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論　著

Using Integrated Governance and the Circular Economy Model to Solve River Watershed Pollution: A Case Study of Taiwan's Donggang River

運用統合治理與循環經濟模式解決流域汙染問題—以臺灣東港溪為例

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ABSTRACT

The Donggang River, located at the Taiwan Pingtung Plain, has a total length of 44 km. It supplies 300,000–350,000 m^3 of industrial-use water to the adjacent Kaohsiung City. However, the wastewater discharged by livestock-rearing businesses around the midstream of the Donggang River has resulted in a serious deterioration of water quality, causing 74% of the total pollution. Water samples indicated that the river water has been severely polluted, and that most pollutants are ammonia and nitrogen. After conducting extensive interviews with livestock farmers and scholars, convening multiple expert meetings and workshops, and analyzing the dilemmas and issues related to the deep-rooted, lingering pollution problems, a transition model from the conventional linear-economy wastewater-handling was recommended in this study. Accordingly, this study proposed an innovative multi-strategy intervention, which involves the implementation of a "circular economy" model (i.e., the conversion of the pollutants into resources and energy) to solve the deep-rooted, lingering pollution problems. From the technical perspective, the reapplication of postanaerobic digestion biogas slurry and residue was used to replace the three-stage wastewater treatment method, a complex and expensive method that requires much energy. The greater implementation of the circular economy must, however, involve the amendment of existing laws. Therefore, this study also details how laws were amended, including the team's efforts in these amendments. In line with the six-year "Forward-Looking Infrastructure Plan" proposed by the Executive Yuan in 2017, this study adopted green banking and those business models and provided a new governance model for solving the problems of

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conventional river pollution treatments in conjunction with the subsequent formation of the industry chain.

Keywords: Watershed integration management, Circular economy, River pollution remediation, Biomass energy, Gasifier (Pyrolysis).

摘　　要

位於台灣屏東平原的東港溪，全長約為44公里；並提供鄰近的高雄市每日30萬–35萬立方米的工業用水。然而，東港溪中游附近畜牧業排放的廢水導致水質嚴重惡化，佔總污染量來源的74%，水質皆呈嚴重汙染等級，大多數污染物以氨氮污染為主。本研究從探討汙染成因，歷經密集訪談畜牧業者與相關學者，並召開多次專家會議與工作坊後，從技術面與社會面分析污染問題沉苛多年之困境與課題，得以必須超脫於原先「線性經濟」模式之汙水處理方式的共識。因此，本研究提出了創新的多元解決方案，即將污染源轉化為資源和能源的「循環經濟」模式(即，將污染物轉化為資源和能源)來解決根深蒂固的汙染問題。本文以技術面、法令面與政策面探討屏東縣四年來以「循環經濟」模式改善畜牧與農業汙染之初步成果，並提出後續發展建議。在技術面上主要以厭氧消化後之沼液沼渣「還肥於田」取代之前高成本、耗能且操作複雜之三段式廢水處理方式，另以氣化(炭化)裂解產氣發電方式處理農業廢枝材與牛糞渣，解決農民露天焚燒與牛糞渣排入河川成浮渣河之汙染沉苛問題。循環經濟的推動涉及許多舊法令的修正，故在法令面修正則本研究也記錄修法的過程與努力，亦提出部門整合綜合治理的分工。本研究2017年適逢行政院推動為期六年的前瞻基礎建設計畫，本研究亦獲致行政院極力支持為重點推動計畫，兩年來多項子計畫陸續推動已見成果，已為農業循環經濟模式建立良好經驗範例，本研究最後亦提出了後續形成產業鏈之商業模式與綠色金融之可行建議，期能提供解決傳統治理河川汙染困境之新的整治模式。

關鍵詞：流域統合治理，循環經濟，河川汙染整治，生質能源，氣化(裂解)爐。

1. INTRODUCTION

Taiwan's Pingtung County has a traditional economy based on agriculture, particularly in livestock. According to the November 2017 "Pig Headcount Survey Report" published by the Council of Agriculture (COA), Executive Yuan, Pingtung county had 1710 pig rearing farms and 1,233,642 pigs, making Pingtung the second-largest pig-rearing county in Taiwan. The livestock industry has long been an important source of income for Pingtung County's farmers. However, the foul smell and river pollution caused by the industry have disrupted the everyday lives of county residents, causing much resentment among them. The primary reason for the foul smell and river pollution is farm owners' tendency to handle sewage using the easy, conventional method of disposal. Relative to other countries, the Taiwanese government's discharge standards are lax. For example, the stipulated chemical oxygen demand (COD) standard is at 600 ppm. Despite these relatively lax standards, many livestock farm owners are still unable to meet them. These farm owners have been using equipment that has been obsolete for the past 30 years, sometimes even refusing to operate the equipment to save on electricity costs. Therefore, wastewater discharge operations in Taiwan have fallen short of stipulated standards, resulting in major pollution.

The Donggang River is a major river of the Pingtung Plain. It has a total length of 44 km, a watershed area of 436 km^2, and a watershed scope that covers 17 townships of the Pingtung County. The Dongang River has an extraordinary formation. According to a book published by the Southern Region Water Resources Office of Water Resources Agency (WRA), Ministry of Economy Affairs—*The study of facilities for the public water supply of Donggang River (2011)*—Donggang River comprises springs supplied by a perennial

flow of groundwater (including subsurface water); these water resources constitute more than 90% of the available river water sources. Therefore, the water resources supplying the Donggang River are abundant and have a steady flow, with a mean daily flow of 2,060,000 m^3. The decades-old Donggang River Weir (also known as the Gangxi Weir) was constructed downstream of the Donggang River to remedy the industrial water shortage in Southern Taiwan. The Donggang River supplies 300,000–350,000 m^3 of water to the adjacent Kaohsiung City daily for industrial usage via a transbasin diversion. However, the livestock-rearing businesses that flock around the Donggang River's midstream (these livestock-rearing establishments have covered almost 74% of the watershed area of the river) have resulted in a serious deterioration of water quality. In the past five years, water samples taken at the river sections between the lower stream (at Cinsheda Bridge) and the Gangxi Water Pumping Station have exhibited a Water Pollution Index (WPI) as high as 5.0, sometimes even reaching 6.0; indicating severe pollution in these river sections. In response, backend water treatment plants require much money and energy to handle the ammonia and nitrogen in the untreated river water. Even with existing purification efforts, the treated water is still often unable to meet the stipulated water quality standards (Donggang Creek Sewage Information Statistics, 2018).

The only existing pollution control measure that acts as a deterrent is the inspections conducted by environmental protection departments. However, the area has many pig and cow farms. According to livestock-farmer data in the Water pollution Management Information System Data Bank, on November 2018, 401 livestock-rearing facilities were located on the upstream of the Gangxi Water Pumping Station (371 pig-rearing facilities and 30 cow-rearing facilities), with an official livestock headcount of 430,085 (426,641 pigs and 3,444 cows). Additionally, Pingtung County had 1,914 wastewater-discharging livestock-rearing facilities. In contrast to these large numbers, routine inspections are only carried out by less than 30 environmental protection personnel, and the yearly fine of NT$30,000,000 paid by Pingtung County's livestock industry ranks as one of the highest in Taiwan. These indicate the futility of inspections alone, as a deterrent, and the necessity of supplementary counseling and subsidiary measures from other departments (e.g., the agricultural department). In general, the problem of wastewater handling and livestock housing must be addressed at its root causes.

