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Innovative Promotion of Renewable Energy Development for Challenging Sustainable Low-Carbon Society: Case Study of Pingtung County, Taiwan

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Received: 20 November 2013; in revised form: 30 December 2013 / Accepted: 31 December 2013 / Published: 8 January 2014

Abstract: Pingtung County, located in the southernmost part of Taiwan, has been selected as one of the Smarter Cities Challenge by the International Business Machines (IBM) in 2013 due to its innovative promotion for renewable energy exploitation in recent years. In this regard, the objective of this paper will be to present an in-depth analysis of the success of environmental sustainability efforts through aggressive measures and profitable plans by this tropical county. The description in the paper is, thus, summarized on the central regulations and economic measures for promoting renewable energy in Taiwan, focusing on the feed-in tariff (FIT). Then, some innovative promotion plans for renewable energy in Pingtung County, including swine-derived biogas-to-power and “Raise Water, Grow Electricity”, were further addressed to show the preliminary results under the funding supports of the central and local governments. With a practical basis of the total swine population (around 433,000 heads), from the farm scale of over 5,000 heads in Pingtung County, a preliminary analysis showed the annual benefits: methane reduction of 2.2 Gg, electricity generation of 8.3×10^6 kilowatt-hour (kW-h), equivalent electricity charge saving of 8.3×10^5 US Dollar (USD), and equivalent carbon dioxide mitigation of 50.9 thousand tons (Gg).

Keywords: feed-in tariff; biogas-to-power; photovoltaic power; promotion measure; benefit analysis

1. Introduction

In recent years, there has been growing interest in renewable energy use at the local government level, trying to track local energy use, and greenhouse gas emissions under the clean development mechanism, thus, transforming a city into low carbon society [1]. As a result, municipalities at the city level around the world, including megacities like London and New York [2], and local cities like Graz in Austria and Freiburg in Germany [3], have taken up the challenging task of pursuing eco-cities or green cities in connection with environmental sustainability. These local governments are known for their ambitious environmental policies and feasible promotion measures that can create significant transitions towards more sustainable society. To be successful, however, the municipal or local authorities must play an important role in pioneering the search for innovative promotion plans, which can lead to joint-ventured participation from policymaking experts, city officials, and local citizens. Therefore, the collaborative partnership between central governments and local authorities has been closely built in fostering renewable energy through urban planning [4].

Pingtung county is a local government in southern Taiwan, which belongs to the tropical region. This county occupies about 2,800 km², covering 33 towns, and has a population of around 860,000 at the end of 2012. Its largest city is Pingtung City, with location coordinates of E120 °29' and N22 °40', which is also the county's capital. Based on its warm climate, the county is rich in agricultural and solar energy resources, which are potential sources for renewable energy development. In order to overcome any obstacles that were encountered in the renewable energy promotion, the low-carbon strategies of the central government and local authority were transformed into local action plans, through the strategy model of shared visions [5], thereby ensuring that the local government is now on the way to a sustainable society under the regulatory and administrative supports for promoting renewable energy and other green energy.

In 2010, the Citizenship of International Business Machines (IBM) created the Smarter Cities Challenge to help municipal governments (*i.e.*, cities or counties) around the world to address some of the critical challenges, putting them on the ground for few weeks to work closely with the city leaders/officials, and deliver recommendations on how to make the city smarter and more effective via the right investments in infrastructure. At the end of 2012, there were 31 cities/counties that had been announced to win IBM Smarter Cities Challenge grants for 2013 [6]. Pingtung County was the only Taiwan municipality to be the final winner that year and was selected on the strength of its renewable energy promotion plan, especially in the biogas-to-power and photovoltaic (PV) system installation. Moreover, the county leaders distinguished themselves among their peers by convincingly demonstrating their willingness to make the kind of improvements that will improve their residents' quality of life and make their towns even smarter toward a low-carbon society.

