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# 再生能源發展政策： 整合總體面、需求面與生產面的分析模式

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執行單位：南華大學環境管理研究所

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# 再生能源發展政策： 整合總體面、需求面與生產面的分析模式

摘要

本計畫的主要研究目的在探討如何整合政府的環境、能源、與科技政策，用以發展再生能源的市場，減少 CO2 的排放。本計畫從三個面向著手，(1)從總體經濟面看過去台灣的再生能源發展狀況，亦即探討影響總體能源的使用的相關社經因素。(2)從需求面來看則是分析哪些因素影響再生能源的需求，除了消費者的環境意識之外，環保標章的識別作用對再生能源購買應該會有顯著影響。換句話說，從消費面所得到的資訊可以協助建立綠色電力市場，以吸引更多廠商投資綠色電力生產，減少 CO2 排放，改進環境績效。(3) 從生產面來看則是在變動的消費者需求與技術下，生產者應何時引進再生能源技術，生產並供應再生能源，同時，生產者也必須檢視環境變數對再生能源市場佔有率的影響。政府必須掌握這些訊息，建立適當政策，改善綠色再生能源生產技術的流通，以擴大再生能源的發斬。換句話說，透過這三種面向的分析所獲得的相關資料，政府可以作為依據，再制訂相關的環保、科技、與科技政策。本計畫為三年期計畫，至今為止，已經完成 5 篇論文，如附錄。另外，尚有部分資料還在整理中，預計字在外來一年內，可以再完成 1-2 篇期刊論文，並考慮投稿於國際期刊。

本計畫整理分析國內能源政策目標，並以過去幾年國內再生能源發展的數據，評估分析國內能源政策的缺失，以作為政府參考，並從理論面，發展出再生能源的評估模式。本計畫所產生的結果，除了提供有關再生能源發展理論的相關模型外，在實務上也針對國內再生能源現況，例如太陽能、風力發電、或國內家電使用型態詳細分析，因此，所得的結果，將具有相當運用價值。由於本計畫所運用的資料涵蓋最近 10 年的歷年資料，因此，所得到的結論不僅具有時效性，而且充分運用本土的環境特色，在實務運用上，將減少失真現象。

另外，本計畫的實施也提供學生參與計畫，瞭解如何觀察問題，如何切入問題並加以解決。也讓學生有更多的機會與師長互動，對於培養學生的學術研究能力，應該會有相當大的助益。

關鍵字：再生能源、庫茲涅曲線、碳標章、綠色消費、環境意識、綠色科技

## Abstract

This project aims to integrate the governmental policies among departments for the development of renewable energy. We start from the macroscopic, the consumer and the producer's perspective to examine the factors affecting the consumption of renewable energy. In other words, we attempt to examine the socio-economical factors affecting the consumption of renewable energy, to investigate the factors affecting the market demand, and the factors affecting the adoption of renewable energy production. This project was implemented in 3 years. After the implementation of this project, we have completed five articles in English. One of them has been accepted and published and the others were submitted to international journals for reviewing. In the coming future, we believed that more articles can be yielded based on the data generated by this project.

In brief, the conclusion of this project emphasizes the role of integration between producers, consumers and the governments for the achievement of renewable energy developments. In fact, the role of technology plays a high impact on the cost of renewable energy and eventually the market competitiveness of renewable energy products. Due to the low technology level, Taiwan has to import the key parts or machine for production of renewable electricity or solar PV systems. Such a circumstance brings about the relative high cost of renewable electricity and reduces the market competitiveness of renewable electricity. Currently, the government focuses on the subsidy programs for the renewable electricity and neglects the integration among the departments of the governments. The conclusion of this project suggests that the renewable energy policy should be formulated through the integration among the relevant departments of governments.

Keywords: renewable energy, Kuznets curve, carbon-label, green consumption, environmental attitude, clean technology

# 目錄

## 一、前言

在 2000 年政府就宣布發展再生能源政策，在 2003 年 6 月之「全國非核家園大會」上研議，希望在 2010 年再生能源比率可以提高到 10%（經濟部能源局，2007)。至今為止，已有許多廠商從事再生能源的開發與投資。例如苗栗竹南、台北金山、澎湖附近海岸，已有廠商在投資設立民營風力發電廠。去年石油價格高漲，使得風力發電或太陽能電池或太陽能光電生產，太陽能或風力發電成本等再生能源相對下降，在商業營運上，更具有競爭力。由於太陽能或風力發電的經濟規模相對較小，具有相對彈性，比較適合用於偏遠地區，用於節省輸配電損耗與成本；或是作為一般電力供應不足時的補充品，以便減少對石油的依賴。利用風力取得廉價的電力，還可用它來電解水生產氫，作為汽車燃料電池引擎的燃料。另外，政府對於家戶太陽能熱水器裝設的補貼，工業汽電共生的輔導等，顯示政府發展台灣的再生能源運用，相當用心。

基本上，所得和人口的成長，而引起大量消費，是造成溫室氣體上升的主要推手(Schmalensee, et al., 1998)，沒有節制的消費，不僅排放更多的二氧化碳，也造成資源匱乏，對整體地球或地方環境都有不良的負面作用。降低消費或是志願購買綠色產品，可能有助於整體環境的綠色化。雖然環保團體呼籲的社會上所有人自我限制，降低慾望，減少消費，但是，此種運動有可能流於政治語言，不會持久，也不容易引起廣大信任(Schmalensee, et al., 1998)。Jessop (1998) 認為政府的角色對促進生產者與消費者互信互相理解，發展出制度性的機制以達成整體社會目標的實現，扮演重要角色。政府可以透過立法機制，建立組織的內部凝聚力，或可以操作的單位，用以實行政府治理權力，已達成社會共同目標(agreed

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objectives)。政府的實施策略，必須透過建構特定的社會制度(social institution)，用以推動特定的社經互動(socio-economic intervention)，以達成社會共同目標(Brenner, 2003)。

因此，本計畫的主要目的在探討影響再生資源發展的主要因素，並提出適當的政府政策，用以鼓勵再生能源的生產與消費。基本上，政府的角色必須分工中又能整合，才能產生效率，如『溫室氣體減量法草案』所強調的溫室氣體減量政策上必須分工與整合。因此，計畫提出理論架構，分析影響再生能源發展的因素，並提出整合性政策（包含環境政策、能源政策和科技政策）。政府如何提供適當的鼓勵，提高廠商發展新科技，政府政策對開發綠色清潔科技的影響，目前，非常少學者討論此一議題或是提出驗證性研究。也很少論文涉及廠商對引進清潔科技的激勵因素和障礙因素，做調查分析。本計畫從整體消費、生產廠商、與消費者立場出發，分析再生能源的消費與所得的關係，並驗證其他社經變數對再生能源消費的影響，用以發展適當的環境、能源與科技政策，以追求更穩定與永續的再生能源消費，以求永續發展及強化我國整體競爭力。

## 二、研究目的

本計畫分成三個年度實施，第一年後即在探討再生能源消費與社經變數中的關係，第二年度的主要探討哪些因素會影響在生能源的需求，從圖一來看，社經變數會影響環境意識願付價格，並進而影響再生資源的需求，另外一個因素則是再生資源的環境資訊透明度問題，消費者是否可以充分的資訊去了解再生能源與一般能源的差異性，目前所使用的環保標章制度主要適用於一般製品，是否適用於能源諸如電力，且能充分的傳達產品的環境資訊給消費者殆有疑義。因此，第二年的計畫是站在消費者的立場，分析影響消費者購買再生能源的因素及透過模式估計消費者對再生能源願意付出的額外價格（Willingness to pay, WTP），並依據問卷結果，設計適當的碳標章，作為消費者在購買能源時的參考。由於國內再生能源科技研發較少，主要依賴技術引進。因此，第三年的計畫，主要針對技術的流通為主。從生產者的立場出發，探討哪些因素影響廠商引進再生能源，並以政府立場，提出適當的政府政策。

## 三、文獻探討

從總體面來看，影響再生能源或二氧化碳排放的影響社經因素有許多種，不同的研究或不同的環境之下，這些社經變數可能會不同。導致庫茲涅曲線發生的主要原因有兩項： 規模效果(scale effect)和經濟結構效果(compositeon)。經濟發展初期，產能持續上升，所得提高，但由於技術的限制，石化能源使用量或二氧化碳排放也跟著提高，此種因社會經濟產能的增加導致污染增加，稱之為規模效果。但隨著石化能源使用量或二氧化碳排放提高，政府開始提出政策，要求採用再生能源以降低二氧化碳排放，規範生產廠商改善技術，或強迫污染廠商外移。由於各種誘因，例如技術進步，或是教育發展，使得消費者環境意識提高迫使廠商改變生產製程，或改變產品設計，養成綠色消費習慣 (Stern, 2004)。這些轉變都是導因於成長所帶來得結構改變，往往發生在所得較高的階段，此種效果稱之為結構效果。

Stern (2004)、 Stern et al. （1996）、 和 Ansuategi et al. （1998）等論文針對有關 EKC 的文獻，提出回顧和細緻的批判。Andreoni and Levinson (2001) 認為經濟規模的變化就足以產生 EKC；Stokey (1998)、Lieb (2001)則是以內生性技術變化為基礎，考慮消費的滿足所帶來的污染情形， Ansuategi and Perrings (2000)則是將跨國污染納入模式， Magnani (2001) 討論個人偏好對公共政策的影響，發展出 EKC 模式。Skonhoft and Solem (2001)發現野地的相對數量和經濟活動水準呈現負面關係，亦即經濟成長會有較少的野地，因此，此一研究並未發現兩者有 EKC 關係。Cole et al. (2005)、 Dasgupta et al. (2002)、Merlevede et al., ( 2006 ) 考慮公司規模納入模式中，認為大規模廠商才是排放污染的罪魁禍首。Dasgupta et al. (2006) 認為大部分的 EKC 研究都不夠完整，所得的結論也都有缺失，主要的原因是這些研究大多沒有將兩項重要因素納入模式，環境污染所造成的傷害所必須面臨的治理與支撐能力（ governance and vulnerability to environmentaldamage）。這兩項因素不容易量化，尤其是政策變數在納入模式的錯誤，似乎更為明顯，例如在落後地區或是新興國家，政策的執行能力與效能並未在模式中得到適當的處理。此外，也有部分學者提出理論分析，探討隔代間的外部問題，例如 John and Pecchenino, 1994, 1997; John et al., 1995; Ansuategi and Perrings, 1999, McConnell (1997)，以跨代為基礎，並考慮生產活動、消費所帶來的污染，發展出 EKC 模式。

從消費者的立場出發，許多學者強調人口變數（例如所得、年齡、教育水準）或社經變數（例如失業率、政府補貼）等都會影響綠色消費與需求，換句話說，消費者個人的背景以及經濟變數都會影響消費者的環境意識與行為，也會造成後續的綠色消費選擇( Burton et al., 1999; Sureshwaran et al., 1996)。Luzar and Diagne (1999), Willock et al. (1999), Bourke and Luloff (1994), Vogel (1996) 利用問卷訪談，發現態度是最主要力量影響民眾進行綠色改進行為，Bjørner et al.(2004)透過消費者在超市的實際購買行為證明：男性有小孩的消費者相對於女性有小孩的消費者而言，比較不會購買環保標章產品；Loureiro and Lotade(2005)研究結果也得到女性與高教育程度者對於有環保標章咖啡願意支付較高的價格，老年人對於環保標章咖啡則沒有太大的興趣；Straughan and Roberts(1999)的研究結果也指出：年輕人、女性、教育程度較高、收入較高的消費者比較會從事綠色消費行為（Rex and Baumann，2007）；Laroche et al.(2001)的研究結果也顯示已婚的人願意對綠色產品付出較高的價格。另外，影響再生能源消費的因素是再生能源的價格，Bjørner et al.（2004）的研究結果得到：產品價格與消費者對環保標章產品的購買行為是負相關的；Basu et al.(2003)研究裡有說明到綠色消費市場市場無法擴展是因為綠色產品比一般產品貴的因素，消費者基於成本的考量而不願意去購買綠色產品。再生能源如太陽能、風力發電、生質能等在使用後，相對於傳統電力，會產生較少的環境衝擊（污染），但是，以國外實施的情況看，再生能源相對價格會高 10% 到 30%。國內目前雖然已經有部分再生能源的生產，但是並沒有供應給消費者，國內再生能源的消費仍然侷限於特定的公務單位，一般民間消費幾乎不存在。

同時，政府政策也未適當的引導消費者進行綠色消費，例如政府對於產品的相關環境資訊，並未強迫廠商提供，因此，既使是具有環境意識消費者進行採購時，也沒有任何資訊分辨哪些能源是再生能源，無法從產品包裝判讀所欲購買的產品，是否是綠色產品，綠色程度如何。而且，消費者選擇商品或勞務時，可能會參酌產品環境資訊與品質資訊，再去找出最適當的購買組合。完整的環境資訊可以透過網路系統，即時傳輸給會大眾，也可以將歷史事件或資料提共給大眾，

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以激發大眾參與環保的決心(Schimak, 2003; Sharma et al., 2003)。許多組織嘗試改善資訊流通，讓產品的環境資訊更為透明，易讀。甚至透過立法程序要求生產廠商充分披露產品的品質、環境資訊，並希望能利用 ISO14020 的原理與程序，提供充分資訊，協助消費者進行綠色消費。

雖然已經有許多學者開始探討環保標章的使用和有效性，但很少將之與行銷結合。一般來說，影響再生能源市場機制運作的主要力量是消費者的環境意識，進而所採取的環境消費行為，這些綠色行為形成一股力量，產生再生能源的需求，進而影響生產者的清潔科技的開發或引進，然後則是綠色產品的生產（Dillon and Baram 1993; Midgley and Dowling, 1993; Lenschow, 2002)。

整體而言，一般對影響環保研發或環保技術引進的因素，仍然付諸闕如。基本上，影響新科技接受與引進的因素含括組織因素和環境因素，以及這些因素的互相衝擊。技術價格下降或是技術水準上升是直接影響接受技術的主要條件，但產業中技術領先的同業的特性，也會對後面廠商產生示範作用。因此，以整體市場來看，技術傳播主要是依賴經濟吸引力，換句話說，如果引進新技術可以帶來利益，廠商必然是會引進的。

清潔生產技術與管末處理技術不一樣，前者強調事前預防後者則專注於事後（污染發生後）處理，清潔生產技術可以節省許多事後處理成本相對的，後者導致大量的外部成本。但是，清潔生產受制於技術研發，因此生產成本可能偏高，或是買不到適當的技術進行生產。Rehfeld and Rennings (2007) 實證調持發現 53%受訪企業同意消費者反應綠色產品比一般產品貴，也有 10% 受訪者同意綠色產品品質較差。因此，價格因素可能是影響消費者採用綠色產品的主要因素。許多研究發現技術進步或流通主要是受產品價格優惠或是法規所影響，例如 Jaffe and Stavins (1995)發現：在新的住宅建設內的能源效率和能源價格、技術成本有非常敏感的關係。Newell et al. (1999)也發現高度使用能源的持久性商品，其研發與能源價格有強烈關係 。

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一般來講，這些研究分兩大主流：檢視傳播型態和機制，瞭解企業對新科技、研發產品是否接受的決策機制。前者主要再探討一定時間內，接受新技術者佔總數的比率，也就是分析新科技接受者在某一特定市場內與時間的關係。後者主要是探討個人接受新技術時，在理性思維的假設下的決策過程。Arora and Cason (1995)探討什麼動機影響廠商志願投資設備，預防污染產生，Henriques and Sadorsky (1996)則檢視影響廠商參與 ISO 14000 的認證的動機。至今為止，已經有許多學者針對新科技研發的傳播問題，在管理、行銷、或是研發政策上，提出各種有價值的報告或是理論（請參考 Meade and Islam, 2006; Geroski, 2000; Sakar, 1998 的一般性評論）。許多學者透過 logistic 模型，檢視技術隨著時間經過的傳播型態並預測未來技術的發展狀況(Islam and Meade, 2000; Islam, et al. 2002; Sohn and Ahn, 2003)。Logistic 模型是指技術流通型態像 S 型。一開始的時候，成長速度較慢，然後以指數方式成長，最後階段成長速度下降。

## 四、研究方法

本計畫將能源消費分成兩大類：一般能源 $E_{1t}$ 與再生能源 $E_{2t}$，分別驗證此兩大類以是否具有庫茲涅現象。考慮以上所有影響因素，本計畫所採用的 EKC 模式也納入許多社經變數，分別如下：

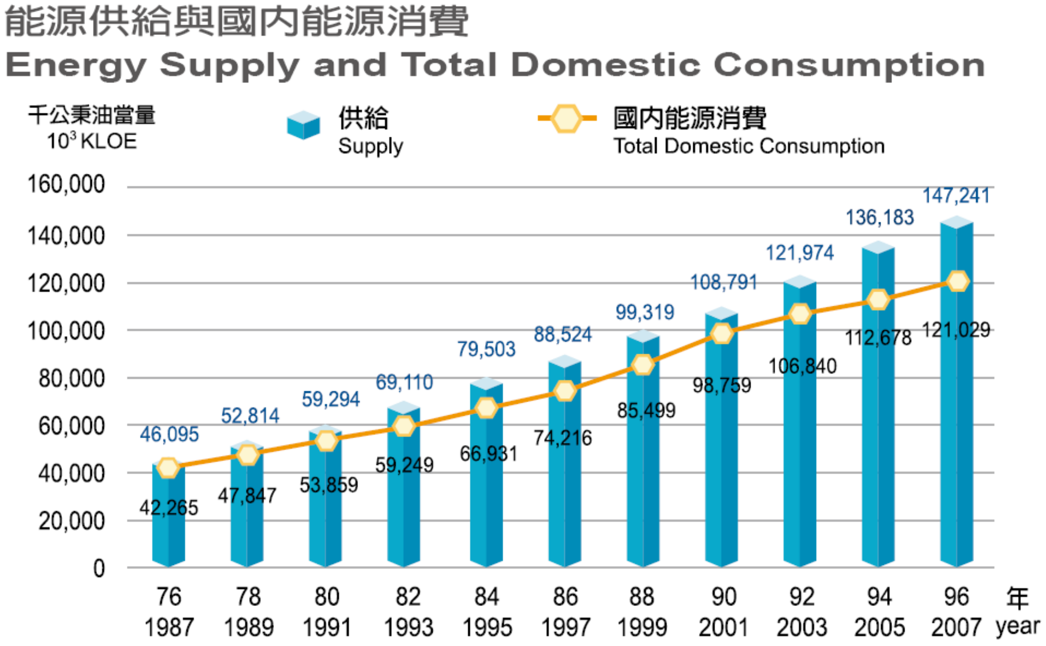
$$E_{1t} = \alpha_0 + \alpha_1 I_t + \alpha_2 I_t^2 + \alpha_3 I_t^3 + \alpha_4 Trade_t + \alpha_5 Y_t + \alpha_6 unemp_{it} + \alpha_7 edu_{it} + \varepsilon_{it} \tag{1}$$

$$E_{2t} = \alpha_0 + \alpha_1 I_t + \alpha_2 I_t^2 + \alpha_3 I_t^3 + \alpha_4 Trade_t + \alpha_5 Y_t + \alpha_6 unemp_{it} + \alpha_7 edu_{it} + \varepsilon_{it} \tag{2}$$

式中，$I_t$ 代表 GDP，$Trade_t$ 代表貿易開放程度，$Y_t$ 是製造業產值佔國民所得比率，

$unemp_{it}$ 代表失業率，$edu_{it}$ 代表教育水準。

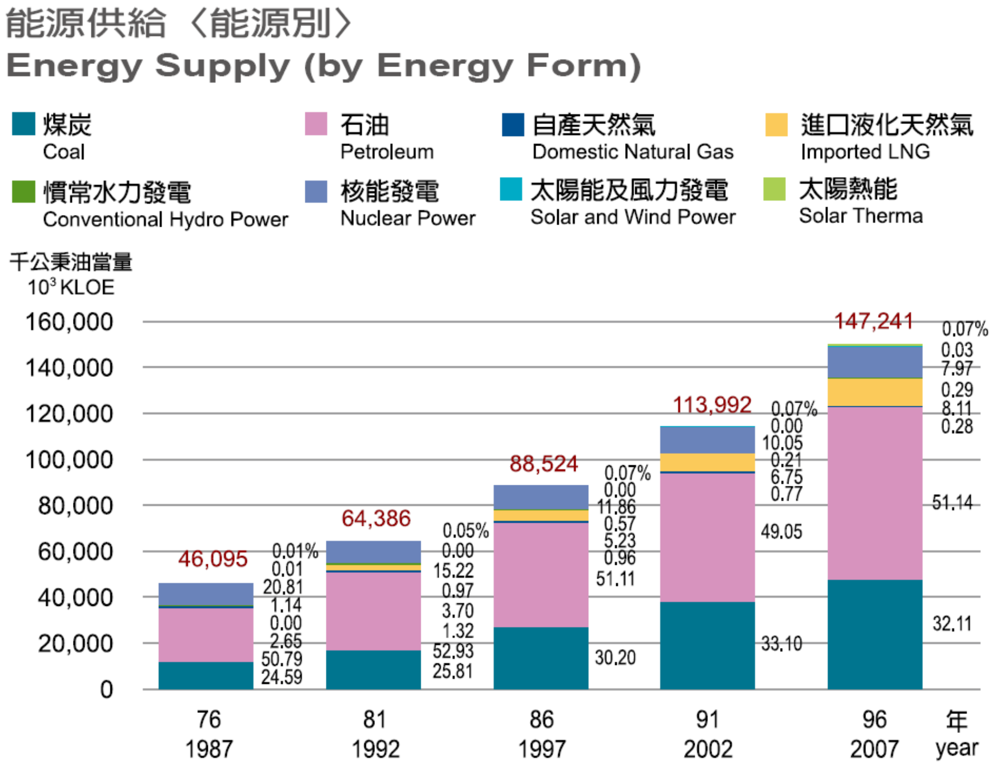
本計畫所運用的有關一般能源和再生能源的追蹤資料取自經濟部能源局 2008 年能源統計年報，國民所得、教育水準等社經資料，則取自行政院主計處網頁。從資料中顯示，我國平均每人國民所得與能源消費都一直保持成長趨勢(請參看圖二、圖三)。總能源消費量從 1998 年的 81,449.7 mloe（$10^6$ liter oil equilivalent)增加到 2007 年的 121,028.5 mloe。 96 年國內能源消費量若按能源別分，則煤炭、石油、天然氣等消耗性能源佔 51.31%，電力占 48.46%，太陽熱能占 0.09%。電力供應中來自再生能源的佔 5.08%而已，亦即總再生能源佔總能源消費量僅有 2.55%。如果以每人能源消費量計算則從 1998 年的 3,740 loe 增加到 2007 年的 5,302 loe。



圖三、能源消費量（資料來源：經濟部能源局 2008 年能源統計年報）

能源供給中，水力發電、太陽能發電、風力發電、或太陽能使用等再生能源

的所有能源供給中[1]的相對比率，從1998 年的1.16% 到2007年的0.39%（請參考圖四），不進反退，顯示再生能源的發展，並沒有受到應有的重視。再生能源的供給中，大部分仍然依賴水力發電，但是由於台灣的水力發電幾乎開發殆盡，且水水力發電必須依賴水壩蓄水，造成河流生態的破壞，也屢屢引起環保團體或是生態專家的撻伐。至今為止，太陽能可以說是取之不盡，用之不竭的一種能源，在能源轉換過程，也比較沒有副作用，因此，值得大力發展。



圖四、能源供給量（資料來源：經濟部能源局 2008 年能源統計年報）

本計畫主要運用條件評價法（contingent valuation method, CVM）來探討分析消費者對再生能源需求的願付價格。條件評價法的基本觀念是經由調查受訪者願意以多少個人的消費量（或金錢）來換取再生能源的使用，以估算再生能源（綠色產品）在消費者心目中所具備的環境價值。除了條件評價法外，較常用來評價

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非市場財貨的方法還有特徵評價法（hedonic price method, HPM）及旅遊成本法（travel cost model, TCM），這兩種方法都是屬於事後的評估。Carson （1998）認為條件評價法（contingent valuation method, CVM）的使用可以改變傳統對於綠色資源過於狹隘的處理，更有不少學者堅持條件評價法是評估綠色資源唯一且最好的方法（Bishop and Welsh, 1992；Larzo, et al., 1992；Blomquist and Whitehean, 1995）。Kotchen, Reiling（2000）在進行遊隼、短吻鱘保育價值調查時，將受訪者的付款意願假設為下列函數式：

付款意願 Yes/No=（*BID, NEP, KNOWLEDGE, INCOME*）

*BID* 代表每段詢價金額，*NEP* 為受訪者的環境信念傾向，*KNOWLEDGE* 為受訪者對緬因州特殊物種的知識程度，*INCOME* 為受訪者的年收入。調查結果顯示遊隼在短吻鱘保育願付意願的 Logit 模式中，*BID*、*NEP* 和 *INCOME* 數變均通過 0.01 的顯著水準，其中又以 *NEP* 這個變數的影響力最大。環境信念愈以環境為中心的受訪者，回答願意付款的可能性愈高。本計畫嘗試建構下列 Logit 模型，期望能以此模型利用檢視受訪者的願付金額、環境態度、環境知識、家庭年收入和其他社經變數之間的關係：

$$\ln \frac{p}{1-p} = \alpha_0 + \alpha_1 WTP + \alpha_2 A + \alpha_3 K + \alpha_4 I + \alpha_5 E + \varepsilon$$

式中，$WTP$ 是願付價格，$A$ 代表環境態度，$K$ 代表環境知識，$E$ 是教育水準，$\varepsilon$ 則是誤差項。

本年度計畫的問卷設計過程，首先針對政府機關負責綠色採購人員，進行深度訪談，試圖瞭解國內綠色採購在進行中所碰到的障礙和影響綠色採購的激勵因

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素，並參考國內外過去環保標章相關理論與實證研究，建構研究架構。然後，再參考前人的研究，設計制定問卷量表，以國內一般消費者和學生為研究對象。問卷中環境信念的部分，採用最新的新生態典範（New Ecological Paradigm, 以下以 NEP 代表）來測量（Dunlap et al., 1992），這是從社會學家使用超過二十年以來的最新版本（Dunlap and Van Liere, 1978），其中包含十五個萊克特式（Lickert scale）的態度評量問題，受訪者針對每個子題回答非常不同意代表 1 分，不同意代表 2 分，普通代表 3 分，同意代表 4 分，非常同意代表 5 分，十五個子題滿分為 75 分。

## 五、結果與討論

本計畫的實施，至今為止，共產生 5 篇論文，都已經投稿到國際期刊，詳細內如如附錄。主要研究目的如下所述：

第一篇 An examination on the feed-in tariff policy for renewable electricity: Taiwan’s case example ：主要的目的在探討國內再生能源收購價格政策對再生能源發展的影響，同時，比較臺灣與先進諸國的再生能源政策，並預測臺灣的太陽發電成長情形。

第二篇 An examination on Taiwan’s PV industry：本篇主要的目的在分析國內現有太陽能產業經營上的困境，考慮臺灣太陽電力的轉換效率相對落後先進國家，在發展太陽能技術時，受制於其他國家，因此，本文比較分析台灣在太陽能產業上與其他國家的消長情形，並提出適當的管理策略，給政府相關單位參考。

第三篇 An examination on the effectiveness of energy policies aiming at CO2 mitigation：本篇論文分析國各主要國家的二氧化碳排放情形，是否有庫資鎳現象，並比較臺灣與先進國家在二氧化碳排放上的差異，台灣在過去，再生能源的發展，是否對二氧化碳排放減量有幫助，是本文的重點。

第四篇：The variation of environmental governance across countries and its effect on energy policies：本篇論文主要再探討社會經濟產生變化時，尤其是跨入民主行列時，能源政策制訂的治理權會受到如何影響，本文比較三個國家，分析其治理與能源政策的變化。

第五篇：An analytical framework for energy policy evaluation （本文已刊登在 Renewable Energy **36**, 2694-2702, 2011）：本文以臺灣的能源政策為例，分析臺灣過去幾年的能源消耗量的變化，並提出分析性架構，整合生產者、消費者、與總體需求。本文建議影響能源需求與二氧化碳排放的主要關鍵在能源結構與產業結構，因此，如何引導產業走向低耗能、高產值的清潔生產方式，是為當務之急。

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計畫成果自評

本計畫在執行期間，總共完成5篇論文，部分資料尚在整理中，可望在未來的時間，繼續完成論文寫作。所完成的論文已投稿國際期刊，大部分在審稿中，其中，已經一篇被國際期刊-Renewable Energy 接受並刊登。

所完成或已發表之論文，都是針對國內能源現況，探討影響再生資源發展的主要因素，並提出適當的政府政策，用以鼓勵再生能源的生產與消費。在學術成就上，本文不僅提出理論性架構，探討能源政策制訂時的一些考慮因素，同時，也從台灣在發展再生能源政策上，所制訂的政策目標與執行結果，提出分析與檢討，發現政府政策內容中所制訂的再生能源目標值，往往都不能完成。主要再生能源目標值不能完成的原因是臺灣缺少再生能源設備技術，例如風力發電設備至今為止，仍然必須進口。另外，關鍵性零組件或原物料長外在國外廠商手裡，例如太陽能電池的原料，矽土仍然仰賴進口，且晶圓製造設備，也必須進口。因此，所產生的電力成本或太陽能電池發電效率太低，無法與傳統電力競爭。

在學術上成就來說，本計畫開創了一扇窗，結合理論與實務需要，務實的以臺灣的過去太陽能、風力發電等再生能源的發展狀況作依據，分析影響再生能源發展的因素。由於本計畫在方法論上有學理根據，在資料的應用上，也是以最新最可靠的官方資料，如此，所產生的結果在實務應用上，當具有非常務實的效益。同時，利用過去再生能源的發展數據，用來檢視政府過去的能源政策，例如非核家園政策的可行性，更能一針見血診斷出政策制訂的盲點。

由於再生能源的生產，在國內屬於新興產業，所需設備又必須進口，不僅成本無法與國際大廠競爭，且技術受制於人。本計畫研究結果認為再生能源的發展，不是純粹的能源部門可以決定，必須與經濟部門與環保部門密切合作，改善國內產業結構，提高自有技術比率，鼓勵消費者進行綠色消費，刺激環保產品的茁壯，增強環保產品的競爭力，才會有效果。目前的再生能源補貼政策，似乎無法有效的改善再生能源的發展。本計畫的研究結果顯示，掌握關鍵性能源科技技術，然後再鼓勵消費者支持，透過媒體與學術批判，增強再生能源的相對環保地位，甚至透過政治上的合作，制訂國際公約或標準，嚴格要求貿易（輸入）產品使用清潔能源（再生能源）的比率，如此，對於再生能源的發展，將會有革命性的影響，這些議題，可以作為後續的研究。

本計畫以國內再生能源的發展為依據，分別考慮總體面、消費面與政策面的各種狀困，深入分析導致再生能源發展成功或失敗的原因，以作為政策設計的參考。在學術上，本計畫的推動已產生五篇論文，並投稿在國際期刊上，其中一篇以刊登在國際期刊上，剩下的論文相信很快就會有進一步的結果。另外，本計畫的實施，可以引導學生復習其已得之知識，並運用到社會上的實際工作上，以印證其所認知與理論是否一致。本校研究生在與社區民眾的互動中，了解人性因素與個人或社會價值觀對環境政策的影響，並從其中，找出素材，作為研究的主要議題。培養學生運用圖書設備收集相關文獻的能力，訓練學生如何製作問卷，收集資料，利用統計分析工具，分析並解讀資料的技巧，強化其實務操作能力。

附件一：

# An examination on the feed-in tariff policy for renewable electricity: Taiwan's case example

## Abstract

Taiwan's feed-in tariff (FIT) policy, revised in 2009, sets a goal to increase the installation capacity 6,500-10,000 MW (megawatts) of renewable power systems in 20 years. The purpose of this paper is to examine whether the goal can be achieved or not. This paper presents an overview of FIT policy implemented in some leading countries and their performance involving renewable electricity installed capacity and generation. This paper presents two outlook scenarios for Taiwan's renewable power installation capacity by using Germany as a benchmark after a detailed analysis and discussion on Taiwan's historical evolvement of renewable energies. The Moderate Scenario projects that total cumulative capacity of renewable power systems increases from 5,814 MW in 2010 to 7,246 MW in 2030 while the Optimistic Scenario estimates the total renewable power capacity will be 11,977 MW in 2030. The total increase of the new installation capacity attain to 1,432 and 6,164 MW for the two scenarios, respectively.

