An Economic Analysis of the Use of Water Hyacinth for Phytoremediation and Biogas Production in Dianchi Lake, China

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WorldFish

Published by WorldFish (ICLARM) - Economy and Environment Program for Southeast Asia (EEPSEA)
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ISBN: 978-971-9994-11-4

Front cover photo credit: Richard Portsmouth

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February, 2013

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EEPSEA is supported by the International Development Research Centre (IDRC) and the Swedish International Development Cooperation Agency (Sida). WorldFish of the CGIAR consortium has been administering EEPSEA since November 2012.

EEPSEA publications are also available online at http://www.eepsea.net.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals and institutions that have provided assistance.

The Economy and Environment Program for Southeast Asia (EEPSEA), especially Dr. Herminia Francisco and Ms. Catherine Ndiaye, for their invaluable support. Dr. Ted Horbulyk, Department of Economics, University of Calgary, Canada, for his comments and suggestions. Dr. Carl Folke, Director of the Beijer Institute of Ecological Economics, Royal Swedish Academy of Science, Stockholm, Sweden, for his advice and support when Zanxin Wang worked there as a visiting researcher at the Beijer Institute in 2011.The staff from the Dianchi Administration Bureau, Kunming City, Yunnan Province, China, for providing background data and assistance in field surveys. The employees of an anonymous biogas plant for providing the basic data on biogas plant configuration, capital compositions and their costs, which are important for estimating fixed costs. Finally, we appreciate the help given to us by anonymous respondents, who provided useful information for this study during the field surveys.

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AN ECONOMIC ANALYSIS OF THE USE OF WATER HYACINTH FOR PHYTOREMEDIATION AND BIOGAS PRODUCTION IN DIANCHI LAKE, CHINA

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EXECUTIVE SUMMARY

The excessive growth of water hyacinth is a common environmental problem in tropical regions. The use of water hyacinth to remove nutrients from bodies of water and to produce biogas is a technically feasible way of controlling water hyacinth, but its environmental and economic performance are not well understood. This study collected data from an experimental biogas plant to develop a lifecycle analysis and a cost benefit analysis for the control of water hyacinth in Dianchi Lake, a eutrophic lake in China. A comparison was made between the proposed project and the current approach at Dianchi Lake of disposing of water hyacinth via collection and landfill. The results revealed that the proposed project is economically feasible with a desirable energy gain. The results also showed that the project is not financially feasible but, compared to the current landfill practice, the government would be able to spend less on controlling water hyacinth if they implemented the proposed project. The removal of water hyacinth to produce biogas can also contribute to water quality improvement and GHG emission reduction; however, these values depend on the scale of processing undertaken by the biogas plant. Since both the current approach and the proposed project can remove nutrients from bodies of water, the additional value resulting from the proposed project of an improvement in water quality only becomes possible when the processing scale of the biogas plant is greater than the amount of water hyacinth disposed of by landfill. The proposed project can avoid methane emissions when the processing scale is greater than the amount of water hyacinth currently disposed of via landfill. The internalization of GHG emission reduction alone is not sufficient to make the project financially feasible and therefore other sources of compensation are needed in order to promote the production of biogas from water hyacinth. The proposed project could be a potential microeconomic option, which could respond to China's macro water pollution control policies, renewable energy development, and energy saving and emissions reduction. However, institutional arrangements are required to coordinate these diverse policies when they are applied to the proposed project.

1.0 INTRODUCTION

1.1 Background

Dianchi Lake is situated to the south of Kunming City, the provincial capital of Yunnan Province, China, at 102°29'-103°01'EL, 24°29'-25°28'NL.The Dianchi watershed forms part of the water systems of the Yangtze River, the Pearl River and the Red River. The total area of the watershed is 2920 km^2, with the lake taking up 309 km^2. Dianchi Lake is the water source for agriculture, industry, households and fisheries in Kunming. It also plays an important role in climate mediation. At present 3.57 million people live in the watershed and it's 61.9 thousand hectares of agricultural land play an important part in the economic and social development of Kunming City and Yunnan Province.

As well as being a water source for Kunming City, Dianchi Lake also serves as a sink for urban sewage, industrial wastewater and agricultural runoff (Xu et al. 2006; Pu et al. 2009). With the rapid development of the economy and urbanization, Dianchi Lake has been severely polluted for several decades. Before the early 1970s, the water quality was judged to be level II, or drinkable with regular treatment. The water is now graded at level V or undrinkable without intense purification. The lake is suffering from eutrophication[1], with COD, BOD, TN, TP and NH_3-N well above standard levels (Pu et al. 2009). As algae flourishes all over the lake, the aquatic system and biodiversity are destroyed, and the lake can no longer supply drinking water to the city. The city is now resorting to Songhuaba reservoir for water.

[1] Eutrophication is the accelerated production of organic matter in a water body and is linked to an increase in nutrients, in particular nitrogen and phosphorus, being discharged into aquatic ecosystems (Bricker et al. 1999).

Excessive amounts of water hyacinth (*Eichhorniacrassipes*) are associated with the eutrophication of bodies of water, a result of the addition of nutrients, mainly nitrogen and phosphorus, to the water (Jørgensen and Bendoricchio 2001). The nitrogen content and phosphorus content of Dianchi Lake has stayed level at 1.82-3.31 mg/l and 0.131-0.640mg/l, respectively, for several years but algae proliferates as the content increases by 0.1 mg/l and 0.02 mg/l, respectively (Deng 1998; Zhang 2007; Lü et al. 2009). Although many measures have been taken, the eutrophication of Dianchi Lake has not been reduced (Zhang 2007; Pu et al. 2009).

As the water of Dianchi Lake has become eutrophic, water hyacinth has thrived. Studies have confirmed that the detrimental effects of water hyacinth are closely linked to its capacity to rapidly multiply and spread (Gopal 1987; Mehra et al. 1999). Due to its fast growth and the robustness of its seeds, the water hyacinth has depleted the oxygen in the lake, which has led to a reduction in the numbers of fish, the loss of water in irrigation systems due to high evaporation, increased sedimentation, as well as providing environments for insects and fungi which negatively affect local residents' health.

Water hyacinth growth can be controlled by mechanical, biological and chemical methods. However, it is expensive to remove water hyacinth from the lake because of high labor costs. It usually takes a long time for biological methods, such as the cultivation of the predator *NeochetinaEichhorniae* (Zhao 2005), to take effect. If herbicide is applied, dead water hyacinth can further pollute the water by adding silt and releasing nutrients into the water (Cheng et al. 2004). There is also the risk that herbicides will pollute the water. At present, there are eight working units designated by Kunming municipal government to remove water hyacinth from Dianchi Lake.

Many studies have shown that water hyacinth can be an effective phytoremediation[2] plant, especially for absorbing nitrogen and phosphorus. The problem is that if water hyacinth is not removed from the water, what it has absorbed will go back into the water body as it decays. Since it requires a lot of labor to collect and remove water hyacinth from water, it is expensive to use water hyacinth as a phytoremediation plant. However, if the collected water hyacinth can be used for an additional purpose, there is a possibility that the cost of collecting water hyacinth will be completely or partially offset.

Although it has been used to feed pigs and produce compost, water hyacinth is consumed on a very small scale and the rate of consumption is far less than its growth rate. However, a new use for water hyacinth has emerged as global climate change becomes a concern and thought is given to renewable energy. Due to its high growth rate, water hyacinth is a good plant for carbon sequestration. Many studies have also revealed that water hyacinth is ideal for the production of biomass gas due to its high content of water and appropriate carbon/nitrogen (C/N) ratio. Therefore, it is technically viable to produce biomass gas from water hyacinth after it has been used as a phytoremediation plant to reduce pollutants in Dianchi Lake.

Water hyacinth is also promising in terms of ameliorating CO_2 emissions. According to Hall (1997), using biomass as a substitute for fossil fuels is more beneficial from social and economic perspectives than sequestering the carbon in forests. The Chinese Government now considers the utilization of biomass as one of the means to achieve sustainable development. As stipulated in the "Directive on the management of clean development mechanism (CDM) projects", which came into force in 2005, China's CDM projects will focus on the improvement of energy efficiency, the development of new and renewable energy, as well as the utilization of biomass gas and coal gas.

Water hyacinth is a noxious weed that has attracted worldwide attention due to its rapid spread and growth. When looked at from a resource angle, water hyacinth appears to be a valuable resource with several unique properties. As a result, research activity concerning the control and utilization (especially wastewater treatment or phytoremediation) of water hyacinth has proliferated in the last few decades. As proven in many studies, it is now technically viable to control and use water hyacinth in an integrated manner. However, studies assessing the biogas production potential of water hyacinth used in the phytoremediation of eutrophic lakes are scarce.

Chinese Central Government has given priority to the environmental problems of Dianchi Lake by designating it one of the three lakes (i.e. Taihu, Caohu and Dianchi) with national importance for treatment and restoration in the 9th Five-year Plan and Targets for the Development of the National Economy and

[2] Phytoremediation refers to the use of plants to remove pollutants from the environment (Agunbiade et al. 2009).

Society of the People's Republic of China. There is potential to utilize water hyacinth as a phytoremediation plant coupled with the production of biomass gas. On one hand the Law of Water Pollution Control, the 12th Five-year National Plan for Environmental Protection, and the Plan for the Development of Energy-saving and Environmental Protection Industries offer an opportunity for water hyacinth to be used as a phytoremediation plant. There is also the possibility of compensating the cost of using water hyacinth for phytoremediation under the ecological compensation mechanism proposed in these plans. On the other hand, the Chinese Government has adopted many policies and measures to develop renewable energy and address the issue of climate change. The new Energy Conservation Law, Renewable Energy Law, and the 11th Five-year Plan for the Development of Renewable Energy have provided a solid foundation for the development of renewable energy, including biomass gas. In order to reduce carbon emissions the Chinese Government formulated and issued the National Assessment Report on Climate Change in 2006 and China's National Climate Change Program in 2007. All of these policies have laid out a development plan for energy and will contribute to the control and mitigation of greenhouse gas (GHG) emissions in China. However, it is necessary to adopt concrete and applicable activities to meet the objectives of these polices.

Water hyacinth can be used to produce landfill gas, along with urban and agricultural waste, and the gas is then used as a substitute for fossil fuels. The production of biomass gas using water hyacinth is now within the framework of China's policies on renewable energy.

Using water hyacinth to produce biomass gas may offer socio-economic and technical benefits compared to other energy sources; however these benefits have not been valued and the economic feasibility of the application of the technology is still unknown. In the Dianchi watershed, the annual average growth of water hyacinth is around 250,000 tonnes in fresh weight. A quantification of the socio-economic benefits of using water hyacinth as a phytoremediation plant, coupled with the production of biogas and organic fertilizer, is not yet available. It is evident that there is a need to work out the economic viability of such integrated model systems, in particular the economic value of water hyacinth absorbing pollutants from Dianchi Lake and sequestering carbon or producing biomass gas. The results could provide vital evidence for policymaking.

1.2 Review of Literature

Water hyacinth belongs to the pickerelweed family (*Pontederiaceae*) (Chillers 1991). It is a native of Brazil and possibly other central South American countries, but now it lives in lakes, rivers and swamps in most countries of the world lying between 40°N and 40°S, including Asia, Africa, Australia and North America, but especially in tropical areas (Gopal 1987; Center and Spencer 1981; Center 1994).

Water hyacinth is one of the most productive plants on earth (Gopal 1984; Malik 2007). A review by Gopal (1987) reported that the doubling time for water hyacinth varied from six to 28 for weight and from four to 58 days for number of plants as measured in the open (outside ponds) or in the field. A mat of medium-sized plants may contain 2 million plants per hectare that weigh 270 to 400 tonnes (Epstein 1998). Gao and Wang (2008) showed that when COD_{cr} is 500-700 mg/l, the biomass of water hyacinth can double every five days. Experiments show that the annual yield of water hyacinth can reach 750 tonnes of dry biomass per hectare in relatively static and eutrophic bodies of water and it can be as high as 13,500 tonnes of dry biomass per hectare if the water hyacinth mat is well managed (He et al. 2008). Water hyacinth is also considered one of the world's most destructive aquatic plants because it can quickly grow to very high densities; thereby completely clogging bodies of water, which in turn may have negative effects on theenvironment, human health and economic development (Fernández et al. 1990; Epstein 1998) by interfering with navigation, recreation, irrigation and power generation (Epstein, 1998).

Productive and hardy as water hyacinth is, attempts to control this weed have incurred high costs and significant labor requirements, leading to nothing but its temporary removal (Gunnarsson and Petersen 2007). Proper and large-scale utilization of water hyacinth could provide a positive approach to its control – in other words, the only means of controlling water hyacinth may lie in finding a way to make it economically viable (Gajalakshmi et al. 2002).

Despite its negative effects on water, water hyacinth can be utilized for phytoremediation, thereby reducing the harm it causes and generating social benefits. The use of water hyacinth to purify polluted water started throughout the world in the 1940s and began in China in the 1980s. In recent decades more effort has been made in China to study water hyacinth as water pollution has become more and more severe. Using water hyacinth for phytoremediation is a growing field of research in environmental studies because it is environment-friendly and offers the additional possibility of harvesting the plants for the extraction of absorbed contaminants, such as metals that cannot be easily biodegraded for recycling (Maine et al. 2004; Malik 2007).

In Israel Zimmels et al. (2006) used water hyacinth and water lettuce in a free water surface flow system and its low maintenance system to treat urban and agricultural sewage. The results showed that these plants are capable of decreasing all the tested indicators, including BOD, COD, total suspended solids, and the turbidity of water quality, to levels that permit the use of this purified water for irrigating tree crops. In China, Lu et al. (2008) found that a water hyacinth system was effective in treating wastewater from an intensive duck farm. Song et al. (2008) showed that water hyacinth can effectively remove nitrogen and phosphorus in sewage. Zheng et al. (2008) showed the contents of nitrogen, phosphorus and potassium in water hyacinth to be 3.07%, 0.46%, and 5.70%, respectively.

