DECOUPLING OF ENVIRONMENTAL PRESSURES FROM ECONOMIC ACTIVITIES: EVIDENCE FROM TAIWAN

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ABSTRACT

Between 1998 and 2010, under the thrice industrial structure, Kaohsiung's output ratios of the secondary and tertiary industries fluctuated dramatically every four years. This study examines the decoupling degrees of underlying environmental pressures from Gross Domestic Product in order to analyze how industrial structure influences environmental sustainability by using Tapio's method. Based on aggregate data, calculations are made of the Gross Domestic Product elasticities of garbage collection, tap water consumption, electricity supply, suspended particle matters, SO_2, CO, NO_2, and O_3, during the periods of 1998-2002, 2002-2006, and 2006-2010 in Kaohsiung. Analytical results indicate that the electricity supply during the period 1998-2010 exhibited negative decoupling, while tap water consumption and O_3 during the period 1998-2002, as well as suspended particulate matter and SO_2 during the period 2002-2006 were also negative decoupled. Moreover, industrial structure is not the major determinant to relieve environmental pressures. Fulfilling price strategy and further reducing emissions is a promising measure for sustainable development in Kaohsiung.

JEL: E62, H23, O14

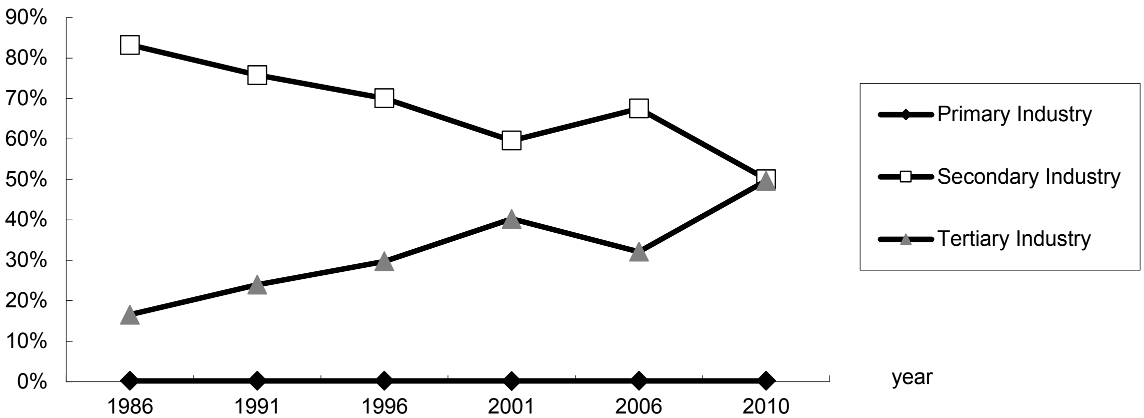
KEYWORDS*:* Industrial Structure, Price Strategy, Sustainable Development, Decoupling

INTRODUCTION

Located in southern Taiwan, Kaohsiung has a temperate, damp and subtropical climate. With a 12-kilometer-long coastline, well-developed transportation network, as well as prosperous industrial and commercial activities, Kaohsiung is an ideal setting for industrialization. The steel, petrochemical, ship building, cement industries as well as two export processing zones have made Kaohsiung a productive and commercial city in Taiwan. In 1986, the ratio of the secondary industry reached 83.22% of the entire industry (EDBKCG, 2010).

In contrast, industrialization incurs serious environmental problems. Kaohsiung residents suffered from poor air and water quality for a long time (Chen *et al.,* 2004). Industrial activities from sources such as China Steel Corporation, China Shipbuilding Corporation, China Petroleum Corporation, and Taiwan Power Company once severely polluted the Kaohsiung Harbor district (Ko and Chang, 2010). Therefore, high levels of NO_2 and O_3 significantly raised hospital admissions for asthma in Kaohsiung (Tsai *et al.,* 2006). To create a sustainable economy and environment, the Kaohsiung City government is aggressively pursuing an industrial transformation. Under the framework of a thrice industrial structure (i.e. primary, secondary, and tertiary), Figure 1 shows the ratios of output value of Kaohsiung City from 1986 to 2010. Since 1986, output values of the secondary and tertiary industries of Kaohsiung City have begun to change. The secondary industry has declined from 83.22%, while the tertiary industry has risen from 16.55%. These two industries then approached each other in 2001. In 2006, the distance in ratios again increased between these two industries. Finally, the two industries ended up at the same level in 2010. However, during this period, the primary industry remained nearly constant (i.e. less than 1%) (EDBKCG, 2010).