Keywords: feed-in tariff (fit); wind power; solar PV; renewable electricity; energy policy.

## 1. Introduction

Renewable electricity has relatively higher costs in production than conventional fossil-fueled electricity, and thus, it has not yet fully developed in the world. Numerous promotional and subsidy programs have recently been implemented by many countries in the world for the development of various renewable energies. The feed-in tariff (FIT) policy has been implemented by many countries and proved to perform well to trigger a considerable increase of renewable electricity production. In general, it may be seen as an effective supporting mechanism for the successful development of newly emerging renewable energy technologies [1-4] since it can reduce the financial risks for renewable energy technology developers [5] and deploy the installation of renewable energy systems at lower cost than other policy mechanisms [6-8]. The FIT policy is basically used to promote renewable energies that aim to reduce emissions of green house gases and air pollutants, together with several competing objectives that attempt to reduce dependence on fossil fuels and to increase portfolio diversity and energy security. To follow such a trend and improve the market efficiency, Taiwan has started to liberalize the electricity market. In 1999, a coal-fired power plant was installed by Formosa Plastics Corp with total capacity of 1,800 MW. The liberalization campaign asked Taiwan Power Company (TPC, the government's attorney) to purchase electricity from the private-owned power plant (independent power producers, IPPs) at a price that is determined at the levelized cost based on a 25-year power purchase agreements between IPPs. The electricity generated by IPPs should be fed in the grid. Such a system may be the first FIT policy implemented in Taiwan.

Taiwan government argues that the major purpose of FIT policies is to promote the consumption of renewable energies for the increase of energy security, enhancement of domestic power generation capacity, minimization of power generation costs, stabilization of fuel stocks cost and the mitigation of CO2 emissions, leading to a goal of 50% of 2000 emission levels by 2050 [9]. In 2009, the "Directive for promoting renewable energy (DPRE)" was passed and put into effect after a long time of legislative debate. In the DPRE, the government set a goal to increase 6,500-10,000 MW of renewable installation capacity in 20 years. The level of new feed-in tariffs (the payment for purchasing electricity generated from renewable source), announced in March 2011, rises up in a great leap for a variety of renewable power generation.

The purpose of this paper attempts to answer the question: "Is the feed-in tariff for renewable electricity appropriate to achieve the policy goal in Taiwan?" And thus, the theme of this paper focuses on the outlook on the future development of renewable power systems in Taiwan. This article is organized as follows: Section 2 provides an overview of the renewable electricity generation in the leading countries. In Section 3 we review the historical evolution of Taiwan's renewable energy policies and analyze the policy performance by comparing the goal designed in earlier days and the data performed. Section 4 introduces the 'feed-in tariffs' scheme implemented in Taiwan and describes the programs adopted in the some selected countries. Section 5 provides two outlook scenarios for Taiwan's installation capacity of renewable power systems. The scenarios attempt to examine whether the goal set in the DPRE can be achieve or not. A brief conclusion is made in Section 6 with a summary of lessons learned from the past policy making in Taiwan.

## 2. The renewable electricity generation in some leading countries

The renewable electricity generation for some selected countries in 2008 is listed in Table 1 according to the statistics databases of International Energy Agency [10]. China totally generated 600,797 GWH (gigawatt-hour) of renewable electricity in 2008, ranked the top in the world. Its hydroelectric power generation contributed the major share of renewable electricity generation, attaining to 97.4% of total renewable electricity production. In contrast, the share of non-hydro renewable generation is relatively low. Under such a case, China still enjoys the relative advantage of hydro resource and plans to expand its investment on the hydro power projects. The Three Gorges Dam along the Yangtze River is still under construction, including 32 separate 700 MW generators, for a total of 22.5 GW. The low share of non-hydro renewable energy supply implies that a large room exists for China to develop the non-hydro renewable energy like solar PV and wind power in the future. Currently, the share of solar PV power generation is still very negligible in China. Compared to EU, the US, and Japan, China's PV power generation falls far behind. By 2010, China had installed about 893 MW of solar PV power systems, accounting for 2.29 % of the world's capacity [11] and started to implement FIT in July 2011 to meet a goal of 5 GW by 2015 and 20 GW by 2020 for the solar PV installations [12].

The US and Canada followed after China for renewable power supply, generating 429,546 and 394,920 GWH of renewable electricity in 2008, respectively. However, The US leaded the world for the generation of wind power in 2008, contributing to 55,696 GWH, ahead of Germany and Spain that produced 40,574 and 32,203 GWH respectively. In Canada hydro power contributed 89.1 % of total renewable power supply in 2008 due to the abundant hydro power potential. Canada's hydro electricity production reached 382,580 GWH in 2008, ranked the second place in the world. Japan and Germany have implemented FIT policies earlier to encourage the renewable power generation and thus the two countries have achieved a relatively stable market than other countries. In 2008, the two countries generated 113,309 GWH and 101,194 GWH of renewable electricity respectively.

Insert Table 1 about here

Table 1 demonstrates that hydro power dominated the renewable power generation in many countries and the contribution of wind power ranked the second place in 2008. In fact, wind power and solar PV power grow rapidly and become more and more important presently. By 2009, the US still leaded the world for wind power generation with the highest wind power capacity of 35 GW, ahead of China's 25.853 MW and Germany's 25.777 GW (please see Table 2). However, the wind power capacity additions in the US dropped to the second place in the world in 2009, capturing roughly 26% of the worldwide market while China's seized 36% market share [13]. China has become the first place for the new installation of wind power in the world since 2009.

Insert Table 2 about here

Total Europe by end of 2010 had installed 86,321 MW of wind power systems, among which 84,324 MW were installed in European Union, accounting for 98.83 %. Table 3 lists the wind capacity of the top 10 countries in EU during 2008-2010, and demonstrates that Germany have leaded EU in the development of wind energy since early 2000s. Germany installed approx. 27, 214 MW with 32.27 % of shares by end of 2010 while Spain kept a closed pace with Germany, ranking the second with capacity of 20,676 MW, accounting for 24.52% of EU's wind power markets. The market for wind power other than Germany and Spain is much less. For example, Italy, ranking the third place, had installed only 5,795 MW only, accounting for 6.87 % of the whole EU market by end of 2010.

Insert Table 3 about here

As to solar PV electricity generation, Table 1 indicates that Germany contributed the most in 2008, generating 4,420 GWH and Spain followed, producing 2,562 GWH. According to ESTELA [14], more than 500 MW of solar PV power systems would be connected to the grid for EU countries by 2010. The share of solar PV electricity could contribute to 20 % of electricity generation by 2020. EPIA [11] point out that approx. 15,000MW of new solar PV systems was installed in 2010 in the world, and the accumulated capacity reached 40,000 MW. The data shown on Page 10 of EPIA [11] demonstrates that EU may continue to lead solar PV power generation with over 70% of global installation capacity [11].

Figure 1 depicts the cumulative PV capacity of the leading countries through 2010. Among these countries, Germany stood at an outstanding position for the promotion of solar PV electricity generation and had been far ahead of other countries for the production of solar PV electricity. Spain, Japan and Italy ranked the second, third and fourth place in the world, respectively, but all of them kept a large distance from Germany. The share of German's PV installation in the world was 43.49 %, much higher than Spain's 9.57%, Japan's 9.16% and Italy's 8.84% by end of 2010. Table 4 demonstrates the historical development of PV capacity in these selected countries. German's cumulative capacity reached 2,899 MW in 2006, accounting for 41.43 % of the global installation capacity, ahead of Japan's 1,708 MW, the US' 624 MW and other countries. The average growth rate of installation capacity in Germany reached 56.65 % during 2006-2010, still little higher than the world's growth rate of 54.95 % (please see Table 4). EPIA [11] indicates that Germany by 2010 had installed 17,193 MW of solar PV power systems, accounting for 58.77% of EU installation capacity (29,252 MW), and 43.49 % of the global installation capacity (39,529 MW). In 2010, Germany is the largest producer for solar PV electricity with output of 12 TWH. By 2015, Germany will reach a cumulative installation capacity of 42,200 MW.

The high success of Germany solar PV installation may attribute to its feed-in tariff policy, starting from January 1, 1991 when the 'Electricity Feed Law, (EFL)' was effective. In April 2000 – it was revised and replaced by a new act called the 'Renewable Energies Law' (REL). The grid companies are obliged to purchase renewable electricity from eligible sources at an annually fixed feed-in tariff. Without a doubt, the feed-in tariff policy implemented in Germany has contributed a substantial consequence of renewable electricity production as a share of about 14 % of total electricity production was attained in 2008, exceeding its goal of at least 12.5% set for 2010. In 2009, Germany amended the Renewable Energy Sources Act that sets feed-in tariffs to be EUR cents 43.01/KWH up to 30KW, 40.91 from 30 to 100KW, 39.58 from 100KW to 1MW, and 33 over 1MW for roof-mounted facilities, and EUR cents 31.94/KWH for free-standing facilities [10].

Spain had installed 3,784 MW by end of 2010, ranked the second place in the world for solar PV installations, but far behind Germany's 17,193 MW. A large portion of Spain's solar PV power systems was installed during the period of 2007-2008 when generous feed-in tariffs were implemented. In the early 2000s, feed-in tariffs in Spain played a prominent role in stimulating solar PV electricity generation. The growth rate of Spain's solar PV power system increased 3.6 folds and 3.9 folds in 2007 and 2008, respectively, but it dropped to 0.5% in 2009 and 10.8% in 2010. After 2009, the annual installation rate of solar PV power systems in Spain fell behind a lot of countries, such as Italy, France, China, Japan and US because of decreased feed-in tariffs. The decline after 2009 may attribute to the 2009 global finance disaster and the reduction in feed-in tariffs that decreased by 50% in 2009. Compared to Germany that kept a stable growth of installation capacity, Spain had a fluctuating growth pattern.

Similar to the growth pattern of Germany, the installation capacity of Japan's solar PV power systems grew stably, increasing from 1,708 MW by 2006 to 3,622 MW by 2010 with average growth rate of 21.10 %, much lower than other leading countries and world's average level. Based on the growth pattern, Japan's solar PV installations may be taken over by other countries like Italy very soon. The tragic disaster of the Fukushima nuclear power plant occurred in 2011 may affect Japan's energy policy and provide a brighter prospect for solar PV power plants and other renewable energy.

Compared to its high demand for energy, the US installed few solar PV power systems. By 2010 the cumulative capacity reached 2,528 MW, ranked the fifth place in the world, far behind other leading countries. The growth rate in the US was only 42.05%, lower than the world's average level. This implies that a large room exists for the US to deploy the solar PV power generation.

Insert Table 4 about here

## 3. Taiwan's renewable energy policy review and renewable energy production

The renewable energy resource has been seen as the major priority of energy source in Taiwan's relevant policies until now. In 2003 Taiwan set a goal of 10% share of renewable electricity in total generation by 2010 according to the "Non-nuclear homeland policy". In 2005, Ministry of Economic Affairs (MOEA) set a goal that the renewable power systems should be installed more than 5,130 MW by 2010, 7-8,000 MW by 2020 and 8-9,000 MW by 2025 [15]. Furthermore, the installed capacity would reach 2,159 MW for wind power and 21 MW for solar PV power systems by 2010.

In order to promote the installation of various renewable production systems, Taiwan has implemented some promotion programs to encourage the installation of renewable power systems by providing financial subsidy. As of 2000, a support program was announced by Taiwan MOEA for wind power demonstration projects with subsidies up to 50% of the installation costs for wind power demonstration systems. In 2005, a formal support mechanism in Taiwan was implemented for the installation of renewable power systems including wind turbines and solar PV power system. The subsidy rate depends on the type of technology, locations, capacity, etc., covering 15–50% of the total investment cost.

The subsidy mechanism seems to work well as some types of renewable power generation systems grow very much, shown in Table 5. Wind capacity in Taiwan grew more than 56 folds during 2004-2010 with average annual growth of 117.5%, expanding substantially from 8.5 MW in 2004 to 477.6 MW in 2010. The share of wind power capacity in total renewable power increased from 0.05 % in 2000 to 8.21 % in 2010. Total wind power generation grew 733 folds, increasing from 1.4 GWH in 2000 to 1,027.5 GWH in 2010, indicated in Table 6, and its share in total renewable electricity production increased dramatically from 0.013 % in 2000 to 8.65% in 2011. Between 2000 and 2010 the installation of wind power systems produced 3,294.2 GWH and already reduced CO2 emissions by about 2.21 million tonnes.

Insert Table 5 about here

The capacity of Taiwan's solar PV power systems also increased very much from 0.1 MW in 2000 to 17.5 MW in 2010, but its share in total renewable installed capacity and electricity generation by 2010 was still very low, reaching 0.3 % and 0.175 %, respectively.

Until now, hydropower and electricity generated from waste-to-heat incineration facilities (EGWIF) has formed as the major constitution of renewable energy supply in Taiwan. In 2010, total renewable electricity generation amounts to 11,879 GWH, accounting to 4.8% of total power generation (247,045 GWH). Among renewable electricity generation, hydropower supplied 7,255 GWH (61.07%), EGWIF contributed to 3,036 GWH (25.56%), wind power provided 1,028 GWH (8.65%), biomass generated 540 (4.54%), and solar PV power systems only 20.8 GWH (1.75%).

Table 6 indicates that hydro power led the renewable electricity generation and installation capacity in Taiwan. It installed more than 4,579 MW, accounting for 78.77 % of total renewable installations by end of 2010. The hydro power production, however, dropped very much from 8,877.70 GWH (82.88%) in 2000 to 7,255.10 GWH (61.08%) in 2010 due to the exhaustion of water resources. The share of hydro power installed capacity also kept a declining pattern, dropping very much from 90.9 % in 2000 to 78.77 % in 2010. This implies that hydro power may lose its leading role in supplying renewable electricity in the future.

EGWIF also provided an obvious contribution to renewable electricity production and was seen as a considerable potential for biomass energy development in Taiwan. Its production increased from 1,502.7 GWH (14.02%) in 2000 to 3,036.1 GWH (25.56%) in 2010 and its capacity reached 622.5 MW in 2010 with share of 10.71 %. Due to the awareness of environmental consciousness, Municipal Solid Waste (MSW) generation has decreased and its consequence leads to a continual reduction in the expansion of MSW incineration facilities [16, 17]. Thus, the installed capacity of WTE plants has remained constant since 2007. This implies that the growth in electricity generation from waste heat is pessimistic.

The growth of biomass electricity production is not so attractive as wind power. The power generation from biomass increased from 329.7 GWH in 2000 to 539.5 GWH in 2010. Table 5 demonstrates that the installed capacity of biomass generation reached 116.8 MW by 2006 and did not increase from then on. In practice, the consumption of biomass will crowd out the land use for food harvesting or the other applications. For example, the growing trees and other plants would remove CO2 from the atmosphere during photosynthesis and store the carbon in plant structure.

Insert Table 6 about here

As time passes, some of these goals are proved to be a dream. Table 6 indicates that renewable electricity generation by end of 2010 reached 11,879 GWH, including 7,255 GWH hydro power, 1,028 GWH wind power, 20.8 GWH solar PV electricity, 539.5 GWH biomass, and 3,026 GWH EGWIF. Compare to total power generation of 247,045 GWH, the share of renewable power generation in 2010 was only 4.81 %, much less than the goal of 10%. The total installed capacity of renewable power generation system by end of 2010 reached 5,813.8 MW that contains 2,602 MW of pump-and-storage hydro power systems, accounting for 11.9% of total installed capacity of power generation (please Table 5). However, if the capacity of pump-and-storage hydro power systems[2] is removed, the total renewable power capacity dropped to 3,211.8 MW, accounting for 6.57 % of total power capacity.

The fact shows that Taiwan's 10% renewable electricity goal by 2010 is proved to be a failure, and the goals mentioned in MOEA (2005) that planed to install more than 5,130 MW of renewable power generation systems by 2010 also completely fail. Among the renewable power installations, the goals for wind power and solar PV power regulated by MOEA (2005) are also proved to be unable to meet the goals. By end of 2010, the total installed capacity of wind power in Taiwan stood at 477.6 MW, falling far behind the goal of 2,159 MW. The cumulative installation capacity of solar PV power systems reached 17.5 MW only by end of 2010, much lower than the goal of 21 MW.

## 4. FIT applications in Taiwan

Even though the policy goals are proved to fail, the past renewable energy policy with financial supporting mechanisms has contributed to environmental improvements with limited success. Taiwan government still keeps a positive and optimistic manner for the development of renewable energies. Based on the past experience in promoting the renewable electricity generation, the policy makers released more clear signals to stipulate more investors for the installations of renewable energy projects. In 2009, Taiwan enacted a new feed-in tariff mechanism called "Directive for promoting renewable energy (DPRE)" that focuses on the financial subsidy to the renewable electricity generation through the implementation of feed-in tariffs. The subsidy for the investment costs regulated in the previous laws

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[2] Pump-and-storage hydro power is categorized into non-renewable energy in Taiwan.

remains valid. Article 6 of the DPRE sets an overall goal that expects 6,500 MW-10,000 MW of new renewable power systems to be installed. According to the DPRE, TPC (the power monopoly in Taiwan) is obliged to purchase the electricity generated from IPPs at the regulated price (feed-in tariff[3]) for a guaranteed period of time. And thus, the solar PV systems should be connected to the grid, and serving as a power supply source through the electricity distribution network. A separate meter is required to install to track the output of the solar PV power system.

The feed-in tariffs implemented in Taiwan is fixed at a certain level over the guaranteed period and determined by the government without any direct relation to the retail price of electricity. Article 9 of the DPRE regulates that the level of feed-in tariffs should be reviewed every year by the "tariff reviewing committee" and revised in the light of technological development of power generating system, the cost change, and policy goals. As of early 2011, the feed-in tariffs were determined and announced, listed in Table 7 that reflects the cost situation of the renewable electricity generation technologies. The feed-in tariff for the solar PV electricity is the highest, ranged from NT$ 7.9701 to 10.3185 per KWH while NT$ 4.8309 per KWH is offered for geothermal electricity and NT$ 2.6138-7.3562 per KWH for wind power (on shore). Compared to onshore wind power, the support level for offshore wind power is significantly increased to NT$ 5.5626 due to the high investment risks of offshore wind power installations (please see Table 7).

Insert Table 7 about here

The FIT policy provides high financial incentives for renewable electricity generation and highly reduces the investment risks as the payment is predetermined for the period of guarantee payments that is valid for 20 years in Taiwan. In practice, a great number of countries have adopted FIT policies to promote the installation of renewable power generation in the world. According to EPIA [12], the following countries have feed-in tariffs in place: China (partly), Japan, Canada, Austria, Belgium, Denmark, Finland, France, Germany, Greece, Luxembourg, Portugal, Spain, and Sweden. The relevant description involving the FIT policies of some selected countries is listed in Table 8.

Insert Table 8 about here

## 5. Outlook on Taiwan's renewable power goals

In practice, it is very difficult to estimate whether the goal can be attained or not as feed-in tariffs should be reviewed every year and adjusted in line with technology development and goals achievement according the DPRE. In this section, we derive two scenarios for the future development of renewable power installations by assuming the continuation of FIT policies for the coming years.

The discussion in Section 3, however, releases that the installation capacity of hydro power and EGWIF may remain unchanged. Wind power is the most promising one to develop renewable energy in Taiwan as its share in the renewable electricity production increased from 0.013 % (1.4 GWH) in 2000 to 8.65% (1,027.5 GWH) in 2010. The average growth rate of wind power generation is 148% annually, much higher than electricity generated from other renewable resources. In contrast, the annual growth rate of solar PV power generation is also very high, reaching 79%, but

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[3] In this paper, the term 'feed-in tariff' is used for the total amount per KWH received by an independent producer of solar PV electricity, paid by the government attorney (Taiwan Power Company).

the share of solar photovoltaic (PV) generation is still very negligible, about 0.175 % of renewable electricity generation in 2010. This implies that a large room exists for solar PV power generation to expand. Therefore, the development strategy of renewable electricity generation has to focus on the solar PV and wind power since the power generation technology for solar PV and wind power systems are still emerging and may work as a leading renewable energy supply in the future.

The two scenarios include (1) the Moderate Scenario and (2) the Optimistic Scenario. The two scenarios assume that Taiwan's growth pattern for wind power and solar PV power systems may follow Germany's development trajectory as Germany started the FIT policies earlier than other countries and have attained a steadily high growth of wind power and solar PV installations. The tariffs implemented in Germany are the highest in the world in the past few years according to IEA [10]. As of January 2009, the Renewable Energy Sources Act (EEG) was revised and came into force. After then, the feed-in tariff for onshore wind farms was increased from EUR cents 8.03 to 9.2/kilowatt-hour (KWH) for the first 5 years of operation, and EUR cents 5.02/KWH after that. Compared to Taiwan's NT 2.6138 (EUR cents 6.53) implemented after 2011, Germany still provided higher feed-in tariff for wind power than Taiwan. In contrast, Germany's feed-in tariff for solar PV electricity is decreasing continually. Even though, the tariff of EUR cents 35.31 is still higher than Taiwan's average feed-in tariff of NT$ 9.07 (EUR cents 22.67) for PV electricity.

Insert Table 9 about here

Table 9 indicates that Germany has performed a dramatic increase in PV installation capacity, increasing from 2056 MW in 2005 to 17,193 MW in 2010 [11], growing 8.36 folds in five years. As to wind power installation, it increased from 18,428 MW in 2005 to 27,214 MW in 2010, with growth rate of 47.7 % in five years. In this case, the Moderate assume that the growth pattern of Taiwan's PV and wind power installation completely follows Germany if the feed-in tariff is kept stable and will not decrease in the future.

In contrast, the Optimistic Scenario considers that the growth rate of Taiwan's wind power and solar PV systems may be higher than the Germany since Taiwan is a newly emerging market for wind power and solar PV power systems and less developed. Additionally, the other possibility to increase the renewable power supply is to develop the biomass power generation. The installation capacity of Taiwan's biomass power generation increased from 79.7 MW to 116.8 MW, with growth rate of 46.54 % from 2000 to 2010. We assume that the FIT policy may stimulate the investment of biomass power generation with growth rate, doubling the past, i.e. 93.08 % in 10 years. And thus, the Optimistic Scenario assumes a double growth rate of the Moderate Scenario for wind power and solar PV installations and a double growth rate of Taiwan's historical evolution for the biomass energy.

Insert Table 10 about here

The forecast of the two scenarios is listed in Table 10 and 11 for the future development of Taiwan's renewable power generation. The Moderate Scenario demonstrates that Taiwan's total renewable power installation capacity may increase from 5,813.8 MW in 2010 to 7245.99 MW in 2030. The total increase of the new installation capacity attain to 1,432.19 MW, much lower than Taiwan government's goal (a new installation of 6,500-10,000 MW for renewable power generation systems). The result of the Optimistic Scenario shows that the total renewable power installation capacity may increase from 5,813.8 MW in 2010 to 11,977.14 MW in

2030. The total increase of the new installation capacity attain to 6,163.664 MW, that slightly less than the goal.

Insert Table 11 about here

Table 10 and 11 show that Taiwan’s goals to install new renewable power generating systems with capacity of 6,000-10,000 MW may fail again as our projection cannot assure of the achievement of the goals even under the assumption of the Optimistic Scenario. According to the Optimistic Scenario, Taiwan may provide up to 770.45, 1540.91, 3081.82, and 6163.64 MW of new electricity generating capacity by 2015, 2020, 2025 and 2030, respectively, where wind power and solar PV power generation provides a substantial contribution for the newly installed capacity. Among the renewable power, wind power and solar PV electricity may be more feasible to develop for the achievement of the goal for the installation of 6,500-10,000 MW new capacity in Taiwan. It is estimated that new installation capacities will be 458.5, 916.99, 1833.98, and 3667.97 MW for wind power, and 257.6, 515.2, 1030.4 and 2,060.8 MW for solar PV electricity by 2015, 2020, 2025 and 2030, respectively. In contrast, the new installation of the biomass power generating system is only 54.36, 108.72, 217.43 and 434.87 MW by 2015, 2020, 2025 and 2030, respectively. In 2030, hydro power will still dominate the renewable power market, but its share of installed capacity will decline from 78.77% in 2010 to 38.23 % in 2030 while the share of wind power capacity will largely increase from 8.21% in 2010 to 34.61% in 2030. The solar PV power system also becomes more and more important for the contribution of renewable electricity in the future. Its share of installed capacity will expand from 0.3% in 2010 to 17.35% in 2030.

The two scenarios demonstrates that wind power and solar PV power generation may provide a substantial contribution for capacity increase that will come from a wide array of new technologies utilizing the full range of our renewable resources. Wind power is found to be potential along Taiwan's western coastline, southern peninsula, and Penghu group of islands and several small islands. The wind speed is greater than 4 m/s at 10 m above ground in these areas. The total technical potential is estimated to be 4600 MW for on shore wind power and 9000 MW for offshore wind power [18]. Considering the economic viability of siting wind turbines in various locations, the realizable potential, however, is somewhat malleable and reduced to 1,000 MW and 2000 MW for onshore and offshore wind power respectively [18].

If the estimates of MOEA [18] for realizable offshore wind power is accurate, our forecasts for the increase of wind power by 2030 indicated in the Optimistic Scenario seems to be too optimistic and cannot be achieved. The Optimistic Scenario projects that the cumulative wind power capacity will reach 2,311.58 MW by 2025, and 4,145.57 MW by 2030. This means that the newly increased capacity of wind power installation is 1,834 MW by 2025 beyond the realizable potential of on shore power 1,000 MW, or representing 91.7 % of realizable potential of offshore wind power (2000 MW). The total increase is 3,667.97 MW by 2030, beyond the sum of onshore and offshore realizable potential.

All the Taiwan’s wind power presently is generated from onshore wind farms. As the western coastal is more dense in population, the development of onshore wind power projects is limited and hampered by public opposition due to adverse effects of noise concerns and aesthetics consideration. Offshore wind power has relatively advantage with higher wind speed that may generate more electricity. The development of wind power may focus on the offshore wind potentials. And thus, higher feed-in tariffs is provided to promote the investment of offshore wind power projects in Taiwan. Some IPPs argue that wind power capacity may be installed more and the goal can be achieved easily if feed-in tariffs are increased by 100 %. Compared to the feed-in tariff of US¢ 6.16 (NT$ 2.0) per KWH for wind power according to TPC's interim program, the feed-in tariff revised in 2011 was largely raised up to US¢ 8.07 (NT$ 2.6138) per KWH for onshore wind power, and US¢ 18.54 (NT$ 5.5626) per KWH for offshore wind power.

EWEA [21] suggests that offshore wind power may contribute more for renewable power generation in the future. In 2010, offshore wind accounted for 3.5% of installed EU wind energy capacity (up from 2.7% in 2009). Wind power may be the most potential to develop and contribute significantly to achieve the goal of renewable power capacity due to the highly advance in offshore wind power technology.

Considering the competitive status of wind power with LNG fired and oil-fired power [22-24], the development of wind power is viable and used to replace fossil-fired power. Taiwan may endeavor more to exploit wind power as a clean energy resource to achieve a zero-emission country. If Taiwan's wind power capacity can be expanded according to the Optimistic Scenario, 20-30 % of total power consumption in the future can be provided by clean wind energy that emits less CO2.

The projection on the solar PV may be the most uncertain among the renewable power generation technology, as the development of solar PV power systems are largely affected by the cost trends and the FIT policy. The growth of solar PV power system may deviate from the actual electricity demand and beyond the goal if the tariff is much higher than the cost. On the contrary, the growth will be blocked if the tariff is not attractive. As the heart of solar PV power systems, the PV module has gradually improved its physical efficiency with its advancing performance and the cost may be reduced in the future. The change in technology development and tariffs over time may enlarge the variation of newly installation in the consecutive years.

## 6. Conclusions

This paper contributes to the review on the current status of renewable power generation in the leading countries and compares the FIT policies between the leading countries and Taiwan. As a follower to adopt FIT mechanisms to develop renewable energy, Taiwan has to face a lot of challenges that stands on the road. The goal of 6,500-10,000 MW new capacity installation within 20 years seems to be optimistic. The attainment of the goal is significantly affected by the intensity of the FIT policy to expedite renewable power expansion. Of course, the accuracy of our estimation may be affected by the technical and policy uncertainty. The technical uncertainty stems from the nature of technology development and diffusion. A large room still exists for soar PV and wind power technologies to improve the conversion efficiency and reduce the power generation cost.

The policy uncertainty is owing to the rapid change of FIT schemes and scheme validity. According to the current regulation, the feed-in tariff will be reviewed every year and reduced if the new installation capacity reaches to the goal. Such a system may block the investment desire for the continual installation of renewable power systems. Thus, the main policy challenges may lie at (1) the design of an appropriate feed-in tariff scheme among various technologies that can encourage the development of potential one, (2) the level of feed-in tariff that can sufficiently attract investment with an attractive rate of return, and (3) a policy certainty that can cover the risk of technical uncertainty.