The objective of this paper will be to present an in-depth analysis of the success of environmental sustainability efforts through innovative measures and plans by Pingtung county. These innovative approaches will play a relevant role in integrated policies that will be expected to offer cost-effective strategies and to provide a case demonstration for other cities or counties.

2. Central Regulations and Economic Measures for Promoting Renewable Energy in Taiwan

In Taiwan, the energy consumption reached a total of 4.50×10^{18} J in 2011, in contrast to 2.14×10^{18} J and 3.65×10^{18} J in 1991 and 2001, respectively [7]. On average, the annual growth rates are about 5.5% and 2.1% during the periods of 1991–2001 and 2001–2011, respectively. It should be noted that the turn-down trend in the energy consumption was mainly attributed to the economic growth decline, and energy saving and renewable energy promotion. In this country, the central regulations for promoting renewable energy is in accordance with the Renewable Energy Development Act, passed in June 2009. According to the new act, one of the most important features, concerning the aspects of promoting renewable energy, is to decide the feed-in tariffs (FIT) and the calculation formula for the electricity generated by the renewable energy power generation equipment every year. The above tariffs calculating formula shall be determined according to the average installation cost, operating life, operation and maintenance cost, annual electricity generation, and relevant factors of renewable energy power generation equipment, separately, for each category of the renewable energy. Table 1 listed the feed-in tariffs (FIT) for various categories of renewable energy production in Taiwan, effective in 2013 [8].

Table 1. Feed-in tariff (FIT) for renewable energy (RE) production in Taiwan ^a.

RE Category	Type	Scale (kW)	FIT (USD/kW-h) ^b	
			2013	2014
Photovoltaic power	Roof	1–10	0.285 (0.277)	0.243
		10–100	0.256 (0.248)	0.218
		100–500	0.241 (0.234)	0.205
		≥500	0.215 (0.203)	0.177
	Surface	≥1	0.203 (0.191)	0.167
Wind power	On-shore	1–10	0.249	0.277
		≥10	0.089	0.089
	Off-shore	--	--	0.190
Biomass-to-power	Non-anaerobic facility	--	0.084	0.085
	Anaerobic facility	--	0.095	0.110
Waste-to-energy	--	--	0.096	0.096

Notes: ^a Source [8]; ^b The rates only applied to the PV power system completed from 1 January 2013 to 30 June 2013. By contrast, the rates in parentheses only applied to the PV power systems completed from 1 July 2013 to 31 December 2013. The exchange rate of Taiwan's currency (*i.e.*, NTD) to USD is about 29.5 (*i.e.*, 1 USD = 29.5 NTD).

3. Innovative Promotion and Measures for Renewable Energy

3.1. Photovoltaic System in the Aquaculture Industry

Near the Tropic of Cancer, Taiwan is located in the sub-tropical region and, thus, possesses plenty of solar irradiation. In order to utilize solar energy, the central competent authority promulgated the “Subsidiary Program for Photovoltaic System Installation” for the dissemination of photovoltaic (PV) systems, since 2000, including solar community project, solar top project for each county, solar campus project, public building installation project, and million rooftop PV's project. Under the funding

support by the central government, many PV systems have been installed in public buildings for demonstration purposes. Moreover, the PV system was also widely installed in schools, remote areas in offshore islands, and residential construction, for the functions of education demonstration, disaster reduction, and even money gain by selling their surplus electricity to Taiwan Power Company (Tai-power, one of the state-owned companies). According to the energy statistics by the central competent authority [7], the cumulative installed capacity reached 231.4 MWp by the end of 2012, generating electricity of 173 GW-h from PV systems.