Figure 1: The Ratios of Output Values



This figure shows the ratios of output values of primary, secondary, and tertiary industries in Kaohsiung, Taiwan from 1986 to 2010. Output values of the secondary and tertiary industries approached each other in 2001.Then the distance in ratios again increased and ended up at the same level in 2010.

Given the above situation, the following question arises: can industrial transformation ensure sustainability? To achieve sustainability, environmental pressures should be decoupled from economic activities. Kaohsiung City thus requires an effective means of monitoring the effect and effectiveness of policy responses. Adequate indicators can provide information on the conditions and trends of sustainable development, enabling policymakers to evaluate the severity of environmental problems (Segnestam, 2002; Smeets and Weterings, 1999). Utilizing appropriate environmental indicators can greatly facilitate the efforts of Kaohsiung City to become a green society.

Based on Tapio's decoupling indicators, this study elucidates the dynamic relationships between economy and environmental pressures in Kaohsiung City during the periods 1998-2002, 2002-2006, and 2006-2010. Exactly how industrial structure influences decoupling degrees is also discussed. The rest of this paper is organized as follows: Section 2 reviews the decoupling concept and Tapio's method. Section 3 then introduces the criteria and source of selected data. Next, Section 4 describes how decoupling conditions are determined based on their elasticity values. Section 5 discusses in detail environmental pressures presenting negative decoupling. Conclusions are finally drawn in Section 6, along with recommendations for future research.

LITERATURE REVIEW

Decoupling Concept

Decoupling refers to breaking the relation between "environmental bads" and "economic goods" (OECD, 2002). In 2001, Organization for Economic Cooperation and Development (OECD) prioritized decoupling as one of the main objectives of the Environmental Strategy for the first decade of the 21st century (OECD, 2002). Increasing production normally leads to growing environmental pressure. Decoupling occurs when an economy develops with a lower increase or decrease rate of environmental pressure. For instance, if a situation in which the Gross Domestic Product (GDP) growth between two years is 5% implies that the rate of increase for SO_2 emissions during this period is less than 5%, SO_2 emissions is assumed to be decoupled from the economic growth.

Factors causing decoupling can be various. First, economic recession results in decoupling. Owing to a slow GDP growth rate, Japan experienced decoupling in the 1990s. During the same period, both energy use and GDP broke down after the collapse of the former Soviet Union, but the drop in GDP was greater than the drop in energy use, which exhibited decoupling of the energy consumption from GDP (Azar *et al.,* 2002). Second, the development of low-carbon energy creates decoupling. For instance, the United Kingdom (UK increased its coal prices in the 1990s to spur a switch towards gas in power generation. Use of imported nuclear electricity in steel production in Luxembourg lowered greenhouse gas emissions. Sweden's drop in emissions is largely thanks to its reliance on nuclear, hydro and biomass power for energy supply (Azar *et al.,* 2002). Last, some other factors contributing to decoupling include economic structural change, energy efficiency, or change of lifestyle. In addition to its extensive use of renewable energies, New Zealand's decoupling originates from economic structural change and emission-reducing innovation (MfE, 2005). An 89% car acquisition tax and high fuel prices in Finland have led to a consumer preference for smaller cars, resulting in decoupling of CO_2 emissions from GDP growth between 1990 and 2001 (Tapio, 2005).