Water hyacinth can also effectively absorb some metals, including arsenic, Cd (II), Cr(VI), Cu(II), Ni(II), Se(VI) (Alvarado et al. 2008; De Souza et al. 1999).

Water hyacinth is a potential source of cellulose and hemicellulose, which can be converted to useful products including biomass gas and other bio energy. Due to its high water content and appropriate C/N ratio, water hyacinth can be anaerobically fermented (Liu et al.2003; Singhal and Rai 2003). Anaerobic digestion[3] has been proven a relatively efficient conversion process for producing a collectable biogas mixture with average methane content of 60%, which can be used as a substitute for fuel in boilers. The resultant left-over slurry has a high N, P and K content and that can be used in agriculture (Verma et al. 2007). It has been found that the rate of gas generation can be improved by controlling the content of C and N and the C/N ratio (Widyanto et al. 1971; Zhou et al. 2005; Cao and Zhao 2005). However, it cannot be fed, either directly or after chopping or mincing, into conventional biogas digesters because it is lighter than water and will rise to the top of the water level in the digester, thereby clogging the digesters (Andersson and Bjornsson 2002). To circumvent the multiple problems of feeding, frothing, clogging and low reactor efficiency, Ganesh et al. (2005) developed an inexpensive and simple process by which volatile fatty acids (VFAs) are extracted from water hyacinth and the VFA-laden slurry is then used as feed supplement for conventional cow-dung-fed biogas digesters. Multi-phasic reactors can also be used to overcome these problems (Annachhatre and Khanna 1987).

Water hyacinth can be degraded easily and gives a high gas yield (Gunnersson and Stuckey 1986). According to the results of experiments conducted by Jiangsu Academy of Agricultural Sciences, the yield of biomass gas is $0.21 m^3 kg^{-1}$ dry biomass of water hyacinth, which is much greater than that from rice straws and other agricultural residuals (Zheng et al. 2008). Zha et al. (2006) showed that biomass gas generation from water hyacinth is 834 ml/g volatile solids using a batch fermentation process in an environment of 25°C.

If appropriately chopped, the plant material of water hyacinth can increase biogas and methane production. In particular, plants with a higher content of heavy metals (Cr, Cu, Ni and Zn) and those used for phytoremediation produce higher CH_4 yield than the control (Geeta et al. 1990; Singhal and Rai 2003).

Besides biogas, anaerobic digestion produces digestate, which is the sludge in the digester or biogas pit that consists of a mixture of liquid and solid fractions. Applying digestate to agricultural land is an attractive environmental option because it allows nutrients to be recovered and reduces the loss of organic matter suffered by soil that is repeatedly used for farming (Gomez et al. 2005). Essentially, all of the nutrients contained in biomass used for anaerobic methane generation remain in the digester sludge (Hons et al. 1993) as long as it is not de-watered and is stored in an airtight manner.

In addition, water hyacinth can be used to produce bioethanol. Bioethanol can be made from waste biomass produced by agricultural and forest industries such as corn cobs, sugar cane bagasse, wheat straw, and wood chips. Instead of terrestrial plants, aquatic plants are a promising renewable energy resource because they offer many advantages such as growing on and in bodies of water, meaning that they do not

[3] Anaerobic digestion is the biological process by which organic matter is degraded in the absence of oxygen and biogas is produced.

compete against most grains and vegetables for arable land; they can also be used for water purification to extract nutrients and heavy metals (Mishima et al. 2008).

It has been proven that water hyacinth can provide hemicellulosicsugars for bioconversion to ethanol because it has high hemicellulose content (30–55% of dry weight) (Ibraham and Kurup 1996; Nigam 2002). However, because of the high lignin content, the hydrolysis of water hyacinth to produce bioethanol results in a negative energy balance (Thomas and Eden 1990).

So far, studies assessing the biogas production potential of water hyacinth used in the phytoremediation of eutrophic bodies of water are scarce.

The production of biomass gas or other products is seldom commercialized, despite technical viability. One of the principal barriers to this is that current energy markets tend to ignore the social and environmental costs and risks of fossil fuel use (Johansson et al. 1993), and the social and environmental benefits of products from water hyacinth are not internalized. Reasonable values for these external effects may provide justification for government support of biomass gas in the form of subsidies or tax exemptions. If this were the case then biomass energy systems using low-quality biomass originated as a by-product of food, feed and/or fiber production, would be a promising niche for energy from agricultural biomass (Lunnan 1997). Compared with agricultural residuals, water hyacinth has a higher production rate of biomass gas (Zheng et al. 2008), and, as a phytoremediation plant, plays an important part in absorbing pollutants from bodies of water. What is more, agricultural waste materials are limited in quantity, are location-specific, and are not always of appropriate quality for power generation applications (Thornley 2006).

Growing political and economic pressures are prompting various stakeholders to evaluate technologies for generating green energy that were previously considered technologically unfeasible or uneconomical (Browna et al. 2007). Implementation of biomass gas projects requires government policies that will internalize the external economic, social and environmental costs of fossil fuel sources or the social and environmental benefits of bioenergy so that biomass gas can become competitive on a level playing field (Hall 1997; Lunnan1997).

The application of water hyacinth for decentralized wastewater treatment, coupled with biogas, manure or animal feed production from the harvested biomass could offer a sustainable system (Malik 2007). However, no report on such a system is currently available. With technologies available on various aspects of this process, a dedicated field scale testing of region-specific integrations is needed (Malik 2007).

1.3 Objectives of the Study

The general objective of the study is to assess the economic feasibility of the use of water hyacinth to reduce nutrients in eutrophic water (a lake), coupled with the production of biogas. The specific objectives of the study are to:

(1) Estimate the economic value of using water hyacinth to purify a eutrophic lake;

(2) Estimate the potential and value of water hyacinth in reducing GHG emissions;

(3) Estimate the value of manure from the digestate of anaerobic digestion;

(4) Assess the financial and economic feasibility of producing biogas from water hyacinth; and

(5) Suggest policy options for the promotion of water hyacinth as a means of reducing pollutants from eutrophic lakes coupled with biogas production, if economically justified.

1.4 Significance of the Study

The surface of most of China's major bodies of water is severely polluted due to rapid economic development and a lack of environmental management. This neglect has taken place over the course of several decades. The restoration of freshwater bodies of water is one of China's sustainable development strategies. Dianchi Lake is one of three lakes given national priority for treatment. Dealing with the pollution in Dianchi Lake requires economically viable technology. Using water hyacinth to reduce pollutants in affected bodies of water coupled with biogas production is technically viable. Before this technology is applied it is necessary to assess its economic viability. This assessment can provide economic justification for policies that promote the use of the above-mentioned technology.

Using water hyacinth to produce biogas has potential for the reduction of carbon emissions. This study will provide evidence for the proposed project to have CDM potential by estimating the potential and economic value of GHG emission reduction.

There is scant literature on the integrated utilization of water hyacinth. Although it is technically possible to use water hyacinth as a phytoremediation plant and an energy feedstock, there is no available literature that reports the economic viability of this integrated use of water hyacinth. This study will provide a detailed picture of the costs and barriers faced by developers, generators, and farmers. Dianchi Lake may serve as a reference for the remediation of other eutrophic bodies of water.

1.5 The Scope of the Study

The study was conducted in the Kunming region. Kunming City has a high demand for resources and is very polluted. Dianchi Lake, which is close to Kunming City, is one of three lakes given national priority for treatment, and is one of the most polluted lakes in China. The dominance of water hyacinth is one of the lake's biggest problems.

Although many pollutants can be absorbed from the water by water hyacinth, only nitrogen, potassium and phosphorous will be considered in this study. The value of water hyacinth in reducing pollutants will be estimated against the cost of using wastewater treatment plants and silt dredging to remove the same amount of pollutants from the water.

As shown in the review of literature, a proliferation in water hyacinth may result in great economic loss. This study assumes that water hyacinth for the production of biogas comes from two sources; from natural growth and from cultivation.

2.0 RESEARCH METHODS

2.1 Study Framework

Before the government promotes the use of water hyacinth to reduce pollutants from eutrophic water coupled with biogas production, it is necessary to obtain information about the financial and economic viability of this course of action, as well as information about operational procedures that minimize costs and stabilize the performance of the process. In order to achieve these objectives and to answer the above-mentioned questions, the study was conducted according to the following framework (Figure 1).

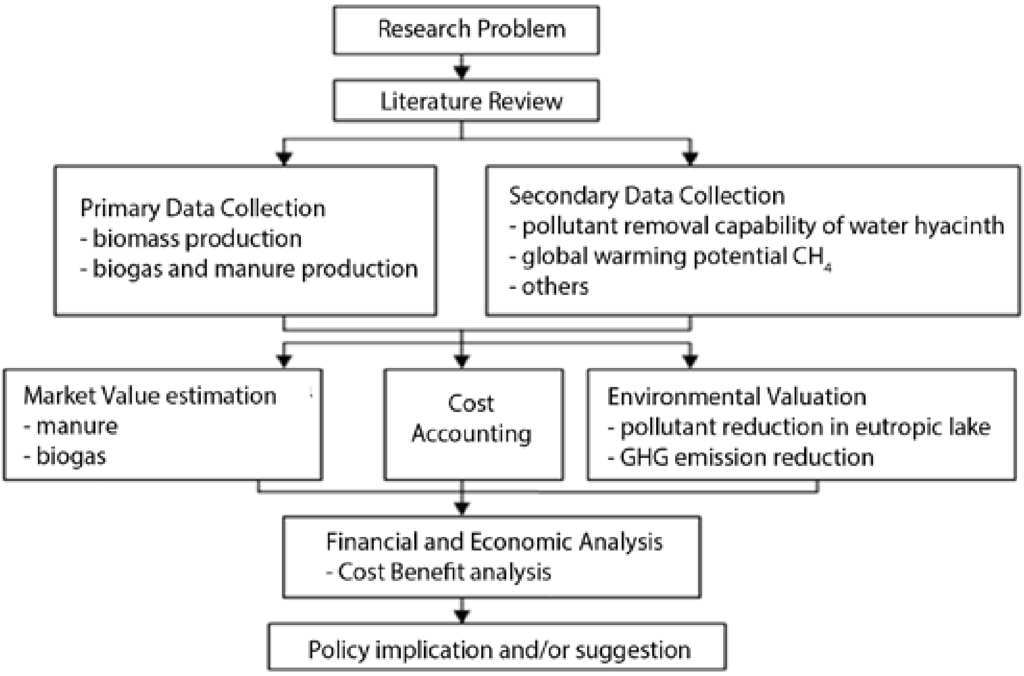

Figure 1. Research framework

2.2 Data Collection and Sources

Data was collected according to the production chain. When it is a nuisance, naturally-growing water hyacinth is collected and buried or used to produce biogas. If only a small amount of water hyacinth is in the lake, it is necessary to cultivate water hyacinth for the purposes of phytoremediation and biogas. Natural or cultivated water hyacinth mats need to be harvested for the production of biogas. The methane from the anaerobic digestion of water hyacinth biomass can be consumed as an alternative to water gas. Besides biogas, anaerobic digestion also produces digestate or sludge, which is the solid material remaining after the anaerobic digestion of a biodegradable feedstock. The digestate can be used to produce organic fertilizer.

Two methods were used to collect data: field work and a review of relevant literature. The fieldwork involved travel to Dianchi Lake and its management agencies and to biogas plants in Yunnan. The review of literature involved examining relevant books and academic material. The major fieldwork in the study area included conducting interviews with key people in the Dianchi Lake management office, conducting interviews with key people at the biogas plant, and making observations. The review of literature was conducted with the express aim of obtaining information that could not be obtained via interviews, observation and surveys. Specifically, the review of literature was used to gather information on the growth rate of water hyacinth, on its capability to reduce pollutants, on methane emissions from the anaerobic digestion of water hyacinth, and on biogas production technologies.

The data on the growth of water hyacinth and its ability to absorb pollutants was collected from the Dianchi Management Bureau and related literature. Information on the cost of harvesting, transportation and labor was obtained by interviewing workers and managerial staff at the Dianchi Management Bureau.

Techno-economic data about biogas production was collected from the experimental biogas production plant in Jinning county of Kunming municipality, which is a demonstration project funded by the Yunnan Provincial Department of Science and Technology.

2.3 Data Analysis

2.3.1 Delineation of scenarios

Without-project scenario

The without-project scenario is a base case representing the current ways (status quo) of dealing with the proliferation of water hyacinth in Dianchi Lake. This scenario will serve as a reference for the with-project scenario.

For several years, water hyacinth has been viewed as an aquatic weed because it could not be utilized in a financially feasible way. Dianchi Administration Bureau (DAB) has taken a great deal of care to control the proliferation in water hyacinth. Although many methods have been tried, the water hyacinth is currently controlled by being physically removed. In 2010, the DAB financed eight companies to remove water hyacinth from Dianchi Lake. Owing to financial constraints, the removal activities focused on floating water hyacinth mats greater than 2 Mu, or 0.145 hectare, and water hyacinth in estuary regions and the areas surrounding some scenic spots. Before any further potential measures are justified, this is currently the most effective way of controlling water hyacinth.

The current average annual growth of water hyacinth is 250 thousand tonnes. If not controlled, water hyacinth is expected to cover the whole water surface and it will eventually destroy the entire aquatic system of Dianchi Lake. For the past five years, much effort has been made to control water hyacinth, with a total of 820 thousand tones of water hyacinth being removed. The removed water hyacinth is placed in landfill. If no better approach is found, this current practice should remain in order to control the water hyacinth.

So far, there are only a few floating mats of water hyacinth visible on the off-port water area. However, large mats of water hyacinth can still be found in abandoned ponds, lotus fields, and unused bays along the banks of the lake.