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Table 1. The cumulated installed capacity of renewable power systems in Taiwan. Unit: MW

| | Hydro[#] | | wind | | PV | | biomass | | waste | | total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 4,422.00 | 0.9090 | 2.6 | 0.0005 | 0.1 | 0.0000 | 79.7 | 0.0164 | 360.2 | 0.0740 | 4,864.6 |
| 2001 | 4,422.00 | 0.8764 | 5 | 0.0010 | 0.2 | 0.0000 | 68.8 | 0.0136 | 549.4 | 0.1089 | 5,045.4 |
| 2002 | 4,510.80 | 0.8806 | 8.5 | 0.0017 | 0.3 | 0.0001 | 68.8 | 0.0134 | 534.2 | 0.1043 | 5,122.6 |
| 2003 | 4,510.80 | 0.8784 | 8.5 | 0.0017 | 0.5 | 0.0001 | 92.2 | 0.0180 | 523.3 | 0.1019 | 5,135.3 |
| 2004 | 4,511.70 | 0.8734 | 8.5 | 0.0016 | 0.6 | 0.0001 | 103.1 | 0.0200 | 541.8 | 0.1049 | 5,165.7 |
| 2005 | 4,511.70 | 0.8661 | 23.9 | 0.0046 | 1 | 0.0002 | 99.1 | 0.0190 | 573.8 | 0.1101 | 5,209.5 |
| 2006 | 4,511.70 | 0.8444 | 103.7 | 0.0194 | 1.4 | 0.0003 | 116.8 | 0.0219 | 609.5 | 0.1141 | 5,343.1 |
| 2007 | 4,523.20 | 0.8295 | 187.7 | 0.0344 | 2.4 | 0.0004 | 116.8 | 0.0214 | 622.5 | 0.1142 | 5,452.6 |
| 2008 | 4,539.90 | 0.8199 | 252.1 | 0.0455 | 5.6 | 0.0010 | 116.8 | 0.0211 | 622.5 | 0.1124 | 5,536.9 |
| 2009 | 4,538.90 | 0.8014 | 376 | 0.0664 | 9.5 | 0.0017 | 116.8 | 0.0206 | 622.5 | 0.1099 | 5,663.7 |
| 2010 | 4,579.40 | 0.7877 | 477.6 | 0.0821 | 17.5 | 0.0030 | 116.8 | 0.0201 | 622.5 | 0.1071 | 5,813.8 |

[#] The capacity of hydro powers include pump-and-storage power generation systems.

Source: BOE [25]

Table 2. The renewable electricity generation in Taiwan (2000-2010). Unit: GWH

| year | hydro | wind | solar PV | biomass | waste | Total renewable | total power generation |
|---|---|---|---|---|---|---|---|
| 2000 | 8,877.70 | 1.4 | 0.1 | 329.7 | 1,502.70 | 10,711.6 | 184,862.00 |
| 2001 | 9,178.60 | 12.2 | 0.3 | 242.8 | 2,106.20 | 11,540.1 | 188,540.90 |
| 2002 | 6,368.30 | 15.9 | 0.3 | 270.3 | 2,658.50 | 9,313.3 | 198,837.50 |
| 2003 | 6,896.50 | 23.8 | 0.5 | 323.2 | 2,686.00 | 9,930.0 | 209,071.80 |
| 2004 | 6,555.60 | 25.3 | 0.6 | 363 | 2,824.70 | 9,769.2 | 218,396.60 |
| 2005 | 7,824.70 | 91.3 | 1 | 336.4 | 2,853.00 | 11,106.4 | 227,364.30 |
| 2006 | 7,999.00 | 277.4 | 1.5 | 385.3 | 2,904.80 | 11,568.0 | 235,464.70 |
| 2007 | 8,350.30 | 443.5 | 2.2 | 609.1 | 3,014.10 | 12,419.2 | 243,120.00 |
| 2008 | 7,772.30 | 589.3 | 4.3 | 486.2 | 2,934.60 | 11,786.7 | 238,314.10 |
| 2009 | 7,053.40 | 786.6 | 8.1 | 494.8 | 2,907.00 | 11,249.9 | 229,694.00 |
| 2010 | 7,255.10 | 1,027.50 | 20.8 | 539.5 | 3,036.10 | 11,879.0 | 247,045.40 |

Source: BOE [25]

Table 3. Gross renewable electricity generation from selected countries in 2008, unit: GWH

| | Waste | Biomass | Geo-thermal | Hydro | Solar PV | Tide, etc. | Wind | Total |
|---|---|---|---|---|---|---|---|---|
| China | 0 | 2359 | 0 | 585187 | 172 | 0 | 13079 | 600797 |
| US | 22190 | 50201 | 17014 | 281995 | 1572 | 0 | 55696 | 429546 |
| Canada | 157 | 8298 | 0 | 382580 | 33 | 33 | 3819 | 394920 |
| Japan | 7309 | 15079 | 2752 | 83295 | 2251 | 0 | 2623 | 113309 |
| Germany | 9368 | 19851 | 18 | 26963 | 4420 | 0 | 40574 | 101194 |
| France | 3776 | 2116 | 0 | 68325 | 41 | 513 | 5689 | 80460 |
| Italy | 3255 | 4409 | 5520 | 47227 | 193 | 0 | 4861 | 65465 |
| Spain | 1564 | 2473 | 0 | 26112 | 2562 | 0 | 32203 | 64930 |
| UK | 2871 | 8090 | 0 | 9257 | 17 | 0 | 7097 | 27332 |

Source: IEA [10].

Table 4. The installed wind capacity for the selected countries. Unit: GW

| | 2005[a] | 2006[a] | 2007[a] | 2008[a] | 2008[b] | 2009[b] | 2010[b] |
|---|---|---|---|---|---|---|---|
| US | 8.706 | 11.329 | 16.515 | 24.651 | - | 35.000[c] | - |
| China | 1.260 | 2.599 | 5.912 | 12.170 | - | 25.853[c] | - |
| Germany | 18.428 | 20.622 | 22.247 | 23.895 | 23.860 | 25.777 | 27.214 |
| Spain | 9.918 | 11.722 | 14.779 | 16.546 | 16.701 | 19.160 | 20.676 |
| Italy | 1.635 | 1.902 | 2.702 | 3.525 | 3.735 | 4.849 | 5.795 |
| France | 0.723 | 1.412 | 2.220 | 3.422 | 3.486 | 4.574 | 5.660 |
| UK | 1.565 | 1.955 | 2.477 | 3.406 | 2.974 | 4.245 | 5.204 |
| Canada | 0.684 | 1.460 | 1.770 | 2.369 | - | - | - |
| Japan | 1.227 | 1.805 | 1.527 | 1.756 | - | - | - |

[a] Source: EIA [19].
[b] Source: EWEA [20]
[c] Source: Wiser and Bolinger [13].

Table 5. The installed wind capacity of top 10 countries in EU-27 (2008-2010). unit: MW

| | end 2008 (MW) | end 2009 (MW) | end 2010 (MW) | Share in 2008 | Share in 2009 | Share in 2010 |
|---|---|---|---|---|---|---|
| Germany | 23860 | 25777 | 27214 | 0.3679 | 0.3432 | 0.3227 |
| Spain | 16701 | 19160 | 20676 | 0.2575 | 0.2551 | 0.2452 |
| Italy | 3735 | 4849 | 5795 | 0.0576 | 0.0646 | 0.0687 |
| France | 3486 | 4574 | 5660 | 0.0537 | 0.0609 | 0.0671 |
| United Kingdom | 2974 | 4245 | 5204 | 0.0459 | 0.0565 | 0.0617 |
| Portugal | 2862 | 3535 | 3898 | 0.0441 | 0.0471 | 0.0462 |
| Denmark | 3131 | 3465 | 3798 | 0.0483 | 0.0461 | 0.0450 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| Netherlands | 2176 | 2215 | 2245 | 0.0336 | 0.0295 | 0.0266 |
| Sweden | 1048 | 1560 | 2163 | 0.0162 | 0.0208 | 0.0257 |
| Ireland | 1077 | 1310 | 1428 | 0.0166 | 0.0174 | 0.0169 |
| Total | 64857 | 75103 | 84324 | 1 | 1 | 1 |

source: EWEA [20]

Table 6. The cumulative installation capacity of solar PV power systems for the selected countries (2006-2010), unit: MW

| Year | 2006 | 2007 | 2008 | 2009 | 2010 | Average growth rate (2008-2010) |
|---|---|---|---|---|---|---|
| Germany | 2899<br>(543)[#] | 4170<br>(1271) | 5979<br>(1809) | 9785<br>(3808) | 17193<br>(7408) | 0.5665 |
| Spain | 148<br>(102) | 690<br>(542) | 3398<br>(2708) | 3415<br>(17) | 3784<br>(369) | 1.9249 |
| Japan | 1708<br>(286) | 1919<br>(211) | 2149<br>(230) | 2632<br>(483) | 3622<br>(990) | 0.2110 |
| Italy | 47<br>(10) | 117<br>(70) | 456<br>(338) | 1173<br>(717) | 3494<br>(2321) | 1.9844 |
| US | 624<br>(145) | 831<br>(207) | 1173<br>(342) | 1650<br>(477) | 2528<br>(878) | 0.4205 |
| France | 30<br>(8) | 41<br>(11) | 87<br>(46) | 306<br>(219) | 1025<br>(719) | 1.5888 |
| UK | 1<br>(1) | 5<br>(4) | 11<br>(6) | 21<br>(10) | 66<br>(45) | 2.0630 |
| Canada | 21<br>(4) | 26<br>(5) | 33<br>(7) | 95<br>(62) | 200<br>(105) | 0.8728 |
| China | 80<br>(12) | 100<br>(20) | 145<br>(45) | 373<br>(228) | 893<br>(520) | 0.9166 |
| world | 6,980<br>(1,581) | 9,492<br>(2,513) | 15,655<br>(6,168) | 22,900<br>(7,257) | 39,529<br>(16,629) | 0.5495 |

[#] Brackets refers to the annual installation capacity.
Source: EPIA [11]

Table 7. Feed-in Tariffs implemented in Taiwan, unit: (NT$/KWH)

|  | 1-10 KW | 10-100 KW | 100-500 KW | > 500 KW |
|---|---|---|---|---|
| Solar PV | 10.3185 | 9.1799 | 8.8241 | 7.9701 |
| Wind (onshore) | 7.3562 | 2.6138 | 2.6138 | 2.6138 |
| Wind (offshore) | 5.5626 | 5.5626 | 5.5626 | 5.5626 |
| Biomass | 2.1821 | 2.1821 | 2.1821 | 2.1821 |
| Geothermal | 4.8039 | 4.8039 | 4.8039 | 4.8039 |
| hydropower | 2.1821 | 2.1821 | 2.1821 | 2.1821 |
| Waste | 2.6875 | 2.6875 | 2.6875 | 2.6875 |

|  |  |  |  |  |
|---|---|---|---|---|
| energy |  |  |  |  |

Table 8. The comparison of FIT policies for solar PV electricity generation implemented in the selected countries

|  | Policy Title | Description |
|---|---|---|
| China | Interim Feed-in Tariff for Four Ningxia Solar Projects | A special feed-in tariff of CNY 1.15/kWh (equivalent to USD 0.17) is set up for four PV power plants with total capacity of 40 MW in the Ningxia province. |
| Japan | New Purchase System for Solar Power-Generated Electricity | Utilities are obliged to purchase the excess electricity generated from households at a rate of JPY 48/kWh, and from non-household sources (e.g. schools and hospitals) at JPY 24/kWh. |
| Germany | Amendment of the Renewable Energy Sources Act -EEG- | Feed-in tariffs are EUR cents 43.01/kWh up to 30kW, 40.91 from 30 to 100kW, 39.58 from 100kW to 1MW, and 33 over 1MW for roof-mounted facilities, and EUR cents 31.94/kWh for free-standing facilities.<br>A new tariff of EUR cents 25.01/kWh was introduced for systems up to 30kW when electricity produced is used within the building or facility in the revised law. |
| Spain | New regulation on electrical energy from wind and thermal electric technologies (Royal Decree 1614/2010) | The period of guarantee payment is 25 years for solar PV power plants. The existing feed-in-tariffs will be cut down by:<br>- 5% for small-size roof installations. Tariffs will decrease from EUR 320/MWh to EUR 304/MWh<br>- 25% for medium-size (21 to 100 kW) roof installation. Tariffs will decrease from EUR 286/MWh to EUR 215/MWh.<br>- 45% for ground installations. Tariffs will decrease from EUR 258/MWh to EUR 142/MWh. |
| France | Renewable Energy Feed-In Tariff: Solar PV | As of 2010, a base feed-in tariff of EUR 0.314/kWh is provided for ground-mounted solar arrays. The tariff varies according to a regional coefficient ranging from 1 to 1.2, depending on locations. In Corsica and overseas regions, the tariff is EUR 0.40/kWh.<br>As of March 2011, a feed-in tariff of EUR 0.46/KWH is offered for building-integrated photovoltaic installations (BIPV) no larger than 9kWc, and EUR 0.40/kWH for installation between 9 -36 kWc. |

| | | |
|---|---|---|
| Italy | New Feed-In premium for photovoltaic systems | The period of guarantee payment is 20 years for the PV systems entering service after 31/12/2010 and before 31/12/2011. A bonus is offered in addition to a given set of tariffs in case of innovative technologies of integration of photovoltaic in buildings. |
| UK | Feed-in Tariffs for renewable electricity | Electricity suppliers are obliged to purchase the electricity from renewable resources with following level of tariffs that is valid until March 2013 in GBP pence/kWh (which will be adjusted for inflation):<br>Solar PV (25 years)<br>Under 4 kW (new build) and 4-10 kW: 36.1, 33.0 from April 2012-March 2013;<br>Under 4 kW (retrofit): 41.3, and 37.8 from April 2012-March 2013;<br>10-100 kW: 31.4, 28.7 from April 2012-March 2013;<br>100 kW-5 MW and stand-alone system: 29.3, 26.8 from April 2012-March 2013. |
| Canada | Ontario Feed-in Tariff Programme | Ontario's Feed-in Tariff (FIT) programme offers a fixed tariff for electricity produced and fed into the electricity grid. FIT payments varies across capacity size, up to 80.2 CAD ¢/kWh for residential solar rooftop projects 10 kW or smaller. |

Source: IEA [10]

Table 9. The fit and cumulative installed capacity of wind and PV systems in Germany.

| | fit for PV, EU cents | PV[#1] | PV[#2] | fit for wind, EU cents | wind[#2] | wind[#3] |
|---|---|---|---|---|---|---|
| 2005 | 54.53 | 2,056 | 1508 | 8.53 | 18428 | n.a. |
| 2006 | 51.80 | 2899 | 2831 | 8.36 | 20622 | n.a. |
| 2007 | 49.21 | 4170 | 3811 | 8.19 | 22247 | n.a. |
| 2008 | 39.12 | 5979 | 5333 | 8.03 | 23895 | 23860 |
| 2009 | 37.16 | 9785 | n.a. | 9.20 | n.a. | 25777 |
| 2010 | 35.31 | 17193 | n.a. | 9.11 | n.a. | 27214 |

[#1] data source: EPIA [11]
[#2] data source: EIA [19]
[#3] data source: EWEA [20]

Table 10. The Moderate Scenario for the outlook on the installed capacity of Taiwan's renewable power systems, unit: MW

| | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| hydro | 4579.40 | 4579.40 | 4579.40 | 4579.40 | 4579.40 |
| wind | 477.60 | 706.85 | 936.10 | 1165.34 | 1394.59 |
| PV | 17.50 | 146.30 | 275.10 | 403.90 | 532.70 |
| biomass | 116.80 | 116.80 | 116.80 | 116.80 | 116.80 |
| waste | 622.50 | 622.50 | 622.50 | 622.50 | 622.50 |
| total | 5813.80 | 6171.85 | 6529.90 | 6887.94 | 7245.99 |
| increase | 0.00 | 358.05 | 716.10 | 1074.14 | 1432.19 |

Table 11. The Optimistic Scenario for the outlook on the installed capacity of Taiwan's renewable power systems, unit: MW

| | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| hydro | 4579.40 | 4579.40 | 4579.40 | 4579.40 | 4579.40 |
| wind | 477.60 | 936.10 | 1394.59 | 2311.58 | 4145.57 |
| PV | 17.50 | 275.10 | 532.70 | 1047.90 | 2078.30 |
| biomass | 116.80 | 171.16 | 225.52 | 334.23 | 551.67 |
| waste | 622.50 | 622.50 | 622.50 | 622.50 | 622.50 |
| total | 5813.80 | 6584.25 | 7354.71 | 8895.62 | 11977.44 |
| increase | 0.00 | 770.45 | 1540.91 | 3081.82 | 6163.64 |

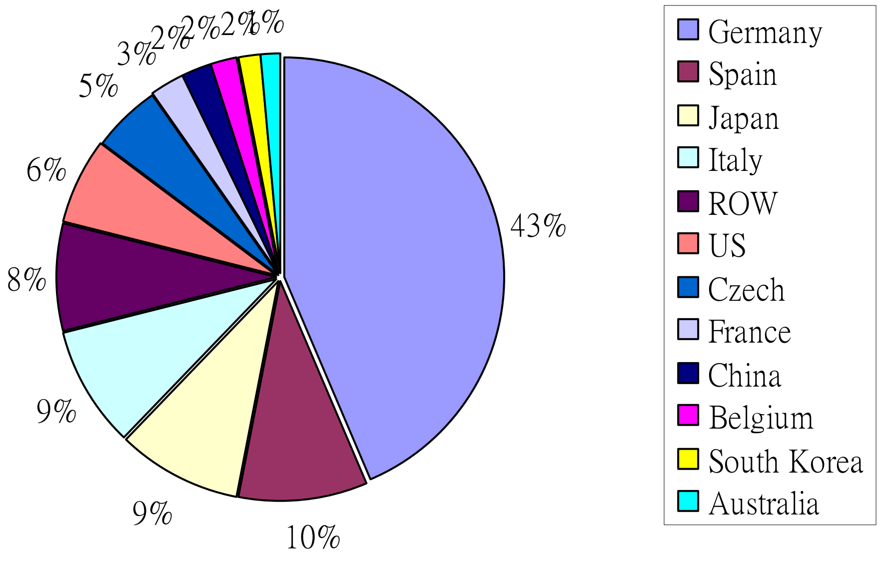

Figure 1. The cumuative PV capacity for the selected leading countries through 2010

附件二：

# An examination on Taiwan’s PV industry

Abstract

This paper reviews the development history of Taiwan’s PV industry and investigates the evolution of solar PV installations in the world. We employ the SWOT (Strength, Weakness, Opportunity, and Threat) analysis as an evaluation tool to explore the possible means to convert possible threats into opportunities, and to change weaknesses into strengths. Supported by the excellent infrastructure and abundant skilled labors, Taiwan’s PV industry may keep a growing trend through strategic alliances with the world leading firms to recover the problem of insufficient R + D capacity. Some challenges, however, stand in front of Taiwan’s PV industry. These challenges falling into three dimensions: market uncertainty, technology development, and the recycling and recovery of spent modules, should be recovered to avoid blocking the growth in the future.

Keywords: c-Si; solar PV; feed-in tariffs; SWOT

## 1. Introduction

Photovoltaic (PV) electricity is seen as the most potential to replace the fossil fueled electricity, and an effective energy resource to cut down CO2 emissions. PV Cycle (2011) indicates that PV technology offers following advantages: “Fuel source is essentially infinite. PV produces energy without emissions (e.g. Greenhouse Gases). PV is a reliable technology (no moving parts, module lifetime >25 years). PV is scalable, modular and flexible: It can be installed in almost every size and in every place. The materials of PV-modules and cells can be recycled. Photovoltaic energy is sustainable, even in the strict meaning.”

Some developed countries like Germany, Japan, and Spain has adopted Feed-in Tariff (FIT) as a supporting mechanism to promote the deployment of solar PV power generation since early 2000s. Later on, some developing countries such as Korea, Taiwan and Thailand follow. The increasing demand may continuously expedite the growth of the photovoltaic industry. Until now, many countries or regions have adopted solar PV power systems to produce electricity.

The global PV market (the annual increase of solar PV power installations) grew annually from 280 MW in 2001 to 2010 (EPIA, 2011a). The cumulative installation increased from 5.4 GWp in 2005 to 39.5 GWp in 2010. The installation growth had a remarkable achievement, recording an average annual growth rate of 146% over the past 5 years. The top 5 regions dominated the world markets in terms of cumulative installed capacity at 87% in 2010, reaching 36.24 GWp. The EU led the world with 29.25 GW installed, accounting for about 75% of the global cumulative PV capacity. Japan (3.6 GW), USA (2.5 GW) and China (0.89 GW) followed.

Compared to the global market, Taiwan is relatively small but grew very much during the past few years. Taiwan’s PV Industry has also experienced a strong growth with totally 17.5 MW of cumulative PV capacity by 2010 and 8 MW of solar PV power systems installed in 2010. The growth is estimated to expand to reach a total cumulative capacity of 300 MW by 2015 by EPIA (2011a).

The increasing domestic demand for solar PV results in high investment on solar PV production. Taiwan’s cell production increased from 88 MWp in 2005 to 177.5

MWp in 2006, and 360 MWp in 2007 (DIS, 2011b). The total revenue of solar PV industry covering wafer processing, multi-crystal growth furnace, wire sawing, wafer polishing, crystalline cell production, thin film (TF) cells, modules, and system installation was NT$7 billion in 2005. It increased to NT$21.2 billion in 2006, NT$53 billion in 2007 with an annual growth rate of 300%, accounting for 3% of global production in 2007, NT$ 105 billion in 2009 (Lu, 2011).

By using the SWOT analysis, this paper attempts to examine the status of solar photovoltaic industry in Taiwan, to analyze the probable industry dynamics, and to assess the potential challenge for Taiwan's solar PV industry. In general, SWOT analysis is successfully used to evaluate the relative competitive position involved in a project or in a business venture. A great number of studies have employed this method to formulate the strategic action plan (e.g. Arslan and Deha Er., 2008; Dyson, 2004; Nikolaou and Evangelinos, 2010). Thus, this paper employs SWOT analysis to investigate the status of Taiwan's solar PV industry and its relative competitive position in the world market. The internal and external factors affecting the competitiveness of Taiwan's solar PV industry are identified based on the comparison between Taiwan's solar PV production and the global market. In consideration of the value chain of solar PV, we attempt to find out some solutions to improve the competitiveness of Taiwan's solar PV production by enhancing the strengths and opportunities, adjusting the internal weakness, seizing the opportunities and reducing external threats. In the SWOT analysis, the benefits of Taiwan's solar PV production is evaluated and assessed.

This paper is organized as follows: Section 2 describes the development history of solar PV production in the world and the status of Taiwan's solar PV industry as well as the current situation of global solar PV production. Through a close comparative analysis of documents and reports relating to solar PV production, the development history may provide more insight on the role of solar PV electricity in substitution of fossil fuel energies. Section 3 makes a comparison between Taiwan and the globally leading countries in solar PV production, and analyze the strength, weakness, opportunities and threats of Taiwan's solar PV industry. Section 4 presents challenges that Taiwan's PV industry has to face and recover in the future. In Section 5 a brief conclusion is made.

## 2. The development history of solar PV industry

The conversion of solar energy into electrical currents was observed as early as 1839 when Alexandre-Edmund Becquerel (physicist) observed that "electrical currents arose from certain light induced chemical reactions" (Chapin, et al., 1954). The first application of solar energy started in 1954 when Charpin, Fuller and Pearson announced that the first solar cell was developed with an efficiency of 6% (EI Chaar, et al., 2011). Solar cells were used in the space PV market for providing electrical power to satellites as early as 1950s. In 1958, the first solar power generating system was installed in the US satellite Vanguard 1. In 1980s Thin Film (TF) cells was developed and applied to consumer electronics like calculators, serving as a power supply. In 1990s, Sharp developed the crystalline silicon PV module and applied it to the roof top of households, and later to the larger power plant for power generation.

After energy crises occurred in 1973 and 1979, petroleum price roared up. Furthermore, the consumption of fossil-fuel energy yielded various adverse impacts, among which warming-house effects caused by CO2 emissions are seen as a global problem. In 1997, the Kyoto Protocol was signed, asking the countries listed in Annex I to mitigate the greenhouse gases averagely 5.2 % in 2008-2012 based on the actual emission of 1990. Under such a circumstance, many researchers argue that the power generation by solar PV systems may be an effective tool to solve the CO2 emission problem and enhance energy security. Some countries started to employ economic subsidies such as feed-in tariffs, tax reduction, subsidy on investment etc. to encourage the installation of solar PV power systems.

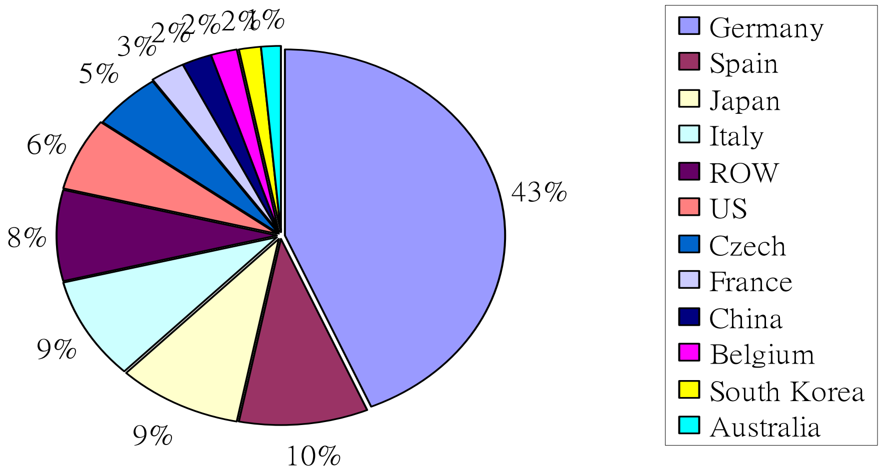

Figure 1. The cumuative PV capacity for the selected leading countries through 2010

EPIA (2011a) point out that approx.16,629 MW of new solar PV systems was installed in the world in 2010, and the accumulated capacity reached 39,529 MW. The data shown on Page 10 of EPIA (2011a) demonstrates that EU may continue to lead solar PV power generation with over 70% of global installation capacity (EPIA, 2011a). Figure 1 depicts the cumulative PV capacity of the leading countries through 2010. Among these countries, Germany stood at an outstanding position for the promotion of solar PV electricity generation and had been far ahead of other countries for the production of solar PV electricity. Spain, Japan and Italy ranked the second, third and fourth place in the world, respectively, but all of them kept a large distance from Germany. The share of German's PV installation in the world was 43.49 %, much higher than Spain's 9.57%, Japan's 9.16% and Italy's 8.84% by end of 2010.

After 2008, Spain dropped very much from 2,708 MW of annual installation in 2008 to 369 MW in 2010 due to huge reduction in FIT. EPIA (2011a) indicates that Germany was still the leader in 2010, installing 7,408 MW solar PV systems, followed by Italy (2,321 MW), Czech (1,490 MW), Japan (990 MW), US (878 MW), and France (719 MW). In overall, the PV market experienced an explosive growth of 153 % in 2010 and may keep a continual growth in 2011 even with the FIT reduction in both Germany and Italy in the first half of 2011. Some countries in EU such as Italy, the Czech Republic and France are characterized with growing markets and promising in 2011. Among the developing countries, China realized very high growth rates at annual growth rate of approx. 300 % in the past few years, and its annual installation capacity in 2010 was 520 MW, ranked the seventh place in the world.

## 2.1 The status of solar PV industry

The PV industry, in general, consists of three streams including (1) the production of solar PV modules, (2) system components, and (3) system design and engineering. The whole system includes the photovoltaic modules, inverters, storage batteries, all associated mounting and control components, distribution and installation of these products for final customers. The supply chain for the production of PV modules in general contains the fabrication or manufacturing of polysilicon, solar glass, bulk chemicals and gases, manufacturing equipment and parts, junction boxes and connectors, module materials (such as films, string, and silver paste), module frames, silicon wafers, and PV cells. System components include solar inverter, solar charge controller, solar combiner box, PV mounting system, cable, wiring, conduit, and connectors. A consultant/engineering company in general is responsible for the design and installation of solar PV power systems on the field by integrating with other components such as inverters, racking, and wiring. And thus, the design, production, marketing, delivery and support functions through a consultant/engineering company are also a part of the supply chain.

Stimulated by the high demand from solar PV power plants, the corresponding PV industry also grows significantly in the past decade, with a 10-year compound annual growth rate (CAGR) of 46% and a 5-year CAGR of 56% through 2008 (NREL, 2011). Table 1 lists the global market share for each sub-sectors of the solar PV value chain in 2008. The USA, Japan and Germany dominated the major market of the PV systems from the raw material of poly crystalline silicon to the system installations. Table 1 indicates that Taiwan contributed very little to the world market supply for the whole PV systems except solar cells in 2008.

Table 1. The global market share for sub-sectors of solar PV industry in 2008, calculated by output value

| | Poly Crystalline silicon | Silicon wafers | Solar cell | modules | TF modules | system |
|---|---|---|---|---|---|---|
| Taiwan | 0 % | 4 % | 11 % | 1 % | 0.3 % | 0.1 % |
| China | 9% | 42% | 28% | 40% | 3% | 2% |
| USA | 43% | 10% | 6% | 7% | 71% | 16% |
| Japan | 19% | 17% | 22% | 12% | 18% | 14% |
| Germany | 18% | 20% | 21% | 25% | 7% | 36% |
| others | 11% | 7% | 12% | 15% | 0.7% | 32% |

Source: Wang, M.C. (2009).

The global production capacity for silicon materials may reach 370,000 tons in 2011, up from approximately 350,000 tons in 2010 (EPIA, 2011b). In 2008, the global output of poly crystalline silicone materials was 87,458 tons, among which USA supplied 43 % of the global market, followed by Japan, Germany and China. By production quantity, the world's top 5 manufacturers were Hemlock (the USA), Wacker Chemie (Germany), MEMC (the USA), REC (Norway), and Tokuyama (Japan). The combined market share of the top 5 manufacturers was about 66 % in 2008. The balance of market was shared by Elkem, DC Chemicals, LDK, Mitsibishi, Setec, and Sumitomo. Most of the Chinese manufacturers were new comers and engaged in mass production in 2008 with market share of 9 % only.