Environmental pressure indicators as numerators and economic indicators as denominators can reflect different degrees of decoupling. Decoupling concepts vary in their use of indicators. Heiskanen and Jalas (2000) referred to "dematerialization" as de-linking of economic activity from its material base, and can be estimated by material used per GDP unit. "Decarbonization" refers to a decreasing energy intensity of economic activities, determined by CO_2 emissions per GDP unit (Tapio, 2005). Some studies further suggested that carbon intensity (i.e. carbon emissions per GDP unit, the same concept as decarbonization) can be decomposed into two parts: "carbonization index" (i.e. carbon emissions per unit of energy consumption) and "energy intensity" (i.e. energy consumption per GDP unit) (Grubler, 1998; Mielnik and Goldemberg, 1999; Liou and Wu, 2009). High carbonization index refers to consumption of high carbon energy. For instance, gaseous fuels (e.g., natural gas) have a smaller carbonization index than solid fuels (e.g., coal) in terms of their output emissions. Low energy intensity can be attributed to economic structural shifts towards a low-energy industry or improved efficiency of energy production and end-use technologies.

Categories of decoupling have evolved over time. According to OECD (2002), decoupling can be categorized to "absolute decoupling" and "relative decoupling". Absolute decoupling occurs when an economy grows and, simultaneously, environmental pressure remains constant or diminishes. Relative decoupling occurs when environmental pressure grows at a lower rate than economic growth does. Vehmas *et al.* (2003) also used "de-linking" for decoupling and "re-linking" for negative decoupling in environmental economics.

<u>Tapio's Decoupling Method</u>

Tapio (2005) described how GDP and traffic volume in Finland are related from 1970 to 2001 by proposing eight scenarios of decoupling situations. By adopting Tapio's terminology, that study divided decoupling situations into three categories of "decoupling" (i.e. GDP growth rate is obviously higher than that of transport volume), "coupling" (i.e. GDP growth rate is slightly higher or lower than that of transport volume), and "negative decoupling" (i.e. GDP growth rate is apparently lower than that of transport volume). Tapio's classification appears to be more exquisite than the typologies of OECD or Vehmas *et al.* in describing decoupling scenarios, and also provides an effective informative approach for policymakers.

Tapio described various decoupling situations by adopting the concept of elasticity value, where the percentage change of transport volume is divided by the percentage change of GDP in a given period (Tapio, 2005). Tapio's decoupling terminology further established several subcategories under each main category. Each subcategory has its corresponding elasticity value range. Table 1 lists all eight possibilities of decoupling situations and their elasticity values.

Some important factors should always be considered while explaining the messages conveyed by decoupling indicators. First, the messages are not evident except for confirming absolute levels of environmental pressure and economic growth individually. Second, the selected time interval may affect the interpretation of the outcomes because while countries attempt to solve environmental problems, the outcomes vary according to different timetables (OECD, 2002).

Table 1: Categories of Decoupling Possibilities

		Increase of Environmental Pressure (△P)	**Increase of Economic Activities (△D)**	**Decoupling Elasticity (=%△P/%△D)**
Decoupling	Weak Decoupling	**ΔP >0**	**ΔD** >0	0-0.8
	Strong Decoupling	**ΔP <0**	**ΔD** >0	<0
	Recessive Decoupling	**ΔP <0**	**ΔD** <0	>1.2
Coupling	Expansive Coupling	**ΔP >0**	**ΔD** >0	0.8-1.2
	Recessive Coupling	**ΔP <0**	**ΔD** <0	0.8-1.2
Negative Decoupling	Expansive-Negative Decoupling	**ΔP >0**	**ΔD** >0	>1.2
	Strong-Negative Decoupling	**ΔP >0**	**ΔD** <0	<0
	Weak-Negative Decoupling	**ΔP <0**	**ΔD** <0	0-0.8

This table shows lists 3 main categories and 8 subcategories under each main category. Based on Tapio's decoupling terminology, eight possibilities of decoupling situations and their elasticity values are established.

DATA AND METHODOLOGY

This section introduces the GDP elasticities of environmental pressures developed in this study by using Tapio's method. The criteria and source of selected data are then discussed. By using Tapio's decoupling methodology, this study elucidates how economic driving forces and environmental pressures are related. Based on the DPSIR framework, "economic driving forces" refer to social, demographic, and economic developments concerned mainly with population growth and changes in individual's needs and lifestyles that may yield environmental pressures. The term "environmental pressures" includes individual's use of natural resources and land, as well as production of waste and emissions (Gabrielsen and Bosch, 2003; Omann *et al.*, 2009; Maxim *et al.*, 2009). Hence, the decoupling levels can be evaluated as in (1):

$$\text{Economic driving force elasticity of environmental pressures} = \frac{\%\Delta EP}{\%\Delta EDF} \quad (1)$$

Where %ΔEP denotes the percentage change of environmental pressures, and %ΔEDF denotes the percentage change of economic driving forces.

