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A Way from Renewable Energy Sources to Urban Sustainable Development: Empirical Evidences from Taichung City

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ABSTRACT

Taiwan pursues economic growth, but the environment also faces major threats. How to balance economic growth and environmental maintenance has become a priority for sustainable development. This study analyzes this issue from a regional perspective. Taichung City is a scaled-down version of Taiwan's economic development. This case study will help to think about how the economy and the environment can achieve a win-win situation in the future. This study analyzes the economic effects of investments in solar systems and then analyzes the differences in CO_2 emissions between electricity consumption and electricity sources. As a source of electricity needed to provide economic activities in Taichung, solar power systems will avoid the large-scale CO_2 emissions generated by economic growth and achieve a win-win goal of economic growth and environmental maintenance, which will help to achieve the possibility of sustainable urban development.

Keywords: Solar Power, Investment, Economic Growth, CO_2 Emissions, Sustainable Urban Development
JEL Classifications: C67, Q01, Q58, R58

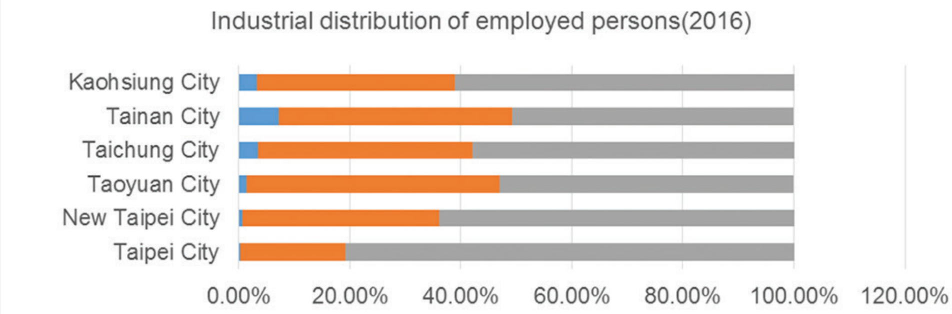
1. INTRODUCTION

In the past, regional development often led to economic growth through investment, but it was accompanied by uneven regional development and environmental damage. In recent years, air pollution from overseas and inland has become increasingly serious, and CO_2 and PM2.5 generated by thermal power generation have become the focus of discussion. The provision of a stable power system is an indispensable basic condition for modern economic development and quality of life. When considering regional development from an economic point of view, although thermal power generation provides low-cost and stable power, it also produces environmentally-loaded substances.

Taiwan cannot completely detach its dependence on thermal power generation. Nevertheless, establishing a power generation system by investing in renewable energy to reduce thermal power generation has become a reflection direction for regional sustainable development. Under the Renewable Energy Development Act and the Electricity Act, the government is fully promoting the new energy policy. The new energy policy is based on renewable energy investment as Market Stimulating Technology Policies, towards Energy Saving, Energy Creation, Energy Storage and Energy Smart System.

Taichung City is located in the central and western part of Taiwan and has the second largest city with a population of about 2.792 million. The distribution of industrial structure is more balanced than other cities. In terms of employment status of industrial classification, primary sectors, secondary sectors and tertiary sectors were 3.37%, 38.79% and 57.92% respectively, of which agriculture and manufacturing exceeded the national average (Figure 1). This means that Taichung City is more suitable for the development of the technology industry in combination with green industries than other cities. In the past, Taichung's economic development model was dominated by traditional

Figure 1: Industry employment status of six major cities in Taiwan



	Taipei City	New Taipei City	Taoyuan City	Taichung City	Tainan City	Kaohsiung City
Primary Industry	0.23%	0.56%	1.30%	3.37%	7.21%	3.26%
Secondary Industry	19.00%	35.49%	45.70%	38.79%	42.10%	35.74%
Tertiary Industry	80.78%	63.94%	52.90%	57.92%	50.68%	61.00%

industries. After the establishment of Central Taiwan Science Park in 2003, the development of technology-related industries gradually became the development feature of Taichung City.

In accordance with the process of international economic development, the industrial development of Taichung City will absorb the new technology of Central Taiwan Science Park with the investment method of "accumulation theories," and combine the different industry characteristics to achieve the effect of the "assimilation theories." In other words, the development characteristics of Taichung's future industry will be the combination of Neoclassical economics and Evolutionary economics.

