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（計畫名稱）

永續水資源管理模式研究—從工業用水需求面出發

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永續水資源管理模式研究—從工業用水需求面出發

摘要

台灣水資源幾乎已開發殆盡，加上溫室效應所產生的氣候變遷等後果，導致各季節下雨頻率差異極大，各地雨量的分配也不均勻，因此，自然界水資源的供給似乎已無法再增加。因此，本計畫擬從用水需求面出發，探討在水資源供給固定下，如何透過水資源管理模式用以改善水資源的消費，以達到永續發展的目標。本計畫的主要研究目的在探討如何制定適當的水資源管理政策，用以鼓勵廠商(工業用水)透過廢水回收或雨水回收系統，自備水資源；改善設備或製程以減少用水量，以提高水資源用水效率。

本計畫調查過去幾年國內水資源消費以及廢水回收的相關數據，以及國內各行政區域的相關設經變數，用來分析國內水資源處開發與廢水處理的績效，並探討分析總體水資源消費量與國民所得的關係，透過庫茲涅曲線的運用，檢視水資源消費量與國民所得是否具有倒U 字形的關係。本計畫所產生的結果，除了提供有關水資源源發展的相關模型外，在實務上也針對國內水資源現況，提出詳細分析，因此，所得的結果，將具有相當實用價值。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。

本計畫為三年期計畫，至今為止，已經完成4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。

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：水資源、庫茲涅曲線、用水效率、用水自備率、廢水回收

Abstract

Water resources have been almost exploited completely in Taiwan and it is very difficult to develop new water resources. Moreover, the warming-house effect also aggravates the uneven distribution of rainfalls across regions and seasons in a year. The fresh water supply from natural environment seems to be given and cannot increase. Under such a circumstance, this project focuses on demand side to solve the problem arising from insufficient supply of fresh water. In general, the demand for water resources is categorized three sectors: industry, agriculture, and domestic use. This project focuses the anlaysis of water resource policies and attempt to examine the factor in affecting the resource management performance. And thus, this project also aims to present some policies to encourage industrial water recycling.

Based on the data collected invovling water consumption, waste water recycling and socio-economics status in each administration unit in Taiwan, this proejct analze the water management performance and examine whether the Environmental Kuznets Curve (EKC) exists or not for water consumption. After the implementation of this project, we have completed four articles in English. Two of them has been accepted and published in Water Resoruces Management and Water Policy that are indexed by SCI citation. And the other articles 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 sewerage system, volunteer participation rate and educatio level in affecting water management performance. In fact, the role of technology also plays a high impact on the generaton of reclaimed water. Currently, the equipment for reclaimation of waste water still depends on foreign manufacturers. Such a circumstance brings about the relative high cost of waste water recycling and discourage the local industry to invest in waste water recycling. In the future, the results of this project may be extened to cover this issue.

Keywords: water resources, Kuznets curve, water use efficiency, self-provision rate, waste water recycling

目錄

一、前言

在全球水資源中，陸地淡水僅佔3%，其於97%為海洋水。而在陸地淡水中，又有77.2%分布在南北極，22.4%分布在很難開發的地下深處，僅有0.4%的淡水可供人類維持生命 (Miller, 1999)。由於人口持續成長，經濟發展掛帥之下，可供使用水資源卻並未隨之成長，經年累月的開發及使用，水資源不再是取之不盡用之不竭，世界上許多國家早已面臨缺水窘境，水資源越來越不易取得，不僅影響經濟發展，也影響生活品質。

水在地球上的存量是固定不變的，只是以不同型態出現而已。水透過氣體、液體、和固體的型態，在地球上各個角落存在。雨水是水資源的主要來源，下雨後，流入河川、湖泊等形成地表水，或滲透到地下，形成地下水，最後，經由河川流入大海。雨水或灌溉用水被植物吸收，再透過植物表面揮發，變成水蒸氣，逸散到空中。水經由人體或動物吸收，變成廢棄物（大小便、汗水），再由土壤吸收。海水或地面水蒸發，或是植物表層水揮發，成為空氣中水氣，結合成雲，在碰到低溫而下雨。如此，形成水循環，生生不息，用以滋養人類生活、農業生產、工業生產所需。

臺灣在2008年總供水量為179.84億噸，水庫提供用水34.27 億噸，佔總供應量的19.1%，河川取水87.24億噸，佔48.5 % (如表一所示)，地下水取水58.31億噸，佔32% （經濟部水利署，2011）。地下水取水已成為重要的供水來源，大量採取地下水的結果，使得臺灣西部沿海地區，地層下陷非常嚴重。依照經濟部水利署 (2011)統計，全省最嚴重地區是雲林縣，在2009年，地層下陷速率達到7.4公分，其次是彰化縣、台南縣沿海地區。主要原因可能是超抽地下水，用來養殖、農耕，所導致的後果。

表一、水資源的供應與消費（2008 年，單位： 10^6 m^3)

Water supply			Water consumption		
surface water	subtotal	12,152.19	Agricultural use	Subtotal	12,960.11
	River	8,724.60		irrigation	11,212.18
	Dam	3,427.59		farming	101.16
Groundwater		5,831.93		Aquatic	1,646.77
Others (e.g. desalination)		0.83	Household use		3,357.30
			Industrial uses		1,667.54
Total supply		17,984.95	Total consumption		17,984.95

Source: 經濟部水利署 (2011)

水資源屬於公共資源(public goods)，目前臺灣的供水完全由政府負責，自來水是由自來水場負責供應，一般用水（包含地下水和地表水）都由水利署負責。水資源供應可以說是純屬獨佔型態，脫離私有財產和市場機能之運作。且水資源的供給幾乎固定，主要仰賴雨水供應，具有非常不確定性。傳統水資源幾乎開發殆盡，其他開發方法例如海水淡化，主要採用逆滲透法 (the reverse osmosis, RO)，一般認為 RO 是最進步、成本相對低廉的一種海水淡化方法，其生產成本約 0.42-0.68 US$/m3 (Haddad and Lindner, 2001)，但相對於一般水資源的取得，其成本仍然過高，未來新開發的水資源的邊際成本會大幅上升。因此，達成水資源永續利用的方法可能是從水資源的需求面著手，因此，本計畫考慮如何從需求面來解決水資源不足問題。

水資源主要用途可分為：農業用水（包括灌溉、畜牧及養殖用水）、生活用水、以及工業用水（包括商業）等三大類。表一顯示：2008 年，臺灣總用水量為 179.84 億噸，其中，農業用水量為 129.6 億噸，佔總用水量的 72%，生活用水量為 33.57 億噸，佔總用水量的 18.67 %，工業用水量為 16.67 億噸，總用水量的 9.2 %。農業用水密集度為 0.064 m3/NT$, 遠低於所有產業的 1.42 x 10^{-3} m3/NT$，更是大幅低於工業的 0.45 x 10^{-3} m3/NT$ (Chen, 2012)。雖然農業用水

效率遠低於工業，但是由於政府長期的保護，由於選舉考量，以免費或補貼方式供應灌溉水給農民，刻意予以保護。依據現有辦法，缺水時，農業用水優先供應。

民生用水的消費量取決於消費者（家庭）的主觀需要、環保意識、所得狀況。許多研究發現：假如民眾相信水資源不足，且其他人也認真節水時，民眾對水資源的維護與節約用水行為會比較明顯(Corral-Verdugo et al., 2002).。部分學者研究結果認為資訊提供或社會教育也會引起民眾關心水資源議題，透過媒體，進行教育宣導，厲行節約用水，會影響民眾協助改善水資源維護(Nancarrowet al.,1995; Syme et al., 2000; Winter, 2000; Gregory and Di Leo, 2003; Barta, 2004;Campbell et al., 2004)。當然，水價也會影響民生用水需求(Campbell et al., 2004)， Kenney et al. (2008) 發現住家用水需求是價格的函數以外，實施限水或氣候也是影響民生用水量的主要因素。

對工業生產而言，水資源是生產財，是生產過程中必備的一種中間財，其需求量取決於水資源在生產過程中的邊際產值。工業用水主要用製程上的清潔、冷卻、加熱，或是用於產生蒸汽，或產品的主要成份(例如汽水飲料的製造)，或作為溶劑等等。世界糧食政策研究組織報告，發現發展中國家的工業用水成長率高於已開發國家，到了 2025 年，開發中國家的工業用水量會達到 121 km3（Rosegrant, et al., 2002）, 比以開發國家還多出 7 km3。此種狀況下，工業用水需求持續上漲，是不可避免的事情。

在 2008 年，台灣工業用水佔總用水量的 9.27%，農業用水量佔 72.06%。雖然工業用水量遠低於農業用水量，但工業用水的用水優先權卻排在最後，且其產值遠高於農業。Chen (2012) 的研究發現：工業的用水效益（產值）卻高達 NT＄2,220，相反的，農業每 m3 用水量只產生 NT＄15.58 的 GDP，兩者的供水效

益相比差距甚大。工業用水是維持我國經濟不墜是不可或缺的一環，且短期內，臺灣的產業結構無法大幅改變，工業用水仍然有持續性需求。考慮工業產值是構成國民所得的重要一環，並且，產業榮衰也會影響科技開發與流通，進而影響永續發展成敗的關鍵角色。因此，本計畫擬以工業用水為主軸，探討分析如何有效使用水資源，以提高水資源的貢獻度，並達成永續使用水資源的目標。許多學者的研究已經確認制度上的缺失是水管理的主要問題 (Gandhi and Namboodiri, 2009; Herath, 2009; Pagan, 2009)。 這些缺失引起水資源投資成本回收困難，並使得用水績效不彰進而導致新投資不足；管理上的缺失最後會引起浪費或用水缺乏效率(Gandhi and Namboodiri, 2009)。 另外，隨著人口上升和生活水準提高，更進一步使水資源缺乏問題更形惡化。因此，本計畫的主要目的是如何制訂適當的水資源管理政策，從經濟面獎勵水資源的使用效率，以強化水資源的合理分配。

本計畫擬從工業用水需求面切入，站在政策設計者的立場，建立一套制度，規範廠商用水自費率，用來引導廠商自備水資源，促進水資源的永續利用。由於國內水資源的供給是屬於獨佔型態，短其間之內，無法改變，因此，政策上採用經濟工具(economic instruments)建立水資源市場制度，重新制訂水權的定價，比較不可行。本計畫所採用的廠商自備水資源的政策，類似環境標準制(command-and-control)，透過廠商自備水資源的制訂，引導用水者珍惜水資源，改善用水效率，平衡水資源之合理分配，使得水資源管理能達成永續發展目標。

二、研究目的

本計畫為三年期計畫，第一年先做總體分析，主要研究目的在分析我國水資源的運用是否具有 EKC 現象，亦即：用水量在達到高峰之後，是否會隨著國民所得的提高而下降，用以檢視水資源的使用是否具有自我調整的特性，並探討所