To comply with the above principles, this study selects several indicators as economic driving forces and environmental pressures. First of all, for economic driving forces, GDP per capita (NT$) is selected as a comprehensive indicator. Secondly, in terms of environmental pressures, the study develops indicators on three aspects. (1) Consumption of resources: power and water supply are essential resources for urban development; therefore, electricity supply (ES, megawatt) and tap water consumption (TWC, m^3) are selected as the indicators of this study, (2) Production of emissions: The most typical emissions of urban air pollutants include suspended particulate matter (SPM, ug/m^3), sulphur dioxide (SO_2, ppm), volatile organic compounds (VOCs, ppm), lead (Pb, ppm), carbon monoxide (CO, ppm), nitrogen dioxides (NO_2, ppm), and ozone (O_3, ppm) (UNEP, 2005). VOCs and Pb are not selected due to unavailable data and (3) Production of wastes: Solid and liquid wastes are two main categories of waste production. The volume of garbage clearance (GC, kg) is selected as the indicator of solid waste generation. Owing to the lack of data, the indicator of liquid waste is not included in this study.

As for fluctuation of the industrial structure and the 4-year time interval, 1998, 2002, 2006, and 2010 are the study years. These corresponding data of selected indicators for the desired years are gathered from

Department of Statistics, Kaohsiung City Government (2012) and shown in Table 2.

Table 2: Data of GDP and Selected Environmental Pressure Indicators

Year	GDP per capita (NT$)	GC (kg)	TWC (m^3)	ES (megawatt)	SPM (ug/m^3)	SO_2 (ppm)	CO (ppm)	NO_2 (ppm)	O_3 (ppm)
1998	670439	1,547	315255	8,285	77.1	0.013	0.82	0.028	0.024
2002	639471	1,216	341754	9,456	63.7	0.007	0.70	0.024	0.030
2006	689132	1,005	342893	11,430	78.7	0.008	0.59	0.023	0.029
2010	713266	786	350364	12,235	73.9	0.007	0.51	0.021	0.028

This table shows the corresponding data of GDP and selected environmental pressure indicators in Kaohsiung for the year 1998, 2002, 2006, and 2010.

RESULTS AND DISCUSSION

Based on evaluation of the GDP elasticities of all environmental pressures in Kaohsiung, Table 3 lists the elasticity values. Tapio's theoretical framework displays all decoupling degrees of environmental pressures from GDP at different intervals (Figure 2).

Table 3: GDP Elasticities of Environmental Pressures

Years	GC	TWC	ES	SPM	SO_2	CO	NO_2	O_3
1998-2002	4.627	-1.819	-3.059	3.754	9.990	3.257	3.092	-5.411
2002-2006	-2.234	0.043	2.687	3.034	2.681	-1.934	-0.747	-0.594
2006-2010	-6.235	0.622	2.012	-1.746	-3.781	-4.297	-1.456	-0.590

This table shows GDP elasticities of environmental pressures in Kaohsiung from 1998 to 2010

Figure 2 reveals all of the elasticity values from Interval one (1998-2002), which are located on the left side of the y-axis due to the negative growth of the GDP during that period. As expected, except for TWC, EP, and O_3, all other environmental pressures presented recessive decoupling. During that period, China and other Southeast Asia countries expanded their traditional industries, including manufacturing. Owing to their inexpensive labor and low operating costs in these countries, some local factories or businesses were relocated out of Kaohsiung, subsequently raising the unemployment rate from 3.4% in 1998 to 5.5% in 2002 (EDBKCG, 2010). Hence, most air pollutants and garbage decreased along with depressed economic growth. Conversely, during the same period, tap water consumption, electricity supply and O_3 increased, possibly owing to societal development.