In 1992, the Taichung Thermal Power Plant was set up with a total generating capacity of 5,824 MW. Taichung Thermal Power Plant accounts for about 20% of the total installed capacity of Taiwan Power Corporation. The world's second largest thermal power plant, Taichung City must face the problem of air pollution caused by power supply stability. Most of the development of traditional regions is based on the economy. Even if the quality of the environment is sacrificed, it will be considered as a necessary evil. As a result, it will cause a great environmental load. Such thinking needs to be changed and the economic development model must be adjusted. For a long time, economic growth has taken precedence over environmental protection policies, resulting in an imbalance between urban and rural areas and regional development. In the future, we need to think about how to develop on a sustainable basis.

This thesis takes Taichung City as the research object and analyzes the possibility of environmental and economic development for urban sustainable development with renewable energy. The purpose of the study is to assess the decoupling between environmental damage and economic development through how renewable energy investments achieve a win-win goal of environmental protection and economic development. Taichung City is mainly distributed in subtropical climates, with sunnier days and more than 2000 h of sunshine per year. In addition, due to the leeward slope due to the protection of the Central Mountain Range, the impact of the typhoon is relatively small. In 2017, the government proposed the renewable energy policy. Taichung City is very suitable for the setting of solar energy and wind power. The introduction of high-tech into renewable energy investment will drive the economic benefits of related industries and further promote industrial upgrading. Taichung City is a coexistence area between modern cities and traditional rural areas. It also combines the modern technology industry with traditional industries. It can use regional resources to develop renewable energy and move towards urban sustainable development.

In general, renewable energy sources (RES) include solar energy, wind energy, tidal energy, geothermal energy, wave energy, and biomass energy. In 2017, Taiwan set 20% of renewable energy in 2025, and the installed capacity of electricity is 27,423 (MW), of which 20,000 (MW) = 20 GW of solar energy, followed by wind power of 4200 (MW). Solar and wind power accounts for 72.93% of renewable energy. Since 2015, Taichung City has begun to plan how to reduce CO_2 and PM2.5 from the natural resource conditions of the region. Among them, the RES attracts solar energy and wind power. Replacing some of Taichung's thermal power generation with solar and wind power generation will help reduce emissions from air pollution sources such as CO_2 and PM2.5. The currently planned solar photovoltaic power generation facilities can be divided into central public ownership, factories, agricultural facilities, and other roofs (homes, shops, roofs of public buildings).

In order to clarify the environmental effects and economic effects of solar energy instead of thermal power generation, this paper establishes a dynamic environmental industry correlation model (energy and environment in dynamic input-output models) to analyze the economic benefits generated by solar energy investment and to consume electricity with economic benefits. Compare the difference in CO_2 emissions in the form of solar, wind, gas and coal-fired power generation.

2. LITERATURE REVIEW

In the past 10 years, due to environmental climate change and energy price instability, energy efficiency improvement and conversion have gradually attracted the attention of countries. Among them, the "green" power system and the sustainability of renewable energy have become the topic of discussion on whether energy can be successfully transformed. Some literatures also analyze the economic effects of renewable energy conversion. For example, renewable energy costs, benefits, prices, investments, grants, and financial incentives (Omer, 2008; Stram, 2016). Some studies focus on energy conversion in the power sector. Analysis of energy conversion has changed the power structure. This is a major reform measure for a country. Some regions in Europe are also promoting it and accumulating numerous research results (Yildiz et al., 2015; Petersen, 2016; Bauwens, 2016). De Jonghe et al. (2009) analyze the relationship between RES in Europe and CO_2 emissions based on the price and quantity-based analysis of how to establish a secure, sustainable and competitive energy markets. In addition, in recent years, relevant research in Australia, the main literature are Cheung et al. (2016) and Mey et al. (2016).

It often plagues the question of how to choose between economic development and environmental protection, especially in countries with high economic growth. Zhang (2000) analyzed the effects of fuel switching, energy conservation, economic growth, and population growth on CO_2 emissions between 1980 and 1997. Zhang and Da (2015) showed that China's increase in CO_2 emissions during 1996–2010 was mainly affected by economic growth factors, and also because of the reduction of energy intensity and final energy consumption structure to improve CO_2 emissions. Qi et al. (2014) emphasize the possibility of achieving renewable energy economic benefits in the short-term through subsidies, and pointed out that if fossil fuels are replaced by renewable energy between 2010 and 2020, they will be reduced 1.8% cumulative CO_2 emissions.