The global production of wafers was about 8.1 GWp in 2009, dominated by LDK (China), MEMC (the USA), REC (Norway), Rene Solar (China) and Solar World (Germany). China was the largest supply of wafers in the world, with more than 50% of world's output by 2009. As to the production capacity of wafers, China ranked the first in the world, accounting for 55 % of global production capacity (about

30-35 GW) in 2010, followed by Germany, Japan, Taiwan, Norway and the USA (EPIA, 2011b).

Table 2 demonstrates that the global production of solar cells increased from 1,815 MW in 2005 to 12,318 MW in 2009 with the growth rate of approx. 7 folds. In 2006, the global cell production was 2.54 GW, where Japan occupied the major market share of 36.5%, Germany 20.1%, China 8.3% %, Taiwan 6.7%, etc. In 2008, China became the largest suppliers of solar cells, accounting for 28% by sales value and Japan's market share dropped to 22%. In 2009, the global production for c-Si solar cells was 9.1 GWp, manufactured by the global top five manufacturers including Q-Cells (Germany), Suntech (China), Sharp (Japan), Yingli (China), and Kyocera (Japan) with combined market share of 32.4% . In 2010, global market demand for cells and PV modules (installed capacity of solar PV systems increased) reached to 16.63 GWp (EPIA, 2011a) with growth rate of 2.3 folds compared to the previous year while the global c-Si cell production capacity reached around 27 to 28 GW in 2010 (EPIA, 2011b). A survey on global cell production published by Photon international indicates that the annual growth rate of solar cell production was 118%, comparing with 12.5 GW produced in 2009 (Photon International, 2011).

Table 2. The production of solar cells (2005-2009) among the leading countries, unit: MW

| | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|
| China | 150.6<br>(8.3%)# | 385.5<br>(8.3%) | 1202.4<br>(28.1%) | 2586.6<br>(32.7%) | 4680.8<br>(38%) |
| Germany | 344.9<br>(19%) | 509.7<br>(20.1 %) | 877.2<br>(20.5 %) | 1463.4<br>(18.5%) | 1847.7<br>(15%) |
| Japan | 827.6<br>(45.6%) | 925.6<br>(36.5%) | 932.8<br>(21.8%) | 1265.6<br>(16%) | 1539.8<br>(12.5%) |
| Taiwan | 74.4<br>(4.1%) | 169.9<br>(6.7%) | 462.1<br>(10.8%) | 917.6<br>(11.6%) | 1502.8<br>(12.2 %) |
| US | 156.1<br>(8.6%) | 175<br>(6.9%) | 273.9<br>(6.4%) | 435.1<br>(5.5%) | 542<br>(4.4%) |
| total | 1815 | 2536 | 4283 | 7910 | 12318 |

# The parentheses indicates the market share of global production.

Source: Lu (2011)

Currently the Asia countries (China, Taiwan, and Japan) are the major suppliers for Crystalline-silicon (c-Si) cells & modules. China was the leader, contributing to 38% of global production in 2009, followed by Germany, Japan and Taiwan. Among these leading countries, China and Taiwan have higher growth rates. China increased from 150.6 MW in 2005 to 4680.8 MW in 2009 with growth rate of 31 folds while Taiwan increased from 74.4 MW in 2005 to 1502.8 MW with growth rate of 20 folds. Based on the production capacity of c-Si cells, China still ranked the top in 2010, accounting for almost 50%, ahead of Taiwan's 15%, the EU's 10%, and Japan's 9.9% (EPIA, 2011b).

In 2009, the output of TF PV modules was 2 GWp only, accounting for about 19 % of the total module market. The global production capacities for c-Si PV modules ranged between 30 and 32 GW, while 3.5 GW for TF modules in 2010 (EPIA, 2011b).

The global market share of c-Si (crystalline silicones) modules was 87.5 % while thin film modules enjoyed the remaining portion of 12.5% in 2008 (EPIA, 2011b). The global production of Si-based PV in 2011 reached more than 15 gigawatts, among which 80 % was supplied from China and Taiwan. The Si-based PV modules account for nearly 90% of 2011 sales of total installation of solar PV power systems (NREL, 2011b). First Solar (the USA) occupied the major share of the world market and leads the world with over 55.3% share of global market in 2009. The other top leading manufacturers includes Uni-solar (the USA), Sharp (Japan), Kaneka (Japan), and Bosch Solar (Germany).

## 2.2 The status of Taiwan's PV industry

Taiwan's solar PV industry started from the production of the first amorphous silicon cell in laboratory developed by Industrial Technology Research Institute (ITRI) in 1987. In the following year (1988), Sinonar Amorphous was established for the production of solar cells. Motech was founded in 1998 to produce the first piece of solar cell. After then, solar PV industry become a focus of investments, encouraged by the booming demands in Europe and Japan. The first piece of c-Si solar cells manufactured in Taiwan was manufactured in 2004 under the technology support from Germany. After then, Taiwan became one of the largest PV producer in the world.

Currently, Taiwan has established a complete supply chain from the manufacturing of raw material to the system design and installation of the solar PV systems. The supply chain of solar PV industry consists of 110 firms, including one firm for the production of silicon material, 16 firms for manufacturing ingot/wafers, 16 firms for c-Si cells, 19 firms for PV modules, 9 firms for TF modules, 3 firms for dye-sensitized thin film cells, 2 for high concentration cells, 39 firms for system designs and engineering, and 9 firms working as distributors (Green Energy Industry Information Net, 2011). In order to avoid the supply shortage of poly silicon material that happened in 2005, a local firm (Real Green Material Technology Corp.) was established to produce the raw material and started on-line in 2009. Most of these wafer producers, however, still depend on the supply of poly-silicon from MEMC, Hemlock, Solargiga, and DC Chemical Wafer even though Real Green Mateiral Technology Corp. has started to produce the solar grade purified silicon with purity of 99.9999% since 2009. More than 45 % of poly-Si material was imported from abroad in 2010

The c-Si products, most commonly constructed from crystalline silicon wafers, are the major supply of Taiwan's PV industry. Taiwan's c-Si cell production increased very much from 88 MWp in 2005 to 177.5 MWp in 2006, 360 MWp in 2007, and then reached to 1600 MWp (Lu, 2011). The production capacity of solar cells has been expanded to 4000 MWp by 2010, ranking the second place in the world, accounting for 14.1 % of the world production, following to China that contributes 46.4% to the global cell production (PV Taiwan, 2011). Compared to the statistics in Wang (2009), the market share of Taiwan's solar production grew very much from 11% in 2008, shown in Table 1, to 14.1% in the world market in 2010. However, the market share of poly crystalline silicon material seems to be dominated by the US, Japan and Germany. The market share of poly crystalline silicone was 43 %, 19% and 18% for these three countries in 2008, respectively.

## 3. Result of SWOT analysis

Many researchers employ SWOT to identify factors that affect the relative competitiveness involving renewable energy development strategy. For example, Dincer (2011) overviews the photovoltaic technology status and perspective in Turkey, and analyze the SWOT of Turkey's photovoltaic industry. Through the SWOT analysis, Terrados, et al. (2007) focus on a renewable energy development project to diagnose current problems and to sketch future action lines. The SWOT (strengths, weaknesses, opportunities and threats) analysis has proved to be an effective tool to provide very valuable information for both the industry and the firm by reviewing the positives and negatives of the industry itself and the environment.

The results of a comparative SWOT analysis for Taiwan's PV industry is presented and discussed below:

### 3.1 strength of Taiwan's PV industry

#### (a) the excellent infrastructure

Up to now, Taiwan has established a complete supply chain from the production of solar-grade silicon material to the installation of the solar PV systems based on the excellent infrastructure of the incumbent industry structure consisting of semiconductor, optical disk, TFT-LCD, and precision machinery. The outstanding performance of the incumbent infrastructure like display and optical disk industries in Taiwan is proved to be very helpful to the development of the solar PV industry (DIS, 2011a). The special competent advantage of Taiwan's imbedded characteristics such as global logistics management, scale up capability and marketing management may provide the appropriate business environment to nourish the growth of Taiwan's PV industry.

#### (b) the high connection in R+D with the incumbent photonics and microelectronic industry

Rooted in the good convention of Taiwan's photonics industry and microelectronic industry, Taiwan PV industry enjoys the relative advantage to develop solar silicon processing technology by improving Si wafer processing technologies that are used in micro electronic applications. For example, TFT technology can easily be transplanted to develop thin-film solar cell technology. By 2007, Taiwan's TFT-LCD (Thin film transistor liquid crystal display) production ranks World's first place and LED (Light Emitting Diode) packaging production the second place (PIDA, 2011). In terms of production value and capacity, Taiwan has become the world's largest TFT LCD supplier, accounting for 42% of the global TFT-LCD market (PIDA, 2011).

#### (c) The abundant skilled labors

The PV, photonics and microelectronic industries require high skill employee with high education level. Currently, more than 3000 PhD graduated from local universities every year and about half of these graduates are specialized in electronic/electrical fields. The outstanding provision of skill personnel in Taiwan plays a key important role in contributing to the high development of solar PV industry. Furthermore, the ambitious personality of high ranking officials in solar PV industry encourages expanding capacity through the quick decision of investment and optimal timing to scale-up.

### 3.2 Weakness of Taiwan's PV industry

After examining the relevant documents, we find that the weakness of Taiwan's PV industry includes (1) lower efficiency of Taiwan-made solar cell, (2) lower capacity for R+D, (3) high reliance on imported raw material of high-grade purified poly silicon, (4) high reliance on foreign-made equipments for production of solar PV products and components and (5) small domestic markets.

(1) Lower efficiency

Efficiency is defined as percentage of sunlight (solar energy), falling on the solar PV systems, that is converted into usable electricity. Theoretically, system efficiency is lower than the efficiency of any individual components. Currently, the system efficiency of commercial solar PV installations ranges from 6% to 25 %, depending on module technologies. The efficiency records of some promising technologies in the world are listed in Table 3. The back contact c-Silicone-based technology is developed by moving the front contact of the cell to the back to increase the cell's surface area. Its efficiency can attain 22 % that is seen as the highest commercial cell efficiency available on the market. The efficiency of *HIT*™ (Heterojunction with Intrinsic Thin Layer) that is developed by Sanyo Electrics can reach 19.8% while Pluto™ developed by Suntech can achieve 19%. In contrast, TF technology offers lower efficiency with efficiency in the range of 4 to 8%. The advantage of this technology is its relative low costs, production of large size per unit of cells as the absorption material can be deposited onto very large substrates (up to 5.7 $m^2$ on glass). Multi-junction thin silicon film (a-Si/μc-Si), Cadmium telluride (CdTe), Copper, indium, gallium, (di)selenide/(di)sulphide (CIGS) and copper, indium, (di)selenide/(di)sulphide (CIS) may achieve higher efficiency over 10 %.

In contrast, most of Taiwan-made solar cells have lower efficiency. For example, Mono c-Si solar cell manufactured by Mosel Vitelic Inc. offer an efficiency of 15.4 % -17.79 %, and Multi c-Si solar cell has efficiency of 15.8%-16.99%, (Mosel Vitelic, 2011). The efficiency of Taiwan-made a-Si is only 5.5%, lower than foreign-made of 7-9% (BEMOEA, 2011, p. 223). BEMOEA (2011) makes a comparative analysis on the efficiency of CIGS solar cells among Taiwan, the US, and Europe and finds that the efficiency of Taiwan-made CIGS solar cells is 9% in 2010, European-made 14 % and US-made 10-12% (BEMOEA, 2011, p. 224). The slight efficiency gap with international levels leaves some space for Taiwan's PV industry to improve and catch up with the world's leading levels.

Table 3. The efficiency records of the commercialized cell available on the market

| Technology | | efficiency record |
|---|---|---|
| c- silicone cells | Mono (back contact) | 22% |
| | HIT™ | 19.8% |
| | Mono (Pluto™) | 19% |
| | Nanoparticle ink | 18.9% |
| | Mono | 18.5% |
| Thin film cells | a-Si | 7.1% |
| | Multi-junction thin silicon film (a-Si/μc-Si) | up to 10% |
| | Cadmium telluride (CdTe) | 11.2 % |
| | Copper, indium, gallium, (di)selenide/ (di)sulphide (CIGS) and copper, indium, (di)selenide/(di)sulphide (CIS) | 12.1% |

Source: EPIA (2011b).

(2) lower capacity for R+D

Currently Taiwan's R+D on photovoltaic products mainly depends on a range of universities, government-funded institutes and industry facilities. Taiwan spent a total of $ 17,453 million on R&D in 2009, accounting for 2.93% of total GDP (gross domestic product) (MOEA, 2011). The photovoltaic sector in Taiwan is still relatively small compared to developed countries. And thus, the PV manufacturers cannot afford to invest on R+D due to uneconomic scale. At present, Taiwan government attempts to integrate the R+D resources by cooperating on project by project with universities, research institutes, and private companies. These cooperating institutions include National Science Council, Department of Investment Services, Taiwan External Trade Development Council, Industrial Technology Research Institute, Taiwan Photovoltaic Industry Association, etc.

Currently, c-Si solar cells and PV modules contributes the major portion of value-added in the supply chain of Taiwan's PV industry and play the key role to drive Taiwan's PV industries moving forward. The relative advantages of crystalline silicon (c-Si) technology are its reliability and relatively high efficiency. With more mature technology, the market for c-Si segment has been well established in the world market. Hence, the entry barrier to the production of c-Si cells and modules is less and the market may become more stringent to competitve for Taiwan's PV industry.

Thin film technology is newer and may replace c-Si technology, but somewhat higher risk due to less reliable and lower efficiency compared to c-Si technology. Thin film panels are manufactured by depositing certain materials on glass or stainless steel substrates to produce thin layers with a few micron (smaller than 10 $\mu$m) thick that is much thinner than crystalline wafers. Hence, TF modules have lower costs due to the high throughput deposition process as well as the lower cost of materials compared to c-Si/mc-Si cells. The First Solar of the USA may be the largest leader in thin film modules. Considering the relative competitive advantage of TF modules in the future, Taiwan started to manufacture the amorphous or crystalline thin film solar cells in 2005. Currently about ten (10) Taiwan-based companies have started mass production for thin film solar cells by purchasing foreign technology (please see Table 4). Among these 10 firms, only two are major in high efficiency of TF solar cells (a-Si/ $\mu$ c-Si). In 2008, NREL developed successfully the CIGS TF with 20% conversion efficiency. In the world, more than 20 firms started to manufacture CIGS TF, but excluding Taiwan.

Table 4. The TF solar cells production in Taiwan

| Maker | Tech. supplier | Tech. | Eff. | remarks |
|---|---|---|---|---|
| 1 | Chronar (EPV) | a-Si | 5.5% | The capacity reached 50 MW in 2008.<br>Size: 1*1.2 m |
| 2 | EPV | a-Si | 5.5% | Capacity: 5.5 MW<br>Size: 1246 mm * 635 mm |
| 3 | ULVAC | a-Si | 7% | The capcity reached 50 MW in 2009.<br>Size: 1.1*1.4 m |
| 4 | ULVAC | a-Si | 7% | The capcity reached 30 MW in 2009.<br>Size: 1.1*1.4 m |
| 5 | ULVAC | a-Si | 7% | Joint-ventured with Itochiu (Japan)<br>Capcity: 25 MW<br>Size: 1.1*1.4 m |
| 6 | Nano PV | a-Si | 5.5% | The capacity reached 60MW in 2010. |

|  |  |  |  |  |
|---|---|---|---|---|
|  |  |  |  | Size: 1400mm * 635 mm |
| 7 | Applied Materials | a-Si | 6% | The capcity reached 50 MW in 2009.<br>Size: 2,2 * 2.6 m |
| 8 | Oerlikon | a-Si | 7% | The capcity reached 106 MW in 2009.<br>Size: 1.1 * 1.3 m |
| 9 | Oerlikon | a-Si/<br>$\mu$c-Si | 8.5% | Capacity: 60 MW<br>Size: 1.1 * 1.3 m |
| 10 | Leybold optics | a-Si/<br>$\mu$c-Si | 8.5% | Capacity: 15 MW<br>Size: 1.1 * 1.4 m |

Source: BEMOEA (2011, p. 198)

(3) high reliance on imported raw material (high-grade purified poly silicon)

The material of purified silicon crystal in the supply chain is a constraint to the growth of Taiwan's PV outputs since the silicon crystal that is almost oligopolized in the world, is completely imported. Before 2005, the major portion of the silicon materials was supplied by Hemlock, Tokuyama, Wacker, REC, MEMC, Mitsubishi Mateiral, and Sumitomo Titanium (BEMOEA, 2011). After 2009, the price of silicon materials dropped very much due to entry of new suppliers from China and Korea and thus the supply of silicon materials became more stable than before. However, the reliance on imported raw materials may damage the complete value chain of solar PV industry in case of a huge change in the global environment. Thus, ITRI (Taiwan) attempts to develop pyro-metallurgical Si technology to produce the material of poly-silicone and to form a complete supply chain of PV productions. Physical metallurgical method for the production of poly-silicon is not yet commercialized in the world, even though some institutes report to have a successful production in the pilot plant. As the supply of the raw material are dominated by very few manufacturers, the benefit of the incentive policy implemented to encourage the deployment of solar PV systems will be flowed to these few manufacturers.

(4) high reliance on imported equipments

As the equipment and facilities for production of PV products are capital and technology intensive, Taiwan PV industry shows little confidence in local equipment. The technology as well as high quality facilities for manufacturing PV products almost depends on the imported suppliers. For example, Top Green Energy Technologies, a Taiwan-based producer of high quality solar cell founded in 2006, signed a contract in 2008 for polysilicon production equipment and services with GT Solar International that is a global provider of specialized equipment and technology for the solar power industry. The contract valued at $46.8 million. In order to survive, some local equipment makers develop a strategy of strategic cooperation with foreign partners in technology development to expedite certain R&D procedures and to expect cost reduction. Even though, the newly emerging technology for compound modules and nano-modules are still under developed.

(5) small domestic markets:

Taiwan's solar PV installation was 8 MW in 2010, accounting for 0.48% of world installations. Under such a circumstance, the export of solar PV products become the key role in affecting the survival and growth of Taiwan's PV industry. Table 5 demonstrates 65%-95% of various PV products manufactured locally were exported in 2010.

Table 5. The export rate of Taiwan's solar PV products in 2010

|  | Wafer | Cell | module |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Capacity (MWp) | 1650 | 2600 | 643 |
| Produciton (MWp) | 716 | 1689 | 117 |
| Revenue ($10^9$ NT$) | 21.5 | 71.5 | 8.1 |
| Export ($10^9$ NT$) | 140 | 690 | 73 |
| Export rate | 65.1% | 96.5% | 90.1% |

Source: Lu (2011)

3.3 Opportunities of Taiwan's PV industry

EPIA (2011a) indicates that the cumulative global installation of solar PV systems amounted to around 40 GW by 2010, producing some 50 terawatt-hours of electricity every year. EPIA (2011a) expects the cumulative installation may reach 196 GW in a Policy-Driven Scenario by 2015. Such a circumstance of a stable growing market may provide sufficient opportunities for Taiwan to reinforce its supply chain in the future and increase its relative competitiveness in the world market.

In order to promote the production of solar PV electricity, Taiwan enacted a new feed-in tariff mechanism in 2009 called "Directive for promoting renewable energy (DPRE)" that focuses on the financial subsidy to the renewable electricity generation through the implementation of feed-in tariffs. According to the DPRE, TPC (the power monopoly in Taiwan) is obliged to purchase the electricity generated from PV electricity producers at the regulated price (feed-in tariff) for a guaranteed period of time. As of early 2011, the feed-in tariffs were determined and announced, listed in Table 6 that reflects the cost situation of the renewable electricity generation technologies. The feed-in tariff for the solar PV electricity is the highest, ranged from NT$ 7.9701 to 10.3185 per KWH that is much higher than electricity price of NT$ 2.1 (for households) to NT$ 5.1 for commercial use (Taiwan Power Company, 2011). Furthermore, China starts to implement a new law titled "Solar PV feed-in tariff" that is effective from July, 2011. As of July 2011, China government guaranteed to purchase the PV electricity at price of 1.15 CNY/kWh (18 USD cent equivalent). In order to meet the steep localized demand ramps and the continual deployment of global market, the solar PV capacity continues to expand in Taiwan and expect to reach a summit by 2030.

Table 6. Feed-in Tariffs implemented in Taiwan, unit: (NT$/KWH)

| | 1-10 KW | 10-100 KW | 100-500 KW | > 500 KW |
|---|---|---|---|---|
| Solar PV | 10.3185 | 9.1799 | 8.8241 | 7.9701 |
| Wind (onshore) | 7.3562 | 2.6138 | 2.6138 | 2.6138 |
| Wind (offshore) | 5.5626 | 5.5626 | 5.5626 | 5.5626 |
| Biomass | 2.1821 | 2.1821 | 2.1821 | 2.1821 |
| Geothermal | 4.8039 | 4.8039 | 4.8039 | 4.8039 |
| hydropower | 2.1821 | 2.1821 | 2.1821 | 2.1821 |
| Waste energy | 2.6875 | 2.6875 | 2.6875 | 2.6875 |

### 3.4 Threat of Taiwan's PV industry

Compared to wind technology, the PV technology is newly emerging and thus changing quickly over time. A newer generation of technology may rise up efficiency and reduce costs. The impact of competing technologies may affect the future installation of solar PV power systems and the corresponding PV market. The past evolution of PV markets shows that the price reduction in PV products has become a trend. The global average price of PV modules decreased by 23% from \$4.75/W in 1998 to \$3.65/W in 2008. During the period 2002-2007, module prices rose slightly due to the shortage of polysilicon material supply. After 2007, the price kept a downward trend by decreasing from \$4.07/W in 2007 to \$3.65/W in 2008 (NREL, 2011). In general, "The price of PV modules has reduced by 22% each time the cumulative installed capacity has doubled" (EPIA, 2011b, p. 30).

In addition to the development of competing technologies, the relative overcapacity is also an important facto to drive module prices further down during the coming years. The rate of the capacity expansions from incumbent manufacturers has increased in the world recently. Many Taiwan-based or China-based PV manufacturers have expanded production capacity to match the growing market of PV industry in the past few years. The foreign debt problems occurred in Greece and some other countries in EU in 2011 may lead to a modest contraction of market demand and oversupply may happen.

The production costs of solar PV electricity are still higher than wind power and other renewable electricity. Electricity generated by solar PV is still expensive and lacking of competitiveness with respect to other renewable energies. Thus the PV market still requires a continual support of government stimulus efforts such as feed-in-tariffs (FIT), rebates, grants, and tax benefits to drive the market forward over the coming several years. Without governmental support, the PV market may face a quickly shrinking demand and decline.

## 4. Discussions and conclusions

Considering the optimistic opportunities predicted by EPIA (2011a) and the newly revised FIT policies by China and Taiwan, Taiwan's PV industry has to use its relative strength of excellent infrastructure and abundant skilled labors to expand its competitive advantages. EPIA (2011b) estimates that the module prices will keep a continual reduction and Asia may become the major market for solar PV products in the future. The increasing relative share of transportation cost for a PV module may help Taiwan's PV industry to be more competitive since Taiwan's production capacity is closer to the newly emerging market covering China and other Asian countries. On the other hand, the high reliance on imported technology may block Taiwan's marketing objectives and should be recovered. As Taiwan's PV industry started later than Germany, Japan, and USA, it seems very difficult for Taiwan's PV industry to keep pace with these technology leading countries in facing the environmental threats. A strategic cooperation with these technology-leading world firms to share the market may be a way for Taiwan to survive and grow. In overall, Taiwan's PV industry may face a lot of challenges in the future including market uncertainty, technology development and recycling and recovery of spent modules.

### (a) Market uncertainty

The governmental support mechanism in each country such as feed-in-tariffs will continue to drive the market and may play a vital role in affecting the expansion decision. Since Taiwan's industry highly depends on export markets, the changing of FIT policies implemented by other countries may affect world market demand, and consequently yield high impact on the growth of Taiwan's PV industry. For example, in 2007, Spain adopted a FIT program that raised the FIT from €0.18/kWh to nearly €0.42/kWh for large scale systems (>100kWp, <10MWp). Such a overly generous incentive program resulted in a installation surge with about 542 MWp installed in 2007, up from 102 MWp installed in 2006, and 2.7 GWp installed in 2008 (EPIA, 2011a). In 2009, the FIT was reduced to €0.32/kWh, and the annual installations in Spain dropped off sharply to 17MWp installed in 2009, and 369 MWp in 2010.

(b) Technology development

Due to the technology improvement, the production costs of solar cells and modules kept a continual decline. The market price was accompanied to drop in the past few years. Thus, the share of the module in the total PV system value decreased. The value of PV modules decreased from about 75% of a PV system price in 2005 to less than 60% in 2010 for large ground-mounted systems (EPIA, 2011b). As the production value of Taiwan's solar cells reached US$ 2,151 million in 2009, accounting for 68.76% of the total value contributed by the whole solar PV chain (Wang, 2009), the price drop of solar cells will reduce the profit margin of Taiwan's solar PV industry.

In order to keep a continual growth in PV industry, Taiwan has attempted to diversify its production of the whole PV industry. A portion of resources and efforts is shifted to R+D by pursuing basic and applied research on silicon materials and devices. The analysis revealed by DIS (2011a) finds that poly silicon material and wafer supply may be the key factor to block the growth momentum of Taiwan's PV industries. Thus, a continual effort through R+D to develop new process, to improve PV product efficiency and to cut cost down is necessary to keep a competitive status of Taiwan's PV industry.

(c) Recycling and recovery of spent modules

The spent modules containing high amount of glass, heavy metal and a variety of semiconductor materials may yield adverse impacts on the environment but are valuable. Thus the modules at end of life or the manufacturing scrap should be collected and recycled based on proven methods to support the sustainable use of raw material. The recovered materials can be reused in either new PV modules or other new products. The recycling process has been developed successfully and used commercially for both thin-film and silicon modules in developed countries. However, Taiwan has not yet established the PV recycling systems due to low installed capacity of solar PV. In practice, the recycling of the defected modules including glass breakage, defect laminate, electrical defects, etc. may benefit for both the environment and the PV producers as it can help reduce costs and environmental impacts.

## 5. Conclusions

This paper has investigated the current status of Taiwan's PV industry and provided the SWOT analysis by linking with the world market of solar PV installations. The results highlight the important role of FIT policies to expand the market demands for solar PV installations and the technology development for efficiency improvements and costs down. As the production costs of solar PV electricity are still higher than conventional power, the environmental consciousness to adopt solar PV electricity is also important in addition to financial subsidies. More detailed investigation may be needed to promote the adoption of solar PV electricity and the installation of solar PV technologies. The eco-label (carbon label) scheme may play a supporting tool to expand the demand of solar PV electricity and thus should be focused and established in the future.

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附件三：

# An examination on the effectiveness of energy policies aiming at CO2 mitigation

## Abstract

The purpose of this study is to verify the existence of an EKC between per capita GDP and per capita emissions by investigating 8 countries that are dividing two groups: developed countries and rapidly developing countries. In addition to per capita gdp, we also employ education level, the share of manufacturing output in GDP, the share of service value-added in GDP, and technology level as explanatory variables. The empirical results from panel data set show that an EKC phenomenon exists for CO2 emissions and the share of service industry and manufacturing sector significantly affect CO2 emissions based on the pooled data. By using a single data set, we find that the EKC phenomenon is not existent for developing countries, but significantly exists for developed countries.

**Keywords:** energy consumption, energy intensity, CO2 emission, carbon intensity, EKC curve.

## 1. Introduction

The Environmental Kuznets Curve (EKC) refers to an inverse U-shaped pattern between per capita pollution and per capita income. The investigation on EKC phenomenon of CO2 emissions has been widely discussed, but the conclusion is still not consistent. A generally accepted conclusion has not yet made until now.

A great number of empirical studies have focused on the EKC relationship by testing the linear relationship between per capita income and CO2 emissions (e.g. Shafik and Bandyopadhyay (1992), Shafik (1994), de Bruyn et al. (1998), as well as quadratic and cubic relationships (e.g. de Bruyn et al. (1998), Heil and Selden (2001), Holtz-Eakin and Selden (1995), Moomaw and Unruh (1997), de Bruyn and Opschoor (1997), Roberts and Grimes (1997), Harbaugh et al. (2002), Friedl and Getzner (2003), Canas et al. (2003). Dinda and Coondoo (2006) find bidirectional causality between emissions and income for North America by using bi-variate analysis.

For example, Martı´nez-Zarzoso and Bengochea-Morancho (2004) employ the data of 22 OCED countries that commit to mitigate CO2 emissions in Kyoto Protocol. Some researchers verify the existence of an EKC curve for CO2 emission (Cole et al. (1997), Agras and Chapman (1999), Galeotti and Lanza (1999), Heil and Selden (2001), Cole (2004) and Galeotti et al. (2006). Some studies test the cubic relationships and find an N-shaped relationship (Sengupta, 1996; Harbaugh et al. (2002); Friedl and Getzner (2003); Canas et al. (2003); Martinez-Zarzoso and Bengochea-Morancho, 2004). Dinda and Coondoo (2006) find bidirectional causality between emissions and income for North America by using bi-variate analysis. Martinez-Zarzoso and Bengochen-Morancho (2004) find that the CO2 emissions execute a contrary pattern to EKC hypothesis, i.e. CO2 emission declines to a certain level as income increases, and then it turns to increase at higher incomes. On the contrary, some researchers argue that an EKC is less likely to occur for CO2 emissions. Many empirical studies find monotonically increasing relations between CO2 emissions and income (e.g. Shafik and Bandyopadhyay, 1992; Shafik (1994), Holtz-Eakin and Selden (1995; de Bruyn et al. (1998); Roca et al., 2001; York et al., 2003; Azomahou et al., 2006).

However, many researchers who focus on the EKC of greenhouse gases can not find a significantly inverted U-shaped curve between per capita gdp and per capita emission. Some others claim that CO2 emissions have monotonically increased with economic growth over time (Shafik, 1994). The possible explanation of the absence of EKC in greenhouse gas emissions is that greenhouse gases are a global pollution and cannot be solved through the effort of an individual country.

Due to the increasing awareness of global warming effect, an examination on the EKC phenomenon of CO2 emissions may provide some significant implications for policies making. In this paper, Japan, UK, Germany and the US that rank the top four of national income in the world are subjectively selected to represent the developed countries (the high-income countries). In contrast, we use the four countries of BRIC (Brazil, Russia, India, and China) to represent the rapidly developing countries (the low-income countries). Our research aims to shed light on the reasons why carbon emissions keeps growing trends in developing countries or even after the effect of Kyoto Protocol.

