering for regulating development of crops and preventing diseases. Biogas liquids being applied into vegetables are able to accelerate them to grow, augment outturn and improve their quality and eventually to raise efficiency. Furthermore, it is evidenced that the liquids as an additive of forage can function on expediting of pig growth, shortening of fattening period and heightening of meat-fodder ratio.

Usages of residues of biogas: Biogas residues, which are the mixture of unresolved crude material solids and newly-produced microorganism bacterial, are full and sufficient in nutritional components due to having plentiful organic substances, humid acid, total nitrogen, total phosphor and total kalium, so exerting a huge positive clout on culturing of soil fertility. Consequently, applying methane relics into soil as a fertilizer or spraying onto greenstuff leaves is capable of ameliorating physical and chemical attributes in connection with soil, retaining land tillability and boosting sustainable development of soil utilization as well as strikingly increasing the output and quality concerning vegetables.

Function principle: In the quaternity structure, which arrays the piggery, the toilet and the greenhouse in the form of word "one", the methane tank is constructed below the piggery, the feed inlet is liked to the entrance of human and animal excrements and the discharge hole stretches into the indoor. Human and animal excrements directly get into the biogas pool, which generates methane fertilizers to be applied into plant growth and produces biogas to be burned mainly for cuisine and illumination. The figure shows the configuration and energy circulation. Significantly, the function concerning this energy engineering largely is reliant upon the circle and comprehensive utilization of ferment substances. During the course of fermentation, organic substances are decomposed into metabolic products, microbes and giblets, all of which make up the material foundation for taking comprehensive advantage of methane. Note that Table 1 displays the size of this engineering for each subsystem.

MATERIALS AND METHODS

Experiment contents: The test zone in connection with this ecological agricultural model is located to the west of the Dong Ling District, Shen Yang, Northeast China, with the latitude and longitude at 123°48′ and 41°50′, the solar radiation and sunshine reaching 12669.4-132313 kj/m^2 and 2571-2745 and the climate falling into the humid and semi-humid continental category of the north temperate zone. Tomato, as a testing crop, is planted in the system. Edaphically, the area belongs to brown earth, whose features in the tilth ranging from 0-20 m are depicted in Table 2.

Devising the experimental programme and accessing data: The energy engineering system has a complete cycle with four months embracing each manufacturing process from potato field planting to reaping. The system's input is solar energy, organic manures, seeds, feedstuffs and human (livestock) force and outcome includes methane, vegetables and pigs. In computing the quantity concerning input materials, facilities like the green house, the methane tank and the toilet are not considered. As for the investigation of energy streaming and material circulation, animal husbandry products, chemical fertilizers and excreta are estimated in energy value on the basis of documents (Wang *et al*., 1998; Luo, 2000).

As per the entire solar radiation of 130,000 kj/m^2.a, the methane, the breeding and the planting subsystem can attain energy in the value of 6.29×10^8, 2.08×10^9 and 1.885×10^{10} J, respectively. Labor input is 2 h/day and 1.885 h/year, the system as a whole consumes labor up to 240 h, being distributed to each subsystem on the average at 80 h.

There are materials once put into the methane system the methane system, representing a proportion of 80% of its capacity, namely, for the methane tank of 8 m^3 there is 6.4 m^3 of feed liquid to be put into it, in which pig excrement accounts for 10%, with dry weight at 108 kg. Over the course of operations, no other forms of energy are input except solar energy. Inside the breeding subsystem, six hogs are fed, each being 25 kg in weight, each expending 330 kg in forage and all 1980 kg. Table 3 displays the status in connection with energy input.

The planting system covers an area of 145 m^2, with 814 individual plants of tomato L402 being raised and the row spacing reaching 33×50 cm. On the basis of 667 planting areas calling for basal manure of 4000 kg, there is a demand for 1087.5 kg on the whole. During the entire growth period of tomato, fertilizing amount can equate 38.994 kg in nitrogenous manure, 21.714 kg in phosphate and 89.40 kg in potassium, among

Table 2: Property of tested soil

	Organic matter (g/kg)	P (mg/kg)	N (mg/kg)	K (mg/kg)	Density (g/cm^3)	PH
Content/value	24.42	137.91	131.72	274.60	1.35	6.94

