An Input and Output Analysis of the Quaternity-Dominating Energy Engineering Model from China’s Countryside

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Abstract. The aim of this study is to qualitatively and quantitatively explore an energy engineering model termed quaternity-dominating pattern emerging in North China’s countryside. This study finds methane produced in this model serves household activities such as cooking, inducing reduction of coal or biomass spending, which otherwise would provoke air pollution, water loss and land erosion, and ultimately leading to ecological environment betterment. Additionally, this project generates byproducts, biogas liquids and residuals, which can, as a category of fertilizer, promote straightening of fertility preservation capacity and improvement in the chemical and physical quality of land as well as increasing crop output and quality. This study also finds this engineering could encourage social stability via efficiently allocating bucolic surplus labor during winter and successful running this engineering project would trigger an increase of scientific and technological qualifications for rural citizens. Moreover, cost-profit analysis indicates this pattern can allow one rural home to obtain access to a hygienic energy resource of biogas in the yearly volume of 375m³, generate annual net earnings of US$3458.82 and make investment return in about 2.73 years. Especially for poverty-stricken areas, this energy engineering project enjoys high values and great significance, which can lift these impoverished areas from poverty both in economics and energy. The paper concludes with pointing out practical proposals on launching and operating this energy engineering project.

1. Introduction

Energy has evolved into a major element required to reduce poverty, increase the standard of living and promote social-economic advancement [1]. The steadfastly swift pace of economy gives rise to strong energy demand and spending having connections with challenges and negative consequences among developing nations. A considerable number of them have suffered a severe energy plague for decades, with some counties lacking of access to electricity. More seriously, rural and remote areas in those middle-low income countries have undergone painful crises including inadequate or no public energy provision [2]. Typically, among vast rural regions of bulky population in China, a representation of high economic growth among the developing world, energy is consumed at a substantial volume, with the power composition taking on diversity. Massive direct combustion of biomass such as stalks and fuel woods is central to power spending in the rustic life [3]. Alarmingly, this extensive pattern has provoked an enormous devastation to the ecological environment as well as low levels in energy efficiency [4]. This, coupled with economic poverty in areas such as loess hilly maintains among Gansu, Ningxia and Shaanxi, has posed formidable threats to sustainable development. Thus, it is getting increasingly imperative to seek out an energy engineering system,
which should comply with principles from the sustainable development ideology and must pave the way to upgrading of power resources, alleviating poverty, and aiding economic growth and environmental conservation.

Over the past decades, China has developed a variety of engineering modes, among which the quaternity-dominating pattern (QDP) denoting four in one, boasts a typical sustainable energy development and moves at a fast pace as it has reversed energy shortage and ecological exacerbation disturbing an expanse of rural areas in north China. Notwithstanding achieving expected results, this energy engineering model remains considerable problems. Thus, it is particularly imperative to make an overall analysis of this mode to formulate countermeasures in favor of extending in other rural areas to lift their households from energy poverty. Thus, this study represents a high worth for northwest China’s poor loess areas, which, with tattered landforms and dense gullies, has degenerated into the most severe area of water loss and soil erosion [5], undergoing a cruel fragility in the ecological environment, and, where bearing lack of energy, families here have to draw on local resources such as stalk, wood and weed for cooking and heating purposes [6], so having provoked a growing ecological deterioration [7].

The aim of this paper is to afford evidence on further extension and application of QDP via exploring this model from the approach of input and output and illuminating its comprehensive benefits including economic, social and ecological. Our analysis uses the newest data, which gives our study to capture current markets. We consider five main aspects: (1) construction costs, (2) production expenditures, (3) economic earnings, (4) ecological benefits, and (5) technological and knowledge improvement. These aspects allow us to address many of energy engineering questions set out in existing energy efficiency studies. Our analysis thus provides a broad evaluation of profit-cost in the energy area and contributes to the growing body of literature on rural energy by answering key questions.

Our major findings are as follows: (1) The quaternity-dominating pattern, which incorporates a methane-generating pit, a pig or poultry house, a sunshine greenhouse and a household court to shape into an ecological system of energy under the closed condition, generating methane, planting crops such as cucumber and cultivating livestock such as pigs and ultimately enhancing an upgrading of energy spending, an alleviating of poverty and an accomplishing of ecological balance among the loess hilly areas, which have undergone energy famine, economic poverty and environmental deterioration. (2) Cost-profit analysis indicates that the suggested QDP can allow one rural home to obtain access to a hygienic energy resource of biogas in the yearly volume of 375m$^3$, generate annual net earnings of US$3458.82 and make investment return in about 2.73 years. (3) By adopting this energy engineering, poor rural populations are freed from the fear which is based on want. Therefore, the energy engineering scheme takes on a promising prospect and merits priority development in energy poverty areas such as central Gansu’s loess mountains.