Ever since the author assumed the role of director of the Pingtung County Environmental Protection Bureau on December 2014, the author has spearheaded the active promotion of the policy "Turning Livestock Manure From Energy-Consuming Contaminants to Reusable Resources through Waste-to-Energy Transformation (Methanogenesis) and Resource Recovery (Fertilization)," a measure started by the previous county magistrate. The aim of this policy is to address the livestock-industry pollution problem at its root causes. Additionally, large quantities of biomass materials (e.g., stems, leaves, and paddy straws) have been generated from agricultural operations, such as fruit tree trimming and paddy harvesting, because waste materials have not been properly utilized. Specifically, farmers are adept at disposing these biomass materials through open burning, where the resultant smoke causes serious air pollution and jeopardizes the road safety of motorists driving on nearby roads. Additionally, soil acidification and food safety problems that have been caused by the heavy use of chemical fertilizers and pesticides must be addressed. Therefore, as the performer of this policy research and the executor of public power, the researchers, with their colleagues, investigated those factors contributing to water pollution. After conducting extensive interviews with livestock farmers and scholars, convening multiple

Table 1. Workshops and expert forums held in 2015 (Organized by the writer)

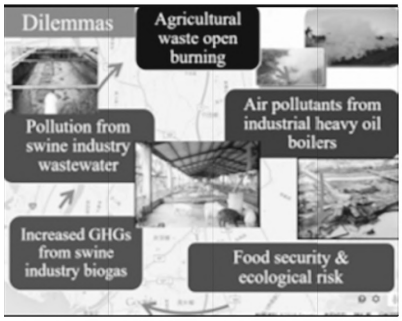
Date	Name of the meeting
2015/3/17	**The Pingtung County Pig Rearing Pollution Tackling Roundtable Forum** We invited the consultancy firms and more than ten scholars responsible for researching and executing the relevant projects. The purpose of the forum was to clarify the issue and organize information on both participant experiences and the problems involved in addressing the pollution problem.
2015/4/1	**The Pingtung County Pig Rearing Pollution Tackling Symposium** Multiple experts and representatives from agricultural, environmental, urban and rural planning, water resources departments were invited to formulate a solution mind map; participants used the focused discussion method and emphasized public–private partnership.
2015/4/20	**Visit to a litter-bed pig house at the Livestock Research Institute, COA** Examine the techniques and multi-strategy solution plan developed by the Livestock Research Institute.
2015/6/29	**The first symposium of the "Donggang River Pollution Reduction Strategy and Environmental Enhancement" comprehensive planning workshop** The preliminary draft of the "2030 Prospective Vision Plan for Donggang River" was proposed and presented. Personnel from central and local environmental, water resources, urban and rural planning, and agricultural departments as well as scholars from the fields of social development and public affairs were invited to review the proposed vision plan, including identifying weaknesses in the vision plan and providing advice.
2015/8/6	**The second symposium of the "Donggang River Pollution Reduction Strategy and Environmental Enhancement" comprehensive planning workshop** The advice given in the previous session was incorporated into the presentation of the vision plan. Circular-agriculture and public-participation mechanisms were then added to the plan, and opinions were again solicited through discussion.
2015/11/12	**The third symposium of the "Donggang River Pollution Reduction Strategy and Environmental Enhancement" comprehensive planning workshop** Participants constructed the vision plan using concepts such as agricultural resource recycling, community building, and rural regeneration, in addition to incorporating flood control measures and measures for the groundwater replenishment of the Chaozhou Artificial Lake.

expert meetings and workshops, and analyzing the problems and issues related to lingering and deep-rooted pollution problems, the researcher and their colleagues proposed that the agricultural circular economy must be immediately adopted to address the pollution problems caused by agricultural waste pollution and the livestock industry. Accordingly, the researcher and their colleagues have proposed an innovative multi-strategy intervention, which involves the implementation of the "circular economy" model (i.e., the conversion of pollution sources into resources and energy) to solve deep-rooted and lingering pollution problems. Not only that, this issue implicates a complex of governance institutions, thence it cannot be solved through the lone effort of the Environmental Protection Bureau. Generally, effective governance strategies and department integration mechanisms have yet to be devised to address this problem. Integrated governance, an emerging mode of governance that involves all relevant departments, is important. Therefore, the author has further proposed an integrated governance framework, and a division of labor framework that has the chief secretary of Pingtung County leading the project. The following sections discuss the implemented strategies and their results.

At the end of 2015, the predicaments induced by pollution problems in Pingtung were transformed into a new sustainable green economic cycle after much discussion. The descriptions, along with schematics, are presented as follows.

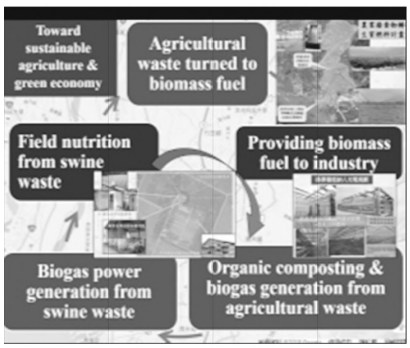
2. INNOVATIVE APPROACHES

This study compares between the circular economy model and conventional linear economy model with regard to the use of agricultural waste



Pollution problems in Pingtung:

1. Methane discharged from the treatment of livestock wastewater results in the greenhouse effect.
2. Despite preliminary processing, the wastewater that is discharged into the river has burdened the environment and caused pollution.
3. The open burning of agricultural stem and branch waste materials causes air pollution and jeopardizes traffic safety.



Transforming these problems into elements of a sustainable agricultural circular economy:

1. Use the biogas generated from the anaerobic digestion of livestock waste in biomass electricity generation.
2. Use the postanaerobic digestion biogas slurry and biogas residues in farm crop irrigation.
3. Collect agricultural stem and branch waste materials for the making of biomass fuels (RDF-5)
4. Replace heavy oil–based boiler fuels with biomass fuels. Biomass fuels produce zero, or even negative, carbon emissions. Therefore, the use of biomass fuels can reduce air pollution.

Fig. 1. Transforming pollution problems into a sustainable agricultural circular economy model.

Theory: Livestock Industry from Linear Economy to Circular Economy

1. **Linear economy: livestock and poultry waste → energy consumption treatment → emissions as environmental pollution**
2. **Circular economy: livestock and poultry excrement as energy and resources → resource treatment → as organic fertilizer and biogas energy**

Fig. 2. Comparison of circular economy and conventional linear economy models.

products.

2.1 First technical aspect of the circular economy: promoting the waste-to-energy transformation (methanogenesis) and resource recovery (fertilization) of livestock manure

The resource recovery of livestock manure (i.e., conversion of pig manure into farmland fertilizers) was introduced into Taiwan 30 years ago and has been fully implemented since. There is even a Taiwanese proverb that says “scholars who do not study are akin to manure that is not reapplied to farmland.” In 1991, the Taiwanese government proposed legislation to regulate livestock industry–produced wastewater. Pig rearing farms with more than 200 pigs were required to install wastewater treatment equipment. Although this policy has been in force for almost 30 years, livestock farm owners still tend to handle sewage using the simple and conventional method. Relative to other countries, the Taiwanese government’s discharge standards are lax. For example, the stipulated COD standard is at 600 ppm, in contrast to mainland China’s previous and stricter COD standard of 400 ppm. COD standards in Taiwan, however, have been made more stringent in many provinces. At present, most livestock farm owners use a three-stage wastewater treatment method, comprising solid–liquid

separation, anaerobic (facultative) fermentation, and aerobic aeration treatment, to handle effluents. However, many livestock-rearing farm owners use equipment that has been obsolete for 30 years, they are unable to properly handle wastewater and thus fall short of stipulated standards. To exacerbate matters, because the aerobic aeration procedure is expensive due to its high consumption of electricity, some farm owners refuse to even operate the requisite equipment to cut costs, simply discharging improperly treated sewage into the river. Therefore, river pollution has been a long-standing problem in Taiwan. Furthermore, for livestock farmers, the existing process for executing proper water treatment is too tedious, making it difficult for them to work together with the government in mitigating river pollution from sewage discharge.