得之外如產業結構、技術進步、水價等其他變數對用水量是否有顯著影響。

第二年目的在檢視我過各行各業的用水效率，並檢視影響工業用水效率的可能因素。雖然以廠商的立場而言，缺水所引起的壓力遠不如廢水排放所造成的污染問題那麼受到關注，但考慮往後水資源逐漸匱乏，工業用水不足帶來的對經濟、社會、民生的重大影響，廠商必須從製程上與管理上，進行改格，降低用水量，提高用水效率。

第三年的目的則是站在政策設計者立場，制訂各種產業的用水自備率，以作為政策參考。雖然工業用水量只佔產值的一小部分，但是，缺水所導致的損失，卻非常巨大，因此，政策設計者可以透過政策制訂，引導廠商考慮投資設備，創造『自備』水源，透過節水、廢水回收、製程改善等方面來降低用水量，增加用水效率。先決條件一定是要『自備』水源的投資要能回收，因此，政府在制訂水價時，必須考慮對廠商水資源自備率的影響。

三、文獻探討

許多環境指標強調，永續發展目標的達成，除了考慮污染造成人類健康與生態系統破壞之外，環境資源短缺或惡化所產生的負面影響，亦不容忽視（Miller, 1999）。至今為止已有許多學者運用庫茲涅曲線理論檢驗各種污染或生態系統。例如 Chen and Chen (2008) 分析都市垃圾是否具有 EKC 現象，Martı´nez-Zarzoso and Bengochea-Morancho (2004)、Cole (2004) 、 Galeotti et al. (2006)、 Harbaugh et al. (2002)、 Friedl and Getzner (2003)、 Canas et al. (2003)等則是運用在 CO2 排放方面，Ederington and Minier (2003)、 List and Co (2000) 則是運用在環境污染方面，Van and Azomahou, 2007)的研究則在探討森林砍伐的庫茲涅現象。

至今為止， EKC 應用在有關水的研究，大部分都是針對水污染，很少針對

水資源的稀少性提出論述。例如：Tsuzuki (2008) 分析 8 個靠海或湖邊國家的民生用水污染指標是否具有庫茲涅現象，模式中，並分析安全飲用水比率，民生用水用量，以及其他衛生或經濟指標對民生用水污染指標的影響。Ito et al. (2007) 則分析用水特性和經濟發展的相關性，用以協助肯亞政府評估改善用水供應。AQUASTAT (2011) 利用世界各國的用水資料，以 2000-2005 年的數據，以每單位人口的用水量為橫軸，以每單位人口的用水量為縱軸，發現從用水量的歷史記錄看，似乎有逐漸向上增加，到了某一高峰之後，再度下降的趨勢，亦即庫茲涅曲線有存在現象。

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，水資源的消費也跟著提高，此種因社會經濟產能的增加導致用水增加，稱之為規模效果。但隨著用水量提高，政府開始提出政策，要求降低用水，規範生產廠商改善技術，或改變國內產業結構。由於各種誘因，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，降低用水減少污染，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。

換言之，經濟成長所導致的結構效果，是用水降低的主要因素，亦即在高所得階段時，輕工業和服務業會代替重工業，亦即低能源或低資源產業變成所得的主要來源。此外，環保政策也是重要因素，許多耗能或耗水或高污染產業因為國內環保法規日趨嚴格，因而移往國外生產，或是利用進口替代國產。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。

一般而言，工業用水效率或資源使用效率的衡量都以工業生產價值 GDP_{ind} 與用水量(資源使用量) Z 的比率，表示製造業的用水效率，也可以稱之為用水生產力(water productivity)。亦即

$$\eta = \frac{GDP_{ind}}{Z} \tag{1}$$

部分學者透過 DEA 方法，用來計算各國環境績效或資源使用效率，例如 (Färe et al., 2004; Taskin and Zaim, 2001; Zofío and Prieto, 2001, 或不同部門或廠商的環境績效比較例如 Bevilacqua and Braglia, 2002; Hadri and Whittaker, 1999;

Hailu and Veeman, 2001; Jung et al., 2001; Reinhard et al., 2000; Sarkis and Cordeiro, 2001。Schandl and West (2010) 企圖了解亞太地區的資源使用效率，也是以每單位國民所得所耗用的資源用來計算資源效率。其研究結果發現此一區域的資源使用量增加，但資源效率卻下跌。Tiejun (2011) 分析計算煉鋼廠的鐵資源效率，其計算公式以每單位產品中所使用的鐵量作為資源效率的計算公式。

導致用水效率不彰的原因，有各種看法，例如 Ahmad (2000）認為水權定位不當，是導致用水效率不彰的主要原因。Speelman et al. (2010a, 2010) 則主張水權制度不良或定位不明確，所制訂的水價不見得會產生效率狀態，且會使用戶對水資源產生不適當的評價。許多學者也認為制度上的缺失使得水價收入無法彌補水資源成本而產生用水效率不彰 (Gandhi and Namboodiri, 2009; Herath, 2009; Pagan, 2009)。改善用水效率用以降低水資源需求，並不是一蹴可幾，部分研究認為經濟誘因比用戶的心理特質會影響用水需求 (Corral-Verdugo et al., 2002; Gregory and Di Leo, 2003)。但許多學者也發現 一些障礙會影響用水行為(Barta, 2004)。例如，由於水價過於便宜，用水成本佔廠商生產成本之比例極小，因此廠商並不太重視用水方面的投資，例如廢水回收再利用設施，以增加用水自備率。以廠商的立場而言，管理成本可能比浪費損失還高，因此，要求廠商自行減少用水浪費，似乎比較困難。企業界主要仍然以營利為目的，在目前的水資源價格制度下，廠商自行進行水廢水回收，或投資設備開發用水供應的不多。各工業區廢水處理廠，幾乎不考慮回收水的再利用，導致國內目前廢水回收率僅達到52%，遠低於先進國家。例如日本在平成 9 年，汙水回收再利用，就已經佔工業用水的 77.9 %。臺灣的工業用水回收率在 2004 年只有 32 %， 到今年預估也只達到 60%而已（經濟部水利署，2011）。事實上，已有部分研究指出回收水用

來澆灌高爾夫球場，不僅減少新鮮水（淡水）水費，而且還能提升球場的景觀。在民生用水中，廁所沖洗就佔 30%，因此，回收水的再利用，應該有其市場性。Chen (2007) 考慮都會區中水具有水質與水量穩定的特性，提出中水回收系統，建議政府建立中水道二元供水系統，將回收水供給附件居民的澆灌之用，或農業灌溉，或工業用。另外，廠商可以自行分析各類製程現況所需的用水品質，加以分類，亦即對製程、冷卻、鍋爐、民生及其他用途的用水品質需求分成不同等級，再安裝不同等級的用水輸送系統，亦即使用過後的水資源透過簡單處理，則可以用於低級需求上。如若需要高級用水，在考慮外購自來水或自行處理成更高級水。如此，可以大幅降低用水量並提高用水效率。水資源是屬於再生性資源，用過的廢水，透過廢水處理後的放流水，可以進一步的透過各種方法，例如過濾、奈米級膜、蒸餾、逆滲透、活性碳/離子交換等方式，恢復水的品質。換句話說，水資源回收再利用可以提升水資源利用效率。另外，廠商透過水資源淨化設施的設置，資行蒐集雨水、或鄰近社區的中水，自行淨化處理達到可以使用的品質，亦是提高水資源利用效率的重要方法。這些新增供水系統，都可提高水資源的再利用效率，以取代其他水資源的需求。

四、研究方法

本計畫為三年期計畫，針對各年度的研究目的，分別採用不同的研究方法，第一年運用panel data 與統計迴歸模式、探討國內總體水資源與一般社經變數的關係、第二年 運用panel data 與隨機前緣法(stochastic frontier approach)分析國內產業的用水效率 、第三年建構數學模式，以政府立場，制訂最適廠商用水自備率，並以敏感性分析，來檢討自備率的制訂對產業的生產與產品價格的影響。

本計畫所採用的 EKC 模式也納入許多社經變數，分別如下：

$$E_t = \alpha_0 + \alpha_1 I_t + \alpha_2 I_t^2 + \alpha_3 I_t^3 + \alpha_4 Ind_t + \alpha_5 Ser_t + \alpha_6 P_t + \alpha_7 edu_t + \alpha_8 Tech_t + \varepsilon_t \qquad (1)$$

式中，I_t代表GDP，Ind_t與Ser_t代表產業結構，其中，Ind_t是工業產值佔國民所得比率，Ser_t是服務業產值佔國民所得比率，P_t代表水價，edu_{it}代表教育水準，$Tech_t$則是技術水準。本計畫所運用的有關一般用水量、水價等追蹤資料取自經濟部水利署統計年報，國民所得、產業結構、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一直保持成長趨勢，但用水總量則起伏不定。在1991年平均個人國民所得為9,016美元，到了2009年成長至16,353美方。歷年用水量從1991年的176.75 億立方公尺成長到2008年的189.19億立方公尺，然後，持續下降，在1998年的總用水量則是179.35 億立方公尺。2008年國內總用水量若按產業別分，則農業最大部分，用水量為129.6億立方公尺，佔總用水量的72.26%，生活用水量則是33.57億立方公尺，佔總用水量的18.72%，工業用水居於末位，使用16.88億立方公尺，佔總用水量的9.41%。

假設廠商的生產技術為Cobb-Douglas 函數，生產投入要素有只有只有兩種，用水x與資本K，即$q = \mathrm{A} x^{\alpha} K^{\beta}$。

當政府制定用水自備率s時，廠商將以追求成本最低為決策目標，因此，廠商所面臨的問題如下：

$$Min \quad w_x \mathrm{x} + w_k K + f(sx) \qquad \text{(P1)}$$

$$\text{s.t.} \quad q = \mathrm{A} x^{\alpha} K^{\beta}$$

問題(P1)中的w_x與w_k分別表示用水價格與資本價格，是外生變數，廠商無法控制；$f(sx)$則是廠商為因應用水自備率所投入的成本，是自備用水量的函數，亦即是自備率乘上用水量的函數。問題(P2)的 Largrange 函數如下：

$$L = w_x x + w_k K + f(sx) + \lambda (q - A x^{\alpha} K^{\beta}) \tag{7}$$

式子(7) 針對x 與K分別偏微分，得

$$\frac{\partial L}{\partial x} = w_x + s f'(sx) - \lambda A \alpha x^{\alpha-1} K^{\beta} = 0 \tag{8}$$

$$\frac{\partial L}{\partial K} = w_k - \lambda A \beta x^{\alpha} K^{\beta-1} = 0 \tag{9}$$

$$\frac{\partial L}{\partial \lambda} = q - A x^{\alpha} K^{\beta} = 0 \tag{10}$$

廠商的最適用水量與資本量可以從求解上列的一階導函數(8)—(10)得到:

$$K = K(s, q) \tag{11}$$

$$x = x(s, q) \tag{12}$$

政策設計者所面臨的問題可以如下式表示：

$$\underset{s}{Max} \int P(q)dq - w_x x - w_k K - f(sx) + B(s) \tag{P2}$$

問題(P2)中$P(q)$代表廠商所面臨的產品需求函數，前四項表示廠商所得扣除廠商成本，$B(s)$則是表示自備率的制訂所帶來的社會利益。將(11)和(12)代入(P2)，對s 微分，最適用水自備率即可求解。