Table 3: Energy input

	Methane subsystem			Breeding subsystem			
	Solar energy	Swine faeces	Human force	Feedstuff	Labor force	Solar energy	Swine
Volume	6.29×10^8 J	108 kg (dry weight)	80 h	1980 kg	80 h	2.08×10^{92}. J	150 kg
Energy (J)	6.29×10^8	1.92×10^9	6×10^7	3.96×10^{12}	6×10^7	2.08×10^9	3.89×10^9

Table 4: Energy input within the plant subsystem

	Nitrogen	Phosphor	Kalium	Manual labor	Seed	Pig faeces	Solar energy	Plastics
Volume	38.994 kg	21.714 kg	89.40 kg	80 h	7 g	3262.5 kg	1.885×1010 J	45.33 kg
Energy/J	2.87×10^9	2.91×10^8	8.22×10^8	6×10^7	7.23×10^5	5.8×10^{10}	1.885×10^{10}	2.35×10^9

Table 5: Output in energy

	Biogas	Residue	Fluid	Pig	Manure	Tomato	Stalk	N	K	P
Quantity	54 m^3	1 m^3	5 m^3	600 kg	576 kg	4896 kg	2505 kg	66.3 kg	114.2 kg	49.87 kg
Energy/J	1.2×10^7	1.46×10^9	1.555×10^{10}		9.53×10^{11}	4.14×10^9		4.89×10^9	1.05×10^9	6.68×10^8

Table 6: Input and output

	Methane tank	Green house	Pigpen	Whole system
Input energy	2.61×10^9	8.324×10^{10}	3.966×10^{12}	4.05×10^{12}
Output energy	1.47×10^9	1.07×10^{10}	9.69×10^{11}	9.8×10^{11}
Ratio	0.56	0.129	0.244	0.242

chemical and biogas manure accounting for half, respectively. The stance regarding energy input in the planting system is demonstrated on Table 4. Table 5 presents the energy output for the overall system. The input-output ratio is registered on Table 6.

RESULTS AND DISCUSSION

Energy volume: After one cycle of operations of this engineering, the methane subsystem gives rise to production in biogases of 54 m^3 including 65% methane content and 35% CO_2 content, biogas residues, biogas fluids and a biogas production rate of 0.3 m^3/kg. With regard to the planting subsystem, it harvests 4896.113 kg of tomatoes and 2505 kg of stalks (fresh weight). The breeding system posts an average weight of 100 kg for pigs, each producing 576 kg of fresh dung.

Input-output ratio: Table 6 illustrates that the input-output ratio for the biogas tank subsystem is 0.56, meaning a low level, mainly as no continuity in batch feeding exerts a negative effect on the output of marsh gas and steady production of methane liquid. Furthermore, over the phase of biogas tank movement, liquids in the tank failed to be agitated. Nor was the PH value for liquids checked and made adjustment accordingly. As a result, the input-output ratio for the entire methane tank is influenced adversely.

This model is not high in the ratio in its planting subsystem, relative to the input-output ratio of 0.356 in the ecological system of Gao Kan Town to the east of Shen Yang, where maize is mainly cultivated and simultaneously garlic, onion and potato are also cropped, corn seeds including energy as 20 times as tomato. Thus, in order to improve the system's input-output ratio and economic efficiency, it is necessary and imperative to add the areas for intercropping, relay cropping and multiple cropping, in an effort to circumvent the cultivating of a single crop and meanwhile to soil productivity for the sake of providing a certain support for the breeding industry. Furthermore, crop area and breeding scale should be increased and market should be treated as the philosophy for steering business activity. Additionally, those highly economic valued croppers with novel, bizarre and special features need to be prioritized. All this, eventually, can contribute to an enhancement of commodity rate, a formation of production-trade integration and an increase of ecological and economic efficiency.

At 0.244, the input-output ratio in the breeding subsystem is relatively low compared to Gao Kan Town, at 0.453. Feedstuff is a main energy input for this system, so to raise the input-output ratio in feedstuff will be a significant approach to the improvement of output. It is urgent and necessary to transform the production composition in connection with animal commodity production from swine-based unicity into poultry-egg-pig-milk co-existing diversification. Meanwhile, the processing industry of farm and livestock products needs to be developed so as to add to the output value of breeding industry. Significantly, cubic cultivating technology should be implemented with a view to prompting an increase of quantum and species in livestock and poultry and further enhancing the system's energy output.