In 2009, Typhoon Morakot caused catastrophic damage in Southern Taiwan, leaving 461 people dead and 192 others missing. The affected areas included the townships at the boundary between Kaohsiung and Pingtung Counties, and several catchments in Pingtung County where the rivers flow into the Taiwan Strait. The record-breaking rains also caused significant losses in the agricultural and aquacultural industries. For example, this typhoon made fish farms in Pingtung County unable to operate, as well as destroying local wax apple orchards. With the National Land Restoration Policy, the “Raise Water, Grow Electricity” plan was supported by the Pingtung County Government and the aquacultural sector to install PV systems, which has been promoted by the central government under the profitable incentives of feed-in tariffs (FIT) [9]. For example, the wholesale feed-in tariff for solar energy with a capacity of ranging from 10 to 500 kW was set at 0.44 USD (*i.e.*, 12.9722 NTD) per kilowatt hour (kWh) in the first demonstration stage (2009–2010). However, with the cost-down of solar PV power generation facilities, the wholesale FIT price has been gradually reduced by about half, in the period of 2011–2013.

In order to pursue national land restoration, stable income for fish farmers, industrial development of renewable energy, and global warming mitigation in Taiwan, the originality of this plan was to use these abandoned farms, long-term subsidence in coastal areas, and aquacultural ponds as sites for PV power generation facilities without using the aquaculture and other agricultural applications. The solar power generated by the PV stations will be sold back to the electricity grid constructed by Taiwan Power Company. As the farmers lacked the capital to set out on such a venture, the Pingtung county Government invited the PV industry to get involved, organized rental agreements with landowners, and secured investment from enterprises, asking them to cover the application and installation costs. To date, under the subsidization of the central and local governments, four PV station sites have been set up with a total area of 48.7 ha, with a total installed capacity of 25 MWp.

3.2. Other Innovation Promotion and Measures for Renewable Energy

To sail toward the low-carbon society, and to promote green energy economy, the Pingtung county government also announced other innovation promotions and measures for green energy development under the financial funding of the central competent authorities (including the Ministry of Economic Affairs, the Environmental Protection Administration, and the Council of Agriculture). Among them, the swine-derived biogas-to-power project, which will be further analyzed in the description of Section 4, is now in progress since 2013 as Pingtung county ranked first in the swine-raising industry of Taiwan during the past few decades. In addition, other incentive plans include low-carbon sightseeing on the off-shore island by electrical vehicles, extensive forestation in marginal land, and solar PV systems and small-scale wind power systems, installed in schools and public buildings.

On the other hand, one innovative proposal for planting an energy crop, castor (*Rucina communis*), at an enclosed landfill (about 12 ha) has been on the way under the funding support by private enterprises. This energy plant species can easily grow in polluted, infertile fields to make the potential sources for the local production of biodiesel in Taiwan. In the future, closed landfills can be further developed as potential sites for PV power systems [10], connecting with the above-mentioned specific crop plantation for biomass energy.

4. Biogas-to-electricity Potential and Its Benefit Analysis in Pingtung County

The emissions of greenhouse gases from the livestock manure are becoming significant energy and environmental issues. However, waste management (*i.e.*, anaerobic digestion) can produce the biogas associated with its composition, mostly consisting of methane (CH_4), which is now considered as a renewable energy, with emphasis on electricity generation and other energy uses. In this respect, the piggery wastes (including feces and urine) from large-scale swine farmers were mostly treated by the three-step wastewater treatment system in Taiwan [11], which includes solid-liquid separation by a screening method, anaerobic treatment (biogas, thus, generated), and aerobic treatment (activated sludge process). As a result, the central competent authority in Taiwan announced “the Subsidiary Plan for Promotion Project on Biogas-based Power Generation System” on 22 January 2013. The subsidiary plan can be carried out by the local governments (at the municipality level, and county level) to subsidize construction of a waste treatment plant for diversified waste or wastewater treatment system to produce biogas, and installing a biogas-based power generation system in the district interior thereof. In principle, only two, among all of the applications undergoing examination, are granted the subsidy every year, and the installed capacity per application must be higher than 65 kW and lower than 500 kW so as to meet the requirement. The maximum subsidy per kilowatt is about 1,200 USD (*i.e.*, 35,000 NTD) in the installation investment of generator. The local government is also granted promotion fees for demonstration projects. Therefore, by virtue of the cooperation between the central and local government, the application of a variety of biogas-based power generations (*e.g.*, sanitary landfill gas) can be stimulated so as to achieve a double benefit of energy and environmental protection.