五、結果與討論

本計畫的實施，至今為止，共產生4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The optimal reuse of reclaimed water: a mathematical model analysis（本文已刊登在Water Resources Management, 28, 2035-2048, 2014）: 主要的目的在探討國內水資源缺乏的狀況下，政府如何制訂各種產業的用水自備率，引導廠商考慮投資設備，創造『自備』水源，透過節水、廢水回收、製程改善等方面來

降低用水量，增加用水效率。本文透過數學模式，分析最佳之用水自備率，並以數值模擬方式，分析其結果並做敏感性分析。

第二篇An analysis on domestic water management performance across regions in Taiwan（本文已刊登在Water Policy, 16, 704-719, 2014）：本篇主要的目的在分析國內現有國內各地方政府的水資源管理效率，分析影響管理效率的因素，並提出適當的管理策略，給政府相關單位參考。

第三篇The estimation of water shortages through the test of environmental Kuznets：本篇論文分析國內水資源的使用情形，是否有庫資錼現象，亦即：用水量在達到高峰之後，是否會隨著國民所得的提高而下降，用以檢視水資源的使用是否具有自我調整的特性，並探討所得之外如產業結構、技術進步、水價等其他變數對用水量是否有顯著影響。

第四篇：A performance comparison of waste water treatment plants ：本篇論文主要探討國內廢水處理廠的經營績效，並檢視影響績效的可能因素。由於水資源逐漸缺乏，鼓勵廢水處理廠進行回收工作，以彌補水資源不足。

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計畫成果自評

本計畫的研究目的在探討如何制定適當的水資源管理政策，用以鼓勵廠商

(工用水)透過廢水回收或雨水回收系統，自備水資源；改善設備或製程以減少用水量，以提高水資源用水效率。本計畫執行至今，總共完成4篇論文，部分尚在進行中，所完成的論文部分已投稿國際期刊，其中。二篇已經被國際期刊且已刊登，分別刊登於Water Resources Management, 28, 2035-2048，2014，題目：The optimal reuse of reclaimed water: a mathematical model analysis 和 Water Policy, 16, 704-719, 2014, 題目：An analysis on domestic water management performance across regions in developing countries。另外二篇也已投稿國際期刊，尚在審稿中，可望在很快時間內接受。

所完成或發表之論文，都是針對國內水資源現況，探討影響水資源發展的主要因素，並以政府立場，提出適當的策，用以鼓勵廠商提高水資源的用水效率。在學術成就上，本文不僅提出理論性架構，探討水資源的相關議題，以及政府制訂政策時所必須考慮的因素，同時，也分別針對國內水資源的使用，以及廢水處理與回收的管理問題，提出分析與檢討。

已刊登之論文中之第一篇，主要是提出指標，用來測量國內水資源管理績效。本論文的資源管理績效著重在新鮮水的消費與廢水處理的績效，本論文同時比較都會區與鄉村地區的績效，發現地域性差異確實存在。另外，下水道普及率、志工參與率、以及教育水準，也都會影響績效表現。已刊登之論文中之第二篇，主要是探討廢水處理廠所產生之再生水，如何引導至工業內使用，本文分別站在政府立場，廠商立場，對再生水的使用所產生之成本衝擊，提出數學理論模式，所產生之解答，再利用模擬方式，以現行廠商之用水量、用水成本（亦即水價）、再生水生產成本等資料，輸入模式，用以驗證理論模型。

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

臺灣的水資源現況以及水資源的運用作依據，分析影響水資源發展的因素。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，利用過去水資源的消費與水資源再生的數據，用來檢視政府過去的水資源政策，更能一針見血診斷出政策制訂的盲點。

由於水資源具有循環與再生性，因此，廢水回收或海水淡化的生產技術，必然影響其相對競爭地位與未來水資源的供應趨勢。目前，國內在此一領域的研發，上屬新興狀態，所需設備大都依賴進口，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水資源的發展，不僅影響民生，對於產業發展，也具關鍵性地位。因此，如何提出適當獎勵政策，鼓勵廠商研發，開發水資源的生產技術，以增強產品的競爭力，促進經濟發展。這是未來可以進一步研究的議題。本計畫的研究結果顯示，政府制訂適當的用水自備率，可以刺激廠商尋找替代水資源，加強節水生產技術，另外，政府可以考慮公共輸水管，除了新鮮水水管之外，可以增設回收水水管，使用於澆花、洗車、廁所沖水等用途。

以目前技術水準，如果廢水回收的再生水，要代替新鮮水，其成本則遠高於一般用水之產生成本，因此，如何透過政策，鼓勵廠商加強回收技術研發，降低再生水的製造成本，對於水資源的維護與發展，將會有正面性的影響，這些議題，也可以作為後續的研究。本論文不僅有理論上之依據，且配合實務上之需要，因此，在面臨水資源的今日，所得的結果，不僅有學術之價值，更具有實務上的應用價值。

附件一：The optimal reuse of reclaimed water: a mathematical model analysis

Abstract

As recycling effluent from municipal sewage plants is technically a feasible way, this paper presents a mathematical model to analyze the extent to which effluent should be reclaimed for industrial use and examine the factor affecting reuse of reclaimed water. The resulting data shows that the low price of fresh water leads to reduced use of reclaimed water and impedes the investment of the effluent purification plant. A mandated regulation on the substitution rate of reclaimed water is suggested to impose on the industry. Theoretically, the optimal substitution rate as well as the water quality is determined by maximizing the total social welfare that results from the construction of conveyance channels and effluent purification plants. A case example is employed to derive the optimal substitution rate and water quality of reclaimed water. Through the numerical analysis, an effluent plant for treating 20,000 kl/day effluent with the substitution rate of 21.24% is selected as the optimal solution.

Keywords: recycled effluent; reclaimed water; substitution rate; sewerage systems; sewage treatment

1. Introduction

Taiwan government calculates that the total demand for water reached 20 billion kl in 2012 but the current water resources can supply 19.2 billion kl only (Taiwan EPA, 2013). This means a water supply shortage of 0.8 billion kl has taken place. Due to water resources scarcity, the government encourages the industry to recycle the waste water and to use it. However, Taiwan’s industry response to the reuse of reclaimed water is not satisfied though most of researchers suggest recycling gains the priorities among the alternatives. In 2010, the water consumption for industrial use reached 1,628 million kl. About 670.73 million kl was supplied from water works accounting for 41.2%, and 957.27 million kl was extracted from ground water, accounting for 58.8% of total water consumption (Water Resources Agency, 2013).

Some researchers suggest that the reuse of reclaimed water can bring about the benefit in reducing the overconsumption of natural water resources and also enhancing ecological river rehabilitation (Deason et al., 2010. Palmer et al., 2005) and some other researchers suggest that water reclaimed from sewage is recognized as a potential intervention strategy in addressing waster scarcity (Hamoda, 2004). In fact, effluent has become a valuable resource and is seen as an alternative source of water resources. However, Taiwan discharged 2,280,000 kl/day of effluent from the municipal sewage treatment plant to the sea or rivers in 2010, and only 2,960 kl/day of municipal effluent was reclaimed for industrial use. The recycling rate was 0.013% only. This implies that the reuse of reclaimed water in Taiwan seems to be negligible.

As the recycled effluent may help the country to ride out the storm in case of water shortage, the effluent can be seen as potential resources and should be seen as a public good. With the improved technology of waste water treatment, the water quality of reclaimed water is more and more improved, even superior to fresh water. For example, the NEWater plants in Singapore have reclaimed water from waste water for drinking use. The quality of reclaimed water meets the drinking water standard, having less than one NTU (Nephelometric Turbidity Units) turbidity with nitrogen levels below the 10mg/L (PUB, 2012).

Many researchers focus on reclaimed water in irrigation use, but very few on the industrial use. For example, Carr et al. (2011) survey Jordanian farmers to explore the quality perception of reclaimed water through a semi structured interview. Yang and Abbaspour (2007) employ a linear programming model to analyze the reuse possibility of reclaimed water at different level of wastewater charges and reuse prices. They find that wastewater reuse potential is high at competitive prices when the reclaimed water is used for agricultural irrigation and recreation amenities. Hamilton et al. (2005) examine the reuse of reclaimed water for the horticultural industry regarding policy, economics, market access, pragmatic directives (such as state and federal guidelines), environmental impact, agronomic sustainability, and public health.

Considering the huge economic loss due to insufficient supply of water in industrial sector, the application of reclaimed water may become feasible. And thus, this paper suggests that a substitution rate of reclaimed water should be regulated on the industry. This paper aims at exploring the potential for the increased reuse of reclaimed water from municipal sewage treatment plants in Taiwan. Firstly, mathematical models are presented for the analysis of private optimum and social optimum with sensitivity analysis. Secondly, a case example is also presented by analyzing the cost comparison among several alternatives. Thirdly, some suggestions are developed and presented for policy maker’s reference.

2. The framework

The flowsheet of the production and use of reclaimed water is depicted in Figure 1. In general, the reclaimed water is generated through an advanced treatment for effluent from secondary municipal sewage treatment plants. In this paper, such an advanced treatment is called “effluent purification plant”. Without the effluent purification plant, the effluent is in general discharged to the sea or rivers. This paper assumes that the effluent purification plant may receive sufficient amount of effluent from the municipal sewage treatment plant at free costs, and purifies it to a certain level of water quality according to the industrial water requirements. This means that no externalities occur by using the recycled effluent for industry use.

Insert Figure 1 about here

Let E denote the effluent discharged by the secondary sewage treatment plant with a given water quality q_0. The service of effluent conveyance has a property of natural monopoly which is characterized with the decreasing average cost as consumers increase. The natural monopoly exhibits losses when the price (the service charge of effluent conveyance channel) is determined to attain social optimum at the point where the price equals to the marginal cost. Thus, a governmental regulation is required. This paper assumes that the conveyance channel of effluent from the municipal sewage treatment plant to the effluent purification plant is constructed by the government. The construction cost of the conveyance channel is a function of the amount of effluent flow and pipe length, and the distance from the sewage treatment plant to the purification plant is fixed and given. The total cost for the conveyance of effluent is the sum of the depreciation costs, operation and maintenance (O&M) costs of conveyance channel including the administration fee, the fixed personnel fee, water quality testing fee, repair parts and other cost incurred. And thus, the annual total cost for the supply of municipal effluent is expressed as $f(E)$. The marginal cost of effluent conveyance is seen as the supply of municipal effluent, expressed as

$$\mathrm{MC} = f'(E) \tag{1}$$

with the property of $f'(E) > 0$, and $f''(E) < 0$, where prime and double prime denote the first and second derivatives, respectively.