Although reducing nutrients is not the goal of the DAB in this scenario, the removal of water hyacinth can contribute to water purification by taking away nutrients from the eutrophic lake. This is particularly relevant considering the large size of this body of water body and the fact that no other measure has been undertaken for the removal of nutrients from the water.

With-project scenario

The goal of the project is to use water hyacinth to remove nutrients from Dianchi Lake and then to couple this with biogas production. The project is expected to provide an alternative way of controlling water hyacinth by exploring the economic value of water hyacinth as a phytoremediation plant and a biomass resource. Although water hyacinth on the water’s surface can absorb nutrients, the removal of nutrients will only take effect as water hyacinth is taken out of the lake. Otherwise, the nutrients will go back into the water as the water hyacinth decays. The production of biogas from the collected water hyacinth provides an alternative to landfill.

To avoid the expansion of water hyacinth and the trouble it causes, water hyacinth mats will only be cultivated in those water areas that are far from scenic spots and navigation routes. In particular, the total area of cultivated water hyacinth mats will be controlled so as to avoid negative ecological impacts.

The current water quality of Dianchi Lake is graded as Level V. According to Dr. Shaohua Yan, the Director of Jiangsu Academy of Agricultural Sciences, the water quality of Dianchi Lake can be improved to Level III by removing 2,340 tonnes of nitrogen (N) and 81.9 tonnes of phosphorus (P) from the water. The N and P content of the water can be reduced by removing water hyacinth from the water.

Although some water purification measures have been undertaken, such as the installation of wastewater treatment plants and the establishment of buffer zones that target the purification of inflow water, there are still no wider measures in place to purify the water in the lake. Sediment dredging was once considered a possible purifying measure but it is a hotly-debated topic because it is not only highly costly but also devastatingly detrimental to the benthic and profundal ecosystems. Given the alternatives, the purification of Dianchi Lake's water stock using phytoremediation has great potential.

Energy independence and environmental protection attract worldwide attention and the production and use of renewable energy can contribute to the sustainable development of society. It is in this context that biogas is promoted worldwide. The production of biogas from water hyacinth would not only contribute to energy independence but also, as a substitute to natural gas or water gas, has environmental value thanks to its role in reducing CO_2 and SO_2 emissions (and others).

2.3.2 Accounting costs and benefits

Costs and benefits were accounted according to the production chains. Costs include expenditure on fixed assets, the collection and transportation of water hyacinth, workers' wages, transportation costs, repair and maintenance costs, charge on electricity charges, and the cost of CO_2 emissions. The benefits come from biogas, organic fertilizer, water purification, and CO_2 emission reduction.

Although the control of water hyacinth can avoid potential losses from ecological damage, this is not accounted for in the study because it is hard to estimate without knowing how water hyacinth affects the aquatic system. In particular, it usually takes a long time to estimate these effects because the ecological process moves very slowly. However, not knowing the avoided social cost does not harm the analysis because it is the same for each scenario and it is finally counteracted when comparing the economic feasibility of each scenario.

2.3.3 Financial and economic feasibility analysis

To analyze the financial and economic feasibility of the system, net present value (NPV) will be used as the valuation criterion. The difference between financial and economic analysis lies in the fact that the former is from the perspective of individuals or firms while the later is from the perspective of society. NPV is the sum of discounted expected net cash flows and is given by

$$NPV = \sum_{t=0}^{n} \frac{p_t q_t - v_t X_t}{(1+r)^t} - C_o \qquad \text{(Equation 1)}$$

where r is the discount factor, and $C_0$is the initial capital investment cost. p_t and q_t are vectors of the price and quantity of outputs at time t; v_t and X_t are vectors of price and quantity of inputs at time t, including feedstock prices, operating and maintenance costs, labor costs, and the disposal costs of digestate and water.

Note that, while the financial and economic feasibilities are analyzed, the variables in Equation 1 may have different meanings and values. For example, pollutants reduced by water hyacinth are outputs in an economic analysis but not in a financial analysis; the price of biogas will include the government subsidy in the financial analysis but not in the economic analysis. In particular, because removing the pollutants from a eutrophic lake is viewed as an environmental good, costs associated with the cultivation, harvest and transportation of water hyacinth biomass should be allocated among different goods in the integrated production system.

At the end of the financial and economic analysis, a sensitivity analysis will be conducted to explore factors that will have a significant effect on the financial and economic NPVs of the integrated use of water hyacinth. Major factors to be analyzed in financial analysis include discount rate, the growth rate of water hyacinth, the yield of biogas from water hyacinth, and the costs of labor and transportation. Besides those factors examined in the financial analysis, other factors such as the efficiency of pollutant removal and the price of carbon will be included in the economic analysis.

If the integrated use of water hyacinth is economically justified, its financial feasibility will be further analyzed under different policy scenarios.

3.0 THE PRODUCTION PROCESS AND CAPACITY

3.1 The Production Process

A completed biogas project, regardless of its size, includes the following processes:
(1) collection of water hyacinth;
(2) pretreatment of raw materials;
(3) hydrolysis and acidification;
(4) anaerobic digestion;
(5) production of organic fertilizer;
(6) purification and storage of biogas;
(7) transportation and distribution of products.

The production process is shown in Figure 2.

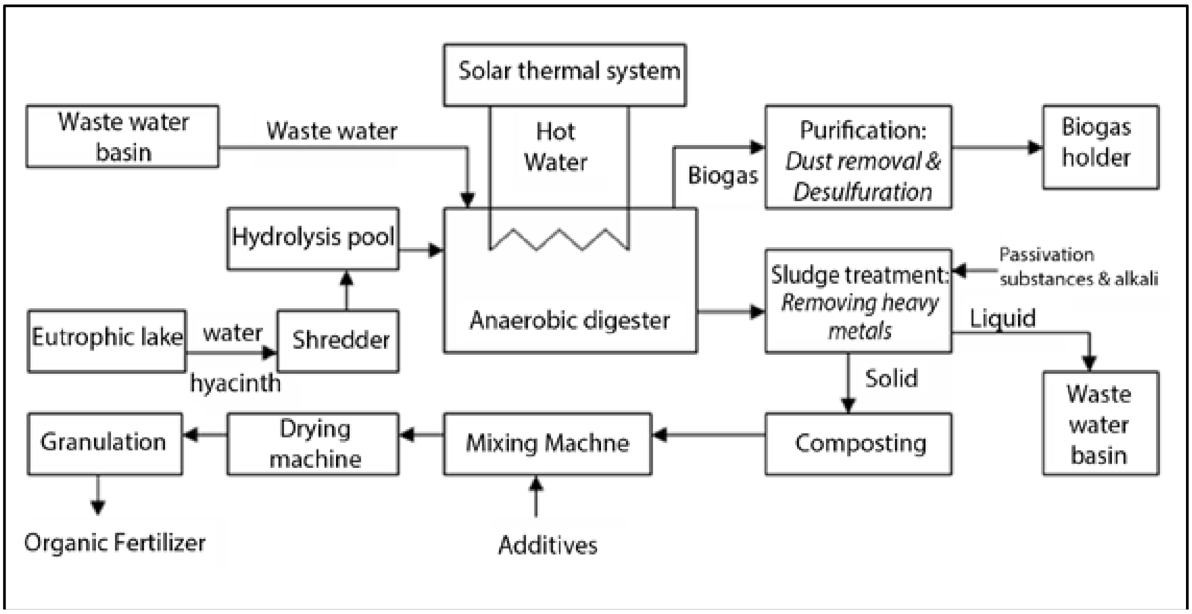

Figure 2. Producing biogas and organic fertilizer from water hyacinth

3.1.1 Collection of water hyacinth

A sufficient and stable supply of raw materials is essential for biogas fermentation. Good materials for anaerobic fermentation include various livestock manure, all kinds of crops, straw, weeds, leaves, and residual material from agricultural products. The collected materials are stored in the storage pool. Because the raw materials are usually collected within a short time and because the digester usually needs to be fed evenly over the course of a day, the pool should be big enough to store raw materials for 24 hours' worth of feeding. In the warm season, acidification can take place in the storage pool. Acidification can improve the performance of raw materials and accelerate the process of anaerobic digestion.

3.1.2 Pretreatment of raw materials

The raw materials are usually mixed with small stones, mud, etc., which should be removed to facilitate transport via the pump, to avoid malfunctions in the process of anaerobic fermentation, or to reduce the content of suspended solids in the raw materials. Moreover, the raw materials are sometimes pretreated by heating or cooling before they are fed into the digester.

3.1.3 Hydrolysis and acidification

The organic matter contains complex compounds, such as carbohydrates, protein and fats, and these are broken down with water into water-soluble compounds. The polymers are reduced to monomers.

The anaerobic and facultative micro-organisms slowly digest the water-soluble compounds and produce mainly acetic and propionic acid.

3.1.4 Anaerobic digestion

Anaerobic digestion is the core of biogas production. It covers the growth and propagation of microorganisms, the decomposition and conversion of organic matter, and the emission of methane. In this process, anaerobic bacteria, also known as methane formers, slowly digest the products of acidification to produce methane and carbon dioxide, a small amount of hydrogen and a trace amount of other gases.

3.1.5 Production of organic fertilizer

The treatment of digestate is an indispensable part of any large or medium-sized biogas project. The digestate contains undecomposed organic nutrients, which would result in secondary pollution if it were directly discharged. However it is a good resource for organic fertilizer, which can be used in agriculture.

Water hyacinth absorbs both nutrients and heavy metals and it is necessary to remove the heavy metals from fertilizer in order to avoid bioaccumulation in crops. The basic steps of this technology are as follows.

1. Passivation substances are added to the digestate to react with heavy metals.
2. Alkali solution is added to make metal compounds into sediment.
3. The sediment is filtered out.

After the removal of any heavy metals, the solution is dehydrated, yielding the nutrient sediment. The nutrient sediment can be used in many ways. The most simple and economic way is to use it as fertilizer in soils or ponds. It can also be further processed into compound fertilizer by mixing it with chemical fertilizer. The compound fertilizer can be applied to various crops. The liquid can be used for irrigation or can be recycled for production purposes.

3.1.6 Purification and storage of biogas

Water evaporates during the process of biogas fermentation and enters the biogas pipeline together with biogas. The pipeline is plugged as water steam condenses in it. Sometimes the gas flowmeter is filled with water. Besides water steam, biogas also contains a small amount of H_2S, which is a product of the decomposition of protein by microorganisms and the reduction reaction of sulfate. The H_2S is a very corrosive gas. It can erode pipelines and instruments quickly. Moreover, as it is combusted, the H_2S produces SO_2, which is poisonous to human beings. When implementing a large- or medium-sized biogas project, a great deal of effort needs to be made to remove water and H_2S from the biogas.

3.1.7 Transportation and distribution of products

Purified biogas and refined organic fertilizer are distributed to surrounding households and farmers.

3.2 Production Capacity

A biogas plant mainly comprises an anaerobic digestion system, an organic fertilizer production system, and supporting facilities including buildings and a solar thermal water system. The output of organic fertilizer is contingent on the anaerobic digestion system because the digestate is the raw material of organic fertilizer. The lifespan of the major machinery is expected to be 15 years. Therefore the lifespan of the project is expected to be 15 years.

The biogas plant has two anaerobic digesters, whose volume is 350 m^3 each. One is a high-temperature anaerobic digester, and the other is a mid-temperature digester. Both are heated by the solar thermal water system. The daily biogas yield is $1.5m^3/m^3$ from the former and $1.0m^3/m^3$ from the latter. That is, per cubic meters of digester stuffed with water hyacinth biomass slurry can yield 1.5 m^3 and 1.0 m^3 of biogas from the two digesters, respectively.

The amount of total solids needed by the biogas plant per day is calculated as follows:

$$W = \frac{P}{C} \sum_{i=1}^{2} y_i \times V_i \quad \text{(Equation2)}$$

where W is the amount of total solids consumed daily by the biogas plant; y is the daily biogas yield of the slurry in the anaerobic digester, with a value of 1.5 and 1.0 m^3/m^3 for the high-temperature (y_1) and low-temperature (y_1) anaerobic digesters, respectively; V_i is the total volume of each type of anaerobic digester, which is $350m^3$, as shown in Appendix 1; P is the ratio of valid volume of the anaerobic digester, which is 85%; and C is the biogas production capacity of water hyacinth, which is 0.34 m^3/kg TS (Huang and Fang, 1999).

According to Equation 2, the total solids needed are 1,312.5 kg a day and 875 kg a day, respectively. Thus, the consumption of water hyacinth by the two anaerobic digesters will be 1,312.5 kg a day and 875 kg a day, respectively.

Assuming that there will be 330 production days in a year, the annual consumption of water hyacinth by the biogas plant is calculated to be 721.875 tonnes in dry weight. Since the biomass content in water hyacinth is 6.56% (Zhen, 2008), a total of 11,004.2 tonnes in fresh weight will be consumed every year.

3.3 Production Scale

To control water hyacinth and improve the amenities of the lake, the Dianchi Management Bureau started to collect and put water hyacinth into landfill. They did this by contracting relevant firms in 2003. The firms are required to collect water hyacinth mats that are greater than 2 mu (around 0.133 ha) within six hours, and to ensure that they do not occupy more than 25% of the area of estuaries and bays. As a result of these arrangements no large water hyacinth mats can be found on Dianchi Lake. However, despite much effort, not all the water hyacinth can be collected due to financial constraints.

In the past five years 0.82 million tonnes of water hyacinth has been collected from Dianchi Lake. This is some 0.164 million tonnes of water hyacinth that could be used to produce biogas and organic fertilizer every year. A single biogas plant of the size studied above is not enough to consume the water hyacinth that is collected every year from Dianchi Lake because the annual consumption of the biogas plant is only 11,004.2 tonnes of freshwater hyacinth. Therefore, there is a real opportunity to expand the scale of production.