In Taiwan, the anthropogenic methane sources from animal agriculture are almost produced by the anaerobic decomposition of livestock (especially in swine) manure. Swine, the major domestic livestock in Taiwan, accounted for over 90% of total feeding livestock. As seen in Table 2 [12], swine population in Taiwan decreased slowly, but steadily, from 6,427 thousand heads in 2008 to 6,008 thousand heads in 2012. However, Pingtung County still ranked first in the swine-raising industry during the past few decades. According to the data in Table 2, it indicates that there are now 1.46 million swine raised in the regional area, and the derived waste has severely polluted the environment. To solve this problem, Pingtung County Government has asked the swine farmers to recycle their livestock residues for green energy. In the current year, Pingtung county government has cooperated with Taiwan Sugar Corporation (TSC, one of the state-owned enterprises) and private swine farms to be a role model of biogas-to-power for promotion demonstration in their pigsties.

Table 2. Statistics on swine raised in Taiwan and Pingtung county during the years of 2008–2012 [12].

Year	No. of Swine Farm		Head on Swine Farm	
	Taiwan	Pingtung County	Taiwan	Pingtung County
2008	10,992	2,640	6,427,597	1,568,194
2009	10,423	2,441	6,130,003	1,408,826
2010	10,076	2,304	6,185,952	1,455,623
2011	9,733	2,233	6,265,546	1,500,948
2012	9,273	2,108	6,008,317	1,458,778

In Taiwan, the anthropogenic methane sources from animal agriculture are mostly produced by the anaerobic decomposition of livestock (especially in swine) manure [13]. To estimate the potential of biogas (methane) generation from livestock manure (*i.e.*, dung and urine) in Pingtung county, the available data on the heads of livestock animals were compiled from the yearly statistics conducted by the Council of Agriculture (COA) of Taiwan [12]. Table 3 listed the total swine-raised heads and scale-categorized farms in Pingtung County during the year of 2012, indicating that a practical basis of the total swine population from the farm scale of over 5,000 heads was around 443,000 heads.

Table 3. Statistics on swine raised in Pingtung county [12].

Scale (Head)	No. of Swine Farm		Head on Swine Farm	
	No.	Percentage (%)	Head	Percentage (%)
1~19	334	15.84	2,501	0.17
20~99	385	18.26	20,746	1.42
100~199	281	13.33	39,993	2.74
200~299	154	7.31	36,830	2.52
300~499	218	10.34	85,832	5.88
500~999	353	16.75	260,899	17.88
1,000~1,999	288	13.66	397,513	27.25
2,000~2,999	40	1.90	93,818	6.43
3,000~4,999	19	0.90	77,731	5.33
5,000~9,999	21	1.00	143,657	9.85
10,000~19,999	7	0.33	105,421	7.23
20,000	8	0.38	193,837	13.29
Total	2,108	100.00	1,458,778	100.00

Due to the simplicity and reliability in requiring less data and expertise than other theoretical methods such as chemical characteristics of swine manure, a simple and straightforward method (*i.e.*, Tier 1 method) developed by the International Panel on Climate Change (IPCC) was used to estimate the potential of methane generation from the swine manure management (anaerobic digestion) in the present work [14]. According to the IPCC methodology, this method is on the basis of the livestock population data and the emission factor as calculated below:

$$MG = LP \times MEF \times 10^{-6}$$

where *MG*: quantity of methane generation from swine (Gg year^{-1}); *LP*: population of swine (head year^{-1}); *MEF*: methane emission factor for swine ($\text{kg CH}_4 \text{ head}^{-1} \text{ year}^{-1}$). In this paper, the value of *MEF* pertinent to the Taiwan area was about $5 \text{ kg CH}_4 \text{ head}^{-1} \text{ year}^{-1}$, which was suggested by the IPCC method.