On the other hand, the industry is assumed to be responsible for the construction of an effluent purification plant to upgrade the raw effluent to a chosen level of water quality q through a variety of advanced operations such as filtration, MBR (membrane biological reactor), RO (reverse osmosis), activated carbon adsorption, ion exchange and so on. The unit purification cost h of water quality improvement is assumed to be a convex function of q, i.e.

$$h = h(q), \quad h'(q) > 0, \quad h''(q) > 0 \tag{2}$$

where $q_0 < q < 1$. In general, the water quality q of purified effluent lower than fresh water that equals to unity. As the reclaimed water has lower quality than fresh water, the water quality q may be seen as fresh water equivalent. When $q = 1$, the reclaimed water R is indistinguishable from fresh water. The purified effluent (reclaimed water) serves as cooling water or other use in industrial sectors and substitutes a portion of water demanded in the industry based on the water quality q of reclaimed water.

This paper also assumes that a Cobb-Douglas production function for the industry, expressed below:

$$y = AK^{\beta_1}W^{\beta_2} \tag{3}$$

where y represents the industry output, K represents the capital investment for the effluent purification plant, W is the water used for the production, β is technology parameters, and A is the constant absorbing other productive factors like labors and lands. The capital investment K is assumed to be the multiplication of the output of reclaimed water R and the unit purification cost $h(q)$, i.e.

$$K = h(q)R \tag{4}$$

To simply our analysis, let

$$\alpha\ (q) \ = \ \frac{1}{h(q)} \tag{5}$$

Eq. (4) is rearranged and yields

$$R \ = \ \alpha\ (q)\ K \tag{6}$$

The water used W for the production is the sum of fresh water F and reclaimed water R, i.e.

$$W = \ R \ + \ F \tag{7}$$

Substituting Eq. (6) into Eq. (7) yields

$$W \ = \ \alpha\ (q)\ K + \ F \tag{8}$$

Substituting Eq. (8) into Eq. (3) and taking the logarithm of Eq. (3) yield

$$\ln y \ = \ \ln A \ + \ \beta_1 \ln K \ + \beta_2 \ln(\alpha(q)K + F) \tag{9}$$

The relationship between inflow municipal effluent E and the reclaimed water R is expressed as

$$R = \ \gamma\,(\,q\,)\,E \tag{10}$$

where γ represents the recovery rate of reclaimed water with properties of $0 < \gamma\,(\,q\,) < 1$ and $\gamma'(q) < 0$. To simplify our analysis, let

$$\delta\,(\,q\,) = \ \frac{1}{\gamma(q)} \tag{11}$$

Substituting Eq. (11) into Eq. (10) yields

$$E = \delta\,(\,q\,)\,R \tag{12}$$

Substituting Eq. (6) into Eq. (12) yields

$$E = \delta\,(\,q\,)\,\alpha\ (q)\ K \tag{13}$$

We assume that the industry aims to seek for minimizing the cost subject to its production constraint of Eq. (9). Hence, the minimization problem is shown below:

$$\underset{K,F,q}{Min} \quad C = p_1 K + p_2 F + p_3 E$$

$$= p_1 K + p_2 F + p_3 \delta(q)\alpha(q)K \qquad \text{(P1)}$$

s.t. $\ln y = \ln A + \beta_1 \ln K + \beta_2 \ln(\alpha(q)K + F)$

where p_1 denotes the investment cost for the effluent purification plant, p_2 is the price of fresh water, and p_3 the service charge for effluent conveyance. The first order conditions of the cost minimization problem are derived:

$$p_1 + p_3\,\delta(q)\alpha(q) - \lambda\left(\frac{\beta_1}{K} + \frac{\beta_2\alpha(q)}{\alpha(q)K+F}\right) = 0 \qquad (14)$$

$$p_2 - \lambda\,\frac{\beta_2}{\alpha(q)K+F} = 0 \qquad (15)$$

$$p_3\,\delta(q)\alpha'(q)K + p_3\,\delta'(q)\alpha(q)K - \lambda\,\beta_2\left(\frac{\alpha'(q)K}{\alpha(q)K+F}\right) = 0 \qquad (16)$$

where λ is the Largrangian multiplier. The simultaneous equations of Eq. (14) –(16) are necessary conditions for the firm to obtain the optimal size of purification plant, the consumption of fresh water, and reclaimed water quality. Integrating Eq. (15) and (16) by removing λ and F yields

$$p_3\,\delta(q)\alpha'(q) + p_3\,\delta'(q)\alpha(q) - p_2\,\alpha'(q) = 0 \qquad (17)$$

The optimal water quality q^* is determined based on Eq. (17), implying that the optimal point q^* depend on the recovery rate $\gamma(q)$ $(=\frac{1}{\delta(q)})$ and the purification cost function $h(q)$ $(=\frac{1}{\alpha(q)})$. In practice, the change of recovery rate is much small than the change of purification costs as the water quality of reclaimed water is improved. And thus, we assume that $\gamma'(q)$ approaches to zero. As $\delta'(q) = -\frac{\gamma'(q)}{\gamma^2(q)}$,

$\delta'(q)$ also approaches to zero. By simplifying Eq. (17) we get

$$\gamma(q) = \frac{p_3}{p_2} \tag{18}$$

Theoretically, Eq. (18) indicates that the optimal water quality q^* should be set at the point that the recovery rate equal to the ratio of effluent conveyance costs and fresh water price. Since $\gamma'(q)$<0, the higher fresh water price or the lower effluent conveyance costs may rise up the water quality of reclaimed water. Integrating Eq. (14) and (15) by removing λ yields

$$F = \frac{\beta_2 K(p_1 + p_3\alpha(q)\delta(q)) - p_2\alpha(q)K(\beta_1 + \beta_2)}{\beta_1 p_2} \tag{19}$$

Substituting Eq. (19) into Eq. (9) and removing F yield

$$\ln y = \ln A + \beta_1 \ln K + \beta_2 \ln(\alpha(q)K + \frac{p_2 K(p_1 + p_3\delta(q)) - p_2\alpha(q)K(\beta_1 + \beta_2)}{\beta_1 p_2}) \tag{20}$$

As the optimal water quality q^* is obtained by Eq. (17), the optimal size K^* of the effluent purification plant can be determined by Eq. (20) and then the amount of fresh water F^* is determined by Eq. (19).

With restricting 0 <β_1< 1, 0 <β_2<1 and ($\beta_1 + \beta_2$) <1 that implies a decreasing return scale, a sensitivity analysis is conducted and the result is listed in Table 1. The fresh water price p_2 has a positive effect on both the plant size K^* of the effluent purification plant and the reclaimed water quality q^*, but negatively influences the consumption of fresh water F^*. If the investment capital cost p_1 increases, the size K^* of the effluent purification plant is reduced, the consumption of fresh water F^* increase but the reclaimed water quality q^* is not affected. An increase in service charge p_3 (effluent conveyance costs) may reduce the plant size K^* and the reclaimed water quality q^*, but result in the increase in the consumption of fresh water F^*. The higher industrial output y may bring about larger plant sizes K^* and more fresh water consumption F^*, but does not provide impacts on the water quality q^*.

Insert Table 1 about here

The optimal solutions of K^*, F^* and q^* for Problem (P1) is derived based on a given service charge p_3 for effluent conveyance. Theoretically, p_3 is determined by the supply of effluent conveyance and the demand for effluent. By substituting Eq. (13) into Eq. (20) and removing K, we get the demand function for effluent, listed below:

$$\ln y = \ln A + \beta_1 \ln h(q)\gamma(q)E +$$

$$\beta_2 \ln(\gamma(q)E + \frac{\beta_2 h(q)\gamma(q)E(p_1 + p_3\delta(q)) - p_2\gamma(q)E(\beta_1+\beta_2)}{\beta_1 p_2}) \qquad (21)$$

Eq. (21) is seen as a demand function for the service of effluent conveyance that links the relationship between the service charge p_3 and the effluent demanded E. Taking the derivative of E in Eq. (21) with respect to the production output y and the fresh water price p_2, and the capital costs p_1, we obtain $\frac{dE}{dy} > 0$, $\frac{dE}{dp_2} > 0$, and $\frac{dE}{dp_1} < 0$. These results demonstrate that the effluent demanded E is positively affected by the production output y and the fresh water price p_2, and inversely by the capital costs p_1. Theoretically the higher fresh water price may bring about more demand for effluent (reclaimed water) and the industry may pay higher price of service charge for effluent conveyance.

Based on Eq. (21), the optimal size K^* for the effluent purification plant is negatively affected by the fresh water price. In other words, the low price of fresh water plays the major factor to discourage the reuse of reclaimed water and the installation of the effluent purification plant. Currently, the water cost accounts for about 0.5% of the total production cost for industrial outputs (Water Resource Agency, 2012) and thus the benefit arising from water saving is very little and economically it cannot encourage private firms to improve water consumption and/or the reuse of reclaimed water.

3. The policy maker’s perspective

As the municipal effluent is generally seen as a public good and valuable water resource, the governmental intervention is needed to encourage the production and the reuse of reclaimed water. This paper suggests that a substitution rate of reclaimed water is regulated on the industry, i.e. a portion of water intaking should be supplied from reclaimed water, i.e.

$$s = \frac{R}{W} = \frac{R}{R+F} \tag{22}$$

where s is termed the substitution rate. The policy maker’s objective is to maximize the total social welfare that is measured in terms of the profit produced by the two parties: the municipal effluent supplier (the conveyance channel investor) and the demander (the effluent purification plant), through the optimization process of the amount of investment, the water quality of recycled effluent and the substitution rate. The maximization problem for total social welfare is expressed below:

$$\underset{K,q,s}{Max} \; p\,y - (p_1 K + p_2 F + f(E))$$

Substituting Eq. (3) and (22) into the problem and removing y , E and F yields

$$\underset{K,q,s}{Max}\; p\; AK^{\beta_1}(\frac{\alpha(q)}{s}K)^{\beta_2} - (\, p_1 + \; \alpha(q)\; p_2 \frac{1-s}{s})K \; - f(\delta(q)\alpha(q)K) \qquad \text{(P2)}$$

To reduce the complication, we assume that the marginal cost of effluent supply $f'(E)$ is c_1, i.e. $f'(\bullet) = c_1$. The first order conditions of maximization problem (P2) are obtained and listed below by taking derivatives with respect to K , q and s , respectively.

$$p\; A(\,\beta_1 + \beta_2)\, K^{\beta_1+\beta_2-1}\, (\frac{\alpha(q)}{s})^{\beta_2} - p_1 - (\frac{1-s}{s})\; p_2\, \alpha(q) - \delta(q)\; \alpha(q)\; c_1 -= 0 \qquad (23)$$

$$p\; A\; \beta_2\; K^{\beta_1+\beta_2}\; (\frac{1}{s})^{\beta_2}\, \alpha(q)^{\beta_2-1}\, \alpha'(q) - p_2\; (\frac{1-s}{s})\; \alpha'(q) \;\; -(\,\delta\; \alpha' + \delta'\; \alpha\,)\, c_1 = 0 \qquad (24)$$

$$p\; A\; \beta_2\; K^{\beta_1+\beta_2}\; \alpha(q)^{\beta_2}\; (s)^{-\beta_2-1} - \alpha(q)K\;\; p_2\; s^{-2} = 0 \qquad (25)$$

The optimal solutions of K^* , q^* and s^* can be obtained by solving the simultaneous equations of Eq. (23)- (25).