Many studies have analyzed whether there is decoupling between economic growth and environmental pollution. Freitas and Kaneko (2011) pointed out that there is decoupling between Brazil's energy combustion and economic activity in 2009, and that decoupling is the result of carbon intensity improvement and economy structure shifts. Omer (2008) shows that energy efficiency is often influenced by the surrounding environment, but it can achieve the lowest energy consumption through energy efficiency. Yuksel and Kaygusuz (2011) argue that energy is an important factor in sustainable development and recommends that Turkey use renewable energy to reduce greenhouse gas emissions to promote clean and sustainable energy policies. Wee et al. (2012) analyzed the impact of the renewable energy supply chain on protecting environmental resources and quality of life. Conversely, Andreoni and GalMarini (2012) pointed out that during 1998–2006, Italy's economic growth and energy intensity were the main reasons for the changes in CO_2 emissions, which meant that there was no decoupling between the two.

Wang et al. (2013) pointed out that China's economic growth has increased CO_2 emissions, pointing out that energy efficiency is an important reason for reducing CO_2 emissions. Wang and Chen (2015) analyzed the relationship between economic growth and energy use, and pointed out that decoupling ability is the trend of China's energy development in the future, and that the optimal way is to determine the energy market. Isenhour and Feng (2016) analyzes decoupling and displaced emissions and advocates the use of consumption-based indicators to enhance the correctness of perpetual consumption policies.

3. SOLAR POWER CONSTRUCTION COST

This paper uses the Rack-mounted Rooftop Solar System (20KW) as an assessment of the economic benefits and environmental improvements created by Taichung's renewable energy strategy. The Taichung Power Plant has a capacity of 5824 MW and a power generation of 42.537 billion kWh. The 20 kW Rack-mounted Rooftop Solar System calculates 25,000 (KWh) per year to completely replace the Taichung Thermal Power Plant. Need to build 1,701,360 Solar System. With 20,943 households in Taichung in 2018, solar energy cannot completely replace the Taichung Power Plant. Table 1 shows the replacement rate of the Taichung Power Plant and the number of Rooftop Solar Systems. Therefore, this study sets the solar energy to replace the 20% of the electricity generated by the Taichung Power Plant (189,040 sets of Rooftop Solar Systems needed to be built) and then calculate the economic and environmental benefits. Based on this, we will look forward to the possibility of promoting the renewable energy and sustainable development of the city in Taichung.

The cost of solar energy construction is mainly divided into power plant cost, construction cost and other cost, as shown in Table 2. Rack-mounted rooftop solar system costs accounted for the most power plant cost, accounting for 68.26%, of which the cost of photovoltaics module is the largest, accounting for 31.81% of the total, followed by Inverter's 14.43%. Each set of Rack-mounted rooftop solar system costs (20KW) is US$61,462.10, and solar energy replaces 20% of Taichung Power Plant's total investment amount to US$11.19 billion.

4. EMPIRICAL MODEL

This study derives the dynamic model from the inclusion of the investment factor into the input-output static model of equation (1).

$$X = [I - (I - \bar{M})A]^{-1}[(I - \bar{M})F^d + E] \quad (1)$$

According to Hong et al. (2017), the dynamic industry-related model can be written as

$$X(t)=AX(t)++C+K[X(t+1)-X(t)] \quad (2)$$

We can write equation (2) as

$$X(t+1) = (K^{-1}D + I)\left[I - A(I - \bar{M})\right]^{-1}\left[E + (I - \bar{M})F^d\right] \quad (3)$$

Assuming $D=I-A-C$, where consumption (C) and investment (K).

4.1. Measurement of the Direct And Indirect Effects

Let Leontief inverse matrix $(K^{-1}D + I)\left[I - A(I - \bar{M})\right]^{-1}$ be Γ*. Total economic spillover effects model is

Table 1: Solar replacement rate and the number of rooftop solar system

Solar replacement rate (%)	Solar energy construction (set)	Proportion of total households (%)
100	1,701,360	175.41
90	850,680	87.70
80	567,120	58.47
70	425,340	43.85
60	340,272	35.08
50	283,560	29.23
40	243,051	25.06
30	212,670	21.93
20	189,040	19.49
10	170,136	17.54

Table 2: Rack-mounted rooftop solar system costs (20KW)

Item	Price (%)
Power plant cost	41,952.00 (68.26)
Photovoltaic Module	19,552.00 (31.81)
Inverter	8,866.67 (14.43)
Array frame (aluminum)	6,250.00 (10.17)
Array mount (steel)	2,850.00 (4.64)
Step-up transformer	2,833.33 (4.61)
Wiring	1,600.00 (2.60)
Construction cost	11,733.33 (19.09)
Foundation civil engineering construction	2,666.67 (4.34)
Related engineering pay	9,066.67 (14.75)
Other cost	7,776.77 (12.65)
Commercial	500.00 (0.81)
Management	2,926.77 (4.76)
Transport	600.00 (0.98)
Other	3,750.00 (6.10)
Total cost	61,462.10 (100.00)
Unit: US$; %	

$$\underbrace{TESE}_{\text{Total Economic Spillover Effects}} = \underbrace{(I-\bar{M})\delta F_1^d}_{\text{Direct spillover Effects}} + \underbrace{\Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect Spillover effects}} + \underbrace{\Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect Spillover effects}} \quad (4)$$