In fact, low developed country emphasize equity and argues that the warming effect should be attributed to the past over-energy consumption that contributed to the economic development of developed countries in the past. When the less developed countries are starting to modernize and abruptly need a lot of energy to fill its big mouth, the limit to carbon emissions is a penalty to barrier their economic growth. These countries insist their perspective that since it was largely fossil-fuel burning in the past by developed countries that is the main cause to lead to most of the excess atmospheric warming gas, the world cannot urge them to born the responsibility for the alleviation of warming effect. They need at lease for some time to burn fossil fuels for attaining to a target of modernization.

## 2. Research methods

Chen (2011) devleops a framework to analyze the factors to affect the achievement of a sustainable economy by linking governmental policies and energy consumption and CO2 emissions. This framework suggests that “industry structure”, “energy structure” and “energy price” may sufficiently affect the final CO2 emissions. To test the existence of EKC for CO2 emisions, we augment the basic EKC model with additional explanatory variables to capture the impacts of “industry structure”, “energy structure” and the oil price. “Industry structure” is measured by two variables, consisting of “the share of industrial production in total GDP” and “the share of service production in total GDP” to capture the composition effect. The decrease in CO2 emisions is theoretically attained through the change from energy-intensive industries towards less energy-intensity industries. Some of the previous studies also incorporate these variables in their studies (e.g. York et al., 2003); Friedl and Getzner (2003). Some researchers have augmented the variable of “the price of crude oil” to test CO2 EKC (Agras and Chapman, 1999; Heil and Selden, 2001). Some researchers emphasize that the technology improvements play an important role in affecting CO2 emissions (e.g. Lindmark (2002); Lantz and Feng (2006). For example, Lantz and Feng (2006) include the variable of technology progress to test the CO2 EKC by using a five-region panel data set in Canada over the period 1970–2000.

Therefore, the empirical model is expressed as Eq. (1), specifying CO2 emissions as a non-linear function of income and some other country specific characteristics

(Cole et al,1997; Jia et al,2006; Kumar and Aggarwal, 2003). Eq. (1) is quite standard and has been widely employed to analyze the EKC phenomenon.

$$\ln CO2 = \alpha_0 + \alpha_1 \ln y + \alpha_2 (\ln y)^2 + \alpha_3 \mathrm{ES} + \alpha_5 \mathrm{IS} + \varepsilon \qquad (1)$$

where CO2 represents per capita CO2 emissions, $y$ refers to per capita GDP, ES energy structure, IS industry structure, T number of patent application in proxy of technology level, and $\varepsilon$ the error term.

Many coutnries worries about the adverse effect of CO2 mitigation on economic growth, and are rleuctant to restrict the use of fossil fuels even though renewable energies are motivated and aimed to improve the growing aggravation of warming effects. And thus, ES refers to the share of fossil fuels in the energy consumption.

and thus the technology level, measured by the number of patent application, is incorporated into the model.

The EKC model is expressed as

$$CO_{it} = \alpha_0 + \alpha_1 y_{it} + \alpha_2 y_{it}^2 + \alpha_3 M_{it} + \alpha_4 S_{it} + \alpha_5 F_{it} + \alpha_6 T_{it} + \alpha_7 P_t + v_i + \mu_{it}$$

where $CO_{it}$ represents per capita CO2 emissions, $y_{it}$ per capita GDP in dollars at 2005 PPP, $M_{it}$ the share of manufacturing outputs in GDP, $S_{it}$ the share of service industry in GDP, $F_{it}$ the share of fossil fuel in the total energy consumption, $T_{it}$ the technology level, $v_i$ the unobservable individual specific effect, and $\mu_{it}$ the error term.

Some researchers also find the significant existence of an N-shaped EKC for CO2 emissions (Friedl and Getzner, 2003). And thus, an additional term of per capita GDP cubed is incorporated into Model (1) for the test of N-shaped EKC.

### 2.2 data descriptions

In this paper, we selected 8 countries, consisting of two groups: (1) developed countries, represented by the four leading developed countried, including the U.S., Germany, Japan and UK, and (2) the rapidly developing countries, represented by BRIC, including Brazil, Russia, India and China that are currently taking off towards a new stage of industrialization. The combined population of these 8 countries is about 2.8 billion, accounting for 45% of the world's population. According to EIA (2011), all these 8 countries emitted 19,087 million tons of CO2 in 2009, accounting for 62.97% of the global CO2 emissions (30,313 millions tons). This implies that the CO2 problem solving should depends on these 8 coutnries as these 8 countreis still rely on CO2 emissions to suport their economic growht. Based on per capita CO2 emisisons, the BRIC countries are still far below the average of the developed coutnries (Please see Table 2). It is reassonable to predict that the BRIC countries will increase their CO2 emissions in the future to support a continually economic growth. Therefore, an examinaiton of the EKC effect on these 8 coutnries may provide some significant implicaiton on policies pertaining to CO2 emisions in these coutnries, especially in the era of post-Kyoto Protocol.

The dataset is selected from World Bank (2011) and U.S. Energy Information Administration (EIA) for the period 1980–2004. Consistent data of some independent variables for most countries prior to 1980 are not available. Hence, the period studied is dependent on the availability of data. The data on carbon dioxide emissions is obtained from EIA (2011). The annual data for real GDP, CO2 emissions, and other variables during 1980-2008 panel data are extracted from Worldbank database (2011). GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are constant at 2000 U.S. dollars.

Share of manufacturing industries in total production: Manufacturing refers to industries belonging to ISIC divisions 15-37. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.

Services correspond to ISIC divisions 50-99 and they include value added in wholesale and retail trade (including hotels and restaurants), transport, and government, financial, professional, and personal services such as education, health care, and real estate services. Also included are imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The industrial origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator

Patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office.

The estimation based on the pooled data assumes that the relationship between the environment and income is homogenous across the panel countries.

The descriptive statistics for the variables including per capita CO2 emissions (metric tons), per capita GDP (US$), the share of industry in total production (%), the share of service industries in total production (%), the fossil fuel’s share of total energy consumption (%), and patent applications in 2008 is listed in Table 1. The mean of per capita GDP is US$ 33,250 for the developed countries, and US$ 2,564 for the BRIC countries. There is a large gap of per capita GDP between the two groups. The value of products and services each person of the BRIC countries produced in 2008 is only about one thirteenth of the developed coutnries. As to CO2 emissons, each person in the developed countries emitted 11.9 ton of CO2 in 2008, almost two folds of BRIC’s emissions (5.12 ton). Among these 8 countries, India has the lowest CO2 emissions. It implies that a rising pattern of CO2 emissions may take place in the BRIC countries.

Fig. 1 shows the trend of per capita GDP and per capita CO2 emissions of the selected 8 countires. The gap between the two series becomes wider as time passes for developed countries while it is flat for almost all the BRIC countries. This implies that the emission intensity (CO2 emissions per unit of GDP) has decreasing trend in dveloped countrie, but it keep flat for most BRIC countries. The increasing gap between the two series may provide some evidence in favor of EKC phenomenon.

Insert Table 1 about here

## 3. Results

### 3.1 EKC test on a pooled data set

The estimated results of quardratic and cubic models are listed in Table 2 based on the pooled data set of the selected 8 countries. The coefficients for per capita

GDP, per capita GDP squared, and per capita GDP cubed are significant for the full forms of the Cubic Model for N-shaped curve test. In contrast, the quadratic term in the Quadratic Model does not appear as significant and thus CO2 emissions are found to have a significantly linear relationship with GDP in the U-shaped curve test. Furthermore, the reduced forms also reject an inverted U-shaped EKC or N-shaped curve to explain the relationship between per capita CO2 emissions and per capita GDP. Based on the preliminary results, we conclude that the EKC hypothesis does not allow any clear conclusions based on the pooled data set. This indicates that the EKC phenomenon does not receive significant support since per capita CO2 emissions may execute in a linear pattern or N-shaped curve as per capita GDP increases. This result coincides with some of previous studies. Many researchers find a linear relationship between per capita CO2 emissions and per-capita GDP (Shafik and Bandyopadhyay, 1992; Roca et al., 2001; York et al., 2003; Azomahou et al., 2006) while few confirm the existence of an inverted-U-shaped relationship with relatively high turning points ranging from US$ 20,000 to 60,000. Gangadharan and Valenzuela(2001) find an upward straight line for CO2 emissions by using the panel data of 51 countries from the World Development Indicators 1998. Hill and Magnani (2002) also find no evidence to support the evidence of an EKC by using the panel data of 156 countries in the world.

In the full form of both models explanatory variables other than GDP are also found to have significant impacts on CO2 emissions. The negative sign of “share of service production” as expected demonstrates that high reliance on service production may reduce CO2 emissions. An increase in oil price or technology progress also leads to significant falls in CO2 emissions as the signs of the coefficients for the two explanatory variables are negative. Hence, this empirical study also concludes that the industry structure (measured by the share of service production), the energy structure (measured by the share of fossil fuel in total energy consumption), oil price and technological progress also play important roles in affecting CO2 emissions.

Insert Table 2 about here

3.2 EKC test on the group data set

As the selected 8 countries contains two groups (the developed countries and the BRIC countries) representing two extremely opposite pole of economic development, the regression results obtained in Table 2 neglect the countries that represent middle zones of economic development. And thus, the results obtained in Table 2 may be misled. In order to have a more clear understanding on the carbon EKC, the test is conducted based on the group data set, and the estimated results are shown in Table 3.

Insert Table 3 about here

Both the two models (the U-test and N-test) show that an U-shaped curve is verified to exist significantly across the developed group as the sign of per capita GDP squared is positive. This demonstrates that a rising trend of per capita CO2 emissions exists as time passes. Per capita CO2 emisions will keep an upward going and cannot return in the future. This finding coincides with previous studies. For example, Martinez-Zarzoso and Bengochen-Morancho (2004) find that the execution of CO2 emissions executes a contrary pattern to EKC hypothesis. The CO2 emission declines to a certain level as income increases, and then it turns to increase at higher incomes. However, the empirical study of Dijkgraaf and Vollebergh (1998) shows that a carbon EKC exists by using a panel data set of OECD countries.

Galeottietal.(2006) compare the EKC phenonmenon between the the OECD and non-OECD countries by using two different data sets and cofirms an EKC for CO2 emissions only for the OECD countries. Lindmark (2002) confirms the existence of an EKC and concludes that CO2 emissions actually depend on GDP in the long run.

The negative sign of the coefficient for technological progress implies that developed countries have more or less developed innovative process that consume less energy and emit less CO2 for unit production. The increased oil price seems to have effective improvements in carbon emissions while higher share of industry production may contribute to more CO2 emissions. However, the positive sign of coefficients for energy structure (the share of fossil fuels in total energy consumption) demonstrates that fossil fuels still work as the major energy source in the developed countries. In general, the continual rising in CO2 emissions seems to be inevitable unless renewable energy is successfully to replace the fossil fuels in the production process.

In contrast, the BRIC group executes an inverted U-shaped curve executes for the reduced form of the Quadratic Model and a linear relationship for the full form. As to the Cubic Model, an N-shaped curve is found for the full form. Narayan and Narayan (2010) examine the EKC hypotheses by using the data from 43 developing coutnries and find that the CO2 emissions has fallen as income rises for the Middle Eastern and South Asia.

All the explanatory variables except for technological progress are found to have significant impacts on per cpaita CO2 emissions.

Most countries of BRIC attempts to reduce poverty by expanding economic activities and raising GDP. At the beginning, BRIC economies just took off, starting from a raw and clean agrarian economy to a polluting industrial economy, and the rapid economy growth also has pushed all these four BRIC to reform their industry structure. After the turning point, per capita CO2 emissions decline through the improvement of production technology by throwing the old-fashioned machines away or by replacing the older process with new ones.

### 3.3 EKC Test on single country data set

The estimated results based on a single country panel data set is listed in Table 4 for the developed coutnries and Table 5 for the BRIC countries. Among the group of developed coutnries, the US and Uk perform in an inverted U-shaped pattern of CO2 emissions, tested by the Quadratic Model and Japan executes an inverted N-shaped, tested by the Cubic Model. In contrast, Table 5 demonstrates that China and India executes an inverted U-shaped pattern of CO2 emissions, tested by the Quadratic Model. All the four countries of the BRIC group perform an inverted N-shaped pattern of CO2 emissions tested by the Cubic Model. This results implies the economic growht in each country has an self-adjusting force to reduce CO2 emissions after it reaches to the turning point. In ocndieration of an individual economic development, it seems optimistic to cut off CO2 emission in each country since per capita CO2 emissions will decline except for Germany in the long run.

He and Richard (2010) use semi parametric and flexible nonlinear parametric modeling methods to investigate the existence of CO2 EKC by using the data from Canada and find little support in favor of the EKC hypothesis. The Spanish case presented by Roca and Alcantara (2001) find out that per capita CO2 emission almost increase directly as a function of per capita gdp, but CO2 emissions per unit of GDP is found to have a peak point at per capita gdp of USD780 (please see Fig. 2, Roca and Alcantara. 2001, p. 555). Friedl and Getzner (2003) find that an N-shaped relationship exists between GDP and CO2 emissions in Austria for the period

1960–1999. Narayan and Narayan (2010) find 35% of the sample countries (47 developing sountries) has an inverted U-sahped curve for CO2 emisisons including Jordan, Iraq, Kuwait, Yemen, Qatar, theUAE, Argentina, Mexico, Venezuela, Algeria, Kenya, Nigeria, Congo, Ghana, andSouthAfrica. This implies that CO2 emissions will decline in the long run for these countries.

Insert Table 4 about here

Considering the impacts of explanatory variables rather than per capita GDP, we find that (1) among the developed group, the energy structure (measured by the share of fossil fuels in total energy consumption) provides a significant impact on per capita CO2 emissions in most countries. As expected, an increase in the share of fossil fuel brings about an increase in per capita CO2 emissions in the US, Germany and UK except for Japan. The technological progress is found to have a significantly negative impact on per capita CO2 emissions in UK only while in other countries no evidence is found. This implies that the development of new innovations may reduce CO2 emission in UK. (2) Among the BRIC group, energy structure, industry structure, and technological progress impact per capita CO2 emissions significantly in most countries. The share of industry and service output in the total production yields significantly a negative impact on per capita CO2 emissions. The technological progress yields positive impacts in both China and Russia. Contrary to the UK case, the growth of technological progress may make per capita CO2 emissions increased. (3) No significant evidence is found to support the relaitonship between oil price and per capita CO2 emissions for the 8 countries selected based on the individual country data set. This result implies that the demand for fossil fuels is inelastic and thus the oil price does not affect the consumption of fossil fuels and eventually CO2 emissions.

Insert Table 5 about here

## 4. Discussions

We listed the x-y plot between per cpaita CO2 emissions and per capita GDP in Figure 1 for the selected 8 coutnries. In Figure 1, the average level of the developed group is much higher than the BRIC group. We cannot expect that the developing coutnries can reduce CO2 emisisons if they intend to maintain a economc poligy of continual growth. The BRIC countries are just beginning to leap upward and preparing to join the rich group and thus they should not be asked to reduce energy consumption and CO2 emissions at the victim of economic growth. Developed countries, in general, own higher level in production technology and green technology. The performance of developed coutnries in CO2 emissions mitigaiton is also suspected if the production technology enhancing CO2 mitigaiton cannot have a large advance in the near future. Hence, Figure 1 seems to demonstrates that the growth of per capita GDP does not absolutely lead to a reduction in per capita CO2 emissions in the long run from the global perpsective. On the contrary, the GDP growth may result in eventual growth in CO2 emissions and thus economic growth cannot work as an autonomous adjusting tool to solve the CO2 emission problems.

The X-Y plot for the developed group in Figure 2 demonstrates that per capita CO2 emisisons declines to a bottom point and then increases as per cpapita GDP increase. The high CO2 emisions from the US is the major causes to explain the U-shaped pattern of CO2 emissions. On the contrary, an EKC executed by the BRIC group in Figure 3 may attriubte to the low CO2 emissions from Brzail. Sicne the economic developemnt path of each coutnry is not identical and dificult to imitate as the natural resources in each country distinguish. And thus, the estimated results based on the pooled data or the group data cannot work to explain the future trend of CO2 emisions.

4.1 the factors to explain CO2 emissions

The major factor to reduce per capita CO2 emissions is due to successful shifting of industry structure from manufacturing industry to service industry, from high energy-consuming industries to low energy intensity industries, and from high carbon-intensity indsutry to low carbon-intensity industry for these selected countries. In Figure 2, it demonstrates that energy intensity reached to a peak in 1978 and 1979 in America.

This implies that the EKC may exist in USA and the peak may happened in 1978-1979, earlier than other countries. On the contrary, China has not reached to the peak. It means that China does not execute an EKC for energy consumption. The peak of the EKC for energy consumption occurred in 1994(?) in Taiwan. This also demonstrates the timing of the peak is proportionally to the economic development (measured in US$ on GDP). Traditonally, researchers attempt to induce an conclusion on the existence and location of the EKC peak, but never to have a consistent conclusion. Conventionaly studies concludes that the social factors affect the existence of EKC. It seems no empirical focus on the factors affecting the location of the EKC peak.

The second factor is the rapid growth of non-fossil fuels to replace fossil-fuels.

The existence of EKC phenomenon (an inverted U-shaped or N-shped curve) based on individual coutnry data sets can attribute to following factors including (1) production factor, (2) industry structure effect, (3) energy structure effect, and (4) technology progress effect.

(1) Energy structure effect: the positive sign of the coefficient for the explanatory variable of “share of fossil fuel energy consumption in the total energy use” demonstrates that higher dependence on fossil fuel energy emits more CO2. The consumption of fossil fuels is seen as a main source of carbon dioxide (CO2) emissions that acooutn for //% of warming effect in the past. Researhcers argues that every country should adopt a minimum percentage of energy from non-fossil sources, such as solar, wind, geothermal, and nuclear so that a sustainable development can maintain (Mackenzie, 2003). Table 1 provides a simple stastics that the developing countries use higher percentage of energy from fossil source than less developed countries.

The total carbon emissions due to fossil fuel use account for ton CO2 equivalents as described in Table 2. The comparison of carbon intensity among these 8 countries is depicted in Figure 1.

(2) technology progress effect: The significantly positive sign of technological progress for China and Russia in Table 5 implies that technological progress may drive the economic growth up but it is also accompanied with a rise in CO2 emissions. Technological progress is an important factor accounting for the growth of output.

(3) Table 4 demonstrates that technology provides a positive role in mitigating CO2 emissions in UK. When testing by the grouped data set, technological progress is significantly affect per capita CO2 emissions in the developed group, but not

found in the BRIC group. The negative sign of coefficient for developed countries based on the group data set implies that innovation on CO2 mitigation is successful. The opposite sign of technological progress for the two groups implies that technology diffusion is not effective between the developed group and the BRIC group even though the new process and these innovative technology adopted by developed countries may reduce CO2 emissions. The empirical study of Lantz and Feng (2006) conclude that technological changes are "supported over the commonly hypothesized environmental Kuznets curve (an inverted U-shaped relationship between GDP/capita and environmental degradation) for affecting CO2 emissions from fossil fuel use in Canada."

Industrial sectors are motivated to promote clean production through the innovation of product redesign and process innovation. The policy may play important role in affecting the CO2 emissions. The BRIC countries encourage in clean production by using cleaner energy, energy recovery technique, etc. Without the support of green technology from developed couturier, developing countries are extremely unlikely to join the effort on the scale and pace required. Technology transfer without charge to developing countries is required to move to a low-carbon growth path.

(4) oil price effect: The price of crude oil is not found to be correlated with CO2 emissions based on individual contry data sets, but it has signficantly negative impacts based on group data sets and the pooled data set.

The higher oil price may induce households to behave environmentally or adopt energy-saving apparatus, and motivate industries to switch to less energy consuming technologies. However, Russia is an exporter of oil and thus the variaiton of oil price seems not to affect its energy consumption and the consequent CO2 emissions. Structural effect and technical effect may reduce per capita CO2 emissions and thus the relevant policies should aim at promoting industrial reform to improve both energy structure and industry structure, and introducing advanced technology enhancing CO2 mitigation. In most developed countries, such as Japan, Germany, the US and UK, the growth of CO2 emissions is due to economic development and the falling can attribute to the technological progress. The success of economic development is more effective to result in the reduction in CO2 emissions than technological progress in China, India and Brazil.

Figure 1 describes the trends of value added by service industry and manufacturing industry in the two groups (the 8 countries). The share of value added contributed by service industry has reached a flat trend in the developed group while it keeps a growing trend in the BRIC group.

Since the share of fossil fuel in total energy consumption has a positive impact on per capita CO2 emissions in both the BRIC group and the developed group except for Japan, we suggest the adoption of non-fossil fuels (both renewable and nuclear energies) is important strategies to reduce per capita CO2 emissions. All these countries may re-consider energy policy to improve energy structure by using more renewable energy. Furthermore, inadequate energy infrastructure hampers the current energy production and distribution (energy supply) but also the energy consumption to support sustainable society. Thus, an adequate and clean energy infrastructure is required to meet the dual requirement of economic growth and environmental protection.

Energy policies possess the central and significant role to facilitate and foster sustainable development strategies by reforming energy structure and industry structure through a market-based mechanism. Since energy is central to the challenge of climate change mitigation, the targets should be feasible and theoretically helpful to solve the climate change problem. It also needs to reflect the extent to which climate change issues have been mainstreamed into its overall operations. We review all energy project documents released by the four countries between 2000 and 2008 available from its online database. Table 2 provides a summary comparison of the non-hydro renewable energy policies and incentives for the reduction of CO2 emissions among the selected 8 countries. All recognized interventions in the energy sector including the need to improve efficiency and reduce GHG emissions. In general, most countries adopted strategies in aiming at moving their economies onto low-carbon growth paths' through activities such as improving energy conversion efficiency in power plants, expanding the use of clean energy sources, saving consumption, reducing fugitive GHG emissions, such as methane released from landfills, and modernizing public transport systems. Funding or subsidy may advance their agenda by playing the catalyst role to the much needed financial infrastructure in order to reshape the current emission trajectories.

Of these strategies, In 2007, China provide the outline of its energy policy goals in the Proposed Energy Law. In these energy policy goals, it plan to launch a fuel tax through a pricing reform mechanism. While large dams were usually opposed because they displace people and inundate productive land, small scale hydropower plants are now operational in China. USA attempts to enhance efficiency and reduce dependence on fossil fuels by identifying specific mitigation targets of energy consumption and CO2 emissions to increase resilience to the likely impacts of climate change. To encourage the development of renewable energy, Japan established the basic rules of net metering, setting the buy-back price of electricity s in 1992 and 1993. Taiwan follows the idea and passed the similar laws to buy-back the electricity driven by renewable energy in 2009. In May 2002, Japan established a law to curb global warming through the incentives on the use of solar, wind, biomass, geothermal, and small hydro (less than 1,000 kW). This strategy allows power companies to produce power from new generation sources, to purchase power from others, or, to trade with other power companies via a renewable energy certificate trading system (please see IEE, Japan, 2004). Generally, strategies and plans for the reviewed countries do not consistently note vulnerabilities specifically related to the expected impacts of climate change.

## 5. Concluions

Based on the framework developed by Chen (2011), we dvelope a model to test the factor affecting CO2 emissions and confirm that the factor of 'energy structure' and "industry structure' have signficiant impacts on CO2 emissions in addition to production factors. Our main contricutions to this paper are (1) the governmental policies are the major factor to affect the final CO2 emisison as "energy structure" and "industry strucuture" that can be determined by govenrmental policies, significanlty affect CO2 emissions, (2) GDP is seen as one factor to affect CO2 emisisons in addition to the factor of "energy structure" and "industry strucutre", (3) the oil price is not so important to affect CO2 emisions in BRIC coutnries as developed coutnreis. We comapre models in which per capita emisison is funciton of GDP augmented by GDP-square and GDP-cybed type variables, and suggest that an multiple points curev (N-shaped curves or inverted N-shaped curves) is more suitable to explain the golbal CO2 emissions. Secondly, this paper contributes to the conclusion that the production effect (in terms of GDP) explain partly for the rising of CO2 emisions only. On the contrary, "energy structure" and "industry strucuture" provides a more important role in affecting CO2 emisions in the BRIC devleoping coutnries while "industry structure" is not found significantly to affect CO2 emisions in devloped coutnries. Thirdly, this paper concludes that oil price is not found to affect significanlty CO2 emisisons.

This paper emphasizes that the institutionsal change is reuqired to set up appropriate governmental policies that is sufficiently farsighted to solve the future impact of CO2 emissions.

The turning point of the inverted U-shaped curve generally occurs at the points around US$ 3000). These turning points in general happen at the earlier stage in developed groups, and are not included in the sample points. In other words, the observations in the early date have been excluded in the developed group. The time frame of observation may play a decisive role in affecting the existence of the EKC. After testing the N-shaped pattern on the developed group, we find that it is significantly exists. The N shaped pattern is seen as the composition of two parts: the EKC that contributed by the front half of the observation points and a growing trend of the rear observations.

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Table 1. descriptive stastics for the selected 8 countries in 2008

| countries | | Per capita GDP (US$) | Per capita CO2 emission* | Share of industry | Share of service | Share of fossil fuels | Patent applica. |
|---|---|---|---|---|---|---|---|
| developed | US | 38345.48 | 19.16431 | 21.29 | 76.2914 | 85.6665 | 221,784 |
| | Japan | 40238.14 | 9.54906 | 27.97 | 68.5172 | 81.2195 | 347,060 |
| | UK | 28871.16 | 9.10929 | 22.56 | 75.6987 | 88.6397 | 17,484 |
| | Germany | 25546.85 | 9.99235 | 29.64 | 69.5672 | 81.5582 | 48012 |
| Developed average | | 33250.41 | 11.95375 | 25.36 | 69.56 | 84.2709 | 158585 |
| BRIC | China | 2032.62 | 5.16335 | 47.45 | 39.9774 | 86.4772 | 122,318 |
| | Brazil | 4468.51 | 2.17241 | 27.91 | 65.7532 | 53.4321 | 3,810 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Russia | 3043.49 | 11.88308 | 35.91 | 56.6253 | 89.2706 | 27,884 |
| | India | 711.9 | 1.28296 | 28.22 | 52.3904 | 68.6795 | 5,314 |
| BRIC average | | 2564.13 | 5.12545 | 34.87 | 53.68658 | 74.4645 | 39,831 |

Source: World Bank, database (2011).

$^*$ Source: US Energy Informational Administration (EIA, 2011)

Table 2. Estimation results based on the pooled data set of the selected 8 countries.

| parameters | Quadratic Mod. (U-curve test) | | Cubic Mod. (N-curve test) | |
|---|---|---|---|---|
| | Full | Reduced | Full | Reduced |
| Per capita GDP | 0.000162$^{**}$<br>(8.22E-05) | 5.89E-05<br>(9.05E-05) | 0.000185$^{**}$<br>(8.17E-05) | 7.35E-05<br>(9.09E-05) |
| Per capita GDP squared | -1.8E-09<br>(1.4E-09) | -2E-10<br>(1.56E-09) | -2.9E-09$^{**}$<br>(1.45E-09) | -8.2E-10<br>(1.61E-09) |
| Per capita GDP cubed | | | 1.24E-14$^{**}$<br>(5.02E-15) | 8.55E-15<br>(6.08E-15) |
| Share of industry | 0.002974<br>(0.025913) | | 0.001662<br>(0.025599) | |
| Share of service | -0.03977$^{*}$<br>(0.021222) | | -0.03992$^{*}$<br>(0.02096) | |
| Share of fossil fuel | 0.086374$^{**}$<br>(0.01634) | | 0.083574$^{***}$<br>(0.016177) | |
| Oil price | -0.00575$^{**}$<br>(0.002673) | | -0.00563$^{**}$<br>(0.002641) | |
| Technology progress | 9.21E-06$^{***}$<br>(1.81E-06) | | 1.01E-05$^{***}$<br>(1.83E-06) | |
| R square | 0.383019 | 0.043205 | 0.401131 | 0.052209 |
| Adjusted R square | 0.35997 | 0.033842 | 0.375554 | 0.038288 |

Notes: standard errors in parentheses.

$^{***}$, $^{**}$, and $^{*}$ refer to stastical significance levels at 1%, 5% and 10 %, respectively.

Table 3. The estimated results based on group data set

| | Developed countries | | | | BRIC countries | | | |
|---|---|---|---|---|---|---|---|---|
| | U-curve | | N-curve | | U-curve | | N-curve | |
| | Full | Redu. | Full | Redu. | Full | Redu. | Full | Redu. |
| GDP | -0.00029$^{***}$<br>(0.000106) | -0.00035$^{***}$<br>(7.83E-05) | -0.00023$^{**}$<br>(0.000113) | -0.00034$^{***}$<br>(7.87E-05) | 0.002133$^{***}$<br>(0.000546) | 0.002269$^{**}$<br>(0.000286) | 0.003568$^{***}$<br>(0.001008) | 0.002033$^{***}$<br>(0.00053) |
| GDP | 7.82E-09$^{***}$ | 6.76E-09$^{***}$ | 5.88E-09$^{***}$ | 6.31E-09$^{***}$ | -5.8E-08 | -2.3E-07$^{**}$ | -7E-07$^{*}$ | -7.5E-08 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| squared | (1.7E-09) | (1.34E-09) | (2.13E-09) | (1.39E-09) | (1.09E-07) | (6.79E-08) | (3.96E-07) | (2.97E-07) |
| GDP cubed | | | 8.11E-15 | 5.63E-15 | | | 8.15E-11* | -2.3E-11 |
| | | | (5.43E-15) | (4.66E-15) | | | (4.83E-11) | (4.39E-11) |
| industry | 0.265757* | | 0.414327** | | -0.0642** | | -0.09874*** | |
| | (0.134992) | | (0.167054) | | (0.02953) | | (0.035709) | |
| service | 0.199667 | | 0.348573** | | -0.10269*** | | -0.13008*** | |
| | (0.127348) | | (0.161156) | | (0.021027) | | (0.026411) | |
| fossil fuel | 0.082732** | | 0.087157** | | 0.079134*** | | 0.079407*** | |
| | (0.033314) | | (0.033239) | | (0.014252) | | (0.014122) | |
| Oil price | -0.02184*** | | -0.01857*** | | -0.01616*** | | -0.0156*** | |
| | (0.00377) | | (0.004341) | | (0.003789) | | (0.003769) | |
| Tech. | -4E-06* | | -2.3E-06 | | 4.58E-06 | | 3.74E-06 | |
| | (2.25E-06) | | (2.51E-06) | | (2.97E-06) | | (2.99E-06) | |

Notes: standard errors in parentheses.