The remaining of this paper is organized as follows. Section 2 contains an outline concerning QDP. Cost estimation is presented in section 3. Section 4 covers benefits and effects arising from this energy engineering model. Conclusions and policy proposals are in section 5.

2. Profile of QDP
This structure (see figure 1), built in a rural household court, arrays a piggery, a toilet and a greenhouse in the form of word “one”, with a methane tank constructed below the piggery, a feed inlet connected to the entrances of human & animal droppings and the discharge hole stretching into the indoor. The methane-generating pit is responsible for fitting together planting, livestock breeding, agricultural production and rural life. Here, human and domestic animal droppings, after fermenting, yield gases that can produce CO$_2$ via combustion as to push an increase of output in fruit and vegetables. Being superior fertilizers, such dregs and liquids can lead to a reduction of both chemical fertilizer and agricultural agent adoption. With regard to the solar greenhouse, it can make agreeable illumination, temperature, and humidity for the methane tank and the swine pen or fowlery. For the toilet, its role is to furnish the biogas-generating pit with excrement, a category of raw material for the
purpose of fermentation. In addition to providing raw materials, the swine pen is devoted to enhancing its temperature by increasing the CO$_2$ density in the interior of the greenhouse.

![Figure 1. System layout of QDP.](image)

Note: 1. fence, 2. trough for spilling water, 3. orifice for charging stock, 4. toilet, 5. inlet pipe for charging stock, 6. passage, 7. methane tank, 8. swine pen, 9. discharging hole, and 10. solar greenhouse.

3. Cost estimation

3.1. Cost for greenhouse construction
It is suggested that the steel frame greenhouse should be adopted because it agrees with anti-seasonal crops such as vegetables during north China’s cold winter due to its high quality of heat preservation. This hothouse covers 350 m$^2$, spanning a length of 35 meters from east to west and internal width of 10 meters. Almost all, except walls, are made into a full steel framework, covered with drip-proof, anti-aging PO films and cotton wadding. Thus, it is strong and durable. For its expense, it is expected to reach US$ 3804 (26248.7RMB) by engineering contract, calculated by virtue of data online, whose proprietor, Agricultural Firm of Wise Monarch located in Shandong province, has been dedicated to engineering construction for greenhouses since 1990 and now enjoys high prestige nationally. Concerning its lifespan, it is estimated to be 20 years [8].

3.2. Cost for biomass-generating pit building
Regarding creating a methane-generating pit, its volume has become a primary concern since a relatively undersized pit may cause a weak output of gas, failing to meet purposes of production and life, and, a comparatively large one could contribute to a lower ratio in the methane-making. Hence, in conformity with the criterion of 1.5-2 M$^3$ per capita [9], a tank with the area ranging from 8 to 10 m$^3$ can satisfy a five member family. Besides, considering winter weather, it is suggested creating a methane-generating pit in the volume of 10 m$^3$. Such a pit, according to the prevailing market of China, is predicted to cost US$577.9 and is computed at 15 years of lifespan.

3.3. Cost for pig house establishment
Above the methane pit and bordering the greenhouse on one end in the east or west, a pigpen with an area between 12 and 14 m$^2$, accommodating 8 swine or so, should be built. Furthermore, it ought to take the form of plastics canopy, which can take advantage of sunlight to cause the internal temperature to rise, thus benefiting pig growth, even over a winter period. Such a 12 square meter pigpen is estimated at about US$ 521.74, on the footing of unit price US$43.4782 [10].

3.4. Pig-feeding expense
Direct expenditure, which encompasses pigs, feed-stuff, medical treatment and so forth, usually
making up 70% of total expenses, is crucial to the cost budget of pig-breeding, and is subject to ever-increasing prices of production factors such as piglets and fodder. It is found that the direct cost for a pig comes in at around US$214, grounded on the current market and data stemming from current literature [11]. Assuming raising 16 swine, annual investment reports US$3424.

3.5. Crop-planting outlay
For vegetable cultivation inside a greenhouse, the cost is made up of three parts: material and services, labor, and land. Concerning an engineering project of QDP, the two latter expenses could be written off because family members as employees are engaged in related activities such as agricultural production and land is of free use, dictated by Chinese legislation. Consequently, the cost for crop planting inside the greenhouse has reduced to the material and service outlay, consisting of two items: (1) the direct production expense, mainly arising from purchase of seed, farming film, pesticide, fertilizer, and maintenance services; and (2) the indirect expense, mainly involving fixed asset depreciation and sales. Owing to difficulty of direct production data availability, Shandong province’s number as an agent value was used for cucumber cultivation. It is at US$ 0.7736/m² in 2012.