The total gross induced added value (TV) is formulated as equation (5), consisting of the direct gross added value, the first and the second indirect gross added value.

$$\underbrace{TV}_{\text{Total gross induced Added value}} = \underbrace{w_j^G (I-\bar{M})\delta F_1^d}_{\text{Direct Gross induced Added value}} + \underbrace{w_j^G \Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect Gross Induced added value}} + \underbrace{w_j^G \Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect Gross Induced added value}} \quad (5)$$

The formula for total induced income of employment (TE) that we could estimate the direct and indirect induced income of employment.

$$\underbrace{TE}_{\text{Total induced Income of Employment}} = \underbrace{w_j^L (I-\bar{M})\delta F_1^d}_{\text{Direct Income of Employment}} + \underbrace{w_j^L \Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect induced Income of Employment}} + \underbrace{w_j^L \Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect induced Income of Employment}} \quad (6)$$

4.2. Measurement of the Direct and Indirect Electricity Consumption

Bringing the electricity consumption coefficient into equation (4) can respectively determine the consumption scale of electricity.

$$EC = \underbrace{EC(I-\bar{M})\delta F_1^d}_{\text{Direct spillover Effects}} + \underbrace{\widehat{\boldsymbol{EC}}\Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect Spillover effects}} + \underbrace{\widehat{\boldsymbol{EC}}\Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect Spillover effects}} \quad (7)$$

Where the electricity consumption coefficient $ec_j = \widehat{EC}_{2_j} / x_j$, and $\widehat{EC}$ is the diagonal matrix of the elements of the emissions coefficients for various industries.

$$\widehat{EC} = \begin{pmatrix} ec_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & ec_n \end{pmatrix}$$

4.3. Estimation of CO_2 Emissions from Different Sources of Electricity Supply

The CO_2 emission factors of different power systems are brought into equations (4) to estimate the scale of CO_2 emissions and compare the differences.

$$\widehat{EC} = \underbrace{EC(I-\bar{M})\delta F_1^d}_{\text{Direct spillover Effects}} + \underbrace{\widehat{EC}\Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect Spillover effects}} + \underbrace{\widehat{EC}\Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect Spillover effects}} \quad (7)$$

$$CO_2 \text{ emission} = \underbrace{\hat{\boldsymbol{E}}(I-\bar{M})\delta F_1^d}_{\text{Direct spillover Effects}} + \underbrace{\hat{\boldsymbol{E}}\Gamma^*\left[(I-\bar{M})\delta F_1^d\right]}_{\text{First indirect Spillover effects}} + \underbrace{\hat{\boldsymbol{E}}\Gamma^*\left[(I-\bar{M})\delta F_2^d\right]}_{\text{Second indirect Spillover effects}} \quad (8)$$

Where the emissions coefficient $e_j = CO_{2_j} / x_j$, and $\hat{E}$ is the diagonal matrix of the elements of the emissions coefficients for various industries.

Table 3: Economic effects generated by solar power investment

Economic effects	Economic effect-induced	Gross induced added value	Induced income of employment
Direct effects	8,206.61	3,412.18	1,951.97
First indirect spillover effects	7,414.14	2,289.30	1,294.64
Second indirect spillover effects	2,525.14	872.73	540.21
Total spillover effects	18,145.89	6,574.21	3,786.82

Unit: US$ million

Table 4: Electricity consumption of solar energy construction

Electricity consumption	Economic effect-Induced	Gross induced added value	Induced income of employment
Direct effects	3,221.61	301.72	172.60
First indirect spillover	1,310.60	202.43	102.10
Second indirect spillover	306.05	62.93	20.56
Total spillover effects	4,838.27	567.08	295.26

Unit: GWh

Table 5: Scale of CO_2 emissions from sources of electricity supply

CO_2 Emissions Spillover	Electricity systems			
	Solar power	Wind power	Gas-fired power generation	Coal-fired power generation
Spillover effects				
Direct spillover effects	148,193.94	38,659.29	1,510,933.91	3,224,829.09
First indirect spillover	60,287.82	15,727.26	614,673.64	1,311,915.37
Second indirect spillover	14,078.46	3,672.64	143,539.09	306,359.56
Total spillover effects	222,560.22	58,059.19	2,269,146.64	4,843,104.02

Unit: Tons

$$\hat{E} = \begin{pmatrix} e_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & e_n \end{pmatrix}$$

5. EMPIRICAL RESULTS

This section will estimate the economic effects, power consumption and CO_2 emissions with solar energy investment, and further compare the CO_2 emissions from different power sources as the basic direction for analyzing the sustainable development of Taichung City in the future.