***, **, and * refer to stastical significance levels at 1%, 5% and 10 %, respectively.

Table 4. The estimated results for the developed countries based on individual country data set

| | Developed countries | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | The US | | Japan | | Germany | | UK | |
| | U-test | N-test | U-test | N-test | U-test | N-test | U-test | N-test |
| GDP | 0.002074** | 0.000585 | 0.000171 | -0.00606*** | 0.000874 | 0.018623 | 0.00092** | 0.000545 |
| | (0.000869) | (0.003815) | (0.000582) | (0.001293) | (0.001906) | (0.01987) | (0.000389) | (0.001669) |
| GDP squared | -3.2E-08** | 1.86E-08 | 1.18E-09 | 1.97E-07*** | -1.4E-08 | -6E-07 | -2.2E-08** | -2.5E-09 |
| | (1.52E-08) | (1.26E-07) | (9.58E-09) | (3.92E-08) | (3.17E-08) | (6.51E-07) | (9.29E-09) | (8.34E-08) |
| GDP cubed | | -5.6E-13 | | -2E-12*** | | 6.38E-12 | | -3.1E-13 |
| | | (1.39E-12) | | (4.01E-13) | | (7.11E-12) | | (1.36E-12) |
| industry | -0.21557 | -0.12729 | -0.13473 | -0.04878 | -0.20864 | -0.10563 | -0.1345 | -0.12568 |
| | (0.593842) | (0.644728) | (0.380628) | (0.258946) | (0.29669) | (0.320849) | (0.245683) | (0.254297) |
| service | -0.38992 | -0.32389 | -0.1125 | -0.05895 | -0.28896 | -0.19569 | -0.09057 | -0.08031 |
| | (0.572574) | (0.607073) | (0.368913) | (0.250658) | (0.291406) | (0.312092) | (0.252883) | (0.262561) |
| fossil fuel | 0.348639* | 0.311729 | 0.034395 | 0.004713 | 0.332416 | 0.34081** | 0.214632*** | 0.227951** |
| | (0.198862) | (0.222813) | (0.043102) | (0.02984) | (0.148642) | (0.1504) | (0.073066) | (0.0944) |
| Oil price | -0.00363 | -0.00152 | -0.02039 | -0.00499 | 0.011737 | 0.011005 | -0.00217 | -0.00182 |
| | (0.013573) | (0.014814) | (0.012929) | (0.00929) | (0.006689) | (0.006804) | (0.008511) | (0.00884) |
| Tech. | 1.24E-05 | 1.22E-05 | -6.7E-06 | -4.5E-06 | -2.2E-05 | -2.8E-05 | -9.9E-05** | -0.00011 |
| | (1.26E-05) | (1.29E-05) | (4.1E-06) | (2.82E-06) | (3.12E-05) | (3.23E-05) | (4.42E-05) | (6.78E-05) |

Notes: standard errors in parentheses.

$^{***}$, $^{**}$, and $^{*}$ refer to stastical significance levels at 1%, 5% and 10 %, respectively.

Table 5. The estimated results for the BRIC countries based on individual country data set

| | Developed countries | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | China | | India | | Russia | | Brazil | |
| | U-test | N-test | U-test | N-test | U-test | N-test | U-test | N-test |
| GDP | 0.002314$^{**}$<br>(0.000884) | -0.00278$^{*}$<br>(0.001356) | 0.003249$^{***}$<br>(0.000573) | -0.00323<br>(0.003064) | 0.005483$^{*}$<br>(0.002954) | -0.05404$^{**}$<br>(0.018649) | 0.001033<br>(0.000759) | -0.01987$^{**}$<br>(0.007312) |
| GDP squared | -1.8E-06$^{***}$<br>(5.89E-07) | 2.23E-06$^{**}$<br>(1.04E-06) | -2.4E-06$^{***}$<br>(4.1E-07) | 1.05E-05$^{*}$<br>(6.05E-06) | -7.8E-07<br>(7.16E-07) | 2.66E-05$^{*}$<br>(8.54E-06) | -9.6E-08<br>(1.06E-07) | 5.54E-06$^{**}$<br>(1.96E-06) |
| GDP cubed | | -7.5E-10$^{***}$<br>(1.76E-10) | | -8.2E-09$^{**}$<br>(3.84E-09) | | -4.1E-09$^{***}$<br>(1.28E-09) | | -5E-10$^{***}$<br>(1.74E-10) |
| industry | -0.02381<br>(0.018915) | 0.009239<br>(0.015975) | -0.00972$^{**}$<br>(0.003745) | -0.01085$^{***}$<br>(0.003499) | -0.01298<br>(0.098906) | -0.09654<br>(0.07726) | -0.01888$^{*}$<br>(0.010657) | -0.01678$^{*}$<br>(0.009219) |
| service | -0.05413$^{***}$<br>(0.017318) | -0.00917<br>(0.016555) | -0.00496$^{**}$<br>(0.0023) | -0.00798$^{***}$<br>(0.002548) | -0.12421<br>(0.085522) | -0.17035$^{**}$<br>(0.064527) | -0.00664<br>(0.008555) | -0.00519<br>(0.007395) |
| fossil fuel | 0.118353$^{***}$<br>(0.023156) | 0.172424$^{***}$<br>(0.021272) | 0.015146$^{***}$<br>(0.00242) | 0.023714$^{***}$<br>(0.004577) | 0.564522$^{***}$<br>(0.164472) | 0.749648$^{***}$<br>(0.133998) | 0.023042$^{***}$<br>(0.004809) | 0.024841$^{***}$<br>(0.004195) |
| Oil price | -0.00601<br>(0.004692) | -0.00145<br>(0.00363) | 0.000267<br>(0.000388) | 0.000337<br>(0.00036) | -0.01703<br>(0.016022) | -0.00461<br>(0.012403) | -0.0007<br>(0.001153) | -0.00075<br>(0.000995) |
| Tech. | 3E-05$^{***}$<br>(7.69E-06) | 1.35E-05$^{*}$<br>(6.87E-06) | 1.97E-05<br>(1.28E-05) | -3.8E-06<br>(1.61E-05) | 6.16E-05$^{***}$<br>(1.73E-05) | 9.06E-05$^{***}$<br>(1.56E-05) | 2.58E-05<br>(2.31E-05) | -2.3E-05<br>(2.62E-05) |

Notes: standard errors in parentheses.

$^{***}$, $^{**}$, and $^{*}$ refer to stastical significance levels at 1%, 5% and 10 %, respectively.

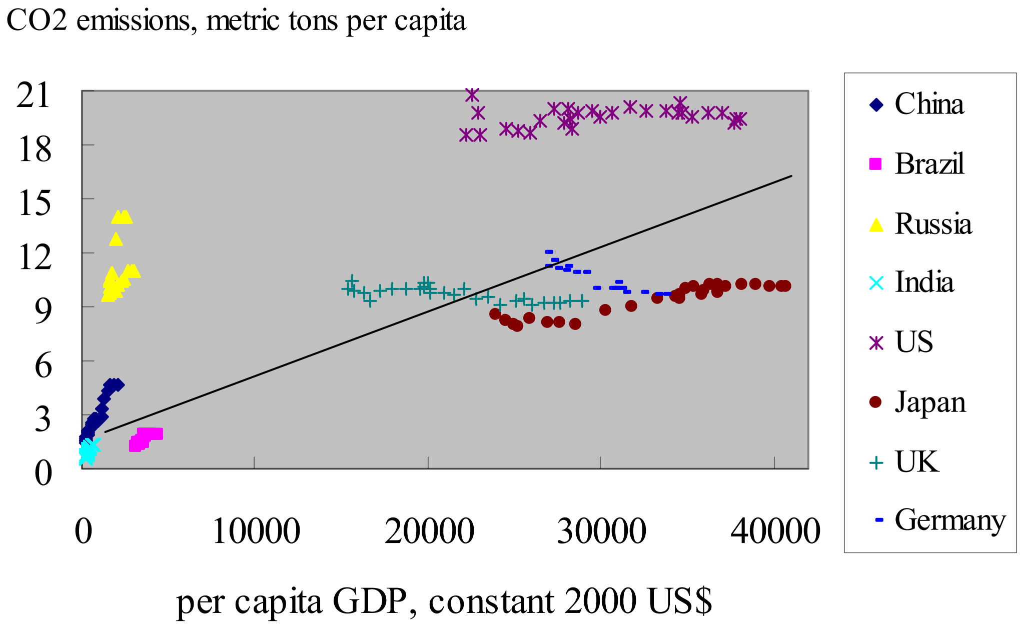

Figure 1. Relationship between per capita CO2 emissions and per capita GDP for the selected 8 countries

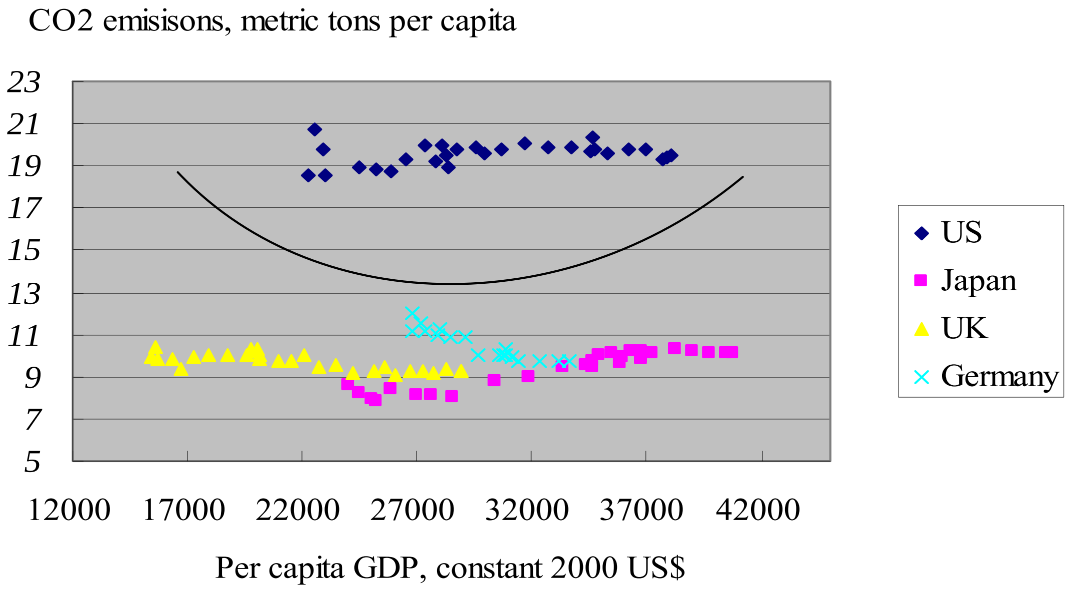

Figure 1. Relationship between per capita CO2 emissions and per capita GDP for the developed group

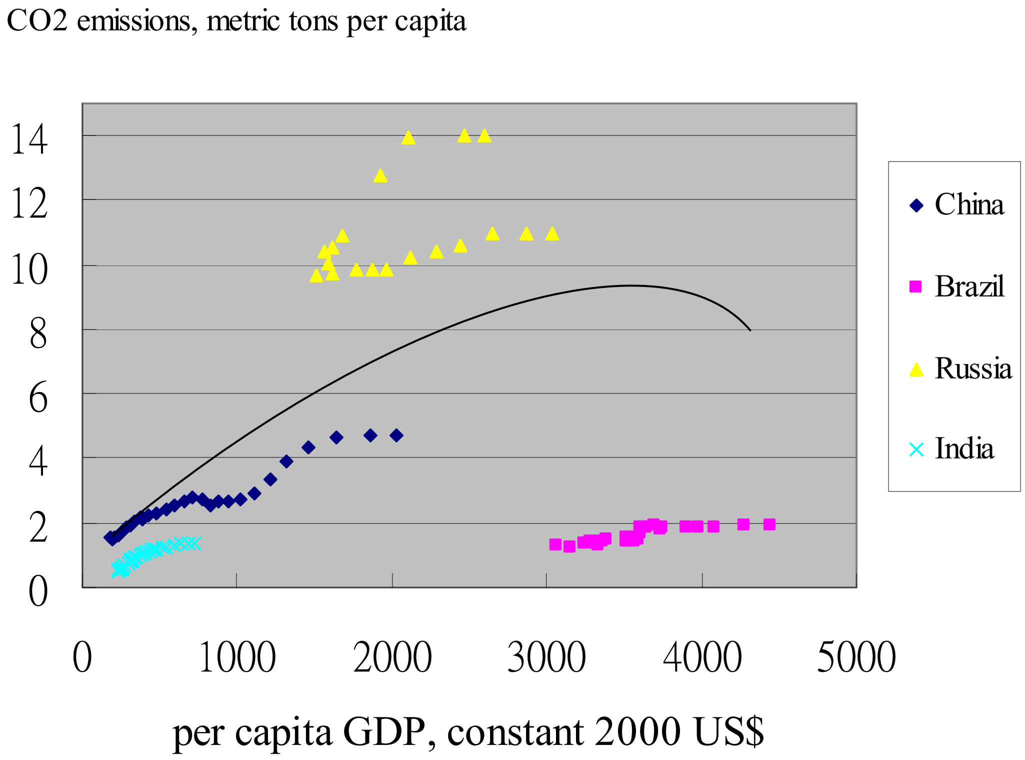

Figure 3. Relaationship between per capita CO2 emissions and per capita GDP for the BRIC countries

附件四：

# The variation of environmental governance across countries and its effect on energy policies

## Abstract

The shifting of environmental governance may affect the energy policy formulation and implementation. In this paper, we select three countries including China, Taiwan and the U.S. as the sample cases to represent the non-democratic country, transition-to-democracy country, and fully democratic country respectively for the analysis of their environmental governance shifting and the environmental governance's effect on energy policies. This paper compares the energy policies enacted these countries and examines the effectiveness of policy implementation. The results provide some insightful issues related to the challenge of environmental governance and discuss the role of environmental governance in affecting the formulation and implementation of energy policies.

Keywords: environmental governance, environmental groups, energy policies, energy intensity, energy demand, democracy

## 1. Introduction

Economic development is still the major focus and concern in formulating energy policies in most countries. Environmental issues have, however, become a substantial material stake in a discursive platform for solving environmental problems in a modern society. In other words, environmental governance has become a subject of much debate and controversy in developing countries or transited-to-democracy countries while it is more or less consistent and unanimous in developed countries or democratic countries. Environmental governance has shifted to a more participatory system involving collective decisions by integrating with stakeholders in a modern society and thus the governing power should be shared among different interest NGOs, such as labor unions, capitalists, environmentalist institutions, etc. (Sampford, 2002; Maddock, 2004). On the contrary, the government in a low democratic country may doubt about the value of public participation and information transparency in relation to economic growth and developmental priorities. Very few have discussed about the policy making in linking with environmental governance although some researchers have focused on the structure of environmental governance. An investigation of environmental policy making is likely to be able to shed some light on the promise (national policy targets) developed by the administrative sectors in the governments.

In this paper, we intend to examine the variation of environmental governance across countries and analyze its impact on energy policy formulation and implementation. A particular set of questions are raised in this paper including: (1) does the efficiency of energy policy implementation differ in the countries? (2) Is the efficiency affected by the environmental institution? (3) Is the formulation process of energy policies different in the countries with different degree of democratization? In this paper, we select three countries: China, Taiwan and US as sample cases to represent the non-democratic country, transition-to-democracy country, and fully democratic country respectively for the analysis of their environmental governance shifting and the impact of environmental governance on energy policies. Furthermore, this paper also intends to investigate the energy and power consumption of the selected three countries in the past and examine the performance of the energy policy implemented.

2. The basic description of the three selected countries

The world population grew very rapidly in the past century so that the environment seemed to be incapable of tolerating the accompanied impacts arising from human activities. In 2007, the population reached to 1,321.85 millions in China, 301.14 millions in the U.S., and 22.86, millions in Taiwan (please see Table 1). The U.S. is still the leading country in economic development with the highest amount of GDP US$ 12,768 million in 2006, almost double folds of China. However, China's real gross domestic product (GDP) is estimated to have grown at about 8-9 percent in 2010 even though it was attached by the recent global financial crisis occurred in late 2008. The economic growth was on an average about 10 percent during 2000 to 2009.

Insert Table 1 about here

The three selected countries differ in energy resource endowments, political systems, and economic development. China and the U.S. are large energy consumers (please see Table 1), but they are also large energy producers. However, more than 91% of energy consumption was provided from domestic source in China in 2007 while 70.76% in US and 12.44 % in Taiwan only were supplied by indigenous sources (please see Table 2). China has a relative abundance of coal resources and thus coal supply accounted for more than 70% of the total energy production. Although China depends less on import energy than other countries, China has become a net importer of oil and natural gas now due to insufficient indigenous energy sources. In order to support the rapid economic growth, the oil consumption will continue to grow in the future, the oil demand will reach an estimated 8.2 million bbl/d in 2010 (EIA, 2010). Taiwan is lacking of natural resources, and more than 87% of primary energy is imported. In 2006, US consumed 99.86 quadrillion Btu of primary energy, followed by China that consumed 73.81 quadrillion Btu (please see Table 1). Among the energy supply, fossil fuels constituted the major portion for all the three countries. In China, renewable energy, including hydroelectric power, wind power, biofuels and other renewable account for less than 8% of total primary energy consumption in 2006. China is also the second-largest oil consumer in the world behind the United States consuming about 7.8 million barrels per day (bbl/d) of oil in 2008 (EIA, 2010).

Insert Table 2 about here

China emitted 6,017 million tons of CO2 in 2006, started to exceed the U.S. and became the largest CO2 emitter in the world (Please see Table 1) while America emitted 5,902 million tons in the same period. Before 2005, the U.S. was the leading country in CO2 emission. Taiwan's annual CO2 emissions were estimated to be 300.38 million tons in 2006, much smaller than the U.S. and China. The U.S. ranked the highest for per capita CO2 emissions among the three countries. In 2006, each American emitted as much CO2 as 4.36 Chinese and 1.44 Taiwanese.

As the consumption of fossil fuel-driven energy emits a large amount of CO2 and leads to the high environmental impacts arising from warming effects, many countries suggest that renewable energy should be adopted as an effective substitute of conventional energy to solve the warming effect problem. In 2008, China ranked the highest to generate renewable electricity of 537.91 billion kilowatthours (BKWH), followed by US that generated 382 BKWH. The energy policies or the climate change policies reflect governmental attempts and supports to achieve sustainable development in each country.

3. The energy policy formulation and implementation

The problem of climate change[4] has emerged as one of the most urgent environmental issues in the world since the end of last century. Widespread concern on the consequently ill effect of green house gases emissions brought about the Rio Earth Summit that was held in Brazil in 1992 and attended by 154 countries. A concluding remark was signed, called “Framework Convention on Climate Change, FCCC”. In 1997, the Conference of the Parties (COP-3) serving as the executive board of FCCC presented a scenario panel and signed the Kyoto Protocol that asked the developed countries (Annex I) to cut down the greenhouse gases averagely 5.2 % in 2008-2012 compared to 1990 level. In 2005, Kyoto protocol was in effect to respond to the growing calls for more efforts to reduce the continuous deterioration of the environment.

In order to response to the serious problem of warming effects, the three countries have reformed their energy policies continually in the past few years (please see Table 3).

Insert Table 3 about here

In China, the National Development and Reform Commission (NDRC) is the key policy maker involving the energy sector in China, together with the cooperation of the National Energy Administration (NEA) that is responsible for the approval of new energy projects in China, the setting of domestic wholesale energy prices, and implementation of energy policies. In November 2004, NDRC issued the energy-saving strategy for mid-and long-term to safeguard the achievement of an energy-efficient society. In 2005, China launched a law to promote renewable energy production (hydro, wind, biomass and solar) that was seen as a major plan in an attempt to reduce fossil fuel reliance. The goal of the law is to integrate the short-term energy needs with the long-term sustainable development objectives. Its targets at least include (1) the increase in the share of renewable energy production from the current level of one per cent to ten per cent, (2) the reduction in the share of coal consumption to 60%, (3) to install renewable electricity capacity over 100 gigawatts (GW) (about 30% of total generation capacity) and (4) to increase the installed capacity of small hydro-power plants from the current 31,000 megawatts to 70,000-80,000 megawatts by 2020 (NREL, 2010). In order to encourage the industrial groups and the public to promote and utilize renewable energy, incentive policies are incorporated into the law through the introduction of market economy for energy production.

As Taiwan is insufficient in natural resources and almost relies on import energy, the improvement in energy efficiency and the development of clean energy are considered necessary to support the sustainable development. And thus, the targets to promote the development of clean energy should be feasible and carefully

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[4] The major cause for climate change and greenhouse effect is due to the over emission of $CO_2$.

reviewed. According to Framework of Taiwan's Sustainable Energy Policy, the targets include (1) the share of renewable electricity in electricity generation system reached to 8% by 2025, (2) the share of electricity fueled by natural gas reached to 25% of total power generation by 2025, and (3) carbon intensity is reduced more than 30% by 2025 (Bureau of Energy, 2010).

Until now, the U.S. has not yet signed on the Kyoto Protocol. However, the U.S. has enforced the energy policy by providing incentives for energy saving to improve energy utilization efficiency in response to the aggravating warming effect by encouraging the growth of renewable energy since 1978. In addition, the U.S. also enacted other measures such as regulatory measures and research and development (R&D) programs to promote the development of renewable energy production. In 1978, US passed the National Energy Act of 1978 (NEA) together with the Public Utility Regulatory Policy Act (PURPA) and Energy Tax Act (ETA), aiming at improving energy conservation and energy efficiency. The introduction of the PURPA in 1978 regulated utilities to purchase power from qualifying third parties.

Basically, the U.S. opposed to set a uniform renewable energy target for all the states. It preferred to allow each state to decide the targets for each state (Fuller, 2002). And thus, the renewable energy of some states employed the renewable portfolio standards (RPS) by requiring utilities to generate or purchase minimum levels of renewable energy, and some other states adopted public benefits funds (PBF) that served as part of state electricity restructuring.

The U.S. federal policies still stuck to the spirit of incentive mechanism. The renewable energy policies adopted by the federal included a favorable production tax credit (PTC) for wind and other renewable resources. The ETA provided a 30-percent investment tax credit for residential consumers for solar and wind energy equipment and a 10-percent investment tax credit for business consumers for the installation of solar, wind, geothermal, and ocean thermal technologies. Although the ETA was expired in 1985, the basic idealism has been transcended to the Energy Policy Act (EPACT) in 1992 to promote renewable energy by providing tax credits for ethanol fuels for vehicles. The incentive programs (policies) was renewed or extended before their expiration.

## 4. The evaluation on the attainment of renewable energy among the three countries

Up to 2007, China had installed electricity generating capacity of 714 GW by all fuels (please see Table 4). As with other countries, China became interested in the development of hydro power generation for the substitution of fossil fuels. Hydropower supply was the major part of electricity source in China, accounting for 20% of total electric generating capacity in 2007. The hydropower generation in Taiwan and US was much less, accounting for 9.8% of total power generation in Taiwan, and 9.2% in US respectively for the same period (please see Table 4).

In China, the installed capacity of hydro power increased 2.45 folds in 10 years from 59.73 GW in 1997 to 145.26 GW in 2007, while the U.S. had a slight increase from 98.83 to 99.77 GW for the same period. No other countries have installed such a large percentage of hydro power into its electric grid as China. In contrast, the wind power capacity is expected to increase to 20 GW from 0.56 GW in China while biomass will increase to 20 GW from the current 2.0 GW by 2020 (EIA, 2010, Energy and Power in China). Compared to its targets that attempted to install renewable electricity capacity over 100 GW by 2020, it seems optimistic to attain the goal for China.

Insert Table 4 about here

On the contrary, Taiwan seems too optimistic to attain its target that the share of renewable electricity generation to reach to 8% by 2025. Taiwan's renewable electricity generation (please see Table 5) totaled to 16,293 GWH in 2007, increasing from 9,667 GWH in 1997. However, the share of renewable electricity generation was falling from 7.24% of total power generation (133,447 GWH) in 1997 to 6.7% of total power generation (243,120 GWH) in 2007. The hydro power in practice contributed to a major role in supplying renewable energy in Taiwan. The hydro power generation drop from 9,567 GWH in 1997 to 8,360 GWH in 2007 (please see Table 5). The share of hydro power generation dropped from 6.36% in 1997 to 3.43% in 2007, and then further declined in 2008 and 2009. The installed capacity of hydro power, however, slightly increased from 4.29 gigawatts in 1997 to 4.52 gigawatts in 2007. It should be noted that the actual hydro power generation keeps a trend of continual drop even though the installed capacity increases.

Insert Table 5 about here

Furthermore, it also seems very impractical to expand the hydro power capacity in Taiwan because of the exhaustion of water resource and the environmental consideration of potential impacts. All the hydro power potential has almost been fully developed and thus it is difficult to discover new hydro resources for power generation. The reliance on non-hydro power generation seems to be the only way to attain the target of 8% power generation from renewable energy by 2025.

The growth of non-hydro renewable electricity is also not optimistic for Taiwan's energy policies. The share of non-hydro renewable power generation was 0.51% in 1997, 1.66% in 2007, 1.69 % in 2008, and 1.83% in 2009 respectively in Taiwan (please see Table 5). Of the non-hydro renewable power generation, waste heat recovery from the MSW incineration plants contributed the major role; rising from 0.33% in 1997 to 1.23% in 2007 and 1.27% in 2009 (please see Table 5). The conversion of waste to energy may be financially viable since MSW has high calorific value and contain low moisture content. In 2008, about 4,137,284 ton of municipal solid wastes is treated by incineration process with energy recovery in Taiwan, accounting for 94.58% of 4,374,154 ton of total MSW for final disposal (please see Table 4.1 in Yearbook of Environmental Protection Statistics 2009, Taiwan EPA, 2009). And thus, the growth of renewable electricity generation from waste heat recovery is not possible in the future as almost all the currently operating solid waste incineration plants have been equipped with heat recovery system.

Under such a circumstance, the expansion of wind power plants becomes a more feasible solution to bridge the gap between the target and the performance of power generation in Taiwan. Wind energy is an importantly reliable and cost effective energy source due to the continuous technology improvement over the past few years. It has been verified to own a competitive position with conventional power generation technologies. Wind power generation increased from 443.5 GWH in 2007, accounting for 0.18 % of total power generation, to 786.6 GWH (0.34% of total power generation) in 2009. The growth rate is very high, about 77% in three years, but the share of wind power is still very low compared to other fuel type.

In 2003, the U.S. generated about 349 BKWH[5] of renewable electricity,

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[5] One BKWH is equivalent to $10^3$ GWH.

accounting for about 9% of 3,883 BKWH total power generation. Of the renewable electricity generation, hydro power generation contributed to about 7/9 and the remaining 2/9 from other renewable fuels including biomass, geothermal, wind, and solar thermal and photovoltaics. In 2008, the U.S. generated 382 BKWH of renewable electricity. The annually growth rate was 1.89% only. This result demonstrates that a big room is still open for the U.S. to improve its incentive system.

5. environmental governance’s impacts on the attainment of renewable energy policy targets

Comparing the actual outcomes involving energy consumption and renewable electricity generation in 2007-2009 with the energy targets listed in Table 3, we conclude that China has better efficiency in its energy policy formulation and implementation while Taiwan seems to fail in attaining its energy targets. The U.S. federal energy policy is consistent over time, based on the incentive mechanism to reduce its energy consumption and promote renewable energy even though the U.S. federal government did not any target to complete, but it allowed each state (local governments) to determine. Both China and Taiwan adopt the method of command and control (CAC) as a tool to implement the energy policy while US adopted economic instruments.

In China, the economic system partly follows the market mechanism but politics is implemented in a non-democratic pattern. And thus, China governments has the right to stop the production of those which have bad environmental performance or low energy efficiency and may take compulsory measures to those that refuses termination of production. For example, NDRC has issued some guidance to expedite the structural adjustment of energy-consuming industries. Furthermore, the state-owned firms contribute to a large portion of GDP in China. The energy industry is almost dominated by three state-owned holding companies: the China National Petroleum Corporation (CNPC); the China Petroleum and Chemical Corporation (Sinopec); and the China National Offshore Oil Corporation (CNOOC). And thus, the implementation of legislated policies face little challenge from the industry. These factors may explain Chna’s high efficiency to attain the energy policy targets presented by China governments.

On the contrary, Taiwan’s targets seem difficult to attain. The price of renewable energy is stll higher than other energy sources on the market and becomes the major barrier for industrial consumers to adopt as most firms seek for the maximization of profit. In the meantime, Taiwan has transited its politics to a way of the democratic system and the need for civic participation in the policy making process in association with environmental issues has increased. In the path of transition to democracy in the past, environmental conflicts flared up sharply. Under such a circumstance, many big projects were delayed or hindered. These factors may play the major role in blocking Taiwan to attain its energy targets.

Through the preliminary analysis, we suggest that the major factor affecting the energy policy formulation and implementation can attribute to the shifting of environmental governance. In fact, the environmental governance has become a debating issue in Taiwan and gradually shifted from government sectors to all the stakeholders (including environmental NGOs). And thus the role of stakeholders becomes more and more important in the formulation process of energy policies in democratic countries. We compare the major elements of environmental governance in Table 6 among the selected three countries.

Insert Table 6 about here

5.1 Environmental Institution

From traditional institution, environmental governing power is completely controlled by policy makers who participate in policy formulation/adoption by using their political advantageous position with an endowed legal power of authority to respond to stakeholders. Policy makers also determine to express their political idealism with their expertise, vitality, and leadership skills to lobby legislators (Meier and McFarland, 1992). China is a typical one to implement the traditional environmental governance, relying on its agencies and institutions to specify the mechanics of actions and acting as the ruling body to set national objectives, to make strategic decisions without consulting with its people. China's ruling party owns the absolute power and may take unilateral action to formulate its energy policies. An order (a policy) can be formulated without public participation in response to environmental problems. The policy initiation or decision making is almost determined by the government only. The function/operation of the state policies and judiciary are also governed by state legislation that is fully controlled by administrative authorities who never look after the public's responses and pay no heed to the achievement of any agenda's attention.[6] In this pattern of environmental governance, interest groups can only use bribery to affect policy formulation.

In a democratic society, the environmental governing power shifts from the traditional legal authority owned by the governmental sectors to stakeholders' expert power arising from the trust and share value in society that relate to the public. The level of trust and of shared values may drive stakeholders to participate in solving environmental problems and enhance people to build a sense of citizenship in order to fulfill obligations and to protect rights. When there is uncertainty on the outcome of policy making, people will worry about the policy outcomes determined by the government to affect their interests.