4. A Case Example

We applied the optimal solution derived from Problem (2) to an actual case in Taiwan. Tihwa Municipal Sewage Treatment Plant and Wuku Industrial Park are selected as the case example to demonstrate the solution of optimal points. The distance between the two parties is only about 7 kilometer. In 1979, Tihwa Municipal Sewage Treatment Plant started to operate, providing the service for the inhabitants of Taipei Municipal City with capacity 250,000 kl/day, and expanded its capacity to 500,000 kl/day with the production capacity 10,000 kl/day of reclaimed water in 2003. So far, the daily inflow of sewage for treatment is about 350,000 kl. About 310,000 kl/day of effluent is produced and discharged to the river every day through specific pipes. The average of biochemical oxygen demand (BOD5), chemical oxygen demand

(COD) and suspended solids (SS) of effluent from the plant are 14.9 mg/L, 23.2 mg/L, and 18.9 mg/L, respectively, which is below the national effluent standards. The dewatered cake of 350-500 tonnes containing at least 20% of solids is transported to land filling sites for final disposal. In contrast, the yearly output of Wuku Industrial Park is NT$ 380 billion (US$ 12.67 billion), contributed by 1,402 firms of various production plants including food and drink processing (65 firms), metal products (211 firms), machinery and parts manufacturing (224 firms), electronic, communication and audio-video manufacturing (192 firms), etc by employing totally 35,000 labors (New Taipei Industrial Park Service Center, 2013).

Considering the fresh water demand of the Wuku Industrial Park, this paper presents five plant capacity alternatives including 5,000, 10,000, 20,000, 50,000 and 100,000 kl/day for cost comparisons. In practice, many reclaimed water production plants have adopted the process of MF/UF/MBR+RO to remove the pollutants and pathogens, to discolor, and to deodorize. Different process may produce different water quality of reclaimed water for different use. The water quality of reclaimed water produced by an effluent purification plant may be classified into three levels based on different processes, shown in Figure 2. The water quality Class C is in general the simplest process, treated by traditional mechanical filtering with disinfection process (chlorination). It can remove the impurities of the size between 5-100μm (Fritzmann, et al., 2007). If the concentration of suspended solids is too high and diminishes the performance of the filter, a pretreatment of incoming effluent is required. The reclaimed water produced is, in general, suggested to be used for low quality requirements such as gardening, toilet flushing, and firefighting only in this paper.

Insert Figure 2 about here

The major role of the process for water quality Class B is MF (microfilter) and UF (ultrafilter) that are designed to remove particulates. More than 99% of solids larger than 2μm can be removed and the turbidity of effluent treated is less than 0.1 NTU. Some practical cases suggest using membrane bioreactor (MBR) systems can eliminate suspended solids through membrane separation and hence can remove a large portion of bacteria and viruses. Basically, the reclaimed water produced by the water quality Class B can be used for cooling, boiler, and a portion of process water.

In contrast, the process for the production of water quality Class A is more complicated including the Reverse Osmosis (RO) or Nanofilter (NF) in addition to the process for Class B to generate high quality reclaimed water. The NF/RO process can remove almost all colloidal or dissolved matter from an aqueous solution by separating the concentrate brine from the permeate which consists of almost pure water. Khosravi, et al. (2011) investigate the use of nanofiltration and low-pressure reverse osmosis membranes at two temperatures for wastewater treatment in the pulp and paper industry. The results of their research find nanofiltration can remove almost all color and organic compounds while a low-pressure reverse osmosis membrane is used in the later stage to remove monovalent anions and inorganic carbon. The NEWater plant in Singapore developed a process by combining the low pressure membrane technologies such as ultra filtration (UF) or micro filtration (MF) with RO to produce high quality reclaimed water for drinking use (Bixio, et al., 2006; Fritzmann, et al., 2007).

The costs comparison for the production of reclaimed water is conducted in this paper to evaluate the five capacity alternatives including 5,000, 10,000, 20,000, 50,000, and 100,000 kl/day of reclaimed water and three treatment alternatives including Water Quality Class A, B and C. The production costs of reclaimed water include the annual depreciation cost of conveyance channels and effluent purification plants and the recurring O&M costs. All the costs are estimated in NT$ for both conveyance channels and effluent purification plants. The piping systems to distribute the reclaimed water (the purified effluent) to industrial operations and the relevant instrumental parts such as pressure regulating valves, flow meter, and the storage tank are neglected in this paper. The data source involving various costs arising from the construction and operation of conveyance channels and effluent purification plants is described below:

(1) The construction costs and the O&M costs of conveyance channels are obtained based on the historical data for the effluent conveyance between Tihwa Municipal Sewage Treatment Plant and Wuku Industrial Park. The data of contracted price for the construction of sewerage systems are obtained from Mao (2011) that lists the total contract price, piping length, unit price, and geographical properties for all the bid projects entrusted by CPAMI in 2009-2010. The mid value of unit price for the construction of sewerage that ranges from NT$ 18,600 to 142,000 (equivalent to US$ 620 to 470) is taken as the base to estimate the cost for the construction of effluent conveyance channels. And thus, the estimated cost for the construction of 7 km long conveyance channel for 5,000, 10,000, 20,000, 50,000, and 100,000 kl/day is obtained. As the service life for the effluent conveyance channels is 60 years in practice (Mao, 2011), the depreciation cost for the effluent conveyance channels for each plant size is obtained. In the meantime, Mao (2011) suggests that the O&M costs for conveyance channels including the labor costs, the administration costs, operation costs, water quality testing fee, and basic maintenance fee can be estimated to be about 5% of construction costs.

(2) The capital expenditure differential for the construction of an effluent purification

plant between different treatment levels are assessed for each plant size by reviewing some reports in association with the construction of waste water treatment plants and consulting with several engineers working in engineering consultant companies. The construction costs of an effluent purification plant and its consequent O&M costs are obtained based on some empirical formulas suggested by Mao (20011). The cost function for a secondary treatment plant and a tertiary treatment plant is expressed by Eq. (22) and (23) respectively according to the empirical estimation formula presented in Mao (2011). In general, the reclaimed water obtained from the tertiary treatment plant can meets the water standard of Class B. As the secondary effluent is used as raw material for the production of various quality levels of reclaimed water in this paper, we see the cost difference between secondary and tertiary treatments as the production costs for Class B reclaimed water.

$$C = 4.9 \text{ x } 10^5 \text{ x } E^{0.7122} \tag{22}$$

$$C = 4.1 \text{ x } 10^5 \text{ x } E^{0.7890} \tag{23}$$

where E is the effluent treatment capacity of an effluent purification plant measured by kl/day.

The service life of an effluent purification plant can last for 30 years and thus, the depreciation cost is obtained.

(3) Mao (2011) suggests that the unit maintenance cost for the operation of a waste water plant depends on the effluent treatment rate, expressed below:

$$\text{Maintenance Cost} = 106.77 \text{ x } E^{-0.2891} \tag{24}$$

The costs of all options vary widely, depending on the size of the proposed effluent purification plant and the desired level of treatment. Table 2 presents the range of estimated costs for the production of reclaimed water based on a matrix of five capacity alternatives and three water quality alternatives. The average cost of reclaimed water production declines with the increase in plant sizes. For example, the unit production cost of Class A reclaimed water is reduced from NT$ 24.60/kl produced by the 5,000 kl/day plant to NT$ 15.39/kl by the 100,000 kl/day plant.

Currently, the water tariff of fresh water supplied by Taiwan Water Corp., owned and operated by the government, is NT$ 11.50/kl only. As the industry can choose between fresh water and reclaimed water (purified effluent), the users' acceptance depends on a logical constraint that the unit production cost should be lower than the fresh water price p_2. In consideration of the high gap between fresh water price and unit production cost of Class A reclaimed water, it seems that the acceptance of the Class A reclaimed water for industrial use should be supported by governmental subsidies or regulations. In the meantime, the economic comparison between fresh water and reclaimed water implies that reclaimed water of Class B and C may be used by Wuku Industrial Park for some particular applications.

Insert Table 2 about here

5. The selection of the optimal substitution rate

The estimated cost in Table 2 is obtained based on the full production at each plant size. In fact, the demand for reclaimed water may be limited for Class B or C reclaimed water that meets a portion of market demand only. In order to meet the practical world, the water balance diagram of Wuku Industrial Park is shown in Figure 3 describing the flow of water intaking to final applications in the industry. The total water intaking currently amounts to 94,159 kl/day, used for cooling (9,465 kl/day), processing (69,626 kl/day), boiler (6,356 kl/day) and living (8,712 kl/day), and the total waste water generated is 86,348 kl/day. The reclaimed water of water quality Class A can be applied to all units in the industry and completely substitute for all fresh water supplied. However, the reclaimed water with water quality Class B can be used for cooling use, boiler use and a portion of living use like gardening, toilet flushing, and fire fighting only while reclaimed water with water quality Class C is used for a portion of living only. And thus, the maximum substitution quantity is only 23,177 kl/day of reclaimed water for Class B and 4,356 kl/day for Class C, that is calculated according to Figure 3.

Insert Figure 3 about here

To obtain the optimal solution of Problem (P2), a given output y of NT$ 380 billion, currently produced by Wuku Industrial Park, is assumed. Since the policy planner attempts to maximize the social welfare presented in Problem (P2), the dual problem is employed to minimize the cost of ($p_1 K + p_2 F + f(E)$) subject to the given output y, where p_1 is calculated by the sum of unit depreciation cost and its consequent O&M costs for the effluent purification plant, the amount of fresh water consumed by the industry F is calculated based on the diagram of Figure 3, and the annual cost of effluent conveyance $f(E)$ is calculated based on the unit depreciation cost and O&M cost of conveyance channel. The fresh water price p_2 is changeable depending on the consumption level. According to the contract between Wuku Industrial Park and Taiwan Water Corp. the water tariff is NT$ 11.50 for the water consumption below 95 kl/day per hectare of plant area. If the water consumption is beyond the rationed value, Taiwan Water Corp. can refuse to supply or impose a 50% surcharge. As the land area of Wuku Industrial Park is 140.55 hectares, the fresh water supply at water tariff of NT$ 11.50 is limited to 13,350 kl/day.

The total annual cost for the 15 scenarios covering the five capacity alternatives and three water quality alternatives is listed in Table 3. The plant size of 20,000 kl/day with water quality Class B has the lowest cost among these alternatives and should be selected as the optimal solution. Compared to other options, the unit cost of the reclaimed water produced by the selected effluent purification plant (plant size of 20,000 kl/day with reclaimed water quality Class B) is NT$ 9.36 only (shown in Table 2). It is not the cheapest, but cheaper than the fresh water price. The reclaimed water produced by the selection can substitute 21.24% of fresh water. Therefore, the optimal substitution rate of 21.24% is obtained.