4.0 FINANCIAL ANALYSIS

Water hyacinth is collected from Dianchi Lake in order to control its growth. This water hyacinth can be further utilized to produce biogas and organic fertilizer. This study was conducted to analyze the feasibility of using water hyacinth to produce biogas and an organic fertilizer. There are two scenarios to consider: the with-project scenario and the without-project scenario.

The without-project scenario represents the current way of controlling water hyacinth on Dianchi Lake – no further use is found for the water hyacinth after collection. The with-project scenario offers a potential option for the control and further use of water hyacinth. The lifespan of the proposed project is 15 years, consistent with the lifespan of the most essential machinery in the biogas plant.

Although many people have argued that water hyacinth can be controlled using a chemical or biological approach, the physical removal of water hyacinth has been the most effective measure taken so far. Between 2006 and 2010, 820 thousand tonnes of water hyacinth (fresh weight) was removed from Dianchi Lake and most of this was disposed of via landfill. This means that about 160 thousand tonnes of water hyacinth is removed from Dianchi Lake every year.

4.1 Financial Costs and Benefits

4.1.1 With-project scenario

The parameters of the financial analysis are summarized in Table 1 (according to the above-mentioned production process). The prices of inputs and outputs were current in 2010, and have been used as the base-year prices.

Table 1. Parameters used in the financial analysis

Item		Amount	Price	Annual amount
Input				
Water hyacinth		33.3 tonnes/day		11,004.2 fw tonnes
Electricity		67.6 kWh/day	1.0 Yuan/kWh	22,312 kWh
Labor	Workers in the plant	15 persons	18,000 Yuan/yr. person	270,000 Yuan
	Workers collecting WH	11,004.2 tonnes of WH	25 Yuan/tonne	275,104.8 Yuan
	Driver	2,201 trip	60 Yuan/trip	132,060 Yuan
Diesel		4l/trips*2201 trips	7.11 Yuan/l	62,596.4 Yuan
Means for collecting WH		11,004.2 tonnes of WH	25 Yuan/tonne	275,104.8 Yuan
Passivation substances and alkali for removing heavy metals		525 m^5/year	1.6 Yuan/m^3 digestate	840 Yuan
Repair and maintenance		20,238 Yuan/year		20,238 Yuan
Land		20 mu	500 Yuan/mu. year	10,000 Yuan
Output				
Biogas		743.75 m^3/day	2.457 Yuan/m^3	602,940.9 Yuan
Fertilizer		420 tonnes	500 Yuan/tonne	210,000 Yuan

The costs

The total fixed cost of the biogas plant is 3.13 million Yuan. The individual costs of the major components of the biogas plant are shown in Table 2. More details about the composition of the plant are shown in Appendix 1.

Table 2. Fixed costs of the biogas plant

Component	Cost (Yuan)	Percentage (%)
Building and construction	1,223,000	39.00
Anaerobic digestion system	941,300	30.02
Organic fertilizer production system	656,800	20.95
Accessories and installation	314,600	10.03
Total	**3,228,142**	**100**

The cost of boat rental and of equipment for collecting water hyacinth is 25 Yuan per tonne. The annual consumption of freshwater hyacinth is11,004.192 tonnes so the cost of collecting water hyacinth from Dianchi Lake is 275,104.8 Yuan per year.

The biogas plant needs 14 workers and a manager. It is assumed that the average wage for formal employees in the biogas plant is 18,000 Yuan per year, per person, according to the local salary level. The total salary bill is 270,000 Yuan per year. The workers collecting water hyacinth are temporary and occasional. Their payment is based on the amount of water hyacinth they collect. The labor cost of collecting water hyacinth is estimated to be 275,104.8 Yuan per year, using a wage rate of 25 Yuan per tonne.

Transportation costs are incurred loading, transporting and unloading harvested water hyacinth. It is assumed that one round trip is 20 km. For each trip two porters are needed to load and unload the harvested water hyacinth and 4 liters of diesel are consumed. The wage rate for the porters is 30 Yuan per trip and the price of diesel in Kunming is 7.11 Yuan per liter. The truck can take a weight of 5 tonnes of water hyacinth. In order to supply 11,004.192tonnes of freshwater hyacinth, a total of 2,201 trips are needed per year. Using these figures, the biogas plant would spend 193,688 Yuan a year on the transportation of the water hyacinth. In the without-project scenario, extra labor is needed to complete the landfill process.

In order to remove heavy metals, and therefore produce organic fertilizer, passivation substances and alkali have to be added to the digestate. As shown in Table 1, this cost is estimated to be 840 Yuan a year.

It is assumed that the cost of repair and maintenance is 10% of the 15-year depreciation of the fixed assets shared by the production of biogas and organic fertilizer. This cost is 20,238 Yuan every year.

Electricity is needed to operate the plant. When the biogas output is 500m^3/day, the consumption of electricity is 22,312.5 kWh per year. At a price of 1Yuan per kwh, the electricity cost is estimated as 22,312.5 Yuan per year.

The benefits: The value of biogas

Biogas is considered to be a substitute for water gas. Since there is no information available from the market, the price of biogas is estimated according to that of water gas, based on their calorific values. The calorific value of water gas is 10.05-10.87 MJ per m^3, i.e. 10.46 MJ per m^3 on average, while that of biogas is 23.36 MJ per m^3, which is 2.23 times more than the former. The current market price of water gas for household use is 1.1 Yuan per m^3 in Kunming. The price of biogas is thus estimated to be 2.457 Yuan per m^3.

The potential of water hyacinth to produce biogas is 0.34 l per g TS (Zhen et al.2008). Since the consumption of water hyacinth is 11,004.2 tonnes a year in fresh weight or 721.88 tonnes a year in dry weight, the annual output of biogas is around 245,437.7 l, with an estimated value of 602,940.92 Yuan.

The energy produced is much greater than the energy consumed. In order to process 11,004.2 tonnes of water hyacinth, the biogas plant consumes 22,313 kWh of electricity and 8804 liters of diesel, and thus the project has a net energy gain of 5.3 trillion joules.

The benefits: The value of organic fertilizer

The digestate or sludge from the anaerobic digestion of manure is valued according to the amount of nutrients it contains and the market prices of corresponding chemical fertilizers –manureisconsidered an alternative to chemical fertilizers.

According to Zheng et al. (2008), the content of nitrogen, phosphorus and potassium in the water hyacinth from Dianchi Lake is 3.07%, 0.46%, and 5.70%, respectively. The value of the manure is estimated in terms of the total value of the nitrogen, phosphorus and potassium. Mathematically, it is estimated as

$$V_{manure} = p_N q_N + p_P q_P + p_K q_K$$

where V_{manure} is the unit value of manure; p_N, p_N, and p_K are prices of nitrogen, phosphorus and potassium fertilizers in the market, respectively; and q_N, q_N, and q_K are quantities of nitrogen, phosphorus and potassium in the manure, respectively.

Water hyacinth can absorb toxic elements so there is a worry that these trace metals will accumulate in biomass and eventually damage human health. According to China's standard (NY/T 798-2004) for compound microbial fertilizers, the limits for some toxic metals are shown in Table 3. As studied by Agunbiade et al. (2009), the toxic elements in water hyacinth are much lower than the set limits. However, the concentration of toxic metals in digestate can be further reduced during the organic fertilizer production process by using dehydration. The digestate can be treated with passivation substances and alkalis in order to remove heavy metals.

Table 3. Standards for non-toxic compound microbial fertilizers

Elements	Standard/limit
As and its compound, mg/kg fertilizer	≤75
Cd and its compound, mg/kg fertilizer	≤10
Pb and its compound, mg/kg fertilizer	≤100
Cr and its compound, mg/kg fertilizer	≤150
Hg and its compound, mg/kg fertilizer	≤5

The residue rate of slurry is 0.6 (Anon. 2008). That is, there are0.6 tonnes of solid residuals in every cubic meter of slurry. According to recent data (25 June, 2010), the price of refined organic fertilizer is 500-1,200 Yuan per tonne. Taking the lower bound into the calculation, the value of organic fertilizer from water hyacinth is estimated to be 210,000 Yuan a year.

The benefits: The salvage value of fixed assets

The lifespan of buildings and major construction is usually valued over a period of 25 years, while the estimated duration of the project is 15 years. Using a straight-line depreciation approach, the salvage value is estimated to be 489,200 Yuan, by multiplying the average appreciation (=1,223,000/25) with the remaining time period (25-15=10 years). It is assumed that the salvage value of the anaerobic digestion system and the organic fertilizer production system is 5% of the initial investment, which is 74,905.0 Yuan. The total present salvage value is thus estimated to be 564,104 Yuan.

The benefits: Interest payments

The cost of a loan from a bank is assumed to be 12%, which is 20% higher than the rate of financial return. The biogas plant needs a loan for the fixed capital and the variable costs in the initial year. Assuming the loan is repaid using the equal total payments method, the present value of the interest payment is estimated to be 0.45 million Yuan.

4.1.2 Without-project scenario

In this scenario, firms are subsidized by the municipal government to collect water hyacinth from Dianchi Lake and dispose of it in landfill. The firms benefit from the grant they receive from the government to collectand dispose of the water hyacinth. The cost of collecting the water hyacinth includes boat rental, equipment, and labor, which is 25 Yuan per tonne. The cost of collecting water hyacinth from Dianchi Lake is estimated to be 550,209.6 Yuan a year, as the same amount of water hyacinthneeded for biogas production is collected.

The cost of putting the collected water hyacinth into landfill includes transport and drivers' and workers' wages. It is assumed that the water hyacinth is transported to landfill sites by a 5-tonne truck and that 2 liters of diesel are consumed every trip. Wages are 40Yuan per hour for a driver and 30 Yuan per hour for porters. Two porters are needed for each trip and two workers are needed at the landfill site. The rent for a truck is 100 Yuan per round trip. To supply 11,004.192tonnes of freshwater hyacinth, a total of 2,201 trips are needed every year. Therefore, around 338,954 Yuan will be spent on the transportation of water hyacinth in a year and 264,120 Yuan will be spent on labor. The harvested water hyacinth goes to landfill on state-owned land so firms do not need to pay to use the land.

Collecting and getting the water hyacinth to landfill cost 1.23 million Yuan in 2010. This money represents tax-free income for the firms contracted to do this work.

4.2 The Financial Net Present Value

The financial net present value (FNPV) is used to assess the feasibility of the project from the perspectives of the companies involved. The discount rate is the firms' financial rate of return, which is 9–11 in real terms (NDRC-MS, 2006). A median of 10% was used as the baseline discount rate in the financial analysis. The effects of other discount rates were assessed in the sensitivity analysis. Corresponding with the real term discount rate, constant prices are used for inputs and outputs.

In the without-project scenario, firms' profits are dependent on the grant they receive from the Kunming municipal government. However in the analysis we assumed that no grant would be given to the biogas plant. The results of the financial analysis of the collection and disposalof 11,004.2 tonnes of water hyacinth can be seen in Table 4.

Table 4. Results of financial analysis

Component	Without project (million Yuan)	With project (million Yuan)
Benefits		
Government grant	10.32	
Benefit of biogas		5.04
Benefit of organic fertilizer		1.76
Salvage value of fixed assets		0.56
Total	10.32	7.36
Costs		
Investment cost		3.22
Operating costs	9.65	10.30
Cost of collecting water hyacinth	4.60	4.60
Workers' wages for disposing of water hyacinth	2.21	2.26
Cost of transportation and landfill	2.84	1.62 (no landfill)
Interest payments		1.46
Others (including land rent, repair and maintenance costs, electricity charges, and payment for passivation substance and alkali)		0.45
Total	9.65	13.52
FNPV	0.67	-6.16

Without the project, a compensation rate of 104.8 Yuan per tonne is needed for firms to break even. Considering the margin that firms require, the practical compensation rate is higher. As a result, the FNPV of the without-project scenario is 0.67 million Yuan for the removal and landfill of 11,004.2 tonnes of water hyacinth. The average annual collection of water hyacinth between 2006 and 2010 was 164,000 tonnes so, given this rate of collection, the FNPV is 9.99 million Yuan over a period of 15 years.

In the with-project scenario, the FNPV is negative and so the financial loss increases as more biogas is produced from water hyacinth. The major costs are from the collection and transportation of water hyacinth and the investment of fixed capital. Without the municipal government grant, it is not financially feasible to produce biogas and organic fertilizer from water hyacinth.

However, if the biogas plant receives the same grant from the municipal government that it currently allocates to firms to collect and dispose of water hyacinth, it becomes financially feasible to integrate the control of water hyacinth with the production of biogas. To make biogas financially breakeven, the required subsidy rate is only 66.8 Yuan per tonne, which is much lower than that in the without-project scenario. In other words, the municipal government can spend less on the control of water hyacinth by implementing the project.

Furthermore, the project has the potential to be registered as a clean development mechanism (CDM) project because of the contribution it can make to the reduction of GHG emissions. The price of certified emission reduction (CER) for biomass projects in China in 2011 was92.76 Yuan tonne^{-1} so the internalization of the externality of GHG emission reduction will increase the FNPV from -6.16 million Yuan to -3.12 million Yuan. In other words, the internalization of GHG emission reduction alone cannot make the project financially feasible and therefore other sources of compensation, e.g. the value of nutrient reduction, are required to encourage firms to produce biogas using water hyacinth.

5.0 ECONOMIC ANALYSIS

5.1 Economic Costs and Benefits

The economic analysis is based on the financial analysis by adjusting the costs and benefits with the shadow price of inputs and adding the external cost and benefit. Instead of using an interest rate, a social discount rate is used in the economic analysis. According to NDRC-MS (2006), the recommended social discount rate is 8% in real terms for short- and medium-term projects, and lower than 8% for long-term projects, which are estimated from the time preference rate, which is 4.5%-6%, and the rate of return on capital, which is around 9-11%, using a weighted average approach. Furthermore, besides long-term projects, environmental projects, such as the CDM reforestation project (Tang et al. 2009), use a discount rate of 5%. This study takes a discount rate of 6% in real terms as a baseline, while the effects of the discount rate are assessed in the sensitivity analysis.