5.1. Economic Effects of Solar Investment

Table 3 shows that the investment in solar energy systems has three effects, namely economic induced, gross induced added value and induced income of employment. First, the economic induced effect was US$18,145.89 million, with a direct effect of US$8,206.61 million and the other two indirect effects of US$7,414.14 million and US$2,525.14 million, respectively.

The solar investment created a gross induced added value of US$6,574.21 million, and the induced income of employment also had US$3,786.82 million, both of which were the direct effects to have the highest impact, accounting for 51.90% and 51.55% of the effect, respectively.

5.2. Solar Energy Investment in Electricity Consumption

The power consumption of the economic effect is shown in Table 4. The total electricity consumption of the economy reached 4,838.27 GWh, of which the direct effect accounted for 3,221.61 GWh. This is quite a 66.59% of the overall economic benefit. On the other hand, the power consumption of the gross induced added value is 567.08 GWh, and the electricity required to create the induced income of employment is 295.26 GWh, accounting for 53.21% and 58.46% respectively.

5.3. CO_2 Emissions from Different Power Sources

From the above information, it is known that solar energy investment in Taichung City does have great benefits for industrial development, but it also needs to consume a large amount of electricity, and the accompanying increase in CO_2 emissions. The source of electricity provided by solar energy will result in a significant improvement in CO_2 emissions. Taichung Thermal Power Plant provides nearly 20% of Taiwan's electricity in two ways, Gas-fired Power Generation and Coal-fired Power Generation. This generates a large amount of CO_2 and PM2.5 emissions that affect environmental quality and hinder the sustainable development of the city. Table 5 compares the scale of CO_2 emissions from different sources of electricity supply.

The solar system generates more CO_2 emissions than wind power, which is 3.83 times that of wind power. However, compared with the CO_2 emission scale of Gas-fired Power Generation and Coal-fired Power Generation, it is significantly reduced. Solar CO_2 emissions are only 9.8% for gas-fired power generation and 4.6% for coal-fired power generation. Therefore, renewable energy generation can produce great results in terms of improvement in CO_2 emissions.

The above empirical estimation shows that Taichung's future economic development and environmental improvement of renewable energy policy is indeed a direction of thinking.

6. CONCLUDING REMARKS

Taiwan's economic development improves national income and quality of life. However, after the economy reaches a certain level, environmental awareness has drawn the attention of the public and strongly appealed to the need for environmental protection. In this context, Taichung City rethinks how the future will move towards sustainable development. There is one of the world's second largest thermal power plants in Taichung City to provide a stable source of electricity in Taiwan. However, the thermal power generation system has caused a large amount of CO_2 and PM2.5 emissions to hinder the development of the city, and the maintenance of environmental ecology has become a part of important urban policies. This study can be achieved by assessing whether economic development and environmental improvement can be achieved simultaneously with the promotion of energy policies. In other words, the road to sustainable urban development must be able to solve the "Decoupling" problem between economic growth and environmental destruction.

This study uses energy and environment in dynamic input-output models to estimate the economic effects and environmental improvement effects of solar energy investment in Taichung City. The results are summarized below.

The investment in solar power generation system has created an economic benefit of US$18,145.89 million for Taichung City. This amount is equivalent to 7.46% of total industrial and service production in Taichung City in 2016, and it also drives the growth of solar-related industries. Economic growth also increases electricity consumption. The benefits of investment require 4,838.27 GWh of electricity supply, which is equivalent to 11.37% of the power generation of Taichung Thermal Power Plant. Thermal power plants must generate huge CO_2 emissions with such power consumption. Based on the estimated results, Gas-fired Power Generation and Coal-fired Power Generation emitted CO_2 scales of 2,269,146.64 tons and 4,843,104.02 tons, respectively. Regardless of the type of power generation, these CO_2 emissions will create an environmental burden in Taichung City, but the renewable energy policy will greatly relieve environmental pressure. With the solar system replacing Gas-fired Power Generation and Coal-fired Power Generation, CO_2 emissions will be reduced by 919.57% and 2076.09%, respectively.

Therefore, the research results show that the investment and power generation of solar energy systems will enable Taichung City to achieve "Decoupling" of industrial development and environmental destruction, and have the opportunity to move toward urban sustainable development.

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