Livestock manure is a highly organic and nitrogenous substance. The water-soluble and solid substances generated through the anaerobic digestion of livestock manure are known as biogas slurry and biogas residue, respectively. Both substances contain enriched nutrients that can enhance plants' disease and pest resistance as well as absorption of nutrients, ultimately increasing the crop yield. Additionally, the use of farmland fertilizers that are based on biogas slurry and residue reduces farmers' reliance on chemical fertilizers, thus promoting organic farming and resulting in considerable cost savings for the farmer. Foreign countries have had cases of the successful implementation of the use of such fertilizers.

1. For several decades, European countries such as Sweden and the Netherlands have adopted the practice of subjecting livestock manure to anaerobic fermentation where the treated manure is then used as fertilizer for farmland, having much experience with this method. In these European countries, pig farmers sign the operation contract with crop farmers.
2. The European Union has stipulated that all livestock-rearing waste products must be reapplied and reused in farmland.
3. United Kingdom has declared postanaerobic digestion biogas slurry and residue to be biofertilizers. These biofertilizers are commercially valuable because they can be traded.

The Pingtung County Environmental Protection Bureau has suggested to the Environmental Protection Administration (EPA) of the Executive Yuan to refer to both the status of the livestock industry and experience of other countries when planning and promoting such projects. Additionally, the Pingtung County Environmental Protection Bureau has also urged the EPA to consult scholars, the R.O.C. Swine Association, and the Dairy Farmer Association R.O.C.. Lastly, the EPA has discussed and negotiated with the COA with regard to the collected information. As a result, the EPA amended and promulgated the "Water Pollution Control Measures and Test Reporting Management Regulations" on November 24, 2015, with 10 special clauses related to the use of biogas slurry and residue–based farmland fertilizer stipulated, to facilitate the management of the reapplication of biogas slurry and residue in the farmland. The EPA amended the "Water Pollution Control Measures and Test Reporting Management Regulations" on October 28, 2016; the amendment was aimed at expanding the scope of applicable subjects for the use of biogas slurry and residue–based farmland fertilizers, simplifying the inspection items, and incorporating additional measures such as the management of flexibility items; these modifications expanded the scope of participation with regard to the use of biogas slurry and residue–based farmland fertilizers. With the EPA-sponsored fund, a three-year promotion project was initiated in Pingtung in early 2016. (EPA Water Quality Protection Web, https://water.epa.gov.tw/Public/EN/HEResource.aspx)

After 3 years of promoting the policy, the Pingtung Country Government has convened more

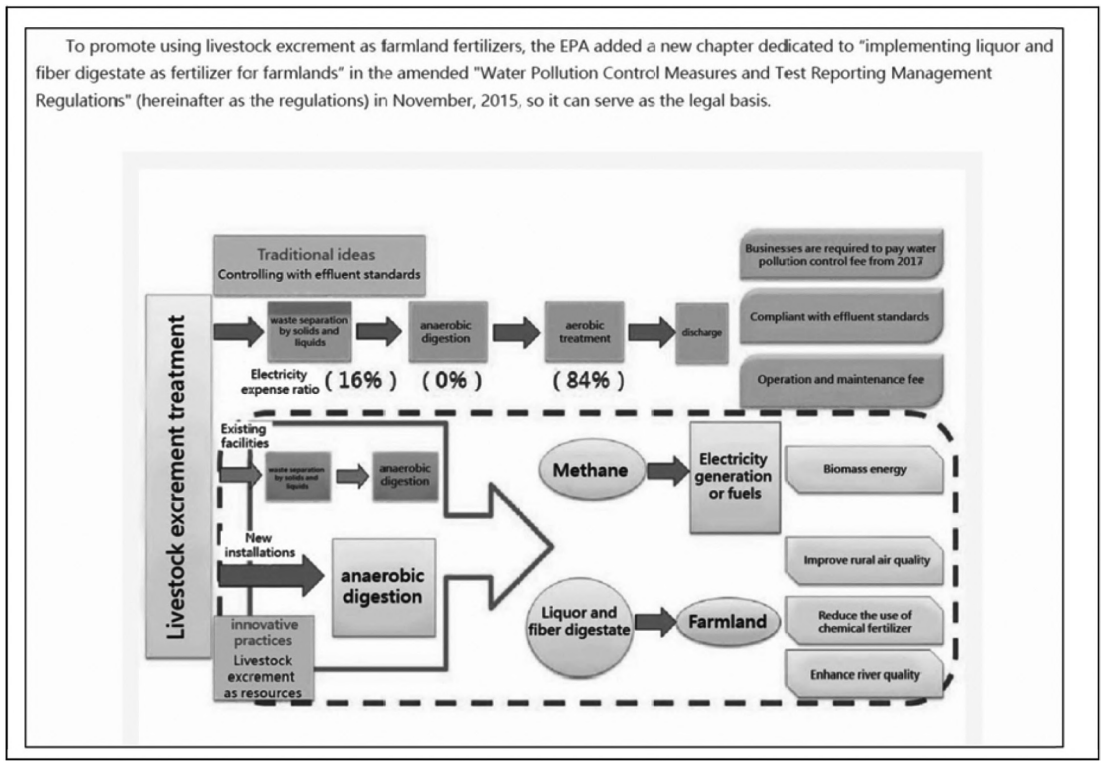


Fig. 3. "Water Pollution Control Measures and Test Reporting Management Regulations" amended and promulgated on November 24, 2015; 10 special clauses related to the use of biogas slurry and residue–based farmland fertilizer were stipulated (extracted from the 2016 Bulletin of Environmental Protection Administration).

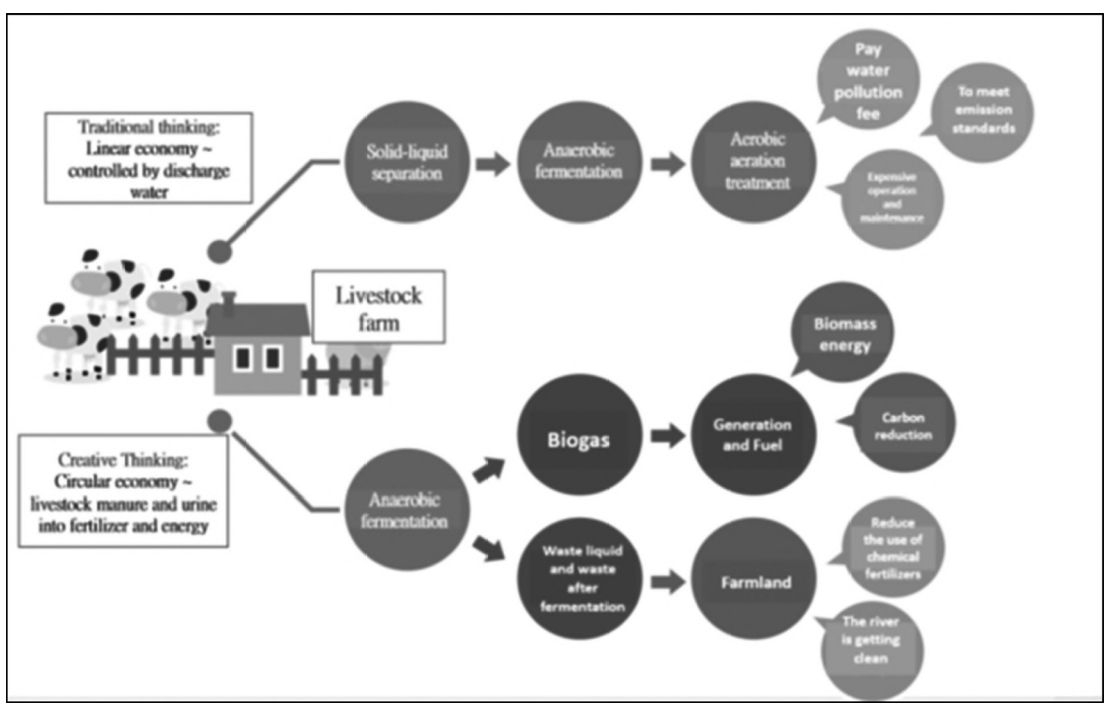


Fig. 4. Inverting existing methods of managing livestock manure through the resource recovery of livestock wastewater (extracted from the 2016 Bulletin of Environmental Protection Administration).

than 50 conferences to brief livestock farmers on the use of biogas slurry and residue–based fertilizers as well as to give irrigation advice. Additionally, the Pingtung Country Government has stipulated various innovative strategies with the purpose of convincing the farmers to join the biogas slurry and residue–based fertilizer use project, the strategies are detailed as follows.