The parameters used in the economic analysis are shown in Table 5. Consistent with the application of a discount rate in real terms, the shadow prices of inputs and outputs are used as constants in calculating the ENPV.

5.1.1 With-project scenario

The costs in the economic analysis have been adjusted based on those in the financial analysis. For items purchased in a relatively competitive market, such as the biogas plant machinery, the market prices were used in the economic analysis. Besides estimating the shadow prices of the goods or services purchased in distorted markets, external costs and benefits were also valued. The major externality included in the study is the improvement of water quality and the effect of carbon emissions and their reduction.

Table 5. Parameters used in the economic analysis

Item		Amount	Shadow Price	Annual Amount
Inputs				
Water hyacinth		33.3 tonnes/day		11,004.2 tonnes
Electricity		67.6 kWh/day	0.85 Yuan/kWh	18955 Yuan
Labor	Workers in the plant	15 persons	14,400 Yuan/yr person	216,000 Yuan
	Water hyacinth collectors	11,004.2 tonnes of WH	12.5 Yuan/tonne	137,552.4 Yuan
	Drivers	2,201 trips	60 Yuan/trip	132,060 Yuan
Diesel		4l/trip*2,201 trips	6.29 Yuan/l	55,377.2 Yuan
Means for collecting WH		11,004.2 tonnes of water hyacinth	25 Yuan/tonne	275,104.8 Yuan
Passivation substances and alkali		525 m^5/year	1.6 Yuan/m^3digestate	743.4 Yuan
Repair and maintenance		20,238 Yuan/year		20,238 Yuan
Land		20 mu	425 Yuan/mu	8,500 Yuan
Output				
Biogas		743.75 m^3/day	1.97 Yuan/m^3	533,576 Yuan
Fertilizer		420 tonnes	442.5 Yuan/tonne	185,840.7 Yuan
CO_2 emission reduction		7,562.38 tonnes	160 Yuan/tonne	1,224,368 Yuan
Water purification			121.1Yuan/tonne of water hyacinth	1,332,581 Yuan

5.1.2 The costs

The cost of collecting water hyacinth

This cost includes boat rental, collecting equipment, and labor. The cost of boat rental and collecting equipment is 25 Yuan per tonne, which is the market price. The shadow prices of labor are estimated according to NDRC-MS (2006). The shadow price of labor is 0.25-0.8 times the market price, while that of highly-skilled labor is the same as the market price. The collection of water hyacinth has a low dependence on technology so the shadow price of labor for collecting water hyacinth is estimated to be 12.5 Yuan per tonne, using an accounting ratio of 0.5.

The biogas plant consumes 11,004.192tonnes of freshwater hyacinth so the economic cost of collecting water hyacinth from Dianchi Lake is estimated to be 412,657.2 Yuan per year.

Fixed costs and land rent

The total fixed cost of the biogas plant is 3.13 million Yuan (Appendix 1). The market price of the machinery represents the shadow prices because of their relatively competitive markets.

According to NDRC-MS (2006), the shadow price of land in Kunming is estimated to be 425 Yuan per mu. This figure has been used to estimate the cost of the land.

Workers' wages

The biogas plant needs 14 workers and a manager. The current market price for plant labor is around 18,000 Yuan per year, per person. Workers with a certain level of skill are needed to run the production system in the biogas plant, therefore an accounting ratio of 0.8 is used to estimate the economic cost of labor, which is 216,000 Yuan a year.

Transportation costs

The water hyacinth is transported to the landfill site and is buried in the without-project scenario. The water hyacinth is taken to the biogas plant in the with-project scenario. As in the financial analysis, the transportation cost comprises the cost of diesel and wages forthe driver and the porters.

The producer price of diesel is used as the shadow price of diesel by cutting the value added tax, 13%, from the market price, 7.11 Yuan per liter, which is estimated to be 6.29 Yuan per liter.

Porters are relatively unskilled labor and so an accounting ratio of 0.5 was used to calculate the shadow price from the market price.

In order to supply 11,004.192tonnes of freshwater hyacinth a total of 2,201 trips are needed every year, therefore a total of 120,614.8 is spent on the transportation of water hyacinth per year.

Removal of heavy metals

The cost of removing heavy metals is estimated according to the shadow prices of passivation substances and alkali, which are obtained by reducing the 15% value-added tax from their market prices. As shown in Table 5, the annual cost is estimated to be 743.4 Yuan a year.

Repair and maintenance

It is assumed that the cost of repair and maintenance is 10% of the 15-year depreciation of the fixed assets shared by the production of biogas and organic fertilizer from water hyacinth (20,238 Yuan a year).

Electricity charge

The electricity charge is estimated by cutting the value-added tax (17%), from the market price (1 Yuan per kWh).

Cost of CO_2 emissions

The sources of carbon emissions are the combustion of diesel during the transportation of water hyacinth and the consumption of electricity that is generated by the consumption of coal.

The CO_2 emission factor of diesel is 2.6765 kg per liter and the value of CO_2 emission reduction is 160 Yuan per tonne (Zhang, 2009). The cost of CO_2 emissions from transportation is estimated as14.47tonne per year. This was obtained by multiplying 2,201 trips with the consumption of diesel (for one trip) and the CO_2 emission factor (2.6765 kg per liter).

The electricity consumption attributed to the production of biogas and organic fertilizer from water hyacinth is 14,875kWh. According to the *Yunnan Statistical Yearbook* (2006), 44% of electricity output came from the combustion of coal and 56% derived from hydropower. To generate 1 kWh electricity requires the combustion of 0.4 kg of standard coal, which emits 0.99 kg of CO_2. For large hydropower technology, the emission of CO_2 is negligible (Okken et al. 1989) and thus it is assumed to have zero emissions. The CO_2emissions from a biogas plant using water hyacinth is1,568.14 Yuan per year.

5.1.3 The benefits

Values of biogas and organic fertilizer

The market prices of biogas and organic fertilizer were estimated according to their substitutes in the market. Assuming that firms are price takers in the biogas and organic fertilizer markets, the market prices of water gas diesel and organic fertilizer were considered their shadow prices.

As shown in financial analysis, the calculated equivalent market price of biogas is 2.46 Yuan per m^3. The shadow price is estimated to be 2.17 Yuan per m^3 by deducting the value added tax (13%) from the market price. Since the annual biogas output produced from water hyacinth is 245,437.5m^3, the value of biogas is 603,040 Yuan per year.

Taking the lower bound of the current market price of organic fertilizer, which is 500-1,200 Yuan per tonne, the shadow price of organic fertilizer is calculated to be 500 Yuan per tonne. The annual value of organic fertilizer from water hyacinth is estimated to be210,000 Yuan per year.

Value of purifying water

The main benefits of purifying the water in Dianchi Lake are increased recreational value and existence value. However, the removal of water hyacinth from a eutrophic lake can also result in other external economic values including benefits to fishing and the better health of water users. Because of financial and time constraints, the value of purifying water was not studied. Rather, it has been estimated using the benefit transfer method, which applies primary non-market valuation estimates from the original study site to a second setting of a policy site at a different time and/or place (Desvousges et al. 1992; Brookshire and Neil 1992).

The study site of East Lake for was chosen from Du (1998), which was also an EEPSEA site. The reasons for choosing Du (1998) include: first, there are many similarities between the study site and the policy site, including a location in the Yangtze River basin, highly eutrophic water, and proximity to a city; second, there are only a few valuation studies of water quality available and the differences are more significant if study sites in other countries are chosen because of fewer cultural and economic similarities. The characteristics of the sites are shown in Table 6.

Table 6. Characteristics of the study site and the policy site

	Study site: East Lake (A)	Policy site: Dianchi Lake (B)
Location	Beside Wuhan City, Yangtze River basin	Beside Kunming City, Yangtze River basin
Lake area (km^2)	73	309
Pollution	Eutrophicated (water quality class V or lower)	Eutrophicated (water quality class V or lower)
Population (million people)	2.511	4.90
Average income per capita (Yuan per month)	407.34 (1996) 904.17（2010）	801.33 (2010)
Education (number of years)	13.01	8.14
Distance between the two sites	About 1,300 km	

In Du (1998), the values of water quality improvement from the existing level to a level where boating can take place, swimming can take place, and the water becomes drinkable are estimated. The estimated values for water quality improvement using a contingent valuation method (CVM) were greater than those using a travel cost method (TCM). As explained in Du (1998), the estimated values from TCM revealed the recreational value only, while those from CVM may include recreational value and existence value. The estimated values and functions from CVM were transferred in the study. Two benefit transfer methods were used in the study; unit value transfer and benefit function transfer.

China's surface water quality standards (BB3838–2002) have five levels.

- Level I: high-quality water, which is drinkable after simple treatment such as filtering and disinfection.
- Level II: slightly polluted water, which is also drinkable after regular treatment, e.g. effective treatment by a water plant.
- Levels III to V: various degrees of the most polluted water.

The waters of both East Lake and Dianchi Lake are graded Level V.

According to data provided by the Dianchi Administration Bureau, Dianchi Lake is loaded with around 3,640 tonnes of nitrogen and 146.9 tonnes of phosphorus. According to Dr. Shaohua Yan, Director of Jiangsu Academy of Agricultural Sciences, the water quality of Dianchi Lake could be improved from its current Level V to Level III by removing 2,340 tonnes of nitrogen and 81.9 tonnes of phosphorus from the water. This could be achieved by removing water hyacinth from the lake.

According to the surface water quality standards (BB3838–2002), water quality that is suitable for swimming should be graded as least as high as Level III. In this study, we look at an improvement in water quality from the status quo (Level V) to a swimmable level (Level III).

According to Du (1998), the willingness to pay (WTP_A) for improving the water quality from the status quo to swimmable was 18.14 Yuan per person, per year. As calculated from the Chinese Statistic database, the aggregate consumption price index of urban areas was 1.2365 from 1997 to 2010. Using the unit value transfer method, the WTP at the policy site (WTP_B) was estimated using the following equation:

$$WTP_B = WTP_A \times \frac{GDP_B}{GDP_A} \times \frac{P_A}{P_B} \qquad \text{(Equation 3)}$$

The result was found to be 28.86 Yuan per person, per year.

The benefit function for improving water quality from the existing level to a swimmable level was Equation 4 in Du (1998). By transferring the benefit function, WTP_B was estimated to be 28.71 Yuan per person, per year.

$$WTP = -7.9098 + 0.033 \text{ income} + 1.2499 \text{ education} \qquad \text{(Equation 4)}$$

Generally speaking, there is little difference between the results from the two methods. Here, we adopted the estimate from the unit transfer method in analysis. Considering the total population surrounding Dianchi Lake, the aggregate value of water quality improvement from the status quo up to Level III was estimated to be 140.68 million Yuan per year.

The change in water quality was measured by the amount of nitrogen stock in the lake, although for an improvement in water quality to take place there needs to be a reduction in the concentrations of both nitrogen and phosphorous in the water. The amount of nitrogen can be used as a measure for two reasons: first, the concentration of nitrogen in Dianchi Lake is much higher than that of phosphorous; and second, water hyacinth absorbs nitrogen and phosphorous simultaneously.

Assuming a static stock of nutrients in the water body, about 2,340 tonnes of nitrogen need to be removed from the water in order to improve the water quality from level V to III. Therefore the value of nitrogen removal is 60,119 Yuan a tonne.

Nitrogen removal per tonne of water hyacinth is 0.0307 tonnes so the unit value of water hyacinth in purifying water is estimated to be 1,846 Yuan per tonne. With the biogas plant consuming 11,004.2 tonnes of water hyacinth annually, the value of water quality improvement was estimated to be 1,332,581Yuan.

Value of CO_2 emission reduction

A reduction in CO_2 emissions comes as a result of using biogas and organic fertilizer as substitutes for water gas and chemical fertilizer, respectively.

The calorific values of biogas and water gas are 23.36 MJ per m^3 and 10.46 MJ per m^3, respectively. As far as calorific values are concerned, a unit of biogas can substitute 2.233 units of water gas. The annual output of biogas is 245,437.5 m^3, which is equivalent to 548,128.11 m^3 of water gas. Since the emissions of CO_2 from the combustion of water gas are45 kg per GJ, or 0.4707 kg per m^3, about 258 tonnes of CO_2 can be reduced every year by substituting water gas with biogas. At the time of writing this report (October 2011), the cost of CO_2 emission reduction is 160 Yuan per tonne (Zhang, 2009). Thus, the annual value of CO_2 emission reduction is 41,280.62 Yuan if water gas is substituted with biogas.

The biogas plant can produce 420 tonnes of solid residual, which can be used as raw material for organic fertilizer. According to Wang (2005), the main nutrients in biogas fertilizer include 1.0%-2.5% of total nitrogen (N), 0.3%-1.1% of available P (P_2O_5), and 0.6%-2.0% of available K (K_2O). The greenhouse gas emissions created from producing chemical fertilizers are shown in Table 7.