Considering production material inflation 1.625%, the current direct cost for cucumber cultivation is figured to be US$0.8251/m². For a 320m² planting area, the direct production cost totals to US$ 528 for cucumber, based on two plantings per year.

3.6. Outlay for complement facilities
Complement facilities, including that straw mulch, covering a 350m² area, with an online offer quoted at US$1.087/m² and 1.5 years of lifespan, represents an annual outlay of US$253.63; and a rolling machine, priced at US$217.4 online and 10 years in life [12], is computed at an annual charge of about US$21.74, cost around US$275.37 annually.

4. Benefit Assessment

4.1. Economic effect
Annual revenue: the temperature inside the greenhouse’s canopy, ranging from 10 to 30 centigrade fits in with two plantings per year. To take cucumbers for example, a planting area of 320m² inside a 350m² canopy can lead to 7116.8 kg in output, on the unit productivity at 11.12kg/m² [13]. According to the online offer of USD0.58/kg, total earnings can hit about US$ 4127.7 (see table 1).

For breeding, one year can witness the annual aggregate output of 16 pigs in two lots, with each pig around Kg115 [14], valued US$ at the unit price US$2.3188/16.0RMB/kg online, pig raising can make US$ 4266.6. A 10 m³ methane tank can produce 375m³ of gas annually, equivalent to 267.75 kg in standardized coal or 669.4kg of ordinary coal (considering heat efficiency), valued at US$ 83.4 calculated on the unit price of 124.64US$/ton.

So, the planting, breeding and biogas system leads to an annual income up to US$8477.7 or so, which, reduced by US$5018.88 (annual cost), yields a net profit of about US$3458.82 (see table 1), implying it would take approximately 2.73 years to make investment return for investors. Provided that some “renowned, specific, superior and fresh” animal breeds or immune-to-season vegetables or fruit are introduced, this model would perform more beneficially. Hence, each household would be thoroughly lifted from poverty and lead a better life by means of this engineering project.

Table 1. Investment Cost and Earnings. (Unit: US$)

| Item         | Greenhouse | Methane tank | Pig house | Complement facilities | Production | Sum |
|--------------|------------|--------------|-----------|-----------------------|------------|-----|
|              | Life span  |              |           | Mulch                 | Rolling machine | planting | Breeding |
|              | 20         | 15           | 15        | 1.5                   | 10         | -     | -        |
### 4.2. Ecological benefit

The biogas manure has been recognized as a category of high quality organic fertilizer, created through ferment of substantial quantities of microbes. It contains (1) nutritional substances supplying nutritional elements such as nitrogen, phosphorous and potassium for crops; (2) trace elements in the form of ions; (3) some hormones such as somatotropin, gibberellins and absciscic; (4) aminoacid and vitamin B \[15\]. Accordingly, the manure of biogas can lead to plenty of positive outcomes following adequate fertilization. One significant consequence is to increase the vegetable output, improve its nutritional quality and enhance its commercial value. Take mini-cucumbers for example, superior to chemical and farmyard manures, biogas liquids and residues are found to push the cucumbers’ vitamin C content up to 48.63mg/100g, dissolvable sugar up to 22.116% and nitrate at 90.74 mg/kg \[16\].

Another positive effect is reflected by biogas liquids soaking seeds, which would bring about a rise of 5%–10% in the germination percentage and 10%–15% in the seedling rate. Third, methane fertilizer can result in rising of organic matter contents, the permeable rate and the water retention and fertility preservation capacity and, ultimately, improvement in the chemical and physical quality of land \[17\]. Finally, biogas both liquids and residuals, including amino acid and antibiotic factor, are endowed with functions such as getting rid of insects and bacteria, including aphids, which might be destroyed through biogas liquids being sprayed on leaves, thus contributing to reduction of plant diseases and insect pests, further to less utilization of chemical pesticides and eventually to production of healthier vegetables.

Moreover, methane serves, as a category of fuel, rural household activities such as cooking and heating, consequently resulting in a reduction of coal or biomass spending and ecological environment betterment. Generally, coal burning could provoke massive pollutants, including SO$_2$, which exerts harmful effects on respiratory tissues through causing serious illness like pneumonia and edema and on the environment through generating acid rain, NO, which is a damaging substance of ozone as well as physical body problems such as bronchitis and lung cancer, and Hg0, which turns out to be deleterious. Additionally, firewood combustion would induce forest and plant damage, water loss and land erosion, and environmental deterioration. All those negative consequences could be alleviated by establishment of the proposed engineering project.