A. Establishing the livestock industry advisory team.

The Pingtung County Government has established a county level advisory team, which comprises the Agriculture Department, the Environmental Protection Bureau, and the environmental consultancy team. Within its first year of founding, the team had conducted door-to-door interviews with 44 livestock farms in various townships, including Xinbi Township, Wandan township, and Chaozhou Township; 17 livestock farms agreed to join the biogas slurry and residue–based fertilizer use project. Meanwhile, the advisory team also collected information on the concerns of crop and livestock farmers; these data were then used in the post-mortem review for the subsequent years of the project, allowing the advisory team to better assist other livestock farms when joining the project.

B. Select exemplary livestock farms and provide them with free irrigation assistance to establish word-of-mouth publicization of the project.

In the first year, we had assisted the farmers of Pingtung in transporting over 5,000 tons of biogas slurry and residue. Most of these farmers reported the biogas slurry and residue to be beneficial for their crops, with no side effects. Additionally, the hydrogen sulphide in the biogas slurry repels insects, which in turn reduces the use of pesticides. The Pingtung Environmental Protection Bureau has also made educational videos to broadcast such information.

C. Collaborate with agricultural technical experts to perform field experiments.

Irrigation using pig manure–based fertilizers have been absent in Taiwan for the past 30 years. Additionally, the increased use of organic fertilizers shrinks the market for chemical fertilizers, the Taiwan Government has provided a 40% subsidy to aid the chemical fertilizers industry. Due to this conflict of interest, some have spread the rumors that biogas slurry and residue are poisonous, eroding farmers' lack of confidence in fertilizers based on these biogas products. In response to such a misconception, the Pingtung County Government invited various agricultural experts (including Associate Professor Lin Yong Hong from National Pingtung University of Science and Technology) to conduct field experiments on the postanaerobic digestion pig biogas slurry and residue; involving irrigation of mango, guava, date, lemon, coffee bean, dragon fruit, betel nut, and banana crops.

Experiment results:

1. In the process of irrigation, the pig manure-based biogas slurry and residue exuded no prominent odor, with the exception of hydrogen sulphide, which some have reported to smell similar to a foul-smelling ditch but only at a close distance.
2. The continual use of pig manure–based biogas slurry and residue heightens the soil's nitrogen content.

The expert from advisory team reminded the farmers that the use of pig manure and digestates is beneficial for the plants and soil and that they need not worry about the presence of residual copper and zinc in the soil. However, the use of biogas slurry and residue as farmland fertilizers results in the problem of phosphorus and potassium deficiency during the flowering and fructicative periods. Therefore, farmers should supplement their crops with phosphorus and potassium nutrients. This highlights the importance of biocharcoal (obtained from the carbonization of agricultural waste materials) as a fertilizer that provides phosphorus and potassium nutrients.

D. Integrating the various governmental pollution control and prevention resources to increase

subsidies for livestock farmers, which in turn function as incentives.

In addition to the competition for funding from the COA for the renewal of existing wastewater treatment equipment, the Pingtung County Government has, since 2017, also started to collect water pollution control fees from the livestock farming industry. However, livestock farmers who do not discharge their wastewater into the river and are willing to cooperate with the biogas slurry and residue irrigation policy are exempt from the water pollution control fees.

E. Integrating existing wastewater treatment equipment in the field and "irrigate pasture grass with biogas slurries and residues" at the high riverbank area.

Several on-site wastewater treatment equipment were set up at the more severely polluted tributaries of the Donggang River. The Environmental Protection Bureau has planted pasture grass (code: Taishiu No. 6) at the 30-hectare high riverbank land located at the convergent point of the Long Jing River's drainage system and the mainstream of the Donggang River. Irrigated using livestock wastewater, these pasture grass can be used to purify water. The pasture grass could be harvested 4 to 5 times per year, and the harvested pasture grass could be used as cow feed; this constitutes another innovative idea in addition to the recycling of livestock wastewater. (Pancheng Engineering Consultants Co Ltd. 2017–2018)

2.2 Second technical aspect of the circular economy: promoting the collection of agricultural stem and branch waste materials after fruit tree trimming and paddy harvesting and turning the mixture of biomass waste materials with cow manure residue into biomass fuel

Farmers in Taiwan typically treat biomass materials (e.g., stems, leaves, and paddy straws) from agricultural operations, such as fruit tree trimming and paddy harvesting, as waste materials, long adopting the practice of open burning to dispose them. Although the open-burning ashes are rich in carbon and potassium nutrients and can thus be reused as fertilizers for farmland, farmers also often burn other agricultural garbage (e.g., plastic sheets used to cover the crops) together with these biomass materials, causing substantial environmental problems. In addition to its pernicious effect on air quality, the resulting smoke jeopardizes the driving safety of cars on nearby roads. The Environmental Protection Bureau is responsible for conducting air pollution inspections from time to time. In Pingtung, the instances of fines for open burning exceeded those of other counties by multiples of ten. Although fines have a deterrence effect, they constitute a considerable financial burden on economically disadvantaged farmers. Furthermore, without a feasible alternative, farmers will find it difficult to change their long-standing habit of open burning. In response, the Pingtung County Government has started advising local farmers to crush the stem and branch waste materials and paddy straws using small machinery to make them into organic farmland fertilizer through fermentation. Practical experience over the past few years has indicated that paddy straws are especially useful in the making of such fertilizers. However, the leftover branches from fruit tree trimmings and the large branches from hurricanes are difficult to process locally. Additionally, although the county government has assisted farmers in forming farmer cooperatives and fully subsidized the purchase of small crushing machinery, operators are expensive to hire and thus constitute a considerable financial burden on farmers. Additionally, Pingtung is a major county in the rearing of dairy cows. The county rears a total of 28,000 dairy cows, and close to 70% of them are reared in Donggang River's catchment area in Wandan township. After the cow manure were subjected to solid–liquid separation treatment and wastewater treatment, the remaining cow manure residue could not be easily disposed

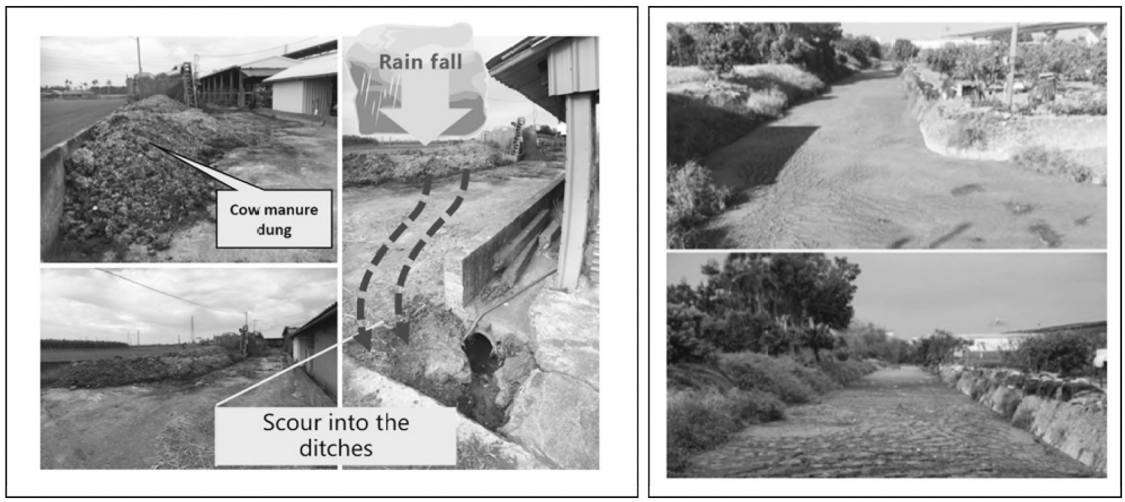


Fig. 5. (left): The post solid-liquid separation cow manure residues that were stacked in open air by the livestock (cow rearing) farmers due to disposal difficulties. (Right): The river that is full of floating manure residues, which is caused by the scouring of openly stacked manure residues into the river on rainy days.