Insert Table 3 about here

The treatment level of water quality Class A may be a best solution for industrial use in the future if the price of fresh water rises up or the production cost decrease due to technology improvements. The visiting professor Aim indicates that the cost of reclaimed water produced by RO process has significantly decreased from $ 1.52/kl in 1991 to 0.48/kl in 2005 (Aim, 2012). The report made by GWI (2010) also shows that the average cost of reclaimed water produced by seawater desalination technologies declined continually from $ 3/kl in 1970 to 0.9/kl in 2010. The evolution of desalination technologies generally drives prices downward. Such a trend may expand the wide use of reclaimed water with water quality Class A in the future. Currently, the production cost of Class A reclaimed water ranges from NT$ 15.39 to 24.60 shown in Table 2, is still much higher than the fresh water price. The other possibility to increase the demand for Class A reclaimed water is to provide the financial subsidy (e.g. tax credits, loans) to the use of reclaimed water.

6. Discussions and Conclusions

The analysis results derived from both the theoretical model and the case example also highlight some key factors for the future improvement regarding the reuse of reclaimed water in Taiwan, discussed below:

(1) According to Eq. (20), the increased price of fresh water supplied may result in the higher demand for higher water quality of reclaimed water. The differential between fresh water price and reclaimed water price theoretically determine the substation rate. Currently the fresh water price is much lower than neighboring countries, and even cannot cover its costs. The water fee paid by each household in Taiwan accounts for about 0.5-0.6% of household expenditure, lower than 2-4% suggested by World Health Organization (Water Conservation Information, 2013). This article suggests that Taiwan’s water tariff should be adjusted to bring about higher water efficiency and to ascend the substitution rate of reclaimed water. Only the relative low price of reclaimed water in comparison with fresh water price can expand the substitution rate. This paper suggests increasing the water tariff from currently price of NT$ 11.5/kl to the unit production cost of NT$ 15.39/kl operated by a 100,000 kl/day plant with reclaimed water quality Class A. The rising of water tariffs may encourage not only the increase in the consumption of reclaimed water but also the reduction in household water consumption. However, the waterworks are operated by the government and the adjustment of fresh water price is determined more politically than economically, it seems difficult to make any change in the near future.

(2) Due to the properties of natural monopoly for conveyance channels, this paper suggests that the government should accelerate plans for the networks of effluent conveyance and reclaimed water to facilitate the expansion of effluent purification plants. If the effluent (the treated sewage by Tihwa Municipal Sewage Treatment Plant) of 310,000 kl/day discarded is purified by an effluent purification plant for production of Class A reclaimed water, the currently water consumption of Wuku Industrial Park can be saved.

(3) With water shortages experienced in the past years, industrial users are inclined to accept reclaimed water as a major water intaking source. According to the survey made by Industrial Bureau, more than 55% of firms in the industrial parks are willing to adopt the reclaimed water used for cooling, firefighting, toilet flushing, and scenic water systems (Industrial Bureau, 2013). However, industrial users concern about the quality standard of reclaimed water such as the high content of salts, nitrogen, phosphorus, toxic substances and pathogens in reclaimed water and its consequent risks. The low quality of reclaimed water used for processing, cooling, and boiler may result in scaling and dirt stick to the piping systems, and thus erode the piping systems. Eventually the use of reclaimed water may damage the product quality and leads to a loss.

Currently, the national standards for reclaimed water have not been established in Taiwan. In order to protect the public health and environment and to reduce the industry users' concerns, a simple and concise guideline and standard is required to assure that the water can achieve the desired performance objectives. Van der Bruggen, et al. (2010) analyze the underlying factors of water supply problems and suggest that sanitation is often kept a closed association with water supply systems. The stricter treatment standards may allow for increased use of reclaimed water (Qadir et al., 2010).

(4) The concept of integrated management has been widely accepted in the water resources and environmental management communities (Grigg, 1999; Margerumand and Hooper, 2001). Water management involves various kinds of interactions, e.g., between surface water and groundwater, or water resources and various human and environmental uses of those resources. Cascetta (1995) overviews the management practices in Italy with regarding to water, wastewater and water bodies and compares

the water industry in Italy with some other European countries. Seeking more water resources from a variety of source becomes very important to affect water supply in the future. Cook et al. (2013) suggest that rainwater intaking is a vital element of integrated urban water management approach and report that rainwater harvesting based on a communal approach can offer a variety of benefits including economies of scale for capital costs, reduced land footprint, centralized disinfection and flexibility in water supply to match water demand. Currently, Taiwan’s water management system is disintegrated into a variety of administrative units and thus it may bring about ineffective performance in conserving water resources due to the disperse authority system for the management of water resources.

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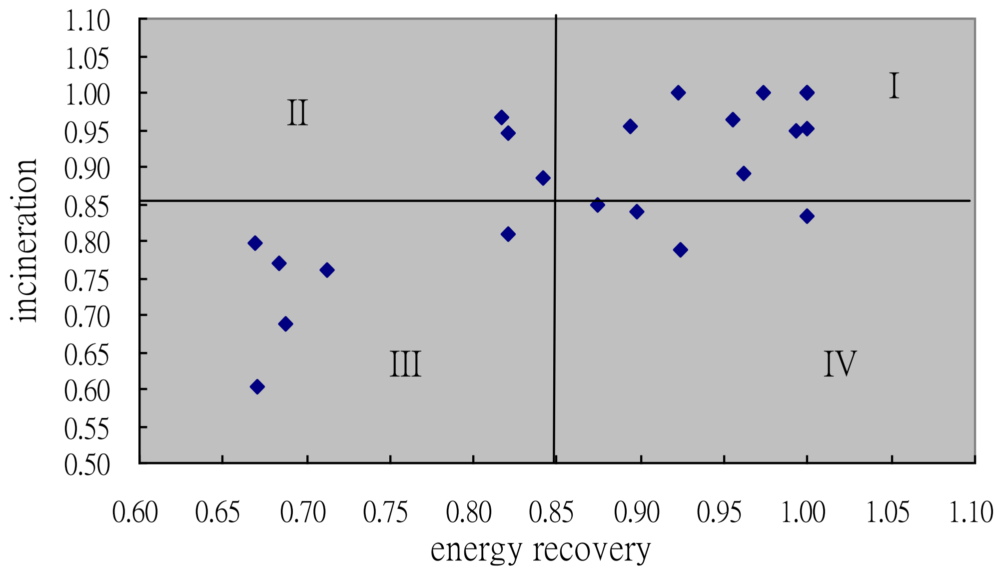

Figure 1. The matrix of incineration efficiency v.s. energy recovery efficiency

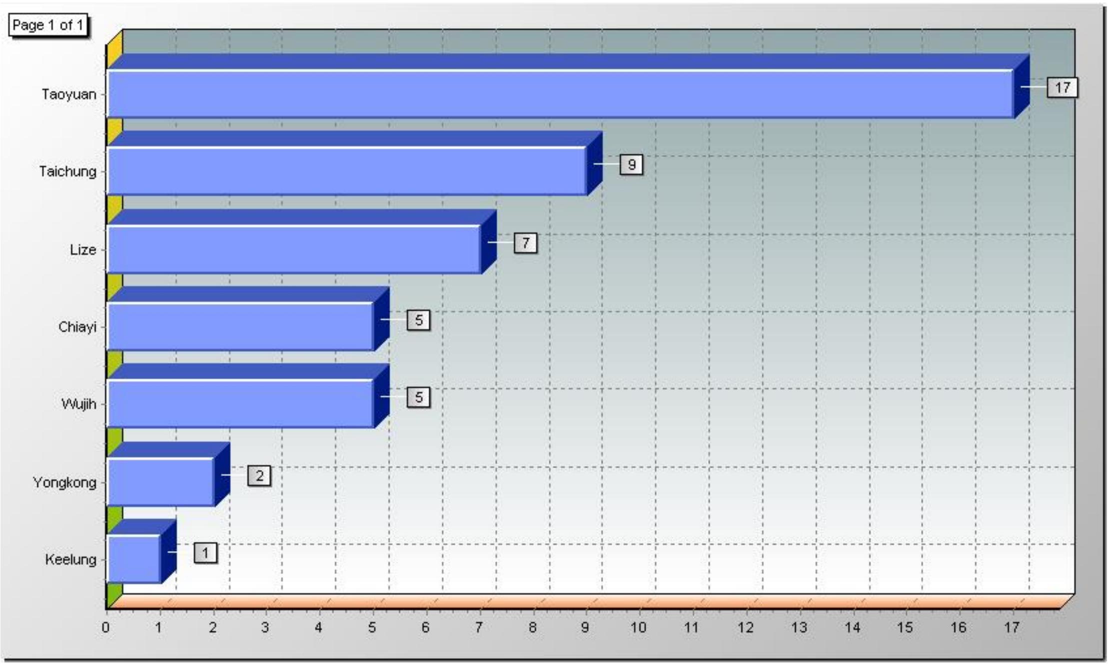

Figure 2. The reference frequency in the CCR model

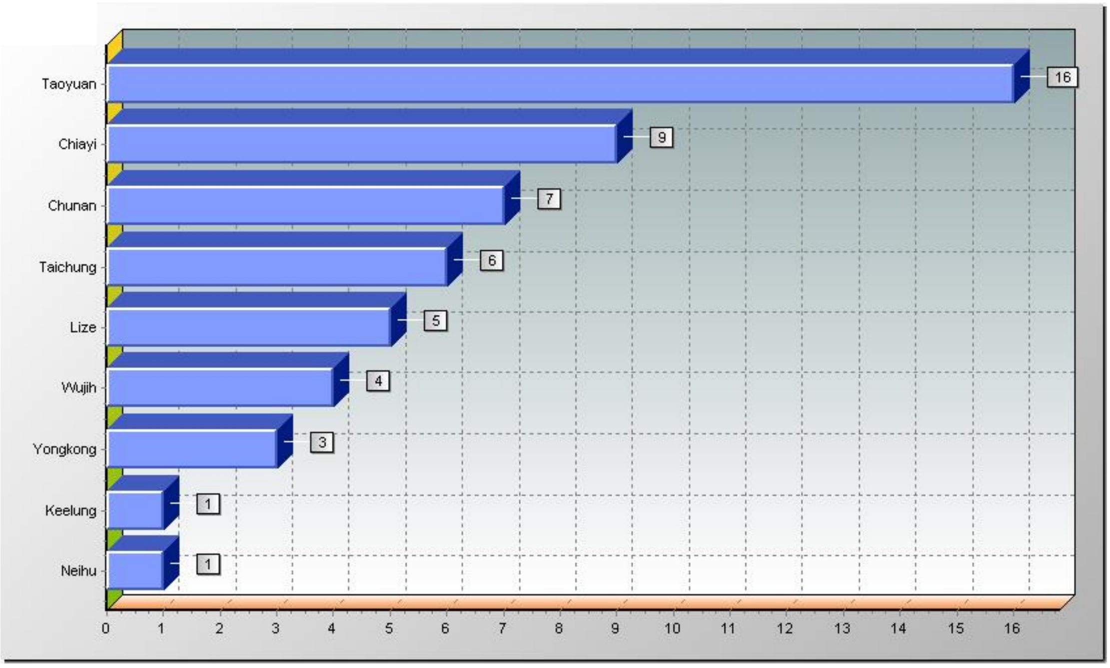

Figure 3. The reference frequency in the BCC model

Table 1. The result of sensitivity analysis

	p_1	p_2	p_3	y
K^*	-	+	-	+
F^*	+	-	+	+
q^*	0	+	-	0

+: positive effect, -: negative effect, 0: no effect

Table 2. The estimated unit production cost of reclaimed (unit: NT$/kl)