The output-input ratio of 0.115 for this system indicates a middle level of performance. With regard to the breeding engineering subsystem, swine has a high rate of energy conversion with pork cherishing a massive quantity of heat, thus contributing to a comparatively high output-input proportion within the energy ecological engineering system in North China rural areas. However, the system itself suffers weak productivity and dissatisfactory linkage between the planting and breeding subsystems. For pledging sustainable production of the whole system, it is vital to endeavor to put on the utilization rate concerning luminous energy and fertilizer, sustain and amass land productive forces and strengthen agricultural stamina. In addition, plastic pellicles are supposed to be dusted for the sake of holding penetration of light, advanced cultivation technology needs to be introduced, organic fertilizer should pick up on the ground of inputting a proper amount of chemical manure to upgrade the utilization rate of bio-energy. All this will lead to a high output-input ratio for the engineering.

Ecological effect: The model of quaternity energy engineering has generated methane sufficient to satisfy the routine cooking demand of peasant households, diminishing the volume of coal or faggot consumption. As per coal quality, a 1 m^3 marsh gas can engender heat quantity equivalent to 2-3.3 kg of coal which has a 0.8% content of sulphur and 20% of ash. On this estimating basis, a methane tank with annual output up to 300 m^3 can contribute to a reduction of 7-12 kg SO_2 and 0.7-1 kg dust emissions. So, a village with 200 biogas ponds can enjoy a contraction in emitting SO_2, soot and CO_2 of 1.4-2.4 tons, 140-200 kg and 82.3 tons.

Concretely, 1 m^3 of methane is able to produce heat equal to 4.5-5 kg of firewood. Likewise, a 300 m^3 tank can create the same quantity of heat as 1400 kg of faggot, giving rise to an economization in faggot equivalent to the annual growth yield of 0.16 hm^2 of fuel forest, furthermore an abatement of forestry and vegetation damage, an easing of environment contamination incurred by fuel wood and coal conflagrating and a waning effect upon water loss and soil erosion. Equally, men and livestock excrements are at any time into the tank for yielding biogases so that the courtyard is beyond stink and contamination, basically altering the past countryside's yards plagued by considerable droppings, mosquitoes and flies. Eventually, this gives rise to cutting off a channel which spreads hurtful bacteria, improving physical health for rural residents.

Social utility: Men and livestock excrements are fermented in the methane tank to engender, biogases, which not only are employed as a form of energy source for life and production activity but through combustion furnish sufficient CO_2 for growing crops inside the green house and, marsh fertilizers, which can serve as a basal manure and additional fertilizer, thus cutting down the volume of chemical manure usage and ultimately facilitating the system's ecological equilibrium and environment protection.

CONCLUSION

This study was actuated by the need for investigation of production and consumption of rural energy which can result in a better understanding of sustainable development of energy and ecology for rural areas. Its contribution is to provide a broad evaluation of the outcomes arising from the energy engineering project of quaternity in north China's rural regions. By virtue of probing into energy flows within the rural energy engineering system, this study finds that this system is a modern agricultural ecologic one with fairly good operations, a relatively rational agricultural production architecture, relative dense energy and substantial comprehensive efficiency. It matters much for guiding the development regarding the ecological system of peasant household courtyards across northeast China's countryside areas. Though, this system suffers some limitations. To name but a few, small crop acreage and single geographic layout, an ecumenic level of productivity and start-up and operation of the methane tank calling for a substantial quantity of energy input triggering a low input-output ratio in the whole system. Therefore, it behooves to ameliorate the structure of cultured plants, realize three-dimensional cultivation and develop the full use of methane fertilizers and biogases for improving performance of the ecological energy engineering.

The specified energy project in China's northern rural areas is a "small and all-inclusive" courtyard ecological system, which can stay in continuous operation and virtuous cycle and enhance economic interests for rustic households. This model should be incorporated into the government planning for constructing new countryside in China, thus to become an underpinning for propping up ecological agriculture growth. Furthermore, similar engineering in different regions should be forcefully encouraged to be evolved into an ecologic coalition, possibly to give rise to an ecologic economy of benign cycle in a larger size. This will generate an economy of scale, boost agricultural modernization and pave the way to the progress of rural energy source and ecological farming. More significantly, this energy model of quaternity and related strategies may be applicable in other developing economies such as Vietnam and India with a similar economic growth to China.

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