(fertilization from cow manure residue occur over months, making the disposal of manure residue a slow process). This causes cow farmers to stack cow manure residue in the open, ultimately leading to the phenomenon of the "floating-manure" river when cow manure residue is scoured into the river on rainy days. In April 2017, members of the public complained about the disgusting "floating-manure" river in Wandan township; this complaint made national news, which severely tarnished the image of cow farmers. However, in Taiwan's earlier history, people did indeed practice gathering, drying, and then accumulating cow manure for use as fuel. The COA has also researched and promoted the use of solid cow manure–derived fuel (Xiao Tingxun Cheng Meiping, 2013).

The agriculture area of Pingtung constitutes a quarter of the total county area. Therefore, the county generates much agricultural waste. If estimated based on the trees of fruits that grow abundantly in Pingtung, the weight of the stem and branch waste materials alone is as high as 120,000 tons. Such waste materials produced by the trimming of sidewalk trees also exceeded 3,000 tons. To address the pollution caused by woody waste materials and cow manure residue in Pingtung, as well as to create economic value from the conversion of waste materials into renewable resources, the Pingtung Environmental Protection Bureau has started designating the woody waste materials as resource materials starting from the end of 2015. The Pingtung Environmental Protection Bureau has sought to achieve the integration and recycling of resources. Additionally, the Bureau has sought to achieve the implementation, through two stages, of the circular economic flow of "resources → pollution products → renewable resources → economic value."

A. Stage 1: An abandoned factory building that was originally used to handle large driftwood from hurricanes was first rented out to attract private investment for restoration. After the building was restored, new machinery were imported. Subsequently, various subsidies were implemented to assist each township in gathering the uncrushable stem and branch waste materials and transporting them to the factory building for further processing. These waste materials were filtered, dried, crushed, and compacted into biomass pellet fuel rods (RDF-5). Such biomass pellet fuel rods could serve as a source of boiler fuel for factories in the industrial area that

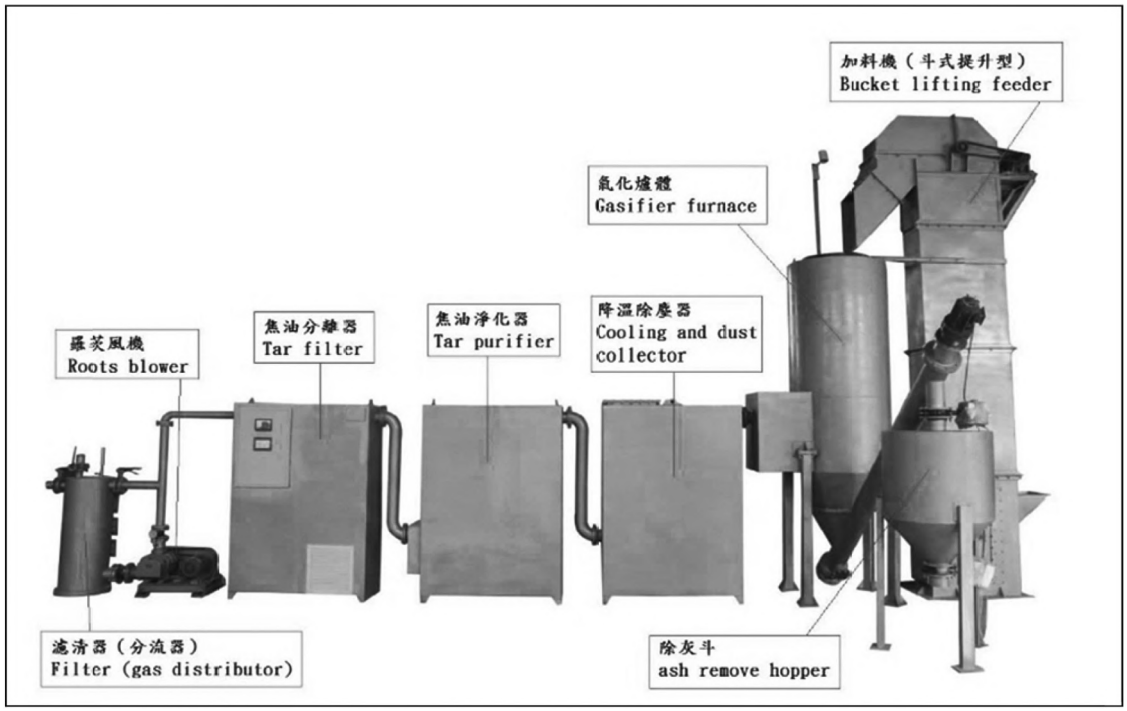


Fig. 6. The 100-KW biomass pyrolysis gasifier (source: the consultant company, Yuh Shan Environmental Engineering Co., Ltd.).

originally use heavy oil fuels for their boilers. Additionally, the Pingtung Environmental Protection Bureau also actively prepared for the generation of electricity using the cogeneration method in stage 2.

B. Stage 2: Relative to the use of heavy oil–based fuels, the production of biomass fuel rods using agricultural waste materials in stage 1 has been proven to be more cost effective and less prone to air pollution. However, the transportation cost involved in biomass fuel–rod production offsets its economic benefits. Therefore, in stage 2, the researcher began investigating the production of combustible gases (i.e., gases such as CH_4, CO, and H_2) from biomass fuel and gasification pyrolysis, where these combustible gases can be used for electricity generation. Several byproducts are produced from gasification pyrolysis, including biocharcoal, pyroligneous acid, and tar. Biocharcoal can be made into fertilizers, which can be used to remedy problems from the excessive nitrogenous content in biogas slurry and residue. The pyroligneous acid can be used in nonpoisonous herbicides, and tar is highly commercially valuable. The vendors, under the coaching of the EPA, have taken the initiative to be the first in Taiwan to invest in equipment for processing biomass waste materials using the pyrolysis gasification method. Such equipment is also capable of processing cow manure residue, whose processing is troublesome for farmers. The cow manure residue is mixed with woodchips to produce RDF-5 biomass fuel rods (Figure 7). Subsequently, the biomass fuel rods would be put through prolysis gasifier equipment to produce biocharcoal, combustible gases, and electricity. After a year of preparation, a pyrolysis gasifier that could operate continually was produced on November 2018. This gasifier could process 6 to 8 tons of agricultural waste materials daily, and it is equipped with 100-KW gas-fired electricity-generation equipment that can operate round

Fig. 7. Fuel rods (RDF-5) made by mixing cow manure with farm and forestry waste (Pingtung Local News TV, 2018.12.03).

the clock. (Circular Economy Project to Reduce the Burning of Agricultural Waste in Pingtung County, 2018)

2.3 Establishing the integrated governance platform for the governance of Donggang River

The aforementioned agricultural circular economy model involves numerous central and local departments. Therefore, the integration of governance operations is much needed. Although this project was proposed by the local Environmental Protection Bureau, much of the governance jurisdiction falls under the agricultural, land management, urban and rural planning, and even water resources departments. The Pingtung Environmental Protection Bureau proposed the "2030 Prospective Vision Plan for Donggang River" in 2015. This plan adopts the circular economy model as the framework, and covers river water quality, water volume, and the living environment along the shores. In this project, the county chief secretary acts as the convener who is responsible for connecting the different departments. Additionally, a policy communication platform was formed by the agency in charge of the Donggang River, the Seventh River Management Office of the WRA.