Taiwan has transited to a democratic system since the end of 20 century. At present, political debating plays a significant role in hindering policymaking and exacerbates the situation. Taiwan's politics is almost dominated by two political parties (Kuomintang Party and Democratic Progress Party) who owns completely opposite perspective towards the two-strait policy (the relationship between Taiwan and China). And thus, the policy formulation process is performed in a noncooperative manner. Coordination is in general required in the policy formulation process and eventually the finalized policy is an outcome of compromise, and is not an optimal one among the options.

Furthermore, the change-over of presidency (the shifting of ruling power) in Taiwan has also resulted in a complete change in energy policy directions or even an opposite policy direction. For example, Democratic Progress Party (DPP) won the election of presidency in 2000. No sooner than his inauguration, President Chen decided to stop this ongoing construction project of Nuclear Power Plant IV on October 27, 2000. The halted project of Nuclear Power Plant IV was re-constructed in 2008 when Kuomintang (the National Democratic Party) recovered the presidency and regained the political power. Kuomintang argues that it is necessary to reconsider the power supply by nuclear generation to support Taiwan economy and reduce CO 2

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[6] Although the decisions of policymaking are affected by the forces of public opinion and political culture, the actions adopted by policy makers are mainly determined by political structuring within the governmental sectors.

emissions. The halting of the project was estimated to have lost several billion NT dollars until now. This example implies that Taiwan is lacking of legal system to balance the political influence and thus a regulatory institution seems necessary to prevent the attack of political pressure and to attract the foreign investment in clean technology production by increasing their confidence in a nation’s governance. Furthermore, Taiwan is confined by its relatively small scaled economy and cannot have a structural design for energy demand forecasting, and thus the targets seems to be too politically concerned to fulfill.

The democratic system has been fully developed in US and thus the bottom-up formulation process is completely followed. Policy initiatives are generally presented at the local level that deals with the ecological chaos. The local government as well as its residents cares more about their homelands and prefers to develop a more sustainable communities, life and work styles. As the leading country in the democratic countries, the U.S. has built up its participative capacities involving policy making. Its political system is equipped with a well-defined legal system that empower to the lower level government or community groups for avoiding the conflicts with sub-level governments. Policy development and implementation, in general, belong to political processes mediated through stakeholders (interest-nested parties and environmental groups) in the country.

### 5.2 environmental norms and values

A democratic country allows the public to review the procedures and develop the working process to ensure whether the objective gap is reduced. Vantanen and Marttunen (2005) emphasize that public participation in policy formulation in altering environmental projects is a coming trend. Adomokai and Sheate (2004) present a case study to highlight the development in community and stakeholders’ participation in the process of environmental decision-making and find some practical problems ranging from financial support, methods used and the willingness of identified stakeholders to participate. Malone (1997) argues that the public have the right to participate in the environmental assessment on a project even though the public participation may increase the complexity of decision making process and delay the approval of the project. In a modern and democratic society, civil rights are taken into account, and thus nongovernmental organizations, environmental groups, the private sector and civil society, individually or collectively, may participate in policy making and contribute to the development of environmental governance.

In general, the institution performed in China follows a unilateral communication or top-down process. It is difficult for citizens or stakeholders to access the relevant information and thus true facts are not believed. China citizens do not know that their governments are pushing forward and seeking to make progress on environmental accountability. Due to lacking of environmental transparency, China governments have not received the general trust from the people. We suggest that its environmental institution should be reformed to close the gaps in trust through the cultivation of democratic systems. China governments, however, gradually recognizes the importance of stakeholders’ participation in public issue while China citizens seem to perceive more and more of the democracy concept. The rapid economic growth in China has also changed people needs and made progress in environmental information transparency. In China some major cities have begun to make systematic disclosure of violations by corporations and demonstrated good initial performance in the disclosure of information on the handling of petitions and complaint cases.

Among the stakeholders, environmental NGOs, serving as the forefront to strengthen civil society and to educate the people to behave environmentally, is believed to be able to improve transparency, rule of law, and official accountability within the political system. The participation of environmental NGOs that advocate policies and influence policy formulation and implementation reflects power distribution and shifting from the authoritative government to the experts in the public. Environmental NGOs are seen as a positive force to fill a critical gap to bridge up the state's capacity for the objective of environmental conservation and protection.

In China, many environmental NGOs, in cooperating with foreign-based NGOs like universities or environmental NGOs to develop their environmental programs, have officially registered and most of them focus on environmental education and biodiversity protection. Most of the environmental NGOs are supported by the government agency (State Environmental Protection Administration, SEPA) and received the financial funds from the government. The environmental group leaders or activists have more or less received internationally environmental awards. Some small-scaled and locally-based NGOs attempt to address local concerns of environmental issues. These environmental NGOs, however, cannot demonstrate on the street to express their opposition to the construction of public facilities due to political limitation. The government still continues to keep a strict control over NGOs through a range of regulations and restrictions.

The scales of Taiwan's environmental NGOs are too small to present any long-term planning to achieve conservation goals. Financial support from the public or the government is weak and insufficient to keep up a long-term plan. Without constant support from the public, NGOs cannot develop appropriate programs to maintain a consistent direction toward their objectives. And thus, most of Taiwan's environmental NGOs basically involve a routine work of environmental education to improve environmental consciousness while few actively participate in a debating environmental issue.

The United States National Environmental Policy Act (NEPA) was enacted in 1969. It has provided a new perspective about the playing role of environmental NGOs towards environmental assessment around the world (Rickson et al., 1990; Momtaz, 2005). NGOs are supported by the public in US and thus they are large enough in size and gain the financial subsidies from the public. Enviornemtnl NGOs more or less participate in the policy formulation and policy context for public issues. However, NGOs must compete because "NGOs compete for access to formal institutions of decision making such as government and compete for the attention of key policy makers in the hope of producing outcomes that favor their interests." (Buchholz, 1998, p. 95). The environmental NGOs have developed sophisticated strategies to affect law making and policy directions to gain competitive position in the process of affecting policy making.

## 6. Conclusions

This study compares the energy policy making and environmental governance among the three countries representing three respectively political systems. The energy policy involves the future prospect of economic growth and sustainability, even in association with the international image. It is the outcome mediated among the potentially conflicting economic and environmental interest groups. The conflict among stakeholders may become severe and incur environmental degradation and undermine livelihoods if it is not focused and solved. In practice, each interest group attempts to pursue its own interests by competiting for the scarce resource in the society. Without an appropriate system, the conflict may become disasters, threaten the structure of the whole society and uproot our communities (Castro and Nielsen, 2001).

Theoretical a democratically political system can promote administrative and political decentralization by allowing the public to participate in policy making, especially involving environmental issues, and solve the potential conflicts through the improvement of governance structure and the value shaping in the society. In contrast, an authoritarian country may have higher efficiency in policy making and implementation, but the effectiveness in environmental equity may be scarified due to lacking of public participation. This paper highlights the importance of environmental governance on policy formulation process and implementation and its impacts on policy performance. The results provides some important political and policy implications about the role of stakeholders in the formulation process and implementation of energy policies.

One suggestion is that democratic system creates a more space for citizens or environmental groups to breathe more fresh air and results in more innovative concepts on the conservation of the environment even though a non-democratic system may be more efficient in responding to the calls of global issues. The other suggestion is that a transition-to-democracy country like Taiwan requires the strong support of legal regulations on the conflict solving among the stakeholders. Democratization is beneficial to reduce the internal conflicts but a legal regulation on the solving of conflicts should be augmented. Under a robustly legal system, the energy policy making can gain the benefits of both democracy ruling and efficiency. In other words, democratic transition may improve stakeholders' participation in policy making and enhance the decentralization of environmental policy responsibility but also reduce efficiency in policy making and implementation due to many impediments arising from diverse perspectives of interest groups. Our suggestion is consistent with the finding of Assetto, et al. (2003). A transition-to-democracy country may face many challenges and impediments, and thus democratization should be treated as "a necessary but insufficient condition for developing local policy capacity for environmental protection in countries newly emerging from authoritarian rule" (Assetto, et al. 2003, p. 249).

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Table 1. The basic statistics among the selected three countries

| | China | Taiwan | US |
|---|---|---|---|
| Population[a] (unit: million) in 2007 | 1,321.85 | 22.86 | 301.14 |
| GDP[a] (Billion 2005 Dollars) in 2006 | 6,014 | 0.3663[f] | 12,768 |
| Primary energy consumption[b] (quadrillion Btu) in 2006 | 73.81 | 4.57 | 99.86 |
| Share of indigenous energy production[c] in 2007[c] | 91.13% | 12.44% | 70.76% |
| Nuclear power generation[d] (billion KWH) in 2007 | 62.6 | 38.5 | 806.4 |
| Renewables electricity generation (billion KWH) in 2008 | 537.9153 | 8.302 | 382.0558 |
| CO2 emission[e] (Million Metric Tons) in 2006 | 6,017.69 | 300.38 | 5,902.75 |

[a] Source: EIA (2010)

[b] Source: EIA (2010), Table 11.3 world primary energy consumption by region,

1997-2006.

[c] Source: APEC (2010)

[d] Source: EIA (2010), Table 11.18 world nuclear electricity net generation, 1998-2007.

[e] Source: EIA (2010) H.1 co2 World Carbon Dioxide Emissions from the Consumption and Flaring of Fossil Fuels, 1980-2006

[f] Source: National Statistics, ROC, (2010).

Table 2. Primary energy supply in 2007, unit: ktoe

| | China | | Taiwan | | US | |
|---|---|---|---|---|---|---|
| | quantity | Share | quantity | share | quantity | share |
| Indigenous Production | 1637717 | 0.911341 | 14249 | 0.124414 | 1673923 | 0.707614 |
| Import | 240314 | 0.133728 | 119902 | 1.046914 | 840306 | 0.355221 |
| Export | -63992 | -0.03561 | -17787 | -0.15531 | -126367 | -0.05342 |
| International Marine Bunkers | -2793 | -0.00155 | -2087 | -0.01822 | -30223 | -0.01278 |
| Stock Change | -14206 | -0.00791 | 252 | 0.0022 | 7948 | 0.00336 |
| Total Primary Energy Supply | 1797040 | 1 | 114529 | 1 | 2365588 | 1 |

Source: APEC (2010), http://www.ieej.or.jp/tmp/tble21170_20100508124321.xls

Table 3. The comparison of energy policies among the three countries

| | The targets of renewable energy policies |
|---|---|
| China | to increase the share of renewable energy production from the current level of one per cent to ten per cent by 2020<br>to reduce the share of coal consumption to 60% by 2020<br>to install renewable electricity capacity over 100 GW (about 30% of total generation capacity) by 2020<br>to increase the installed capacity of small hydro-power plants from the current 31,000 megawatts to 70,000-80,000 megawatts by 2020 |
| Taiwan | To increase the share of renewable electricity to 8% by 2025<br>To increase the share of electricity fueled by natural gas to 25% of total power generation by 2025. |

| | |
|---|---|
| | To reduce carbon intensity more than 30% by 2025 |
| US | Basically, US opposed to set a uniform renewable energy target for all the states and encouraged each state to set the policies and targets for each state. The federal policies in general focus on the establishment of incentive mechanism for promoting the renewable energy. |

Table 4. Net maximum capacity (MW) December 2007

| | China | | Taiwan | | US | |
|---|---|---|---|---|---|---|
| | quantity | Share | quantity | Share | quantity | share |
| Total | 713290 | 100% | 45881 | 100% | 1089501 | 100% |
| Hydro-power | 145260 | 20.36% | 4523 | 9.85% | 99770 | 9.15% |
| Nuclear power | 8850 | 1.24% | 5144 | 11.21 % | 105764 | 9.7% |
| Fossil-fueled | 554420 | 77.72% | 35277 | 76.88 % | 863223 | 79.23% |
| Others (wind power, Geothermal, etc.) | 4760 | 0.67% | 936 | 2.04% | 20744 | 1.9% |

Source: APEC (2010), http://www.ieej.or.jp

Table 5. The total, hydro and non-hydro power generation in Taiwan in 1997 and 2007-2009, unit: GWH

| | 1997 | 2007 | 2008 | 2009 |
|---|---|---|---|---|
| Total | 150,486.4 | 243,114.9 | 238,325.9 | 229,693.9 |
| Hydro | 9,566.8<br>(6.35%) | 8,350.3<br>(3.43%) | 7,772.3<br>(3.26%) | 7,053.4<br>3.10%) |
| Wind power | - | 443.5<br>(0.18%) | 589.3<br>(0.25%) | 786.6<br>(0.34%) |
| Solar photovoltaic | - | 2.2<br>(---) | 4.2<br>(---) | 8.0<br>(---) |
| biomass | 272.0<br>(0.18%) | 609.1<br>(0.25%) | 486.2<br>(0.2%) | 494.8<br>(0.22%) |

| | | | | |
|---|---|---|---|---|
| Waste heat recovery | 499.6 (0.33%) | 3013.9 (1.23%) | 2,946.6 (1.24%) | 2,907.0 (1.27%) |

Source: Bureau of Energy, Taiwan (2010). Energy Statistics Handbook 2009. Taipei, Taiwan.

Table 6. The context of environmental governance among the selected countries

| Elements of governance | | China | Taiwan | US |
|---|---|---|---|---|
| Environmental institution | Formulation process | Top-down | Mixed | Bottom-up |
| | Environmental initiators or decision makers | Governmental agencies | Stakeholders | Stakeholders |
| | Party politics | None | High | high |
| | Principle of decision making | Technical analysis | Discursive approach | Discursive approach |
| | Legal procedure (costs and time) | Flexible | Many exceptions | Strictly regulated |
| | Governing power | Legal authority | expert power, trust, and sharing values | expert power, trust, and sharing values |
| Values | Accountability | Medium | Medium | Medium |
| | Public participation | Low | High | high |
| | Transparency | Low | Medium | high |
| | regulatory independence | Low | Medium | high |

附件五

# An analytical framework for energy policy evaluation

Abstract

This paper presents a framework to evaluate the effectiveness of energy policies and provides a contextual view of measures on energy polices in linking with the objective of a sustainable economy. Firstly, Taiwan's energy policy is overviewed by analyzing the energy-related data to examine its deficit according to the framework presented. This paper finds that the energy policy adopted fails to attain the objective of a sustainable economy because energy consumption and CO2 emissions still keep upward trends. We conclude that an energy policy should focus on (1) improving energy efficiency, (2) reshaping industry structure and (3) to improve energy structure. In other words, the energy policy maker should create an environment that can motivate the development of clean energy supply and utilization for the achievement of energy policy objectives.

Keywords: energy intensity, carbon intensity, energy structure

## 1. Introduction

Energy consumption and electricity generation not only bring about the exhaustion of natural resources, but also are accompanied with a variety of air pollution as well as carbon emissions even though a great amount of effort is devoted to improve environmental pollution via abatement investments. For example, a thermal oil powered plant may release a variety of pollutants like SOx, NOx and other chemicals in addition to CO2 emissions in its operating phase. Conventionally, environmental or energy policies concentrate more on the abatement of conventional pollutants, but recently, especially after the signature of Kyoto Protocol, environmental concern has extended to the mitigation of greenhouse gas (GHG) emissions. Several international meetings were held in an attempt to reduce the greenhouse gases emissions and eventually the Kyoto Protocol was concluded in 1997 as a common agreement that asked industrial countries to cut their greenhouse gas (GHG) emissions by averagely 5.2% at the level of 1990 emissions.

Among the 6 GHGs, the CO2 emission is seen as a seriously global problem. It has received increasing attention and become an important role in affecting energy policies. In general, the energy policy adopted by each country reflects the degree of each government's attempts and supports to attain a low carbon economy of sustainable development.

It is generally accepted that the development and promotion of renewable energy plays a key role for the goal of CO2 mitigation. To analyze the important role of energy policies in affecting the development of renewable energy, many authors present a variety of frameworks (please see Ackermann et al., 2001, and Meyer, 2003). Mitchell et al. (2006) employ the framework presented by Foxon et al. (2005) to evaluate the effectiveness of the renewable electricity policies introduced in England and Germany. They argue that risk reduction is an important criterion in evaluating the effectiveness of policies in supporting renewable electricity. MacKenzie (2003) proposes an analytical approach based on a universal logistic growth curve to establishing the minimum fraction of each country's CO 2 emissions that can arise from nonfossil sources. In his paper, a universal logistic curve relating this fraction to time with complete penetration of non-fossil sources by the end of this century was proposed. He argues that the thrust of his proposal is that "every country would follow the same requirements curve and would have to arrange its energy supply and demand so that the minimum percentage indicated would come from non-fossil sources such as solar, photovoltaic, wind, geothermal, biomass, and nuclear." (p. 1184).

This paper attempts to assess the appropriateness of energy policies by developing a framework in which it integrates energy demand and supply to link with CO2 emissions. This framework provides a better understanding on the relationship between energy policies and sustainable economies that consider the integration of energy consumption and CO2 emissions. We employ Taiwan as a case example and thus first we review Taiwan's energy policies adopted in Section 3, and then examine the historical trend of CO2 emissions, energy consumption, and the changes of energy intensity and carbon intensity in Section 4 and make a brief evaluation on the effectiveness of Taiwan's energy policies. We also discuss the potential for the increased use of renewable sources for electricity generation like wind, solar power and certain forms of biomass in Section 4. A brief conclusion is presented in Section 5.

## 2. An Analysis Framework

Environmental problems arising from energy consumption can be categorized into two aspects: exhaustion of natural resources and adverse effects of environmental pollution. And thus, how to sustain the conservation of natural resources and to avoid pollution becomes an important issue. In this paper, we present an analytic framework for the assessment of energy policies by integrating energy consumption and carbon emissions to attain the goal of sustainable economies (please see Figure 1). This framework serves in this paper as a tool to analyze the possibly efficient and effective solutions for sustainable development in association with energy use.

Basically, the energy policy aims at seeking an economy of sustainable development that attempts to solve the conflict between economic development and environmental protection. Traditionally, the GDP of economic growth works as an indicator for social welfare by measuring the national richness. Recently, the measurement of GDP to reflect social welfare has been challenged[7] and many new indicators are offered to replace it. Castaneda (1999, p. 232) argues that "The GDP is a snapshot of today's economy and does not account for sustainability (i.e. depreciation of natural capital is not included)". Many academic research institutions devote a lot to the construction of sustainability indicators, but its content varies across countries due to the variety of environmental conditions. In the framework of Figure 1, a sustainable economy is used as the policy objective and measured by the integration of economic growth and CO2 emissions.

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[7] To capture the meaning of sustainable development, Hanley et al. (1999, p.56) argue that "It seems unlikely that there exists one single measure of sustainable development which is capable of capturing all that is meant by 'sustainability'. Rather, alternative indicators exist, each of which addresses a number of different understandings of what is most important if development is to be sustainable".

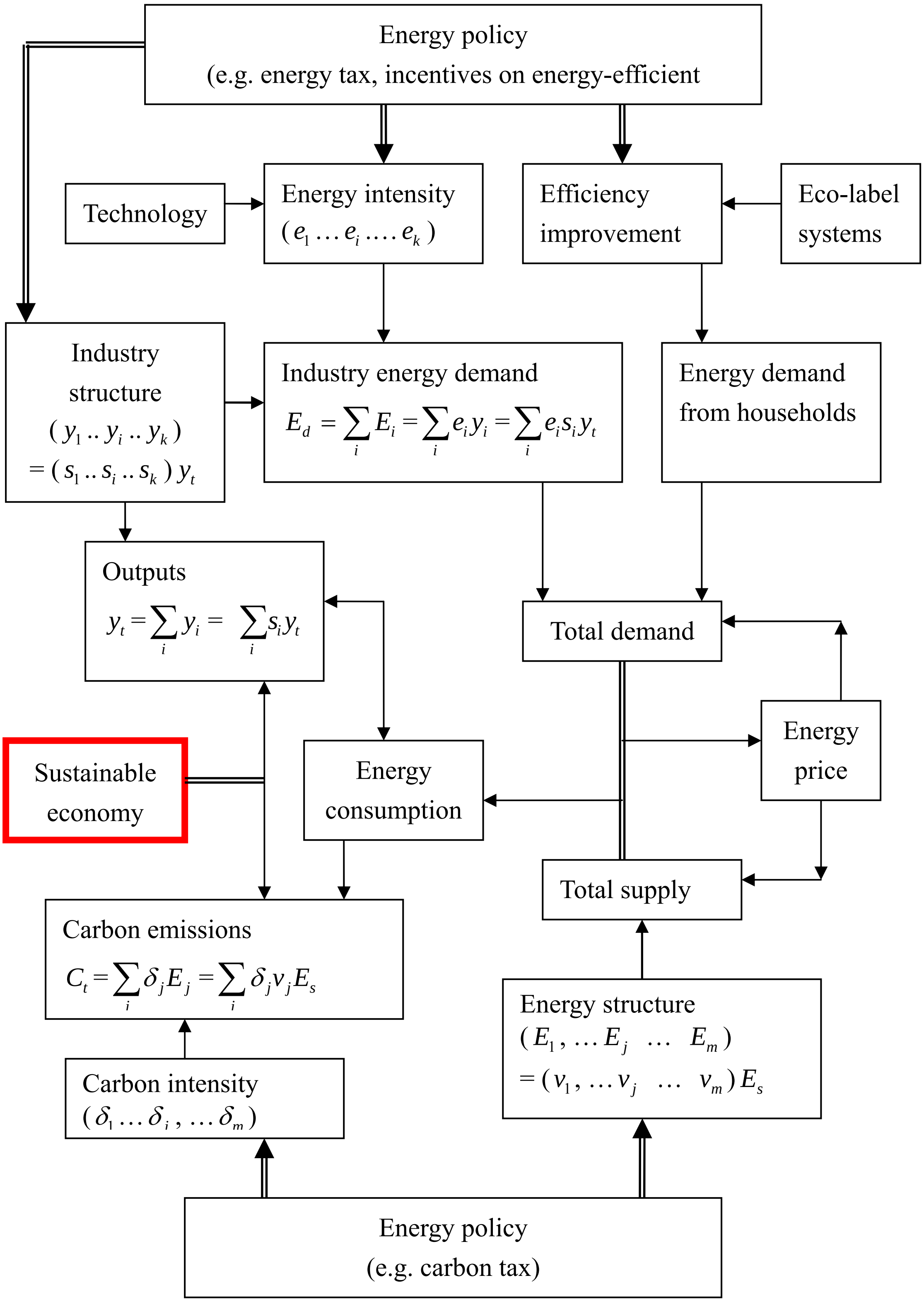

Figure 1. The analytical framework for the assessment of energy policy

### 3.1 Demand side

In the framework of Figure 1, energy is demanded by two users: industry sectors (including agriculture) and households. Basically, industry sectors contribute much more to energy consumption and CO2 emissions than household sectors. This framework addresses that the energy intensity of each sector is affected by technology level adopted while industry structure depends on energy policies[8]. In contrast, energy demand from households is almost determined by income level and partly affected by environmental behaviors that favor in green consumption and energy saving. The possible solution to reduce energy demand from households is to reshape consumer's environmental consciousness to behave environmentally. Thus, the energy policy can be designed to induce consumer behavior change for energy efficiency improvements.

### 3.1.1 Industry energy demand

Energy demand from industry sectors is calculated by:

$$E_d = \sum_i E_i = \sum_i e_i y_i = \sum_i e_i s_i y_t \qquad (1)$$

where $E_d$ represents energy demand from industry sectors, $e$ energy intensity, $s$ the share of outputs produced by Sector $i$, and $y$ the outputs. The subscript $t$ refers to total. According to Eq. (1), energy intensity and industry structure determine the total energy demand from industry sectors. While industry structure shifts over time based on the relative competitiveness of each sub-sector, energy intensity $e$, determined by the technology level, plays more important role in affecting energy demand. This implies that technology improvements in energy saving may lead to decrease in energy intensity $e$. Many authors have analyzed the factor in affecting energy intensity by a variety of methods. For example, Alcantara and Duro (2004) and Sun (2002) using the data from OECD countries, analyze the factors for the decrease in the inequality in energy intensity while Miketa and Mulder (2005) examine the energy intensity across developed and developing countries in 10 manufacturing sectors. Greening et al. (1997) examine energy intensity for manufacturing in 10 OECD countries and find that the major change in energy intensity may be attributed to the changes in individual subsector energy intensity.

Technology can reduce energy inputs for a given amount of outputs. This means that energy intensity in each sector can be reduced. It is widely accepted that cleaner technology can bring about not only environmental gains but also enhancement in national competitiveness (Greaker, 2006). Furthermore, technology can create some advantages by providing unique, inimitable, and valuable intangible resources (Grant, 1997), developing successful new products (Madhavan & Grover, 1998), and reshaping organization (Dougherty, 1992). Some firms obtain strategic advantage by means of innovation activities over their competitors (Nonaka, 1994). We proposed that the energy policy should aim at developing and promoting the energy efficient equipments or apparatuses, or reforming the industry structure so that low-energy intensity sectors are motivated to expand.

### 3.1.2 Energy demand from households

On the other hand, innovation through product design to prevent pollution discharges is also very beneficial to the environment. Consumer behavior is recognized as in essence for the performance of technology rising as green consumption may motivate firms to improve energy efficiency. In the meantime, energy saving behavior may lead to rise in energy efficiency and thus it is seen as one

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[8] For example, the imposition of energy tax may increase the production costs for energy-intensity industries and reduce profits.

of the most constructive and cost-effective ways to address these challenges. Hence, energy policies should be designed to encourage households, businesses, schools, governments, and industries to reshape their behavior for the improvement of energy efficiency.

Eco-label programs such as ENERGY STAR may direct green consumption and motivate the development of energy-efficient products in linking with the development of building codes and appliance standards. The implementation of eco-labeling programs, in practice, can save customers billions of dollars on their energy bills, reduce emissions of CO2 and air pollutants, and contribute to a more secure, reliable, and low-cost energy system. A great number of researchers argue that most consumers recognize, know and trust in the eco-labels and agree to engage in green consumption (Leire, and Thidell, 2005).

3.2 Supply side

In practice, the sufficient of energy supply is a determinant to support an ever-growing economy. A human system requires a variety of energies to support and maintain the operation of building, transportation, housing, schools, health care, communication networks, and recreation. Total energy supply is calculated by:

$$E_s = \sum_j E_j \qquad (2)$$

where subscript $j$ represents the source of energy. In a competitive economy, energy consumption and price are determined by the market (the total energy demand and energy supply). Basically, energy demand and energy supply depend on energy price $p$ and other socio-economic factors, i.e. $E_d = f\ (p;$ socio-economical variables) and $E_s = g\ (p;$socio-economical variables). The equilibrium of energy consumption $E = (E_1, \ldots E_j \ \ldots \ E_m)$ and energy price $p$ is determined by

$$E_d = f\ (p;\text{socio-economical variables}) = g\ (p;\text{socio-economical variables}) = E_s \qquad (3)$$

And thus, carbon emissions are calculated by

$$C_t = \sum_j \delta_j E_j = \sum_j \delta_j v_j E \qquad (4)$$

where $C_t$ refers to carbon emissions, $\delta_j$ is the carbon intensity (defined as the relationship between CO2 emissions and energy consumption) by $j$ source of energy, and $v$ represents the share of $j$ source of energy in total energy consumption. According to Eq. (4), energy structure and carbon intensity play the most important role in affecting carbon emissions. The consumption of fossil fuels including coal, oil, and natural gas is inevitably accompanied with the emissions of CO2, SO2, and smoke dust. These pollutants most probably cause acid rain and lead to global warming. Thus, non-fossil fuels (especially the renewable) are considered to replace the conventional energy for the purpose of CO2 emissions mitigation.

3.3 Energy policies and technology

Energy intensity is more or less affected by technology level, and partly affected by energy policies while energy structure and industry structure are affected by energy policies and economic policies. The simultaneous change in energy intensity and production technology level in each sector is a key engine in affecting energy consumption and greenhouse gas emissions through a multi-dimensional phenomenon.

On the demand side, the energy policy (e.g. energy tax) should direct the change in industry structure. The low energy-intensity industry obtains more incentives and become more competitive in the economy. The incentives on green technology are another way to motivate investments in R&D (research and development) for energy efficiency improvements in the production process. The adoption and practice of green technology may increase energy security, reduce energy costs and increase business competition in addition to reduced environmental pollution associated with energy use.

On the energy supply side, the energy policy should motivate energy suppliers to develop clean energy that emits low CO2 emissions. Economic instruments of energy policies basically provide vital impacts on energy consumption and CO2 emissions and often involve externality pricing in a variety of ways, including carbon trading, carbon tax, etc. In practice, the renewable energy in general is more expensive than fossil fuels. The imposition of carbon tax may be considered to reinforce the relative competitiveness of renewable energy.

Since energy is central to the challenge of climate change mitigation, the targets should be feasible and theoretically helpful to solve the climate change problem. And thus, the energy policy should integrate the problem of energy consumption and CO2 emissions that serve as criteria for financing to steer investment towards low carbon, environmentally sustainable economies.

## 3. An overview on Taiwan’s energy policy

Taiwan’s energy policy has been revised four times in the past few decades in response to temporary energy shocks and long-term global trends, such as energy crises in 1979 and 1984, the Gulf War in 1990, the liberalization of energy industry in 1996, and environment movements, etc. In 1996, Taiwan’s energy policy aimed to “establish a liberalized, orderly, efficient, and clean energy supply and demand system based on the environment, local characteristics, future prospects, public acceptability, and practicability” (Bureau of Energy, 2010). During 2000-2008, Taiwan’s Bureau of Energy claimed that energy policies would adhere to the "Green Silicon Island" policy. The main points of the energy policy adopted in this period aimed at (a) the appropriate development and use of natural resources, (b) the liberalization of the petroleum market[9], (c) the continued emphasis on establishing private power generation facilities[10], (d) the strengthening of energy science and technology research, (e) the promotion of energy efficiency, and (f) the adoption of laws that ensure a public policy favoring the continued use of renewable energy, and eventually lead to a nuclear-free homeland.” Considering the global impacts of warming effects, the energy policy during 2000-2008 emphasized the parallel role of economic development, using energy supply and environmental protection to achieve sustainable development. The final goal was to attain a nuclear-free homeland with an ever-growing prosperity by using green energy, which was believed as a sustainable and clean source of energy derived from nature including solar energy, wind energy, geothermal energy, ocean energy, biomass, and energy recovery from waste. The Democratic Progress Party (DPP) defeated Kuomintang (KMT) in the presidential election and took over the presidency in 2000. After his inauguration, the new

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[9] In 1997 Formosa Petroleum Corp. served as the second producer of naphtha cracking in Taiwan and became a competitor to the state-owned monopoly-Chinese Petroleum Corp.