During Interval two (2002-2006), GDP growth causes all of the elasticity values to shift to the right side (Figure 2). Except for SPM and SO_2, all other air pollutants displayed strong decoupling. SPM increased from 63.7 ug/m^3 to 78.7 ug/m^3 while, during this period, SO_2 rose from 0.007 ppm to 0.008 ppm. In terms of resources, tap water consumption exhibited weak decoupling while the electricity supply showed expansive negative decoupling. Moreover, strong decoupling occurred in garbage clearance. In sum, between 2002 and 2006, the ratio of the secondary industry in Kaohsiung rebounded to 67.53%, along with the negative decoupling of SPM, SO_2 and electricity supply from GDP. Regarding Interval three (2006-2010), all of the air pollutants achieved strong decoupling; garbage collection did as well. However, as for resources, tap water consumption and electricity supply still separately displayed weak decoupling and expansive negative decoupling, the same as in the previous interval. In 2010, the tertiary industry grew to nearly the same output value as the secondary industry. Nevertheless, manufacturing still played a more significant role in Kaohsiung than in other cities in Taiwan.

Figure 2: Decoupling of Environmental Pressures form GDP in Kaohsiung 1998-2010

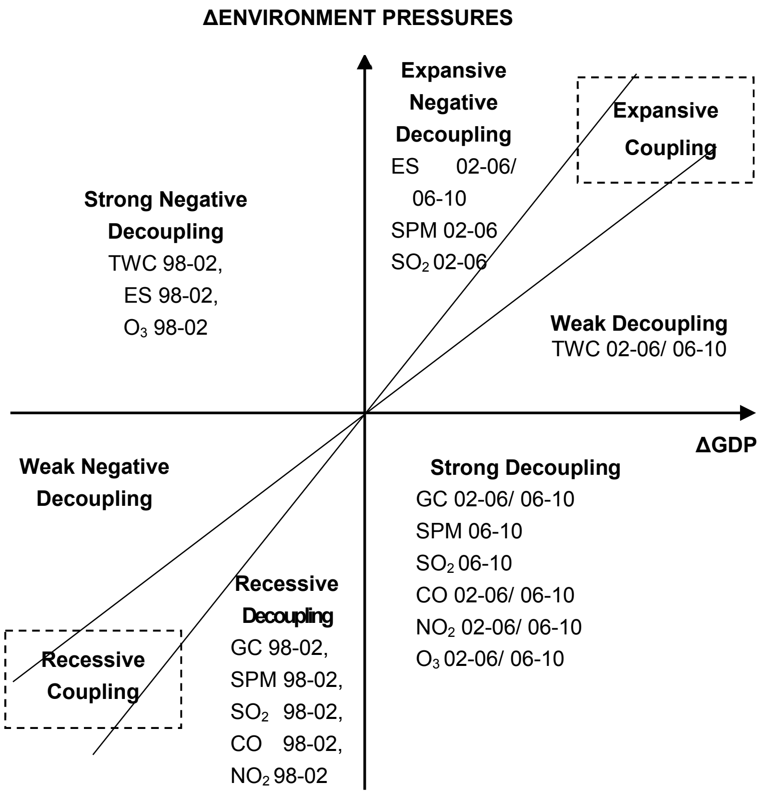


Figure 2 shows all decoupling degrees of environmental pressures from GDP in Kaohsiung at three time intervals 1998-2002 (98-02), 2002-2006 (02-06), and 2006-2010 (02-10) based on Tapio's theoretical framework.

DISCUSSION

Above results demonstrate that electricity supply and other air pollutants experienced negative decoupling, thus warranting a further discussion of the possible causes.

<u>Wide Application of Electricity Price Strategies</u>

As for final energy consumption, electricity is the largest energy type used in Taiwan, with approximately 50% (Taiwan Bureau of Energy, 2010). However, electricity supply exhibited negative decoupling over these three intervals, which indicates that regardless of how the industrial structure transformed, the increase of electricity consumption still surpassed that of GDP growth. Among the factors explaining the above results include economic growth, industrial structures, population growth rate, temperature, electricity price and strategies to reduce electricity consumption (Taiwan Bureau of Energy, 2010). Economic growth and industrial structure are discussed. The population growth rate of Kaohsiung is 4.62% during the period 1998 to 2010, which is lower than that of GDP (= 6.38%) and, thus, is not considered here. This study also does not discuss the temperature issue because the residential electricity consumption only occupied around 11% of the electricity supply over the past two decades (Taiwan Bureau of Energy, 2010). This study covers electricity price and its strategies to explore the origin of its negative decoupling.