		5000 kl/day	10000 kl/day	20000 kl/day	50000 kl/day	100000 kl/day
Class A	Depreciation (channels) cost	0.58	0.40	0.21	0.10	0.05
	O&M (channels) cost	2.67	1.93	1.01	0.58	0.35
	Depreciation (EPPs) cost	15.47	12.66	10.79	9.21	8.31
	O&M (EPPs) cost	5.88	6.17	5.93	5.86	6.68
	Total unit cost	24.60	21.16	17.94	15.75	15.39
Class B	Depreciation (channels) cost	0.58	0.40	0.21	0.10	0.05
	O&M (channels) cost	2.67	1.93	1.01	0.58	0.35
	Depreciation (EPPs) cost	9.10	7.45	6.10	4.68	3.83
	O&M (EPPs) cost	2.35	2.20	2.05	1.83	1.67

	Total unit cost	14.70	11.98	9.36	7.19	5.90
Class C	Depreciation (channels) cost	0.58	0.40	0.21	0.10	0.05
	O&M (channels) cost	2.67	1.93	1.01	0.58	0.35
	Depreciation (EPPs) cost	7.28	5.96	4.88	3.74	3.06
	O&M (EPPs) cost	1.88	1.76	1.64	1.46	1.34
	Total unit cost	12.41	10.05	7.73	5.89	4.80

Table 3. The total annual cost of the industry under a given output of constraint

Unit (kl/day)		$p_1 K$	$p_2 F$	$f(Q)$	Total
Class A	5000	106700	1463200	16200	1586200
	10000	188300	1377000	23300	1588600
	20000	334400	1204500	24400	1563300
	50000	753600	687000	34000	1475000
	100000	1499000	0	40600	1539400
Class B	5000	57300	1463200	16200	1536700
	10000	96500	1377000	23300	1496800
	20000	***162800***	***1270400***	***24400***	***1457600***
	50000	325400	1270400	34000	1629800
	100000	549800	1270400	40600	1860900
Class C	5000	45800	1543300	16200	1605400
	10000	77200	1543300	23300	1643900
	20000	130200	1543300	24400	169800
	50000	260300	1543300	34000	1837600
	100000	439800	1543300	40600	2023800

附件二： An analysis on domestic water management performance across regions in Taiwan

Abstract

This study presents an indicator to measure the performance of domestic water management that focuses on raw water consumption and sewage treatment by using the DEA technique. The data is extracted from 22 counties/cities in Taiwan covering the period of 2009-2011, and eventually 66 observations are obtained. We compare the management performance between urban and rural regions and examine the factor that affects the performance variation by using the Tobit regression. The results find that a spatial inequality exists across urban regions and rural regions. The analysis results derived from the Tobit model find that the extent rate of sewerage systems, the volunteer participation rate, and the education level play significant roles in affecting management performance. An increase in each percent of the extent rate of sewerage systems, public participation and high level educated citizens may lead to an increase of management performance by 0.37339%, 0.9543%, and 0.9756%, respectively.

Keywords: domestic water consumption; water management; DEA; sewage treatment; sewerage systems

1. Introduction

The sustainable use of water is considered an important strategy to support and flourish water to achieve a sustainable society without undermining the integrity of the hydrological cycle or the ecological systems. Many researchers have focused on the issues of sustainability and present a variety of tools to measure it and argue that sustainability consists of three dimensions: economic, social, and environmental aspects. Some researchers suggest that water policy should aim toward sustainable management practices and be tailored to the social, economic, and environmental circumstances (Wong and Brown, 2009).

Among the solutions for sustainable use of water resources, water use efficiency is one of the major tasks. In the past, many researchers have focused on the policy discourses involving the efficiency evaluation, but most of them care more on the water application in agricultural fields. For example, Lilienfeld and Asmild (2007) examine the impacts of irrigation system types, as well as other variables, on irrigation water use efficiency by using the data of 43 irrigators in western Kansas between 1992 and 1999. Hernández-Sancho and Sala-Garrido (2009) focus on the technical efficiency analysis of waste water plants to improve the water reuse rather than domestic water consumption by using the Data Envelopment Analysis (DEA) approach. Bindra, et al. (2003) employ a case study to examine the industrial water use efficiency and suggest that the integration of desalination into a national water management plan to enhance competitiveness and conserve water resources. Lee, et al. (2011) examine the impacts of water conservation incentives on water demand and evaluate the consequential water savings and water use trend shifts after the implementation of water conservation practice.

Considering very few studies on the actual effect of efficiency discourses involving domestic water management, this paper attempts to compare the performance of domestic water management (PDWM) across regions in Taiwan and to examine the factor affecting the variation of management performance across regions. A DEA technique is employed to calculate the PDWM in this paper. DEA was pioneered by Charnes et al. (1978) based on the theoretical concept of frontier production developed by Farrell (1957). It is a linear programming technique to estimate production or cost efficiency by measuring the ratio of total inputs employed to total output produced for each decision making unit (DMU). It has been employed to evaluate the relative efficiency in various application and proved to be an effective approach in identifying the best practice frontiers. For example, a great number of literature employ DEA to calculate the technical efficiency and scale efficiency in power generation plants or energy industries (e.g. Pacudan and de Guzman, 2002; Pombo and Taborda, 2006; Vaninsky, 2006). Pacudan and de Guzman (2002) employ the DEA technique to evaluate whether privately-owned service enterprises are more efficient or not. Vaninsky (2006) estimates the efficiency of electric power generation in the United States by using the data during 1991-2004. Malana and Malano (2006) evaluate the productive efficiency of selected wheat areas in India to monitor the efficiency of water use by means of the DEA technique. Cooper et al. (2003) have provided a comprehensive description about theoretical backgrounds and applications of DEA. The major merits of DEA are (1) it can be easily applied to a multiple input–output framework to examine the relative efficiency of the examined power plants, and (2) it can produce detailed information on the efficiency of the unit, not only relative to the efficiency frontier, but also to specific efficient units which can be identified as role models or comparators (Hawdon, 2003).

Based on the concept of input-specific technical efficiency, this paper evaluates the management performance for domestic water across regions through the support of the DEA technique. We develop an indicator for the measurement of PDWM that focuses on both raw water consumption and sewage treatment. In addition, this paper also attempts to investigate the factors affecting the management performance. The Tobit model is employed to explain the PDWM score calculated by incorporating four explanatory variables that deal briefly with: a) the effect of infrastructure, especially, the extent rate of sewerage systems, b) the effect of public participation in environmental affairs, c) the effect of citizen’s education, and d) the effect of the government expenditure for environmental protection. Eventfully, some improvement strategies are provided for each region based on the presentation of an x-y plot of water consumption vs. the sewage treatment rate. The results derived from this paper may be valuable for policy makers to achieve a sustainable use of domestic water in Taiwan.

2. Research methods

2.1 Indicator of Management Performance for Domestic Water

Many researchers focus on the evaluation of water use efficiency and see it as the performance of water resource management. Based on classical engineering perspectives, water use efficiency is defined as water consumption per capita. In general, single item indicators for water resource management are easy to measure in suitable units using the correct scale of measurement[1], but it may be biased by the environmental status that distinguishes from each county/city to each county/city. In this study, we develop an indicator to measure the PDWM that may involve the policy, public, practice, procedure, decision and action at all levels of the society. This paper suggests that the domestic water management aims at not only the water saving and conservation through water consumption, but also the reduction of environmental impacts arising from the discharge of untreated sewage into the environment at the stage of post water consumption. Hence, an aggregate measure for sustainable use of water resources is more appropriate to evaluate the PDWM by integrating raw water consumption and the final disposal of sewage (waste water).

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[1] Van Halsem and Vincent (2012) investigate the use and abuse of definitions and applications of concepts of irrigation efficiency (IE), water use efficiency (WUE) and water productivity (WP).

In the early 1970s, Paul Ehrlich and John Holdren developed a model to describe the environmental impacts arising from human activities by means of a simplified form as I = PAT, where I is the environmental impact, P the population, A the affluence and T the technology (Miller, Jr. 1999). Many researchers employ this model to derive the status of T technology by using the data on I, P, and A (Sokka et al., 2007; Chen and Chen, 2012). In this paper, we modify this model into Iη = PAT, where η is the PDWM. Rearranging it yields

$$\eta = \frac{PAT}{I}. \tag{1}$$

Theoretically, technology level T plays an important role in affecting the negative impacts of water consumption. Trottier (2008, p. 206) argues that technology should be embedded within social processes when we focus on the performance evaluation. The technology improvement on final product redesign in consideration of environmental impact can reduce water consumption and pollution of discharged effluents. The final products and services, however, are equally distributed to both urban regions and rural regions. And thus, the technology level of products and services is considered the same in this paper and thus assumed to be constant.

In general, the environmental impact is generated from water use to final disposal of waste water (sewage) shown in Figure 1, where W_0 represents the environmental impact arisen from domestic water consumption due to the exhaustion of water resources, W_1 is the environmental impact due to the gray water discharged to the environment directly by households and untreated, W_2 is the environmental impact of the sewage that is treated by a simple septic tank, and W_3 is the environmental impacts of the effluent from the municipal waste water plants after treating the sewage that delivered from households through sewerage systems.

Insert Figure 1 about here

In most cases, water is seen as one kind of common resources and thus the water extraction is non exclusive and free in Taiwan. Under such a circumstance, the ground water is extracted very much and thus the over exhaustion of ground water has yielded a negative impact of land subsidence (Chen, 2012). The consumption of fresh water implies not only the exhaustion of water resources but also the consequent adverse impact on the environment. Hence, water consumption is employed to measure W_0 the negative impact on the sustainable use of water, and it is treated as an input item to evaluate the performance of domestic water management.

Compared to sewage, gray water is characterized with rapid decomposition of pollutants and thus it has a more immediate impact on the recipient body of water when it discharges to a river or a lake. In contrast, sewage consists of largely of organic matters that in general contain disease organisms. As most septic tanks installed in Taiwan are simply designed for a temporary solution, the discharge of effluent may in general generate adverse impacts to the environment. And thus, the amount of gray water discharged to the environment and the effluent from septic tank are seen as a proxy of W_1 and W_2. On the contrary, the effluent discharged from municipal waste water plants is seen as a positive impact on the environment since the effluent standard is regulated. And thus, the inverse of the effluent is employed to measure the environmental impact W_3.