In May 2016, Taiwan had a transition of power in its central government. In early 2017, the new government proposed the "Forward-Looking Infrastructure Plan," which covered crucial infrastructure, such as transport, green energy, digital infrastructure, water resources, and environmental infrastructure. In conjunction with the Executive Yuan's proposal of the "Forward-Looking Infrastructure Plan," the Pingtung County Government submitted the proposal "2030

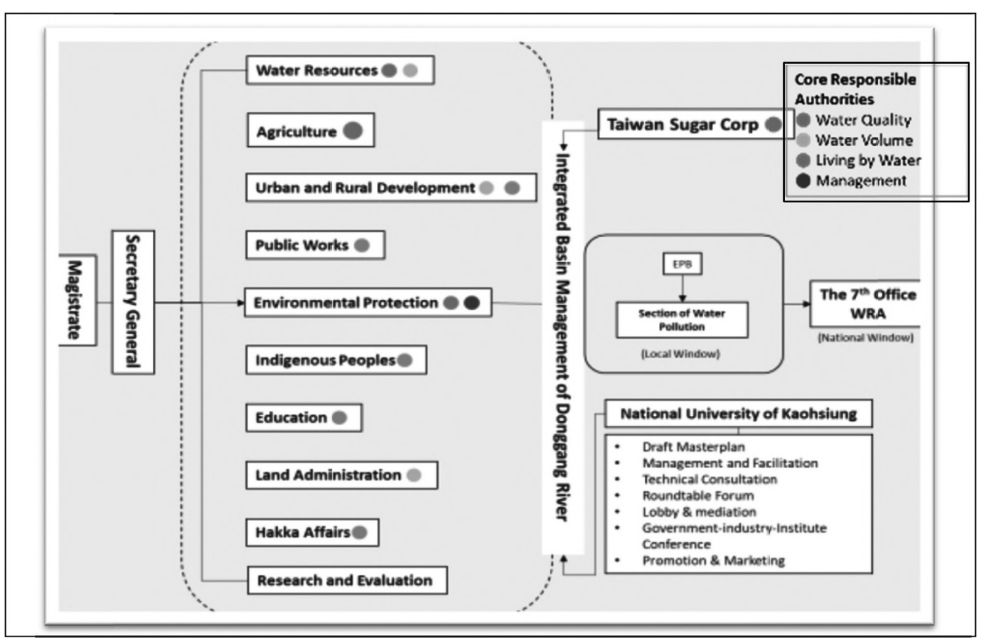


Fig. 8. Structure of the integrated governance platform (proposed under the Pingtung County Donggang River Vision Plan, 2018~2019) led by the County Chief Secretary.

Prospective Vision Plan for Donggang River." After a 6-month review, this project was approved by the central government. Furthermore, the county plan was selected as a water and environment demonstration project. The Ministry of State of the Executive Yuan proactively formed a promotion platform that included multiple parties, such as the COA, WRA, Construction and Planning Agency, EPA, and Taiwan Sugar Corporation. The management of this platform was carried out through meetings that are held once every month or every two months, where rolling reviews were performed. This management model is unprecedented in the current system of governance.

3. RESULTS AND DISCUSSION

3.1 Results of the promotion of waste-to-energy transformation (methanogenesis) and the resource recovery (fertilization) of livestock manure

A. Results achieved over the years

In addition to the aforementioned results in administration and infrastructure construction, the Pingtung Environmental Protection Bureau has also achieved excellent results in water pollution remediation through the project of "Promoting the Use of Biogas Slurry and Residue–Based Farmland Fertilizer." For example, the Pingtung County Government entered the aforementioned project into the Benchmarking Learning Project competition organized by the Directorate-General of Personnel Administration, Executive Yuan, winning the Excellent Project Award, where only three projects throughout Taiwan won this award. Additionally, in the EPA appraisal, the Pingtung Environmental Protection Bureau has obtained an excellent or distinction grade in the water pollution control assessment, soil and groundwater assessment, and ocean pollution control assessment. In the Commonwealth Magazine's 2019 satisfaction survey on county magistrate administration, the county magistrate of Pingtung County, Mr. Pan Men An, was voted the most popular county magistrate of Taiwan, having the highest level of satisfaction in the survey among all Taiwanese county magistrates. The public has also approved projects related to the improvement of the livestock industry around Donggang River.

B. Promotion results achieved up until now

We now describe the project "Promoting the Use of Biogas Slurry and Residue–Based Farmland Fertilizer," which was executed from 2016 to 2019. Until November 2019, 180 applications (including currently processed cases) related to the use of biogas slurry and residue–based farmland fertilizers have been submitted to the Pingtung County Government; 149 and 31 applications were from pig and cow farms, respectively. At present, 101 of these applications have been approved; 83 and 18 of these are from pig and cow farms, respectively. The remaining 79 are still being processed; 66 and 13 of these are from pig and cow farms, respectively. The total area of irrigated farmland is 298.770018 hectares, and the volume of the available biogas slurry is 671,360.40 ton/year. More than 30 types of farm crops have been irrigated using the biogas slurry, including crops such as tomato, pumpkin, chive, radish, pineapple, banana, *Pennisetum alopecuroide*, betel nut, corn, rice, Taiwanese Quinoa, dragon fruit, vegetable, lychee, water apple, vegetation, coconut, bamboo, coffee bean, and mango; houseplants have also been irrigated. The biogas slurry–based irrigation prevented more than 700,000 tons of livestock excretion (that of approximately 90,000 pigs and cows) from entering the rivers.

Table 2 shows the monitoring results of water pollution in Donggang Creek from 2012 to 2017. Before the start of the project in four years time (November 2015), the water pollution monitoring statistics showed non-significant change in the pollution situation. However, a significant change showed after the implementation of this plan

Table 2. Pollution length of the Donggang River's watershed from 2012 to 2017 (data from the Water Quality Monitoring Network Website of the EPA and compiled by the researcher of the current study)

River's name	River length (kilometer)	Year	Not (slightly) polluted		Lightly polluted		Moderately polluted		Severely polluted	
			Length	Percentage	Length	Percentage	Length	Percentage	Length	Percentage
Donggang River	45	2012	12.5	26.65%	10.3	21.96%	15.7	33.48%	8.5	18.12%
		2013	5.3	11.30%	8.2	17.48%	26.4	56.29%	7.1	15.14%
		2014	-	0.00%	4.6	9.81%	35.3	75.27%	7	14.93%
		2015	7.9	16.84%	10.6	22.60%	21	44.78%	7.3	15.57%
		2016	7.7	16.42%	4.5	9.59%	30.9	65.88%	3.8	8.10%
		2017	19.7	42.00%	8.9	18.98%	15.8	33.69%	2.5	5.33%

in one year, the proportion of severe pollution decreased from 15.57% (2015) to 5.33% (2017); the proportion of undiscovered (light) pollution increased from 16.84 % (2015) to 42.0% (2017). This outcome could result from nearly 50 livestock pastures participated in the fertilizer and water infield in 2017 (Pingtung Environmental Protection Bureau's biogas slurry and biogas residue utilization promotion results report, 2017). Comparing the results of pollution monitoring statistics in 2015 and 2017, the improvement of water quality has gradually achieved.

The Pingtung County Government continued to execute the project "Promoting the Use of Biogas Slurry and Residue–Based Farmland Fertilizer" with the help from the central government, thus aiding the sustainable and economical amelioration of river pollution.

3.2 Results from the project promoting the collection of agricultural stem and branch waste materials after fruit tree trimming and paddy harvesting and turning the mixture of biomass waste materials with cow manure residue into biomass fuel

A. RDF was used by the Environmental Protection Agency to mediate a nearby large-scale soy sauce production company in the Pingtung Neipu factory.