Figure 3 shows the growth rates of electricity supply and price in Taiwan from 1998 to 2010. Obviously, electricity supply continued growing most of the time. Nevertheless, despite drastic fluctuations in global fuel prices, the growth rate of electricity price remained at relatively low levels until 2008 and was always lower than the supply. Even in 2010, Taiwan's electricity prices still ranked the second lowest for residential use and the fourth lowest for industrial use out of 34 selected countries (IEA, 2011). Electricity accounts for around 50% of energy consumption in Taiwan; hence, although capable of boosting economic growth, inexpensive electricity also easily produces waste. Owing to the low cost of energy consumption, industry does not need to invest in energy-saving facilities while households can use electrical devices without much concern for the bill. Conversely, for instance, in 2009, after electricity prices were increased and conservation discounts were also made available, electricity consumption dropped 13% over that of the previous year (Taiwan Bureau of Energy, 2010). Figure 3 shows further details. Therefore, electricity price strategies must be developed continuously because more than any other reason, the environment should always takes a higher priority than economy and society (Giddings *et al.*, 2002). Incorporating electricity conservation in the management of demand-side consumption is a more effective approach.

Figure 3: The Growth Rates of Electricity Supply and Prices in Kaohsiung, Taiwan 1998-2010

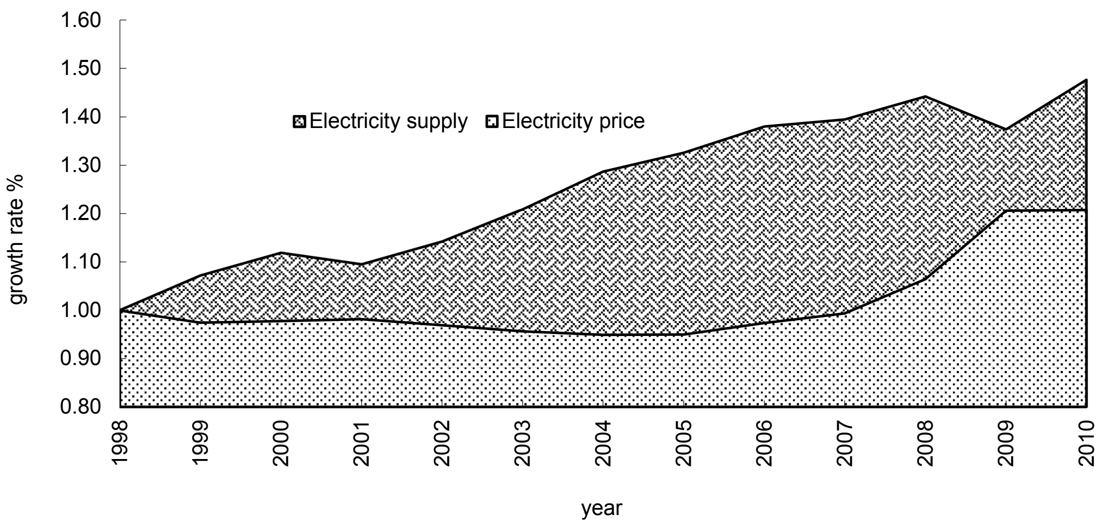


Figure 3 shows the growth rates of electricity supply and price in Taiwan from 1998 to 2010. Obviously, electricity supply continued growing and was always lower than the supply until 2008. In 2009, after electricity prices were increased, electricity consumption dropped 13% over that of the previous year.

Moreover, electricity is not clean. Coal, natural gas, and fossil fuels are the three main sources for power generation of the three thermal power stations, Hsingta, Talin, and South, in the Kaohsiung area. During power generation, except for air pollutants, carbon dioxide (CO_2) emissions also pose a threat to the environment. Therefore, the Mass Rapid Transportation (MRT) and electrical vehicles, strongly promoted by Kaohsiung City government, are the second "worst" option for transportation owing to the high-carbon electricity.