### 4.3. Social benefit

The QDP energy engineering could promote social stability via efficiently allocating surplus labor and thus transforming the bucolic idle status in winter when there is no farming work for rural inhabitants to undertake, a worrying scene concealing possible social risks, just as voiced by the saying “idle hands are the origin of evils”. Next, excrement can flow into the methane-manufacturing pit at whatever time and this would thoroughly reverse the unhygienic, stinking condition of a rural court plagued by flies and mosquitoes and cut off channels of harmful bacterium spreading to create a healthy, living environment productive to local citizens. Third, successful running of this energy engineering project for achieving expected results, lays great requirements on rural citizens, who must, by training and doing, get familiar with and put into practical application various agricultural knowledge and skills ranging from related equipment operations, to biogas generating, to greenhouse vegetable and pig cultivating, to the planning of investment and capital budget. This, undoubtedly,
would trigger an increase of scientific and technological qualifications for rural citizens, an establishment of the correct idea that sustainable development in agriculture is carried out through advanced technologies, and a mastering of modern agricultural marketing skills. Finally, just as addressed above, due to methane liquids and residuals (healthy and nutritional) substituting for chemical manures to fertilize soils and plants or being utilized to feed pigs, the model is able to enhance the supply of healthy foodstuffs such as greener vegetables and healthier pig meat as well as increasing farmer incomes.

5. Conclusion and proposal

5.1. Conclusion
The paper is devoted to exploring QDP, a novel energy engineering project, which, delivering ecological, economic and social benefits, is capable of liberating rural areas from double poverty in energy and economy under environmental conservation to achieve sustainability of energy, ecological, economic and social development. Here are new insights. First, the QDP of energy engineering is proposed for sample areas, which conforms to the ideology of sustainable development. This fresh energy engineering requires that each family should install and put into use a green house with an area of 350 m$^2$, a methane tank of 8-10 m$^3$, a warm awning of 10 m$^2$ for livestock and birds, a toilet of 1 m$^2$ and an energy-efficient kang stove. Such a project, with a one-time investment at about $9453.4, is projected to yield an annual net income of around US$3458.82 and make investment return in roughly 2.73 years. Next, the fresh model can generate marsh gases as a major form of energy to be adopted by rural households, contributing to a reduction in the burning of coal and firewood and ultimately relieving environmental contamination. Third, livestock and human excrement entry into the methane tank at whatever time allows the farm households to be freed from bad smells and contagion, thereby facilitating physical health improvement. Furthermore, biogas liquids and residuals, employed as a category of fertilizer, can promote straightening of fertility preservation capacity and improvement in the chemical and physical quality of land as well as increasing crop output and quality. More significantly, this engineering model can improve overall qualifications of rural citizens by imbuing modern agricultural knowledge, marketing skills of produce and the advanced ideology into their minds.

5.2. Proposal
To initiate and spread an engineering scheme concerning the quaternity-dominating mode, the primary assignment ought to develop the interest and awareness of fresh energy consumption of local residents, trapped in the mire of following the beaten way by the force of habit. Primarily, a certain number of innovation-minded villagers, who are competent and pioneering, should be organized to make an on-the-spot investigation of successful sites in practicing this new energy mode to stimulate their enterprise-seeking desire. Then, those natives need to be imparted systematic knowledge associated with methane, planting, breeding, marketing and circular economy via inviting experts or technicians to teach them, enabling them to have corresponding techniques including management, which are a prerequisite for triumphant operations of this engineering. Third, it is particularly pressing to reinforce establishment of a service network, as the maintenance and use of each equipment in this project leads to great demands for technical services in each of these corresponding areas, and the operation of each activity such as fermentation, crop planting, livestock raising and marketing of products to be manufactured by this engineering puts new demands on professional service sectors for their growing complexity. Otherwise, such a project, however superior, would fail in achieving expected results, even exert a huge waste, for instance, it, whose building may cost considerable resources including funds and materials, couldn’t generate any gain at all if certain equipment can’t be operated or repaired when it goes wrong or a certain link such as fermenting has a problem, in the absence of expert services from technicians. Fourth, governmental grants such as low-interest loans and financial funds ought to be furnished for those rural households, not moneyed, since massive resources of manpower,
material and finance are necessitated by constructing this engineering project. Eventually, remote rural areas such as loess hilly, suffering economic poverty and ecological fragility, the QDP energy engineering style, which can trigger a simultaneous fulfillment of energy, ecological, economic and social benefits and has been referred to as an event productive to lower-level individuals and households, should be legalized and implemented, as an item falling into the local government’s rural development planning. Provided all those suggested proposals are pursued, this model will be increasing and bearing fruit among more rural regions to profit local families. It would exercise a far-reaching effect on rural energy composition upgrading. Significantly, this new-fashioned power engineering could merit extension in other developing nations such as Mongolia and North Korea.

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