Table 7. Greenhouse gas emissions due to the production of chemical fertilizer

Fertilizer	Emissions		
	CH_4	N_2O	CO_2
N(g/g)	0.0029	0.0016	2.4382
P_2O_5(g/g)	0.0018	0.0000	0.9905
K_2O(g/g)	0.0010	0.0000	0.6648

Source: Wang (1999)

According to Wang (1999), the global warming effect of CH_4 and N_2O are 25 and 298 times of that of CO_2 for a time period of 100 years. According to Table 7, the CO_2 emission factors are 2.9876, 1.0355 and 0.6898 tonnes for the production per tonne of nitrogen, phosphorus and potassium fertilizers. Based on the nutrient content of organic fertilizer, the production of a tonne of organic fertilizer can avoid 68.5 kg of CO_2 equivalent. The annual reduction in CO_2 emission is 28.77tonnes. At a price of 160 Yuan per tonne, the value of CO_2 emission reduction by substituting chemical fertilizer with organic fertilizer is 4,603.2 Yuan. Therefore, the total annual benefit of CO_2 emission reduction is estimated to be 45,883.8 Yuan.

Salvage value of fixed assets

The machinery in the biogas plant will be purchased from relatively competitive markets so the present salvage value is 564,104 Yuan, the same as in the financial analysis.

5.1.4 Without-project scenario

The benefit of the without-project scenario is the value of water hyacinth as a phytoremediation plant: it is the same as in the with-project scenario, which is 1,332,581 Yuan a year. The costs in the without-project scenario are as follows.

The cost of collecting water hyacinth

As a given amount of water hyacinth is collected from Dianchi Lake, the economic cost of collecting the water hyacinth is the same as in the with-project scenario, which is 412,657.2 Yuan a year.

The cost of transporting water hyacinth to landfill sites

It was assumed that the water hyacinth is transported to landfill sites by a 5-tonne truck, which consumes 2 liters of diesel per trip. The market rate for a driver is 40 Yuan an hour, and 30 Yuan an hour for porters. Two porters are needed for each transport and two workers are needed at the landfill site. Truck rental costs 100 Yuan for a round trip.

The labor cost and the diesel consumption are the same as in the financial analysis. The shadow prices of diesel and wages for the driver and porters are the same as in the with-project scenario.

In order to supply 11,004.192tonnes of freshwater hyacinth, a total of 2,201 trips are needed per year. A total of336,753 Yuan will be spent on transportation every year and 132,060 Yuan will be spent on the labor cost of treating the water hyacinth.

The cost of CO_2 emissions

The diesel combustion that takes place during the transportation of water hyacinth is a source of carbon emissions. The CO_2 emission of diesel is 2.6765 kg per liter. The CO_2emissions from transportation are calculated to be 14474.512 kg per year (2,201 trips multiplied by the consumption of diesel for one trip and the CO_2 emission factor, 2.6765 kg per liter). The cost of CO_2 emissionsfrom the transportation of water hyacinth is estimated to be 1,885 Yuan per year, at 160 Yuan a tonne.

Cost of methane emissions from water hyacinth in landfill

Water hyacinth in landfill decomposes and emits methane. Without a collection system, the methane is eventually released into the atmosphere. To estimate the amount of methane emitted from buried water hyacinth, a landfill gas model was modified, based on IPCC (2006), by assuming that water hyacinth is disposed of year-on-year at a constant rate. The model was:

$$Q_{CH_4} = 16/12*S*WH_f*MCF*DOC*DOC_f*F*(1- e^{-kt}) \quad \text{(Equation 5)}$$

where Q_{CH_4} is the amount of methane emitted (T/yr) at year t; 16/12 is the molecular weight ratio of CH_4/C; S is the total weight of freshwater hyacinth biomass (T/yr); WH_f is the fraction of harvested water hyacinth used to generate biogas, 1 in the study; MCF is the methane correction factor which is 1 when the anaerobic digestion is well managed (IPCC 2006); DOC is the fraction of biodegradable organic carbon in water hyacinth; DOC_f is the fraction of DOC dissimilated (converted to methane or carbon dioxide), the value is 0.77; F is the methane fraction of landfill gas, the value is 0.65 (Zha et al. 2008); k is a decay rate constant, which is the ratio between ln2 and the half-life time of decay $t_{1/2}$, i.e. $k=\ln(2)/t_{1/2}$ (IPCC 2006).

In water hyacinth, the biomass content is 6.56%, the nitrogen content is between 1.2% and 3.2% in dry matter, and the C/N ratio is around 15. The DOC is accordingly estimated to be 2.16% for water hyacinth. Since water hyacinth is a rapidly degradable material, we assume that the half-life time is two years. It is assumed that the initial disposal of water hyacinth via landfill began 10 years ago.

Cost of land used for water hyacinth landfill

The area of land required to landfill water hyacinth is determined by the space efficiency ratio of the landfill field, which is the ratio of the volume of treated waste in cubic meters to the land area in square meters. Determined by the technology used to design the landfill field, the ratio is around 50-60 in some developed countries, such as the USA, Canada, Germany, and Japan, and 20-30 on average in China (Li and Li 2004). Since the water hyacinthplant is spongy and full of water, the space efficiency ratio for water hyacinth can be higher. Considering the characteristics of water hyacinth and the simple technology used to design landfill sites in China, a ratio of 30 is assumed in the calculation. Because the biomass of water hyacinth decomposes relatively easily, the re-filling or renewal period is one year.

The quantity of water hyacinth per cubic meter is mainly affected by its water content and the crushing effort. It is assumed to be 700 kg m^{-3} in the study. To landfill11,004.2 tonnes of water hyacinth, which corresponds to the annual consumption of water hyacinth by the biogas plant, the required land area is estimated to be 524.6 m^2. Considering accessory land requirement, such as roads and parking areas, it is assumed that a total of one mu, equivalent to 666.7 m^2, of land area is required to landfill 11,004.2 tonnes of water hyacinth. Since the biomass of freshwater hyacinth discomposes easily, the rotation of landfill is assumed to be one year.

Thus, the annual cost of land is estimated to be 400 Yuan, at a rental rate of 400 Yuan per mu^{-1}.

5.2 The Economic Net Present Value

The economic analysis is based on the financial analysis by adjusting the costs and benefits with the shadow prices of inputs and outputs and including the external costs and benefits. Assuming the biogas plant is a price taker, the shadow prices of inputs are the market prices exclusive of value added; and those of outputs are the market prices. The shadow prices of labor are estimated using an accounting ratio of 0.5 for unskilled labor and 0.8 for skilled labor. The major externalities are water quality improvement and GHG emission reduction. Consistent with the application of a discount rate in real terms, the shadow prices of inputs and outputs are used as constants in calculating the ENPV.

According to NDRC-MS (2006), the recommended real-term social discount rate is 8% for short- and medium-term projects, and is lower for long-term projects, especially environmental improvement or protection projects. For instance, Tang et al. (2009) used a discount rate of 5% for a CDM reforestation project. The study took a real-term discount rate of 6% as a baseline, while the effect of a change in discount rate on NPVs was assessed in the sensitivity analysis.

In the economic analysis, the comparison between the two scenarios is based on the assumption that, after introducing the project, the control of water hyacinth should at least be maintained at the current level, namely, an annual removal of 164,000 tonnes of water hyacinth. Therefore, before the biogas plant reaches its processing scale of 164,000 tonnes, the two disposal approaches, landfill and biogas production, must coexist.

Therefore, there are two cases in making the comparison: the processing scale of the biogas plant is either less than and equal to, or greater than 164,000 tonnes. In the former case, each additional amount of disposed water hyacinth will have a direct economic gain from biogas production and water quality improvement and an avoided economic loss for not being disposed of via landfill (Table 8). In the latter case, any additional consumption of water hyacinth, more than 164,000 tonnes, has only a direct economic gain, including the benefits from biogas and organic fertilizer, and the value of water quality improvement.

If the biogas plant consumes 11,004.2 tonnes of water hyacinth per year, the direct economic gain is 11.72 million Yuan and the avoided cost is 1.84 million Yuan for 15 years. In short, the project has an ENPV of 13.14 million Yuan. Therefore, the project is economically feasible.

In the without-project scenario, the benefit is from water quality improvement by water hyacinth, while the major cost is methane emissions, which account for 41.51% of the total cost. This cost is also one of the reasons that the current approach to dealing with water hyacinth has a negative net economic value. If there is no biogas project and the current average removal of water hyacinth (164,000 tonnes per year) is continued, the present value of the total social loss is 21.16 million Yuan for a 15-year time horizon.

In the with-project scenario, the major benefit is also the value of water quality improvement, accounting for 59.31% of the total direct benefit, while the total value of merchantable products, i.e. biogas and organic fertilizer, only accounts for 36.19% of the total. The major costs incurred are collecting water hyacinth, investing in the biogas plant, and labor.

However, without estimating the avoided loss from the control of water hyacinth, we cannot conclude that the current measure is economically infeasible. As far as the study is concerned, the value of water quality improvement cannot be captured if the government stopsprovidinga subsidy for the removal of water hyacinth and therefore the current practice is stopped. If this happened the economic loss would be 13.72 million Yuan rather than 1.42 million Yuan if nothing is done with regard to water hyacinth.

The ENPV of the project is composed of two parts (Figure 3): the present value (PV) of direct economic gain from biogas production; and the PV of the avoided economic loss of disposing of water hyacinth via landfill. The former increases along with an increase in production scale. The latter increases and then remains constant after the processing scale is greater than 164,000 tonnes because any additional consumption of water hyacinth has no more avoided cost. As a result, the ENPV increases as the scale of production increases, but at lower rate when the processing scale of the biogas plant is greater than 164,000 tonnes per year.

Table 8. Results of the economic analysis

Component	Without project (0) (million Yuan)	With project (1) (million Yuan)
Benefits		
Benefit of biogas		6.21 (26.84%)
Value of GHG emission reduction		0.47 (2.04%)
Benefit of organic fertilizer		2.16 (9.35%)
Value of water quality improvement	13.72	13.72 (59.31%)
Salvage value of fixed assets		0.56 (2.44%)
Costs		
The cost of collecting water hyacinth	4.25 (28.06%)	4.25 (37.27%)
Fixed cost (machinery and land rent)		3.14 (27.51%)
Workers' wages for disposing of water hyacinth	1.36 (8.98%)	2.22 (19.51%)
Cost of GHG emissions other than methane	0.02 (0.13%)	0.02 (0.14%)
Cost of methane emissions	6.04 (39.91%)	
Cost of transportation and landfill	3.47 (22.90%)	1.24 (10.89%)
Others (including land rent, electricity charges, repair and maintenance costs, payment for passivation substance and alkali)	0.002 (0.01%)	0.50 (4.38%)
Sub-total (C)	15.56 (100%)	11.40 (100%)
Economic gain (E(i)=B(i)-C(i))	-1.42	11.72
ENPV (=E(1)- E(0))	13.14	

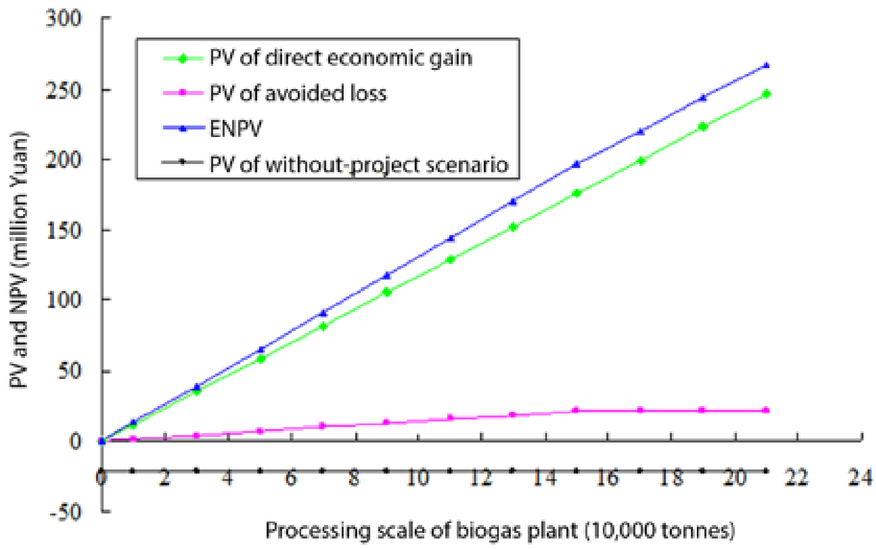

Figure 3. Economic feasibility at different processing scales

When removing the same amount of water hyacinth from the lake in both scenarios, the value of the water quality improvement is cancelled out in the final ENPV calculations in Table 8, and they do not contribute added value to ENPV for the proposed policy change. However, as the production scale is greater than 164,000 tonnes of water hyacinth, an additional consumption of 11,004.2 tonnes of water hyacinth will have an added value of 13.72 million Yuan for water quality improvement.

When the processing scale of the biogas plant is less than the amount of water hyacinth disposed of in the without-project scenario, the avoided loss from GHG emissionsis6.48 million Yuan for using each 11,004.2 tonnes of water hyacinth to produce biogas. As the processing scale increases to more than 164,000 tonnes per year, no more avoided loss is affixed to the additional consumption of water hyacinth. The net value of GHG emission reduction becomes 0.49 million Yuan for each additional consumption of 11,004.2 tonnes of water hyacinth per year for a period of 15 years.

If a single biogas plant has the processing capacity shown in Table 5, then 15 biogas plants of this same size should be built in order to consume the amount of water hyacinth removed at the current level of control, i.e.164,000 tonnes a year. Considering the current annual growth of water hyacinth is 250,000 tonnes, there is potential to increase the processing scale of biogas plants.

6.0 SENSITIVITY ANALYSIS

To identify critical parameters, sensitivity analysis involves changing project parameters by a given percentage and noting the respective changes in financial and economic performance of the project as measured by the net present value. The considered parameters included discount rate, prices or quantities of biogas and organic fertilizer, price or quality of GHG emission reduction, value of water quality improvement, the cost of water hyacinth collection, and the capital cost of the initial investment. Because the benefits and costs are estimated by multiplying the price and quantity, a change in the quantity of a good has the same effect on the NPV as that in the price. Except for the value of water quality improvement, parameters were analyzed on a processing scale of 11,004.2 tonnes of water hyacinth per year.