Transformation to High Added Value and Low-pollution Industry

Despite a revival of the secondary industry in 2006, air pollutants rather than SPM and SO_2 presented strong decoupling; garbage collection did as well. The secondary industry appears to be less-polluted than previously. Based on the Environmental Kuznets Curve (EKC) hypothesis, as economic growth continues, economic activities exert less pressure on the environment (Kuznets, 1955). The de-linking of economy and environmental pressures can be partially interpreted by the EKC theory. For instance, Talin thermal power station has applied electrostatic precipitators (ESP) to lead the flow of gases through the device and remove fine particulate matter such as dust and smoke from the air stream (Taiwan Power Company, 2012). Industrial upgrading is another effective means of lowering environmental pressures. Since 1996, Kaohsiung City industries have gradually transformed into a precision industry featuring hi-technology, automation, high added value and low pollution (EDBKCG, 2010). For instance, research and development (R&D) expenditures in manufacturing (e.g., electronic components, chemical materials, base metal, and transportation equipment) have increased. In 2007, the total R&D investment in Kaohsiung amounted to $US 600 million dollars.

However, the negative decoupling of SPM and SO_2 from GDP revealed that a portion of the GDP led to the production of excessive pollution. The sources of negative decoupling must be traced to understand its origin. Coal burning and oil burning account for around 80% of SO_2 emissions; burning of coal, oil, gaseous fuels, fly-ash emissions from power plants, and some other heavy industries (e.g., smelting and mining activities, as well as metallurgical and cement industries) contribute to SPM accumulation (UNEP, 2005). In 2006, the value output of the secondary industry (including the petrochemical, steel, photonics and optics industries) rebounded with a 12.52% increase in growth (EDBKCG, 2010). These high-polluted, heavy industries more profoundly impacted Kaohsiung's economic development than in 2002, thus providing a hypothetical explanation for the negative decoupling of SPM and SO_2 emissions from GDP.

Transforming to a tertiary industry appears to be an effective means of eliminating environmental problems. Consider Hawaii as an example. As a global tourist resort, Hawaii attracts a tremendous amount of visitors every year. Konan and Chan (2010) investigated greenhouse gas emissions in Hawaii, indicating that the average visitor consumes 4.4 times more energy and produces 4.3 times more greenhouse gas emissions than an average resident does. None of the industries can ensure environmental sustainability, while only conservation-oriented attitudes and measures can achieve this.

CONCLUDING COMMENTS

Kaohsiung, the second largest city in Taiwan, is aggressively striving to upgrade and transform its industries to make the city more sustainable to live. To monitor the effectiveness of the city government policy, this study evaluates the decoupling situations of environmental pressures from GDP in Kaohsiung during the period 1998 to 2010 by using Tapio's method. Along with the rise and fall of the secondary and tertiary industries, electricity supply during the period 1998-2010 experienced negative decoupling; tap water consumption, O_3 1998-2002, and SPM, SO_2 2002-2006 did as well. Electricity abuse should be tackled with price strategies. Moreover, for environmental concerns, widely applying renewable energies should be a long-term goal for Kaohsiung's energy policy. Decreasing air pollutants requires not only an industry upgrade and transformation, but also the fulfillment of pollutant emission reduction.

This study has important implications for governmental authorities. We recommend that Kaohsiung City government introduce and encourage businesses to form a high cluster network with local industries and estimate their degrees of pollution. We further recommend that the government levy pollution taxes on high-polluted economic activities. Furthermore, the application of renewable energies and energy-efficient devices warrants further subsidies. Also, some limitations exist in this study. Several important data, such as liquid waste, VOCs, and Pb, are not accessible and, therefore, we can not discuss the decoupling situation of all environmental pressures. In terms of the time span, this paper covers only 12 years of data due to lack of time. Dating back to the earlier stages when the output value of secondary industry was much higher than that of tertiary industry may reveal some other interesting facts about economic development and environmental pressures. Further researches would encompass more concerned environmental pressures and longer time span to observe the dynamic relationships between economy and environment. This provides an evolving model for the authorities and researchers to build an appropriate industrial structure for sustainable cities.

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