According to the reasonable activity data and available factors given below:

- Swine population in the farm scale of over 5,000 heads: around 443,000 heads, seen in Table 2.
- Methane emission factor: $5 \text{ kg CH}_4 \text{ head}^{-1} \text{ year}^{-1}$ (equivalent to $11.75 \text{ m}^3 \text{ biogas head}^{-1} \text{ year}^{-1}$ based on methane concentration of 65 % in biogas), seen in Table 3.
- Electricity generation factor: $0.626 \text{ m}^3 \text{ biogas per kW-h}$ (based on $5,500 \text{ kcal m}^{-3}$ heating value, 25 % energy efficiency) [15].
- Electricity purchase charge (FIT): 0.10 USD per kW-h, seen in Table 1.
- Global warming potential for methane: 23 (100-year time horizon) [14].

The energy-economic-environment (3-E) benefits from swine manure management were potentially summarized as follows:

(1) Quantitative benefits

- Methane reduction: 2.2 Gg year^{-1} .
- Electricity generation: $8.3 \times 10^6 \text{ kW-h year}^{-1}$.
- Equivalent electricity charge saving: $8.3 \times 10^5 \text{ USD year}^{-1}$.
- Equivalent carbon dioxide mitigation: $50.9 \text{ Gg year}^{-1}$.

(2) Qualitative benefits

- To coordinate with energy policy: promotion of diversification of primary energy, and fulfillment of energy-related technology development.
- To upgrade environmental and living quality: reduction of odorants (*i.e.*, NH_3 , H_2S), mitigation of VOCs hazards, and prevention of gas (*i.e.*, CH_4) explosions and fires.
- To enhance swine farmer's income: reduction in operation cost, and gain from additional electricity generation by the government revenues (*i.e.*, FIT).

5. Conclusions and Recommendations

This paper presented an in-depth analysis of the success of environmental sustainability efforts through innovative measures and plans by Pingtung County, based on the official statistics and website information. In 2010, it was a milestone for PV power systems in Pingtung County, as the Renewable Energy Development Act had finally passed in 2009. The Act provides that Tai-power (one of the state-owned enterprises) must purchase surplus electricity from renewable power sources, based on the feed-in tariff (FIT) announced by the central competent authority. Originally, the Pingtung county government had creatively proposed a "Raise Water, Grow Electricity" plan to use these abandoned farms and aquacultural ponds, which were destroyed by the greatest Typhoon, Morakot, on record in 2009, as base sites for solar power generation facilities. On the other hand, the local government also encouraged some large-scale swine-raised farmers to install the biogas-to-power systems under the central policy support and economic incentive. Using the activity data (around 433,000 heads for the farm scale of over 5,000 heads) and the methane generation factor, a preliminary analysis showed the

following annual benefits: methane reduction of 2.2 Gg, electricity generation of 8.3×10^6 kW-h, equivalent electricity charge saving of 8.3×10^5 USD, and equivalent carbon dioxide mitigation of 50.9 Gg.

To greatly promote the biomass energy in Pingtung County, some recommendations are addressed below:

- Build large-scale centralized manure (and other co-fermented residues like kitchen waste) treatment plant to demonstrate the production of biogas efficiently and economically.
- Provide subsidies to install biogas-to-power systems in the livestock industry under the support of special funds (e.g., “Agricultural Development Fund”) and also increase the preferential electricity purchase charge (*i.e.*, FIT) to encourage the biomass energy promotion.
- Demonstrate new biogas-cleaning-power technologies (including, wastewater treatment system for biogas production and cleaning, and micro-turbine for power generation) that appeared on the market for the purpose of broadening a wide variety of applications to swine-raised farms.

Acknowledgments

This research was partly supported by NSC (National Science Council), Taiwan, under contract number NSC 102-2221-E-020-030-MY3.

Conflicts of Interest

The author declares no conflict of interest.

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