The analysis of heavy oil fuel reduction, a metric ton of heavy oil fuel can generate about 9,840 Kcal of combustion Heating Value. Compared with the use of RDF, it can generate about 4,500 Kcal of combustion Heating Value with the price about $ 75 per ton (Recycling Technology Database of Industry Bureau, Ministry of Economic Affairs, 2019). In order to achieve the same combustion heat, it takes about 2 tons of RDF, which can save US $ 170 compared to the original cost. More importantly, this method reduces air pollution emissions. From Wanjiaxiang Sauce Garden Co., Ltd.'s Pingtung factory, the record in second quarter of 2016 compared with the air pollution emissions for the second quarter in 2015 (Table 3), the emission concentrations of NOx, SOx and particulate pollutants have been greatly reduced.

B. Analysis of the data from the 100-KW biomass gasifier electricity generation system.

The processed fuel rods contain less than 20% moisture, and 1 kg of the compacted raw materials produces 1 kWh of electricity and approximately 2 m^3 of combustible gas. The heating value of each cubic meter of purified combustible gas is approximately 1,200 kcal. Generally, combustible gas can be divided into CH_4, H_2, ethylene, and CO. Based on the principle of mass balance, the gasification of fuel produces 0.15 kg of biocharcoal and 0.15 kg of tar. The condensed combustible gas produces a low amount of low-concentration pyroligneous acid, with gross pyrolysis gases constituting the rest of the condensed combustible gas product. The temperature of pyrolysis

Table 3. A comparison of the reduction in declared air pollution fee between using RDF-5 based fuels and heavy oil-based fuels (compiled by the Pingtung County Environmental Protection Bureau)

SOx is reduced by about 1,404 kg and is estimated to be reduced by 5,617 metric tons per year.

year	SOx emission factor (kg/m^3, metric tonnes)	Sulphur content of fuel	SOx emission concentration (ppm)	SOx emission standards (ppm)	SOx emissions (kg)
2015 year Q2	14.284	0.5	186	300	1406.97
2016 year Q2	0.018	0	2	300	2.82

NOx reduced by approximately 748 kg, estimated to be reduced by 2.99 metric tons per year

year	NOx emission factor (kg/m^3, metric tonnes)	NOx emission concentration (ppm)	NOx emission standards (ppm)	NOx emissions (kg)
2015 year Q2	4.447	159	250	876.06
2016 year Q2	0.821	132	350	128.49

Granular contaminants are also reduced by about 222 kg in a single quarter, with an estimated reduction of 0.888 metric tons per year, due to the addition of cyclone and bag dust collector after 105 years of conversion to RDF.

year	Particulate matter emission factor (kg/m^3, metric tonnes)	Concentration of granular emissions (mg/Nm^3)	Particulate matter emission standards (mg/Nm^3)	Particulate matter emissions (kg)
2015 year Q2	1.129	83	100	222.41
2016 year Q2	0.004	2	50	0.63

gasification is approximately 950 to 1000°C. After being condensed and purified, the combustible gas has NOx < 100 ppm, SOx < 15 ppm, graininess between 2 and 3, and system thermal efficiency of approximately 75%. The system could be used purely for electricity generation or connected to a 1-ton boiler to form cogeneration equipment that can be used for energy conversion operations: every ton of compacted woody raw material generates 1,000 units of electricity, 120 to 150 kg of charcoal, and 5 to 6 tons of industrial steam. (Circular Economy Project to Reduce the Burning of Agricultural Waste in Pingtung County, 2018)

3.3 Achievements of implementing the Donggang River–targeted integrated governance platform in legal amendment and policy promotion

The circular economy constitutes a paradigm shift away from the linear economy. This shift entails a need to change those laws that were passed under the assumption of a linear economy. Many of these laws involve multiple ministries. The Donggang River Integrated Governance Committee has established not only a cross-ministry platform, comprising Central Administration Councilors, but also a local platform led by the chief secretary, who is responsible for coordination between the various local departments. The management of this platform was carried out through fortnightly meetings in the manner of rolling management. Lastly, to enable the joint public–private achievement of the governance target, an integrated advisory team, comprising civil society think tanks, and a "Donggang River Governance Project Office" were established to provide complementary plans (Water Environment Improvement National Water Environment Improvement Plan, 2018).

Additional legal restrictions relating to the usage of biogas slurry and residue were addressed through meetings convened by the Minister of State. For example, laws of the Environmental Protection Bureau were amended to allow farmers to use biogas slurry and residue to irrigate their crops. However, laws of the COA, which remain

unamended, disallows them from doing so; even the WRA face legal restrictions in the use of biogas slurry and residue for irrigation on high riverbank land. This platform allows for the quick resolution of these legal issues. Land use laws had also restricted the use of many types of livestock manure processing equipment (e.g., gasifiers) on farmland; many of these crucial laws were amended due to the communication efforts of this platform and are detailed as follows.

1. The EPA amended and promulgated the "Water Pollution Control Measures and Test Reporting Management Regulations" on November 24, 2015; 10 special clauses related to the use of biogas slurry and residue–based farmland fertilizer were stipulated. These special clauses serve as a legal basis for the reapplication of biogas slurry and residue in farmland.
2. The EPA amended the "Water Pollution Control Measures and Test Reporting Management Regulations" again on October 28, 2016; the aims of the amendment were to simplify the inspection items, expand the scope of applicable subjects in relation to the use of biogas slurry and residue–based farmland fertilizers, and incorporate additional measures, such as the managing of flexibility items. These modifications eased the process of reapplying biogas slurry and biogas residue in farmland. Another purpose of the amendment was to waive the collection of livestock-farming water-pollution fines, thus increasing the incentive to use biogas slurry and residue–based farmland fertilizers.
3. The COA has approved the loosening of "Regulations Governing the Resource Recovery of Livestock Manure and Agricultural Waste" on March 23 2018. As a result, many laws that had impeded the implementation of the circular economy model have been repealed.
4. The EPA amended the "Water Pollution Control Measures and Test Reporting Management Regulations" again on March 9, 2019; the aims of the amendment were to expand the application scope in relation to the use of biogas slurry and residue–based farmland fertilizers. The applicable subjects for this expansion included the river conservation zones (including the high riverbank areas) and aquaculture zones. The amendment diversified the available disposal channels for biogas slurry and residue.

With regard to policy, the agricultural and environmental protection departments have cooperated with each other and invested in various assistive plans.

1. The COA, Bureau of Energy, and EPA have, since 2016, established a co-subsidization agreement on the subsidization of energy transformation and resource recovery equipment.
2. The power purchasing price of biogas-generated electricity has increased significantly since 2017 (from NT$3.92/KWh to NT$5.01/KWh). Additional subsidies have also been provided for electricity generation equipment (NT$40,000/KWh). The Pingtung County Government also provides an extra subsidy of NT$600,000/KWh as an added incentive.
3. In 2017, the EPA expanded the scope of subsidization for the project "Promoting the Use of Biogas Slurry and Residue–Based Farmland Fertilizer" for all major livestock-rearing counties. The EPA has also provided additional subsidies for private and public agencies for the purchase of irrigation vehicles that use biogas slurry and residue (a 90% and 50% maximum subsidy for public and private agencies, respectively).
4. From 2017, the EPA gradually rolled back the 40-year 40% subsidization policy for chemical fertilizers. The policy was fully rolled back in 2018, and the subsidy was transferred to organic fertilizers.
5. In 2018, Pingtung County's "Comprehensive Improvement Project for the Water Quality and Water Environment of Donggang River" was approved. This project was selected as a

high priority project as part of the Executive Yuan's "Forward-Looking Infrastructure Plan" and is thus listed for monitoring and promotion by the Executive Yuan's Public Construction Commission until the end of 2022. A total of NT$ 1,500,000,000 was confirmed to be budgeted for this project (not including the NT$2,750,000,000 that was budgeted and approved by the Ministry of the Interior for the Sanxiang Township sewage project).