According to the European Commission's (EC) criterion, the critical parameters are identified asthose in which a 1% variation (positive or negative) changes the FNPV or the ENPV by not less than 1% (EU 2008). Based on this criterion, no critical parameter is identified in both the financial analysis and the economic analysis.

If the project is registered as a CDM project, the parameter of the price or quantity of CO_2eq is critical because a 10% variation in CER price only results in a 10% variation in FNPV. As the production scale is expanded to be greater than 164,000 tonnes per year, a change in price or quantity of CO_2eq has a slightly smaller effect on the FNPV because there is no more avoided loss from methane emissions.

As an economic externality, the value of water purification was not included in the financial analysis. Its effect on the ENPV depends on the processing scale of the biogas production. When the scale is equal to or less than 164,000 tonnes, the value of water quality improvement has no effect on ENPV because of the reasons previously mentioned.

When the processing capacity of the biogas plant is greater than 164,000 tonnes of water hyacinth, the consumption of each additional unit of water hyacinth is associated with an added value from water quality improvement. However, a 1% change in the value of water quality results in less than a 1% change in ENPV.

7.0 INSTITUTIONALARRANGEMENTS

As shown in Appendix 2, the inclusion of the value of GHG emission reduction does not make the project financially feasible. The project requires external support and China's existing polices have laid a solid foundation for such support.

7.1 Legal Background and Macro Policy

Making biogas from water hyacinth can contribute to energy production, water purification and carbon emission reduction. These objectives are supported by related laws and polices including the Renewable Energy Law, the law on the Prevention and Control of Water Pollution, and the State Council's ordinance on Energy Saving and Emission Reduction.

7.1.1 Renewable energy development

The Renewable Energy Law of the People's Republic of China was adopted at the 14^{th} session of the standing committee of the 10^{th} National People's Congress on 28 February 2005, and came into force on 1 January 2006. The law was created to promote the development and use of renewable energy, improve the energy infrastructure, diversify energy supplies, safeguard energy security, protect the environment, and realize the sustainable development of the economy and of society. The forms of renewable energy covered in the law are mainly non-fossil energy and include wind power, solar power, hydroelectricity, biomass energy (biogas), geothermal energy and wave power.

The government lists the development and use of renewable energy as priority areas for energy development. According to the "management schemes of the special fund for the development of renewable energy" announced by the Ministry of Finance in 2006, a special fund can be used to subsidize the interest charges on loans and to provide grants for investment and compensation for tax on projects listed for renewable energy industrial development.

Based on the Renewable Energy Law, the National Development and Reform Committee announced its "Plan for the development of renewable energy in 2011-2015" in 2008, which highlights the restructuring of energy use by promoting technological and industrial development. In particular, the production of biogas is to be a priority for development in the suburban areas of large- and medium-sized cities and in the conservation areas of water systems.

On 31 October 2007, the National Development and Reform Committee released the Medium- and Long-term Plan for the Development of Renewable Energy, which has a goal of 15% of total energy consumption from renewable energy sources by the end of 2020. It also highlighted the utilization of organic waste biomass.

7.1.2 The prevention and control of water pollution

The proposed project also has a legal basis in terms of water pollution alleviation. The control of water pollution has its earliest legal basis in China's Law on Water Use, which took effect on 1 July 1988. However, a more directly relevant law is the Law on the Prevention and Control of Water Pollution, which came into force on 1 January 2006. This law highlights the alleviation of water pollution using ecological methods. The law also requires local government to set up or improve the payment for ecological services (PES) mechanism and the PES fund will be sourced from central government.

In 2001, the State Administration of Environmental Protection launched the Three Rivers and Three Lakes Program to alleviate the pollution in Huaihe River, Haihe River and Liaohe River and Taihu Lake, Caohu Lake and Dianchi Lake. A special fund was established under the Ministry of Finance to subsidize projects for water pollution prevention, control and alleviation.

At a local level, the Yunnan provincial government and Kunming municipal government have made action plans for the prevention and control of water pollution in Dianchi Lake, including the 11^{th} Five-year Plan for the Prevention and Control of Water Pollution in Dianchi Lake, and the Medium- and Long-term Plans for the Prevention and Control of Water Pollution in Dianchi Lake.

7.1.3 Energy saving and emission reduction

Considering its contribution to GHG emission reduction, the production of biogas from water hyacinth would be a positive response to central government's directive on energy saving and emission reduction. In 2007, the State Council announced its "Comprehensive working plan for energy saving and emission reduction" (No. 15 of Goufa [2007]), in which the research and application of new technology and integrated use of resources are highlighted. Producing biogas from water hyacinth is a combination of the application of new technology and an integrated use of resources.

The State Council released its "National Scheme for dealing with global warming" (No. 17 of Goufa [2007]) on 3 June 2007. According to the plan, China will cut per unit GDP energy consumption by 20% compared with 2005 levels by the end of 2010. The scheme also highlighted the promotion of renewable energy production. In the 11th Five-year National Plan for environmental protection, issued on 22 November 2007, the State Council again emphasized the promotion of renewable energy production and the reduction of GHG emissions.

Before the Copenhagen climate summit at the end of 2009, China announced its target for carbon emission reduction: the intensity of its carbon dioxide emissions per unit of GDP will be cut by 40-45% from the 2005 level by 2020.

7.2 Related Organizations

The goals of water pollution control, renewable energy production, and emission reduction, were set up by the State Council. These actions are to be carried out by different departments. In China the administration follows a top-bottom structure – central government institutions set goals and assign appropriate budgets then provincial governments make plans to achieve these goals and dispatch tasks to municipal and prefecture levels. This process takes place before action is taken to achieve goals.

Using water hyacinth to alleviate eutrophic lakes and to produce biogas is connected with different organizations (Figure4). The organization responsible for the management of Dianchi Lake is Kunming Municipal Bureau of Dianchi Management. Its duties cover water management, fisheries, navigation, land use, planning, water protection, and wastewater discharge in the lake. As shown in Figure 4, a project that can contribute to the achievement of multiple goals will have to establish relationships with many different government organizations, which may put obstacles in the way of the project in the form of red tape and poor coordination and communication. For example, even though central government can provide financial support to achieve these goals, it is difficult for firms to gain access to these resources. In addition, which organization will provide grants to firms when the project can simultaneously generate the benefits of water quality improvement, emissions reduction, and energy production? Will the biogas plant be subsidized for its biogas production or its contributions to environmental protection, including water purification and GHG emissions reduction? If the current practice of collecting water hyacinth for disposal by landfill is stopped, can the portion of the protection fund used for this current practice be channeled instead to the biogas plant? Or does the biogas plant have to compete for money from the protection fund with other more purely protection-oriented projects?

We suggest that a government organization should be established to provide services to enterprises and firms by promoting the coordination of related government organizations. This project is relevant to the goals of many policies. Support based on a single policy might not be able to promote the implementation of the project –for instance, the internalization of GHG emission reduction according to China's policy on energy saving and emission reduction is not sufficient to make the project financially feasible. Furthermore, a new mechanism is required to recognize the role of ecological production in environmental improvement, and thus provide incentives to promote activities such as producing biogas from water hyacinth.

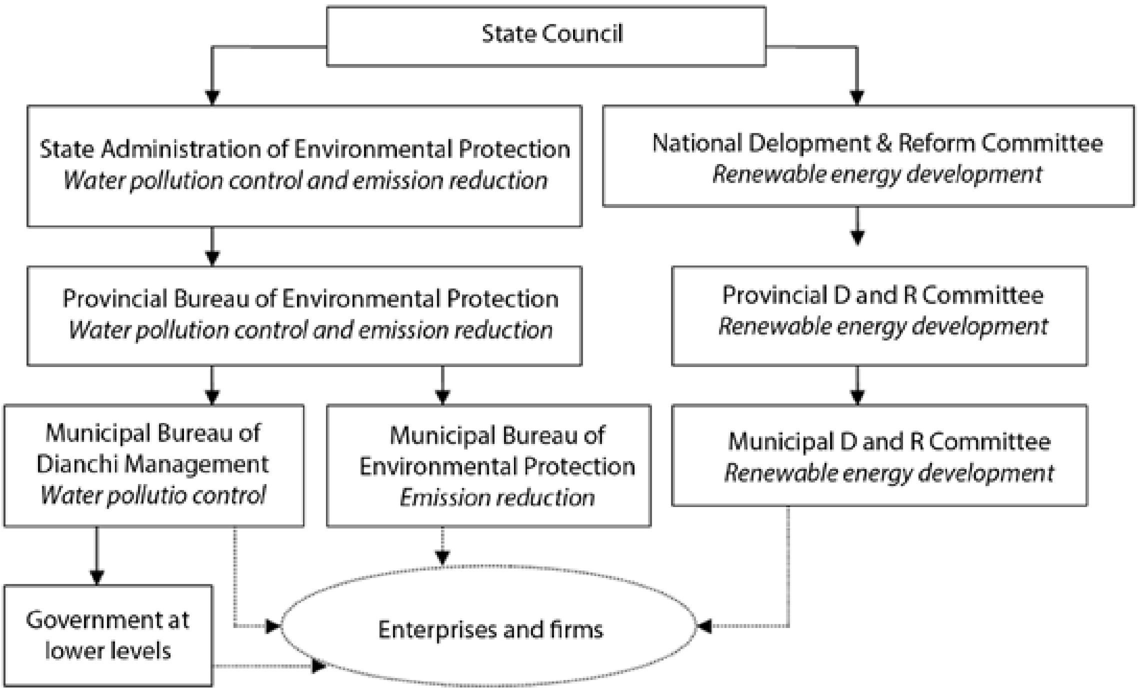

Figure 4. Organizations and processes related to the proposed project

7.3 Policy Instruments

According to previous results, it is economically feasible to use water hyacinth as a phytoremediation plant coupled with biogas production but it is not financially feasible to do so. The government spends millions from its fund on the collection and landfill of water hyacinth and it could cut its expenditure on the control of water hyacinth by implementing the proposed project. Moreover, the project can generate economic value from the products it creates (biogas, organic fertilizer) and from the environmental improvements it brings. In particular, the cost of methane from landfill water hyacinth is not well accounted for in the current practice of dealing with water hyacinth and it can be avoided via the proposed project. If the scale of processing water hyacinth is greater than 164,000 tonnes, the project can also generate additional value in water purification.

The promotion of the project needs policies that provide firms with incentives to be involved in the phytoremediation of water quality and the production of biogas and organic fertilizer. See below for three potential policy instruments.

7.3.1 Subsidies for water quality improvement

As previously estimated, the value of water quality improvement provides an economic justification for subsidizing the removal of water hyacinth. The subsidy can be paid in terms of per unit of harvested water hyacinth, or in terms of per unit of removed nutrients. The former is designed for the policy objective of controlling water hyacinth, and the latter is designed to ensure the improvement of water quality or the reduction of eutrophication. Based on the principle of economic efficiency, the rate of subsidy for per unit of water hyacinth removed can be designed according to the principle of average cost plus margin. The subsides needed in the two scenarios in order to make sure that firms break even are shown in Table 9.

The project can reduce the expenditure from public funds on controlling water hyacinth and improving water quality. However, when the value of avoided loss resulting from excess water hyacinth is not included, the subsidization of the removal of water hyacinth is not economically justified in the without project scenario because of the net economic loss of 1.42 million Yuan (Table 8). That is, the value of water purification by the removal of water hyacinth is offset by its costs, especially the economic loss of methane emissions.

Despite the similar function provided by removing nutrients, the two policy instruments have different implications. The major difference is that there are many competitive measures for the improvement of water quality, one of which is the use of wastewater treatment plants.

According to Chen et al. (1994), the changes in TN concentration once wastewater has passed through three wastewater treatment plants in Kunming are shown in Table 10. Based on the average TN reduction in the three water treatment plants in Kunming and the average cost of 1.1 Yuan per m^3, the cost of reducing TN by wastewater treatment plant is 43,246 Yuan per tonne of TN, which is more competitive than that of the without-project scenario. Compared with a wastewater treatment plant, the subsidy needed for a biogas plant is much lower.

Table 9. Required subsidy rates for the two scenarios

	Without project	With project
Required subsidy for harvested water hyacinth (Yuan per tonne)	104.8	66.8
Required subsidy for nitrogen removal (Yuan per tonne)	52,038	33,169

Table 10. Changes in TN concentration after wastewater treatment

	1st plant		2nd plant		3rd plant	
	In	Out	In	Out	In	Out
TN concentration (mg/L)	30.02	13.05	45	8	30	7-8
Average TN reduction (mg/L)	25.32					

Another major difference is that the TN and TP in Dianchi Lake can no longer be removed by wastewater treatment. This is because the TN and TP in the water discharged by wastewater treatment is much higher than the water in the lake. According to the highest standard for water discharged from a wastewater treatment plant, Level I-A of the national standard GB18918-2002, the TN content can be as high as 15 mg per liter. However, the TN of Level V water is 2.0 mg a liter, according to national surface water standard GB3838-2002. The water quality in Dianchi Lake is Level V. Taken from this point of view, a wastewater treatment plant could not be used to replace water hyacinth as a method of reducing nutrients in the water of Dianchi Lake. In other words, using the chemical technology of a wastewater treatment plant would greatly increase costs if it were used to reduce the TN concentration to a lower level than 2.0 mg per liter.

Although it is more cost-effective to use water hyacinth to reduce nutrients in a body of water, its scale is limited. Considering the millions of tonnes of wastewater discharged by towns and cities every year, wastewater treatment plants are indispensable.

The sources of finance for the two instruments might be different. A wastewater treatment plant is financed by levying a wastewater treatment fee on citizens in their water bills, which is 1.1 Yuan a tonne. At present, the water fee in Kunming City is 3.45 Yuan a tonne, which is slightly lower than in Beijing (3.7 Yuan a tonne), but higher than in Shanghai (1.93Yuan a tonne) and Chengdu (2.15 Yuan a tonne). Considering the low income levels of the local population, the water fee in Kunming is high. Thus, if the reduction of nutrients in Dianchi Lake was to be financed by increasing the water fee, it wouldput a great deal of pressure on the citizens and would probably not be popular.