[10] The Electricity Management Act of 1998 open the door for private production of electricity and the first private-owned power plant started to generate electricity in 1999. The private power plants are regulated to sell their electricity to the monopolistic distributor –Taiwan Power Company.

president decided to perform a policy of non-nuclear homeland (NNH) and halted the on-going project of Nuclear Power Plant IV. Renewable energy was believed to be able to drive not only the economic upwards but also the environment cleaner and thus the share of renewable energy use in terms of installed capacity was designed in 2002 and expected to reach 12％ of the total capacity by 2020.

After 2008 when Ma Eng Chiu (nominated by KMT) took over the presidency, the goal of energy policies was to establish a liberal, orderly, efficient, and clean sustainable energy demand and supply system. In other words, the revised energy policy attempted to balance the goals of energy security, environment protection, and industry competitiveness simultaneously and consider the need of future generations. In detail, the currently operating energy policy intends to attain the following targets:

1. improving energy efficiency by more than 2% annually
2. reducing energy intensity (defined as the relationship between primary energy and GDP) 8
3. 20% by 2015, 50% by 2025 compared with the level in 2005.
4. reforming the industrial sector to reduce carbon intensity more than 30% by 2025.
5. reducing CO2 emissions to the level of 2008 by 2016-2020.
6. increasing the share of low carbon energy in electricity generation systems from the current 40% to 55% in 2025, including the share of renewable energy 8% and that of natural gas 25%.
7. maintaining a continual economic growth at 6% during 2008-2012, and reaching to US$ 30,000 by 2015.

## 4. Energy consumption and CO2 emissions

### 4.1 CO2 emissions

Taiwan's CO2 emissions kept a leaping growth during the past 30 years and show no evidence of slowdown even after 2005 when Kyoto Protocol was in effect (please see Figure 2). Taiwan emitted 70.77 million tons of CO2 (MtC) in 1980 and then kept a constantly increasing trend of CO2 emissions (please see Figure 2). Taiwan's CO2 emissions reached to 300.38 MtC in 2006. Compared with the emission level of 118.77 MtC in 1990 (the base year for CO2 mitigation in Kyoto Protocol), CO2 emissions kept rising with annual growth rate of 9.0 %.

Per capita CO2 emissions also increased from 3.97 tons of CO2 in 1980, 5.86 tons in 1990, 9.73 tons in 1997 (the year that Kyoto Protocol was presented), and then to 13.19 tons in 2006. Compared with the rival countries or the BRIC, even some of the developed countries, Taiwan emits more CO2 for each individual. For example, each Taiwanese emitted 13.19 tons of CO2 in 2006 higher than Japanese (9.78 tons), Chinese (4.58 tons), South Korean (10.53 tons), but lower than American (19.78 tons).

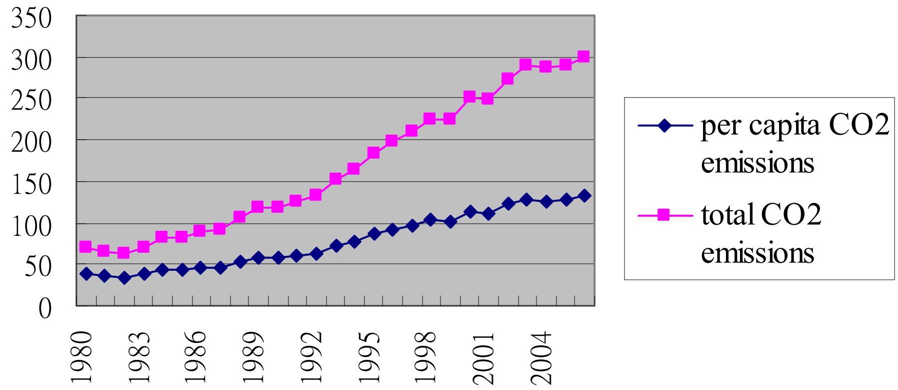

Figure 2. The trend of CO2 emissions in Taiwan
unit: million tons for total CO2 emissions, tons for per capita CO2 emissions
scale: 1:1 for total CO2 emissions, 10:1 for per capita CO2 emisions
source: EIA (2010)

This result reflects that Taiwan has not yet controlled its CO2 emissions effectively. It implies that Taiwan's energy policy inclines to "development the first and environmental protection the second" even though the government has claimed to offset the adverse effect of economic development by enhancing the establishment of clean environment. The above results about CO2 emissions provide strong evidence that Taiwan's energy policy, seeking for sustainable use of energy without sacrificing the environment, has completely failed. This paper suggests that the energy policy needs to interwind with broader issues of human development and technology innovation as presented in Figure 1. And thus, it needs to consider the technical aspects of energy supply, and the effects of industry structure and societal change on energy demand.

## 4.2 energy consumption

Taiwan's total final energy consumption had a stationary increase, from 16,997 ktoe in 1980 to 69,951 ktoe in 2007 (please see Table 1). The annual growth rate is at average of 11.53%. Among the energy consumption, crude oil and Petroleum products constitutes of the major part of energy consumption, accounting from 52%-62 % over the past three decades. It increased from 10,688 ktoe in 1980 to 42,926 ktoe in 2007. The final consumption of electricity increased from 3171 ktoe in 1980 to 18,289 ktoe in 2007. The annual growth rate of electricity consumption is 17.66%, greater than the average growth rate of energy consumption. Electricity consumption accounted for 18.66 % of total energy consumption in 1980 and 26.14% in 2007 respectively.

Table 1. Taiwan's total final energy consumption, unit: ktoe

| | Coal & Coal Products | Crude Oil & Petroleum Products | Gas | Electricity | Others | Total | Per capita GDP (US Dollars)* |
|---|---|---|---|---|---|---|---|
| 1980 | 1799 | 10688 | 2678 | 3171 | - | 16997 | 2,385 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1985 | 3724 | 12640 | 1745 | 4069 | - | 21305 | 3,290 |
| 1990 | 5903 | 16618 | 1852 | 6367 | - | 29814 | 8,124 |
| 1995 | 7881 | 20538 | 3068 | 9045 | - | 38998 | 12,918 |
| 2000 | 8391 | 30197 | 2979 | 13770 | - | 53848 | 14,704 |
| 2005 | 6706 | 38737 | 1986 | 16734 | 88 | 64251 | 16,051 |
| 2006 | 7254 | 38798 | 2010 | 17296 | 92 | 65449 | 16,491 |
| 2007 | 6589 | 42926 | 2051 | 18289 | 95 | 69951 | 17,154 |

Source: APEC (2010), Energy database, http://www.ieej.or.jp/egeda/database/database-top.html

* Source: National Statistics, ROC, (2010).

Table 2 and Table 3 demonstrates that Industrial Sector consumed 22,179.60 MLOE (equivalently to $10^3$ KLOE), accounting for 46.21% of total consumption in 1989. Its share of energy consumption slightly declined to the bottom of 43.18% in 1998, and then kept an increasing pattern to 52.48% in 2009. The energy consumption in Industrial Sector, however, was still growing, from 22,179.60 MLOE in 1989 to 59,351 MLOE in 2009 with annual growth rate of 8.3%. This reflects that high energy-intensity industries still dominate the production even though the government attempts to encourage cleaner production with less energy-intensity products. In contrast, the energy consumption in Service Sector increased significantly from 4,417.9 MLOE in 1989 to 12,980 MLOE in 2009 with annual growth rate of 9.6 %. The share of energy use in Service Sector also increased from 9.2 % in 1989 to 11.48 % in 2009 (please see Table 3). These results demonstrate that Service Sector grows a little more than Industrial Sector, but the development of Service Sector is not enough to substitute Industrial Sector as the major income source.

Table 2. Taiwan's domestic energy consumption by sector, unit: $10^3$ KLOE

| year | 1989 | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|
| total domestic consumption | 48,035.90 | 50,986.70 | 68,475.50 | 91,736.50 | 111,143.50 | 115,701.20 | 113,085.20 |
| energy sector | 4,671.90 | 4,841.50 | 6,399.10 | 8,251.20 | 9,312.00 | 8,476.80 | 8,159.50 |
| industrial | 22,197.60 | 23,145.80 | 30,235.90 | 41,618.70 | 54,417.20 | 61,231.80 | 59,351.00 |
| transportation | 7,369.20 | 8,010.70 | 12,265.50 | 14,435.60 | 16,192.30 | 14,857.50 | 14,879.80 |
| agricultural | 1,394.20 | 1,457.80 | 1,483.00 | 1,436.70 | 1,571.10 | 1,153.20 | 1,010.70 |
| services | 4,417.90 | 4,972.20 | 6,979.10 | 10,596.40 | 12,975.20 | 13,468.20 | 12,980.10 |
| residential | 5,613.70 | 5,944.50 | 8,170.60 | 11,443.70 | 13,112.70 | 13,208.40 | 13,162.10 |
| non-energy use | 2,371.50 | 2,614.20 | 2,942.20 | 3,954.20 | 3,563.10 | 3,305.30 | 3,542.00 |

Source: Bureau of Energy (2010), p. 37.

During the same period, the energy consumed by Residential Sector increased from 5,613.7 MLOE in 1989 to 13,162.1 MLOE in 2009 (please see Table 2) with annual growth rate of 6.7%. In the same period, the population increased from 20.107 million persons in 1989 to 23.12 million persons in 2009. This implies that people's living standard has been increased rapidly and thus more and more electrical appliances at home or passenger cars for traffic are utilized. The growth of motor vehicles and home appliances explain a lot about the increase of energy consumption. Passenger cars increased by 195% from 1,929,775 in 1989 cars to 5,704,312 cars in

2009 (BOE, 2010) and motorcycles increased by 615% from 2,009,698 in 1976 to 14,365,442 in 2008. The delivery of microwave oven increased by 89% from 414,063 sets in 1989 to 784,438 sets in 2007.

Table 3. The share of domestic energy consumption by sector, unit: %

| year | 1989 | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|
| total domestic consumption | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| energy sector | 9.73 | 9.5 | 9.35 | 8.99 | 8.38 | 7.33 | 7.22 |
| industrial | 46.21 | 45.4 | 44.16 | 45.37 | 48.96 | 52.92 | 52.48 |
| transportation | 15.34 | 15.71 | 17.91 | 15.74 | 14.57 | 12.84 | 13.16 |
| agricultural | 2.9 | 2.86 | 2.17 | 1.57 | 1.41 | 1 | 0.89 |
| services | 9.2 | 9.75 | 10.19 | 11.55 | 11.67 | 11.64 | 11.48 |
| residential | 11.69 | 11.66 | 11.93 | 12.47 | 11.8 | 11.42 | 11.64 |
| non-energy use | 4.94 | 5.13 | 4.3 | 4.31 | 3.21 | 2.86 | 3.13 |

The causes for the increase in energy consumption may stem from the increase in population as well as economic growth. Per capita energy consumption is used as a measure of improved quality of life and thus we depict the trend of Taiwan's per capita energy consumption in Figure 3. We find that per capita energy consumption has been rising steadily for the last few decades. Per capita energy consumption increased from 2,389 LOE in 1989 to the peak of 5,191 LOE in 2007, and then slightly declined to 4,891 LOE in 2009. The annual growth rate of per capita energy consumption was 5.23%, relatively lower than total energy consumption.

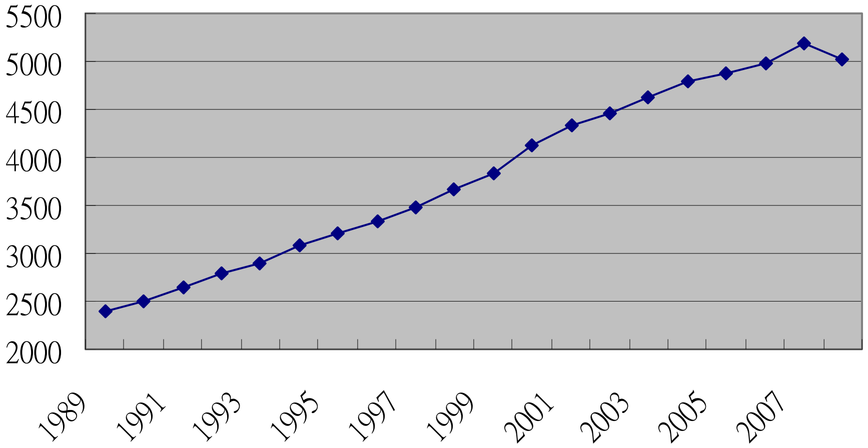

Figure 3. The trend of per capita energy consumption in Taiwan
unit: LOE

### 4.3 Energy intensity and carbon intensity

Both Taiwan's primary energy intensity and carbon intensity currently is still very high. They reached to 8,294 Btu per US dollars of outputs and 2.64 kg CO2 per liter of oil equivalents in 2006 respectively. The energy intensity (Total Primary Energy Consumption per Dollar of Gross Domestic Product) drop from 10,083 Btu per US dollars in 1980 to the rock bottom of 7,974 Btu per US dollars in 1992, and then fluctuated between 8,900 and 8,000 Btu per US dollars during the period of 1993-2006 (please see Figure 4, data source: EIA, 2010, Table E.1p). Taiwan's energy intensity declined by 22% during the period of 1980-1992. This decline could be due to changing industry structure that Service Sector using less energy substitutes manufacturing industry. The other factors may attribute to the technology progress that adopts energy saving process.

After 1992, the trend of energy intensity goes fluctuating due to the rising of living standard and technological progress. The energy consumption in the residential sector and the transportation sector due to rising living standard may push energy intensity up but technological progress may reduce energy intensity across industries. Even though Taiwan's primary energy intensity has declined by 18% only during the period 1980-2006, it is still higher than the neighboring countries (please see Figure 4).

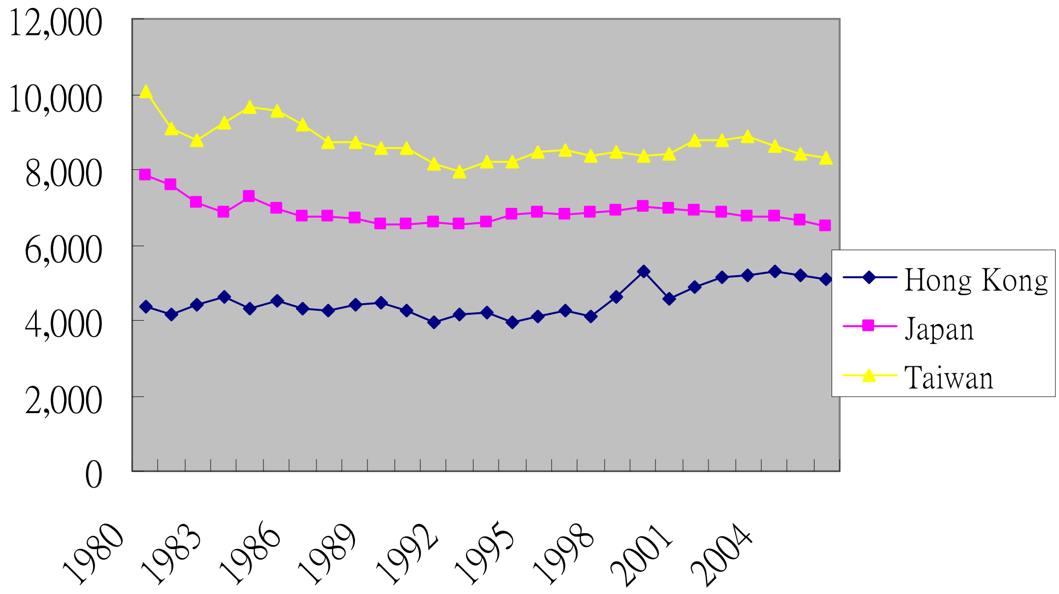

Figure 4. The trend of Taiwan's energy intensity compared to its neighboring countries, unit: Btu/US$
data source: EIA (2010)

Figure 5 shows a fluctuating pattern of carbon intensity[11], ranging from 2.28 to 2.8 kg CO2/LOE. The value of carbon intensity is found to be 2.64 kgCO2/LOE in 2006 and 2.32 kgCO2/LOE in 1990. This implies that energy structure tended to be worse than before and the renewable energy policies seem to fail as the share of renewable energy is not large enough to substitute the fossil fuels. Furthermore, it seems that the energy technology adopted in Taiwan did not improve very much during the past 20 years.

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[11] The carbon intensity is defined as the mass of carbon dioxide emitted per unit of energy consumed.

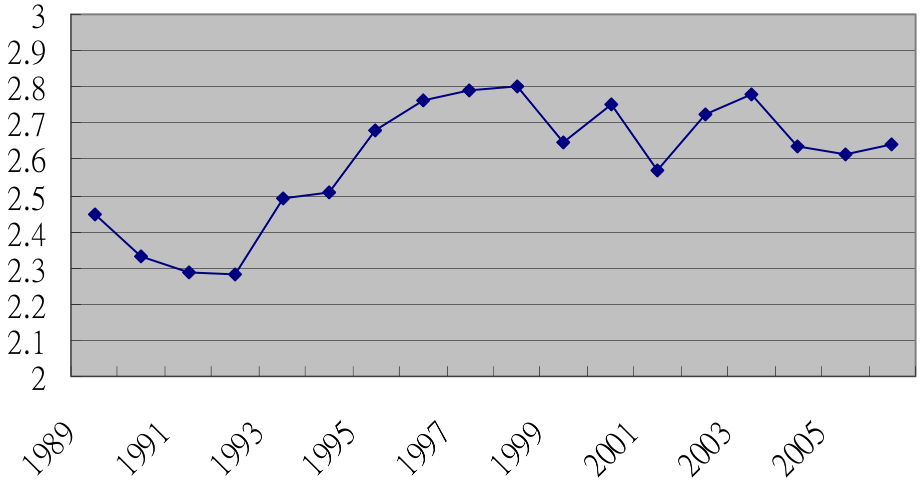

Figure 5. the trend of carbon intensity
unit: kg/LOE

## 4.4 Energy structure

Table 4. Energy supply in Taiwan by energy form, unit: $10^3$ KLOE

| year | 1989 | 1990 | 1995 | 2000 | 2005 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|
| total | 52,880.2 | 58,520.7 | 79,770.4 | 103,808.40 | 135,965.80 | 141,251.50 | 138,057.80 |
| coal and coal products | 13,097.4 | 14,021.3 | 21,403.6 | 33,112.70 | 43,541.40 | 46,186.70 | 42,035.60 |
| crude oil and petroleum products | 29,846.6 | 32,319.6 | 43,470.4 | 52,565.70 | 70,501.40 | 70,467.10 | 71,534.70 |
| natural gas | 1,264.5 | 2,029.5 | 4,151.8 | 6,465.50 | 9,859.60 | 12,196.40 | 11,900.90 |
| conventional hydro power | 464.9 | 610.0 | 462.7 | 436.7 | 381.1 | 411.6 | 358.3 |
| nuclear power | 8,188.8 | 9,518.0 | 10,227.4 | 11,150.40 | 11,575.90 | 11,823.50 | 12,039.00 |
| solar photovoltaic and wind power | 3.1 | 2.7 | - | 0.1 | 8.8 | 56.7 | 76 |
| solar thermal | 14.9 | 19.6 | 54.6 | 77.3 | 97.5 | 109.5 | 113.2 |

Source: Bureau of Energy (2010).

Up to now, Taiwan still relies on fossil fuels as it is difficult to develop low-cost green energy. The total supply of fossil fuels including coal and coal products, crude oil and petroleum products, and natural gas reached to 44,208 MLOE in 1989 (please see Table 4), accounting for 83.6% of total energy supply. The fossil fuels supplied increased to 125,471 MLOE in 2009, accounting for 90.89%. After Year 2000, the share of fossil fuels kept a slightly rising trend and had no sign to drop (please see Table 4 and Table 5).

Table 5. The share of fossil fuels and non-fossil energy supplied in Taiwan, unit: %

|  | fossil fuels | conventional hydro power | nuclear power | solar photovoltaic and wind power | solar thermal | total |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| 1989 | 83.6 | 0.88 | 15.49 | 0.01 | 0.03 | 100 |
| 1990 | 82.66 | 1.04 | 16.26 | 0 | 0.03 | 100 |
| 1995 | 86.52 | 0.58 | 12.82 | - | 0.07 | 100 |
| 2000 | 88.77 | 0.42 | 10.74 | 0 | 0.07 | 100 |
| 2001 | 89.99 | 0.45 | 9.48 | 0 | 0.07 | 100 |
| 2002 | 89.6 | 0.23 | 10.09 | 0 | 0.07 | 100 |
| 2003 | 90.41 | 0.24 | 9.27 | 0 | 0.07 | 100 |
| 2004 | 91.21 | 0.23 | 8.48 | 0 | 0.07 | 100 |
| 2005 | 91.12 | 0.28 | 8.51 | 0.01 | 0.07 | 100 |
| 2006 | 91.31 | 0.28 | 8.32 | 0.02 | 0.07 | 100 |
| 2007 | 91.57 | 0.29 | 8.03 | 0.03 | 0.07 | 100 |
| 2008 | 91.22 | 0.29 | 8.37 | 0.04 | 0.08 | 100 |
| 2009 | 90.89 | 0.26 | 8.72 | 0.06 | 0.08 | 100 |

Source: Bureau of Energy (2010).

Renewable energy is seen as sustainable resources that can curb warming effect and support an integrated matching between economic development and environmental conservation. And thus, Taiwan’s energy policy focused on the increase in the renewable energy supply and the reduction in the fossil fuel’s share in total energy supply to meet the increasingly rigid environment request in the past decade. During the period of Democratic Progress Party’s ruling of 2000-2008, the supply of renewable energy slightly increased from 514.1 MLOE (including hydro power 436.7 MLOE, and solar and wind power 77.4 MLOE), accounting for 0.51% of total supply in 2000, to 577.8 MLOE (including hydro power 411.6 MLOE, and solar and wind power 166.2 MLOE) accounting for 0.41% in 2008 (please see Table 5). The result of the above analysis concludes that the non-nuclear homeland policy has completely failed. In the 8 years (2000-2008) under DPP’s ruling, the supply from renewable energy was also not successful even DPP governments claimed to promote the development of renewable energy.

After KMT’s recovery of the ruling power in May 2008, the energy policy was a little revised. The policy of NNH (non-nuclear homeland) was abolished and nuclear power was reconsidered as a strategy to mitigate CO2 emissions. Furthermore, Taiwan government has introduced a range of measures to attract investment in clean production of power generation and to form a competitive market. Electricity market reforms have been conducted to improve technical efficiency and meet the future challenge by shifting the production-and-engineering-oriented to market-led management systems. In 1996 the government released the monopoly regulation of power generation and then the first private power plant was installed to supply the electricity to TPC. However, most of the newly installed plants generated electricity fueled by fossil energy. The growth rate of non-hydro renewable power plants is still not large enough (please see Table 4 and 5) because of higher power generation costs. Without an appropriate system to subsidize renewable energy, it seems not optimistic to increase the share of renewable energy.

Electricity generation by non-fossil fuels (including nuclear power and renewable electricity) can, in practice, mitigate CO2 emissions effectively, but it declined from 45.94% in 1990 to 23% in 2009 (please see Table 6). Nuclear power and hydro power played the vital role in supplying the non-fossil fueled electricity while the balance of non-fossil fueled electricity contributed relatively very little. Of the total power generation, 36.44% was generated by nuclear power plants in 1990, and 18.10 % in 2009 (please see Table 6) while hydro power generation contributed to 9.08 % and 3.07% for the same period. The rapid drop of hydro power generation may attribute to the exhaustion of hydroelectric resources. In fact, the majority of economically exploitable hydroelectric resources already have been developed. Currently, some small hydro-electric projects is under planning, but is opposed by environmental groups. In the future, it is not optimistic to expand the hydropower generation.

Table 6. Taiwan's power generation by fuel

| Year | 1990 | 1995 | 2000 | 2005 | 2006 | 2007 | 2008 | 2009 |
|---|---|---|---|---|---|---|---|---|
| Grand total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Hydro Power | 9.08 | 6.67 | 4.8 | 3.44 | 3.4 | 3.43 | 3.26 | 3.07 |
| Coal-Fired | 28.17 | 38.54 | 47.04 | 53.7 | 53.49 | 53.62 | 52.02 | 53.35 |
| Oil-Fired | 24.64 | 23.42 | 16.76 | 6.73 | 7.69 | 6.18 | 5.61 | 3.31 |
| LNG-Fired | 1.25 | 4.29 | 9.57 | 17.11 | 16.97 | 18.42 | 20.29 | 20.35 |
| Nuclear Power | 36.44 | 26.53 | 20.83 | 17.58 | 16.93 | 16.67 | 17.13 | 18.1 |
| WindPower | 0 | - | 0 | 0.04 | 0.12 | 0.18 | 0.25 | 0.34 |
| Biomass | 0.4 | 0.31 | 0.18 | 0.15 | 0.16 | 0.25 | 0.2 | 0.22 |
| Waste | 0.02 | 0.25 | 0.81 | 1.25 | 1.23 | 1.24 | 1.24 | 1.27 |

Source: Bureau of Energy (2010), p. 82.

Taiwan currently reconsiders nuclear power as an effective energy source to meet the goal of a sustainable economy (a growing economy with decreasing CO2 emissions). In 1990, the nuclear power capacity was 5,144 MW in Taiwan, contributing to 30.46% of total power generating capacity. After then, the nuclear power capacity remained the same as that in 1990. Even though the currently Taiwan government attempt to reconsider nuclear power as a major energy source, it is still difficult to grow in the future as some issues such as plant safety, radioactive waste disposal, etc have not been resolved and continue to raise public concerns in many countries. In this case, Taiwan government considers to extend the operating lives of the existing old nuclear facilities plants and plans to increase the capacity utilization rates.

Wind power generation increased from 1.4 GWH in 2000, to 443.5 GWH in 2007, and then 786.6 GWH in 2009. The growth rate is very high. However, the wind power generation accounted for 0.18 % of total power generation in 2007, and 0.34% only in 2009. The expansion of wind power plants seems a more feasible solution to support a sustainable economy. Wind energy is an importantly reliable and cost effective energy source due to the continuous technology improvement over the past few years. It has been verified that wind power owns a competitive position with conventional power generation technologies.

## 5. Discussions and conclusions

Some researchers find that energy consumption is the main causes of CO2 emissions (Soytas, et al. 2007) and hence, reduction in energy consumption may mitigate CO2 emissions. Carbon intensity of energy consumption reflects the energy structure in the country while energy intensity is associated with the energy efficiency and industry structure of the economy. In this case, the energy policy should be focused on three components: (1) to improve energy efficiency, (2) to reshape industry structure, and (3) to improve energy structure.

(1) to improve energy efficiency: Energy efficiency, that refers to less energy consumption based on the same or improved level of service, can be obtained through the technological improvement on energy conversion or the electrical apparatus or equipments to reduce energy consumption. Although R&D and other technology development efforts may improve energy efficiency and reduce both energy intensity and carbon intensity, the clean technology is still under-developed. If energy policies can provide substantial and consistent incentives for clean energy adoption (purchase), the renewable energy technologies (e.g. wind power) may develop faster.

    On the other hand, the purchase of energy-saving equipments and appropriate utilization on these equipments are also another factors to save energy. Rehfeld et al. (2007) find that higher prices seem to be major obstacles to the commercial exploitation of environmental products. In practice, the cost of renewable electricity (e.g. solar electricity and wind power) is higher than that of fossil electricity. Under such a circumstance, the integration of price strategy with information transparency of the green product and to aware environmental consciousness is an effective strategy. The motivation on clean energy is a common goal for many governments through two ways: one way is to set up a environmental label system (e.g. Energy Star) and the other is to aware consumers to purchase green products through environmental education. Thus, the improvement of energy efficiency requires societal change through environmental education and technology progress in energy-consuming products through some financial incentives.

(2) To improve industry structure

    Taiwan’s government attempted to increase energy intensity by converting high energy-intensity production into low energy-intensity one. Such an attempt seems not successful as the high energy-intensity sectors such as steel making industry, petroleum industry, and traditional chemistry industry still dominate Taiwan’s economy and make for the major part of the national income. The industry structure is often determined by the combined effect of price elasticity of energy demand and the energy efficiency improvement. In other words, changes in industry structure require a socio-economical transformation that interacts with energy price, energy demand and supply, technological progress, and changes in consumer behavior.

(3) to improve energy structure

    Kyoto Protocol suggests three methods to mitigate climate change including carbon trade, clean development mechanism and joint implementation. When facing the uncertain market demand, it is required that sufficient incentives to attract industries to invest in carbon mitigation. And thus, energy policies should be implemented to motivate firms’ adoption of green energy. Blühdorn (2007) argues that market-based policies can be seen as powerful instruments to mitigate CO2 emissions. Many governments have taken a variety of measures to reduce GHGs including the introduction of permit trading systems; voluntary programs; carbon or energy taxes; and regulations and standards on energy efficiency and emissions. In the framework presented in Figure 1, we also emphasize that the introduction of a price mechanism in generation and supply of energy, power, and CO2 quota is required. The creation of a competitive market for energy supply and demand may motivate the investment on clean energy technology.

In the framework presented, the energy management system is divided into two units: the supply side and the energy demand side that further separated into two sectors, namely, housekeeping and profit-seeking industrial sectors, where the two sectors are the final energy users. The industry is asked to develop new processes to improve energy efficiency while housekeeping may contribute to energy saving by engaging in green consumption. On the supply side, energy policies are imposed for the promotion of more supply in clean energy for the mitigation of CO2 emissions.

In the past, many researchers have present different types of models such as energy planning models, energy supply–demand models, forecasting models, renewable energy models, emission-reduction models, and optimization models to discuss the relevant issues in association with energy consumption or the development of renewable energy source. For example, Rijal et al. (1990) had presented a linear multiple regression energy demand forecasting model to forecast the energy demand in developing countries. Borges and Pereira (1992) present a two stage model for energy demand in Portuguese manufacturing sector. Labys (1990) presented an econometric method to provide an approach for modeling supply processes where time delays, lags and capital formation are incorporated into the model. In this paper, we develop a framework to help for the efficient energy planning, forecasting and optimization of energy sources.

This paper uses Taiwan as an example case to analyze the feasibility of energy policies. The current energy policy emphasize that renewable energy sources such as solar, wind, bio-energy and small hydropower shall be expand in Taiwan in meeting the future energy demand. However, the energy formulation should be careful by evaluating the feasibility according to this framework. The policy maker can be confident in presenting an aggressive national commitment for energy consumption and CO2 emissions based on the proposed framework presented in this paper that integrates energy supply and energy demand to attain sustainable development.

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