4. CONCLUSION AND SUGGESTION

After three years of advocating the circular economy model as a replacement to the conventional linear economy model, the objectives of pollution reduction and the transformation of pollutants into useful resources and energy have been achieved by combining the integrated governance platform and circular economy model. Starting from Pingtung Country, the policy of reusing biogas slurry and residue has already been extended to the other counties of Taiwan. With the exception of the pyrolysis gasification demonstration center (which demonstrates the handling of agricultural waste branch materials using the pyrolysis gasification method) in Pingtung, a vendor has also established a biomass electricity generation plant in Wai Pu Biomass Energy Park, Taichung. Based on the build-operate-transfer model, this biomass electricity generation plant is capable of generating 1.5 MW of electricity, and it is estimated to be able to process at least 15,000 tons of branch-material agricultural waste daily. The examples in this study indicate that the biomass circular economy is the right governance strategy.

The irrigation of farm crops using biogas slurry can prevent more than 700,000 tons of livestock excretion (that of approximately 90,000 pigs and cows) from entering rivers. This irrigation method also helps reduce the problem of groundwater withdrawal by farmers and ameliorate the problem of river pollution. Currently, 180 livestock farms in Pingtung have signed up to participate in the project "Promoting the Use of postanaerobic digested Biogas Slurry and Residue–Based Fertilizers in the farmland." However, 180 farms constitute less than 10% of the 2,000 livestock farms in Pingtung County. Generally, many problems must be solved if the objective of full utilization is to be achieved. For example, the current application procedure for irrigation using biogas slurry and residue is still somewhat inconvenient. Additionally, biogas slurry and residue are yet to be recognized as a fertilizer item by the COA. Therefore, the use of biogas slurry and residue–based fertilizers cannot be subsidized yet, which reduces the incentive for farmers having to use them. Additionally, among small-scale livestock farms in Pingtung County, almost 50% have the "Livestock Rearing Registration Certificate" but not the "Livestock Farm Registration Certificate;" these farm owners are also unable to benefit from subsidies and low-interest financing options offered by Agribank should they want to upgrade their existing equipment. The Pingtung Government and the Central Environmental Protection Agency are still working on simplifying the application process and including biogas slurry and residue–based fertilizers into the organic fertilizers category. In addition to increasing the incentives, the author proposes a multiresolution strategy to improve the processing of livestock wastewater, as illustrated in Figure 9. The researcher proposes to stipulate a three-year "Zero Discharge, Full Utilization" vision for the livestock wastewater management of Donggang River, on the basis of Article 9 (Cap and Trade Legislation) of the Water Pollution Control Act. The details of the "Zero discharge, Full Utilization" vision includes: (1) installation of in-house biogas electricity generation equipment for large-scale livestock farms as well as the full utilization of biogas slurry and residue; (2) formation of cooperatives comprising small-scale livestock farms in the high-density region;

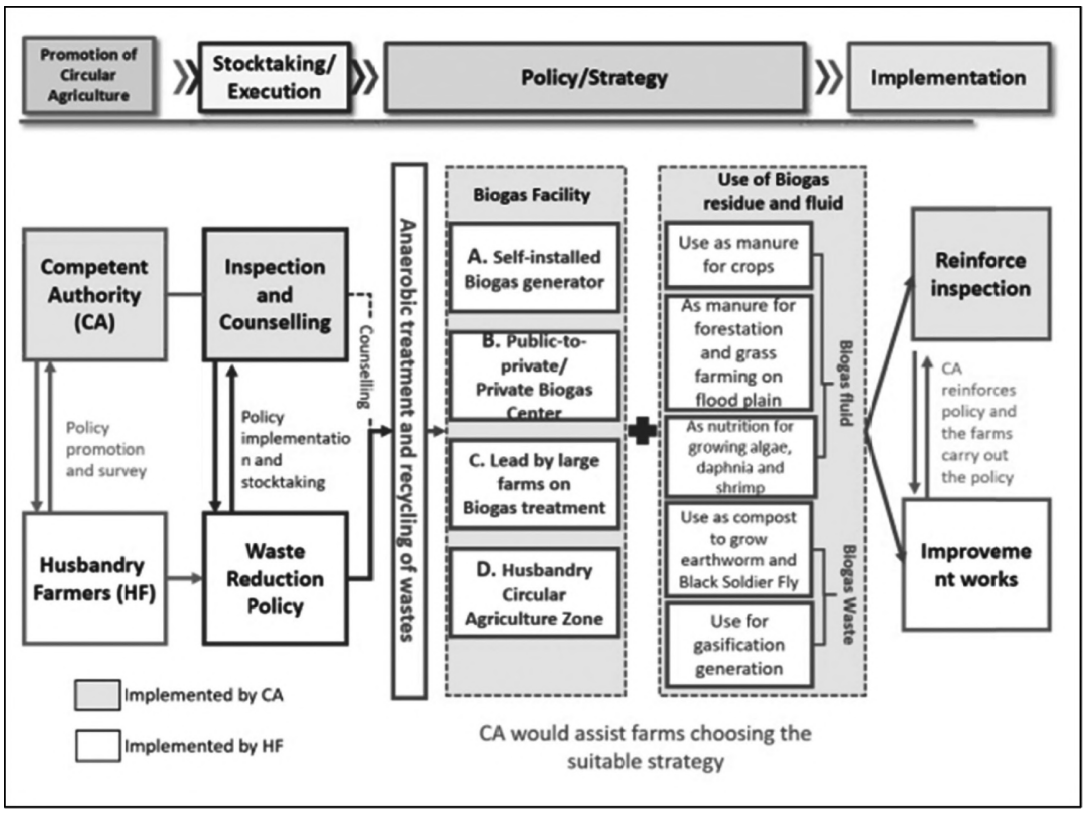


Fig. 9. National University of Kaohsiung. (2019) Report (3-2) for the comprehensive river basin management action plan of the Donggang River.

and because the wastewater to be processed can be sent to the biomass energy center using slurry tankers for uniform processing, (3) other small-scale and geographically scattered livestock farms can be advised to move to livestock-rearing zones with modern equipment and operate in accordance with the circular economy model. For each of the aforementioned operation modes, the COA should subsidize 50% of the requisite fees, with reference to the subsidization model for wastewater treatment equipment installation adopted 30 years ago. The other half of the required fees could be subsidized in the form of a 10-year low-interest loan (the current interest rate is 0.92% to 1.02%). The capital invested by the government in the Donggang River demonstration project is estimated to be no more than NT$3,000,000,000 (estimated based on the design plan of the Pingtung Livestock Manure Biogas Center established in 2016). However, the execution of this project can lead to a reduction of NT$300,000,000 to NT$400,000,000 in wastewater handling fees (Chen, Guo, Shyu, Fan, & Lin, 2008) and a reduction of NT$100,000,000 in the water purification fees paid to the Taiwan Water Corporation (a reduction of NT$1 in the material consumption fee for every unit of water). The listed benefits are only part of the economic benefits associated with the execution of this project; carbon reduction benefits and economic benefits from new investment attracted through the adoption of the circular economy have yet to be considered.

In 2019, Taiwan was removed from the list of areas affected by foot-and-mouth disease; this enabled Taiwan to re-enter the pork export market, which yielded economic benefits valued of NT$10 billion at least. However, Taiwan is currently still under the threat of another African swine fever outbreak. Thus, the clean rearing of pigs

and use of the circular economy model are key to preventing the outbreak of this virus. In her May 2016 inauguration speech, President Tsai Ing-wen stated that, as part of her administration's targets, the circular economy will be actively implemented. Specifically, the circular economy involves the resource recovery and energy transformation of waste materials. However, despite President Tsai's declaration, no ministry for the past three years has been appointed to lead the development of circular economy, despite it being the correct approach. Thus, Taiwan has much work to do to achieve the ultimate zero waste cradle-to-cradle sustainability objective. The author hopes that this research can lead to the circular economy model replacing its linear economy counterpart in the reduction of river pollution in Taiwan.

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