If the policy goal is to control water hyacinth proliferation, the subsidy could be paid per tonne of water hyacinth removed by establishing a special grant for improving the ecosystem of Dianchi Lake. It could be a part of the municipal fiscal budget or the fund transferred from central government.

7.3.2 Grant for initial investment

The initial investment is the biggest cost involved in producing biogas. Thanks to the efforts of the government and non-governmental organizations, the production of biogas has been promoted in rural areas of Yunnan Province. Many farming households have been provided with grants for the construction of biogas pits and to purchase the necessary equipment.

A fermentation tank is required for the commercial production of biogas and the cost of a tank is higher than that of a simple biogas pit. However, considering the economic value of biogas as an alternative to natural gas in reducing carbon emissions, there is an economic justification for providing a grant for this initial investment. The grant could come from the government's special fund for the treatment of polluted bodies of water.

The source of the fund could be central government's special fund for the treatment of pollution in the three rivers selected as national priorities in this area (Huaihe River, Haihe River and Liaohe River) and the three lakes also selected (Taihu Lake, CaohuLake and Dianchi Lake). According to the management articles for this fund, as enacted by the Ministry of Finance of China in 2007, the fund can be used to finance wastewater treatment projects and clean development projects. Obviously, this fund is the biggest potential source of funding for the proposed project.

However, as shown in Table 4, an initial grant that covers all fixed costs will not make the project financially feasible. If it is chosen, the initial investment grant should be implemented in combination with other policy instruments.

7.3.3 Clean development mechanism (CDM)

At present there are two approved CDM projects in the Wuhua and Baishuitang districts of Kunming City. These projects target the effects of carbon emission reduction by landfill gas. These two landfill gas projects have been implemented to treat urban waste, as well as to reduce carbon emissions(the landfill gas is used as an alternative to natural gas or coal). The rationale of these projects holds for the production of biogas from water hyacinth too. As shown in Table 11, by removing and processing or disposing of 11,004.2 tonnes of water hyacinth, the project can reduce GHG emissions by 253.4tonnes of CO_2eq. The current approach adds 3,668.1 tonnes of CO_2eq to the atmosphere. A biogas plant with the capacity to process 11,004.2 tonnes of water hyacinth can contribute to GHG emission reduction by 3,921.5 tonnes of CO_2eq. Hence, there is great potential to promote the production of biogas from water hyacinth through CDM.

Table 11. Lifecycle performance of carbon emission reduction

Source	Without project	With project
Carbon emissions (E)		
Transportation	11.8	23.6
Landfill gas	3,656.3	
Electricity consumption		9.8
GHG emissions reduction (R)		
Substitute water gas with biogas		258.0
Substitution of chemical fertilizer with organic fertilizer		28.8
Balance (=R-E)	**-3,668.1**	**253.4**

Moreover, the Chinese government is attempting to establish a domestic carbon market, which is expected to provide another outlet for the reduction of carbon emissions from biogas via water hyacinth. The revenue from certified emission reduction has the potential to be an income source from the biogas made from water hyacinth. At a time when the central government budget for wastewater treatment is limited, the CDM may provide an alternative funding source for the promotion of the project.

If the main policy objective is to maintain the control of water hyacinth at the current level, i.e. an average removal of water hyacinth of 164,000 tonnes a year, a single biogas plant with a processing capacity of 11,004.2 tonnes of water hyacinth cannot meet this target. In other words, about 15 biogas plants, each of the same size, are required to completely replace the current method of water hyacinth control. Before the biogas plants expand their capacity to process164,000 tonnes of water hyacinth, each unit of water hyacinth disposed of by the proposed project has avoided GHG emissions, unlike the current approach to water hyacinth disposal. If the total amount of water hyacinth harvested at the current level of control, i.e. 164,000 tonnes, is used to produce biogas, a total of 58,443.7 tonnes of CO_2eq can be avoided or reduced.

However, when the processing scale of the biogas plants is greater than 164,000 tonnes any additional disposal of water hyacinth (over 164,000 tonnes) can only reduce GHG emissions by 253.4tonnes of CO_2eq, and there would be no more avoided GHG emissions.

The CDM carbon market was based on the first phase of commitments by developed countries as stated in Kyoto Protocol (1997), which will expire in 2012. Before a new agreement is reached, it is uncertain whether the CDM market will continue to exist or not. However, the future of the CDM market after 2012 seems uncertain because no solid progress was achieved at the Copenhagen and Cancun summits.

However, the proposed project has potential for support due to the Chinese government's policy on energy saving and emission reduction, whichbegan in 2007. The Chinese government set up a target of reducing its carbon emissions per unit of GDP by a rate of 40-45% by the end of 2020 over the emission level of 2005. Against this background, the State Council set up a special grant to be used to finance emission reduction and energy saving activities.

It is necessary to inform local government of the potential part water hyacinthcan play in reducing carbon emissions, while its contributions to water purification and biogas production are already well recognized.

8.0 CONCLUSIONS

To control the rapid spread of water hyacinth in a eutrophic body of water, an economical use forthe water hyacinth that has been removed has to be found. This study analyzed the environmental performance and the financial and economic feasibility of using water hyacinth to reduce the nutrients in a eutrophic body of water, coupled with the production of biogas.

The results revealed that the project is economically feasible and has a desirable energy gain. The results also revealed that the project is not financially feasible but to achieve the same level of control over water hyacinth in the without-project scenario, the government would spend less money on the control of water hyacinth if they were to implement the proposed project. In order for firms to breakeven, the municipal government has to pay 104.8 Yuan per tonne^{-1}of disposed water hyacinth using the current practice but would pay only 66.8 Yuan a tonne^{-1} if the proposed project were implemented.

The results also show that, compared with the proposed project, the current approach to controlling water hyacinthdoes not represent a good social investment because of two major disadvantages: first, the biomass of water hyacinth is not used but is disposed of as waste; and second, the emissions from landfill gas eventually enter the atmosphere due to the absence of a gas capture system, thus adding to GHG emissions. We cannot draw a conclusion on the economic justification of current practice, say, as compared to "do nothing", because the avoided loss from the control of excess water hyacinth has not been estimated. However, emissions from landfill gas deserve more consideration and are more of a source of concern. Therefore, the proposed project is a good alternative to the current approach because the methane emissions can be avoided and the biomass of water hyacinth is used.

Moreover, the project is desirable in terms of energy performance. For disposing of 11,004.2 tonnes of water hyacinth, the project has an energy gain of 5.3 trillion joules while the current approach has an energy loss of 162.9 billion joules.

The proposed project can remove nutrients from eutrophic water and reduce GHG emissions but, compared to current practice, additional value depends on the processing scale of the biogas plant used. When the processing scale is less than or equal to the current amount of removed water hyacinth, i.e. 164,000 tonnes, the project has no additional value of water quality improvement but can avoid the economic loss of methane emissions produced by current practice. If the processing scale is greater than 164,000 tonnes, then the processing of each additional unit of water hyacinth has a corresponding additional value of water quality improvement but no more additional avoided loss from methane emissions. In order to achieve the same level of control over water hyacinth as the current practice, the proposed project should have a processing scale of 164,000 tonnes of water hyacinth. Considering the annual growth of water hyacinth is around 250,000 tonnes, there is great potential for the expansion of biogas production.

Due to its contribution to GHG emission reduction, the production of biogas from water hyacinth is a potential CDM project. With an annual consumption of 11,004.2 tonnes of water hyacinth, the project can reduce 3,921.5tonnes of CO_2 eq per year. The valueof this emission reduction is estimated to be 0.36 million Yuan a year, given the market price of CER in the CDM market in China in 2011. If the carbon emission reduction can be sold in the CDM market, the internalization of GHG emissions alone will not make the project financially feasiblesoother sources of compensation are required.

The results of this study have significant policy implications. The proposed project represents a better policy option than the current approach to disposalof water hyacinth by landfill in terms of both environmental and economic performance. The project has potential as a microeconomic option in response to China's macroeconomic policies on water pollution control, renewable energy development, and energy saving and emission reduction.

The study analyzed mainly the carbon balance and economic feasibility of using water hyacinth to reduce the nutrients in a eutrophic body of water and to produce biogas. However, determination of the optimal processing scale requires further study on the dynamics of water hyacinth in a given aquatic system. Moreover, the possibility of using water hyacinth to move a lake from a eutrophic state to a clean state is affected by both the dynamics of water hyacinth and that of the nutrient stock in the water. The latter is affected by the inflow and outflow of nutrients, as well as by the stock of water hyacinth. Further studies should investigate the effects of harvesting water hyacinth on the state of the water.

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APPENDICES

Appendix 1. Detailed fixed costs of biogas plant

I. Cost of building and construction					
No.	Item	Size	Unit	Unit price (Yuan/unit)	Cost (10^4 Yuan)
1	Grilled pool	80 m^3		250	2.00
2	Hydraulic screen pedestal		1	2,000	0.20
3	Hydrolysis and acidification pool	100 m^3	1	350	3.50
4	Anaerobic digester	350 m^3	2	500	35.00
5	Sedimentation pool	40 m^3	1	350	1.40
6	Oxidation pond	5200 m^2			10.00
7	Biogas holder	150 m^3	1	1,000	15.00
8	Office and power distribution room	50 m^2	1	600	3.00
9	Purification room	20 m^2	1	600	1.20
10	Organic fertilizer workshop	800 m^2	1	350	28.00
11	Liquid storage pool	1,500 m^2	1	100	10.00
12	Inside road etc.	1,000 m		80	8.00
13	Fence	200 m		100	2.00
14	Landscaping				3.00
Subtotal	122.30 (10^4 Yuan)				

II. Cost of anaerobic digestion system					
No.	Item	Standard	Unit	Unit price	Cost (10^4 Yuan)
1	Steel grills	150032000	1	0.1	0.1
2	Hydraulic screen slice	240032400	1	3.2	3.2
3	Sewage delivery pump	AS16－2CB	2	0.28	0.56
4	Anaerobic feeding pump	1PN	2	0.30	0.60
5	Three-phase scatterer		2	6.0	12.0
6	Water distributor			0.5	1.00
7	Overflow sink for anaerobic digester		2	0.5	1.0
8	Warm-holder for anaerobic digester		1	2.5	2.5
9	Elasticity filler		60	0.025	1.50
10	Water and gas disperser	GF－60	1	0.60	0.60
11	Desulfuration tower	TS－250	2	1.20	2.40
12	Water condenser	BC－300	4	0.10	0.40
13	Drymatter back-fire relief valve	AF－80	1	0.24	0.24
14	Biogas flowmeter	LMN－25	1	0.45	0.45
15	Pipeline, valve and fitting, and their installation			10.00	10.00
16	Biogas combustion equipment		20	500	4.00
17	Fire hydrant and firefighting equipment		1	1.000	1.00
18	Electric equipment and its installation		1	4.00	4.00
19	Solid-liquid disperser		1	10.00	10.00
20	Special gas compressor and automatic control system				9.88
21	Gaugeable liquefied biogas tank (with ground scale)				6.6
22	Product canning engine				2.5
23	Auxiliaries canning engine				2
24	Auxiliaries-only carrier				5.6
25	Solar energy system				2
Subtotal	94.13 (10^4 Yuan)				

III. Cost of the production system for organic fertilizer				
No.	Item	Unit	Unit price	Cost (10^4 Yuan)
1	Blender/preparer	1	3.16	3.16
2	Heavy metal removal system	1	10	10
3	Crusher	2	1.10	2.20
4	Dehydrator	1	1.52	1.52
5	Vibrator	1	0.80	0.80
6	Liquid organic fertilizer equipment		20.00	20.00
7	Computerised assembly equipment	1	15.00	15.00
8	Product test and examination equipment	1	3.00	3.00
9	Transformer and its accessories	1	8.00	8.00
10	Installation and test		2.00	2.00
Subtotal	65.68 (10^4 Yuan)			

IV. Other expenditure				
No.	Item	Unit	Unit price	Cost (10^4 Yuan)
1	5-tonne truck (Chunfeng brand, EQ3092F19D5A)	1	8.40	8.40
2	1.5-tonne forklift	1	3.20	3.20
3	Bacteria cultivation cost (2% of direct fixed cost)		5.67	
4	Installation cost		14.19	14.19
Subtotal	31.46 (10^4 Yuan)			

Total	3.14 (million Yuan)

Appendix 2. Project cash flow (unit: million Yuan)

Year	Biogas and organic fertilizer benefits	Residual value	Operating cost	Investment cost	FNPV without carbon value	Benefit of GHG emission reduction	FNPV with carbon value
0	0.81		1.24	3.14	-3.56	0.36	-3.20
1	0.74		1.13		-0.39	0.33	-0.06
2	0.67		1.03		-0.35	0.30	-0.05
3	0.61		0.93		-0.32	0.27	-0.05
4	0.56		0.85		-0.29	0.25	-0.04
5	0.50		0.77		-0.27	0.23	-0.04
6	0.46		0.70		-0.24	0.21	-0.04
7	0.42		0.64		-0.22	0.19	-0.03
8	0.38		0.58		-0.20	0.17	-0.03
9	0.34		0.53		-0.18	0.15	-0.03
10	0.31		0.48		-0.17	0.14	-0.03
11	0.28		0.44		-0.15	0.13	-0.02
12	0.26		0.40		-0.14	0.12	-0.02
13	0.24		0.36		-0.12	0.11	-0.02
14	0.21	0.56	0.33		0.45	0.10	0.55
Total	6.80	0.56	10.39	3.14	-6.16	3.04	-3.12

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