The overall impact I in terms of W_0 (water consumption), W_1 (the gray water discharged to the environment), W_2 (the effluent discharged to the environment from septic tanks), and W_3 (the inverse of the effluent discharged from municipal waste water treatment plants) is expressed below:

$$I = v_0 W_0 + v_1 W_1 + v_2 W_2 + v_3 W_3 \qquad (2)$$

where v_0, v_1, v_2 and v_3 represent the weight for environmental impacts of W_0, W_1, W_2, and W_3, respectively. The affluence A is measured in terms of personal disposable income y. Substituting Eq. (2) into Eq. (1) yields

$$\eta = \frac{Py}{v_0W_0 + v_1W_1 + v_2W_2 + v_3W_3} \qquad (3)$$

The weights v_0, v_1, v_2 and v_3 is determined by the use of the DEA technique.

2.2 Calculation of domestic water management performance

Firstly, the performance of domestic water management (PDWM) is calculated by applying the DEA technique. Assume that N DMUs transform multiple inputs $x \equiv (x_1, x_m) \in \Re_+^m$ into multiple outputs $y \equiv (y_1, y_s) \in \Re_+^s$. The efficiency is used to describe the relative performance of the objective attainment and measured by the DEA method in this paper, stated in the form of a ratio as output/input. This paper employs the basic DEA model of CCR (Charnes, Coopers, Rhodes) to calculate the PDWM. The CCR model, under the hypothesis of constant returns to scale, is expressed as follows:

$$\begin{aligned} & Min \quad \theta \\ s.t. \quad & \theta x_0 - X\lambda \geq 0 \\ & Y\lambda \geq y_0 \\ & \lambda \geq 0 \end{aligned}$$

where y_0 is output, x_0 is the input, X, Y is the data sets in matrices, λ is a semipositive vector, θ represents the technical efficiency of PDWM.

At the second stage, this paper employs the Tobit model to identify the factors influencing PDWM across regions. Many researchers have adopted the Tobit model to explain the sources of efficiency differentials among DMUs (e.g. Barnes, 2006). The Tobit model assumes that the efficiency calculated is a function of various attributes. As the dependent variable of PDWM ranges between 0 and 1, the ordinary least square may lead to biased and inconsistent estimates (Greene 2003). Thus, the Tobit model is employed to examine the factor affecting the outcome of CCR scores in this paper. This model is a hybrid model, consisting of following equations:

$$y_i^* = x_i' \beta + u_i$$

$$y_i = \begin{cases} y_i^* & \text{if } y_i^* > 0 \\ 0 & \text{if } y_i^* \leq 0 \end{cases}$$

where y_i^* is termed latent variables, y_i denotes observed variables, x_i is a known vector of regression variables for the ith observation, β is the unknown vector of parameters, and u_i is i.i.d. normally distributed random variables with 0 mean and σ^2 variance. The estimation procedures of Tobit model are based on maximum likelihood approaches (Verbeek, 2004). Some social realities are considered to explain the PDWM variation in this study as they play important roles in water consumption behavior and eventually affect the outcome of efficiency evaluation. In general, these factors provide indirect effect on water use efficiency. Totally, four independent variables are employed to explain the variation of CCR scores, including the extent rate of sewerage systems (ESS), public participation (PAR), education (EDU), and government environmental expenditure (EXP).

As the sewage disposal basically depends on the appropriate sewerage systems to transport the sewage from households to waste water plants, less extent of sewerage systems implies more untreated sewage or gray water flow into the creeks, sewers or streams, and eventually damages the environment. Thus, this paper employs the extent rate of sewerage systems as an explanatory variable to explain the variation of PDWM.

Public participation in public policy making seems to increase in a democratic society through a process of public engagement involving public affairs in which stakeholders (residents) may influence the decision of development projects such as the construction of sewerage systems. It is seen as a substantive, scientific process, rather than a procedural exercise to formulate a public policy (Shepard and Bowler, 1997). Researchers find that public participation may create incentives for certain stakeholders to devote time and effort to collective action involving common resources (Baland and Platteau, 1996) and thus benefit to the improved environment. For example, the study of Harbaugh et al. (2002) finds that democratic participation can reduce the pollution of suspended particulates. In the Tobit model of Eq. (4)-(5), environmental participation is used as an explanatory variable for the PDWM score and measured by the ratio of volunteers to population.

Particularly, public education may play a major role in affecting basic attitudes towards water use. Residents with higher education level may understand more about the health impacts of untreated sewage and thus push the government to install sufficient sewerage systems. In this paper, the education level is measured by the percentage of the residents having college degree in the population over 15 years.

The mainstream economic theory argues that a strict environmental regulation and monitoring on illegal emissions may improve environmental quality. In fact, some researchers argue that prevention initiatives enacted by local governments may bring about improved efficiency and reduced risks (Moss, 2008). Some empirical studies find that government expenditure for environmental protection plays significant and positive effect on environmental quality (e.g. Xuemei, et al. 2011).

And thus, governmental expenditure on environmental protection may contribute to an extent of improving the sewage treatment rate and result in an improved PDWM, and is selected as one of the explanatory variables.

Some researchers argue that water price also plays an important role in determining the water consumption efficiency (Lee, et al., 2011). Rising water price is necessary to encourage water saving and conservation, and eventually improve water use efficiency. However, the domestic potable water is supplied by the government-owned firms and the price is given and the same for each county/city. And thus, water price is discarded to explain the water management performance.

2.3 The data

The data of sewage generated and treated are drawn out from Yearbook of Environmental Protection Statistics, Republic of China (Taiwan EPA, 2012) and water consumption is provided by Water Resource Agency (2012). The data of population P, and personal disposal income y are provided by Directorate General of Budget, Accounting and Statistics (DGBAS, 2012). As to the explanatory variables in the Tobit regression, the data of ESS (the extent rate of sewerage systems) is provided by CPAMI (2012) whereas PAR (environmental participation), EDU (education), and EXP (environmental expenditure) are provided by DGBAS (2012).

In order to have a preliminary understanding on the status of sewage treatment between urban and rural regions, the descriptive statistics is listed in Table 1. Totally 66 observations are collected including 22 administrative units (cities and counties) covering the period of 2009-2011. This paper regards each administrative unit in each year as a different DMU, and thus the data matrix is formed by 66 DMUs that consists of 22 administrative units and 3 years data.

Table 1 demonstrates that these 22 administrative units consumed 3,703.18 x 10^6 m^3/yr and discharged 2,964.26 x 10^6 m^3/yr gray water into the environment on an average during the three years of observations. Totally Taiwan generated 1003.41, 1033.96, 999.27 BOD_5 ton/day of sewage in 2009, 2010, and 2011, respectively. However, only 437.32, 497.74, 500.74 BOD_5 ton/day of sewage were transported to municipal waste water plants for treatment through sewerage systems for the same period. The sewage treatment rate was 43.58%, 48.14%, and 50.11% in 2009, 2010, and 2011, respectively. The sewage treatment rate seemed to have an increasing tendency while the sewage generated almost kept constant due to almost constant population. The personal disposal income also had a slight increase from NT$ 249.81 x 10^3 in 2009 to NT$ 255.70 x 10^3 in 2011.

Insert Table 1 about here

The observed administrative unit (county/city) is categorized into two classes based on the income level: the urban region and the rural region. The former includes 8 cities (Taipei City, Kaohsiung City, New Taipei City, Keelung City, Hsinchu City, Taichung City, Chiayi City, and Tainan City) and 2 counties where locate in north Taiwan with personal disposable income over NT$ 260,000/yr (Taoyuan County, and Hsinchu County). The remaining counties are categorized as the rural regions. The mean value of these data in the two regions is listed in Table 1. The urban region had population of 17.40 x 10^6 persons with yearly personal disposable income of NT$ 282,580 (equivalent to USD 9,400) while the rural region had 5.79 x 10^6 persons with personal disposable income of NT$ 228,820 (equivalent to USD 7,620). Urban regions in Taiwan consumed raw water 3,024.75 x 10^6 m^3/yr, accounting for 81.68% of total domestic water consumption during the period of 2009-2011 while rural regions consumed 678.43 x 10^6 m^3/yr only. In contrast, the sewage generated in this two regions was 766.01 BOD_5 ton/day and 246.20 BOD_5 ton/day while sewage treated was 426.20 BOD_5 ton/day and 52.40 BOD_5 ton/day, respectively. The sewage treatment rate was 44.64% in urban regions, much higher than 21.28% in rural regions.

The descriptive statistics for the explanatory variables included in the Tobit model are demonstrated in Table 2. The extent rate of sewerage systems covering all the administrative units increased from 21.61% in 2009 to 26.27% in 2011. On an average, about 24% of Taiwan residents were served with sewerage systems during the period of 2009-2011. However, residents in urban regions enjoyed more public service from sewerage systems than rural regions. In 2011, the extent rate of sewerage systems in urban regions had reached 39.63%, much higher than 15.14% in rural regions. The descriptive statistics in Table 2 also demonstrates that more volunteers in rural regions devoted to public affairs involving environmental protection than urban regions. For example, about 112 volunteers in 2011 worked for environmental protection per each million residents in rural regions, but only 53 persons were voluntary to work for the public affairs. As expected, the average education level in urban regions was higher. In 2011, about 41.34% urban residents received college education or higher education levels. In contrast, in rural regions only 27.04% residents received the same education levels. The comparison of these explanatory variables shows that a spatial inequality may exist between urban regions and rural regions. Table 2 also indicates that the average environmental expenditure for these 22 administrative units changed very little over the three years. The average environmental expenditure for each citizen was NT$ 1,590, 1,551, 1,582 for 2009, 2010, 2011 respectively. However, the amount of environmental expenditure in rural regions was a little lower than urban regions. The empirical estimation of the Tobit regression is conducted by using the STATA ver. 10.

Insert Table 2 about here

3. Results and discussions

In Table 3, we list the PDWM score for each county/city calculated by the CCR model. The results show that five DMUs consisting of Hsinchu City 2010, New Taipei City 2010, New Taipei City 2011, Taipei City 2011, and Taoyuan County 2010 form the efficient frontier of the CCR model. The estimated PDWM score ranges from 41.2% to 100% with an average estimate of 70.95%. These results imply that a 29.05% decrease in input items of environmental impacts is possible without changing output level of personal disposal income. If appropriate improvement measures are implemented to reduce per capita water consumption or to increase the sewage treatment rate, the technical efficiency will significantly increase. The DMUs with lower PDWM scores may devote more efforts to reduce the amount of water consumption and untreated waste water (gray water and effluent from septic tanks) discharged into the environment to reduce environmental impacts, or to increase the sewage treatment rate for improving the environmental quality. Considering the overall performance covering the three years, Taipei City performs the best, followed by Hsinchu City, Taoyuan City and New Taipei City. All these units belong to the urban regions. On the contrary, Keelung City ranks the bottom with mean value of 41.7 % only. ***Comparing to other regions, each person in Keelung City consumes 695 liter water each day, ranking the top, while the average water consumption in Taiwan is only 395 liter per day per person. The high water consumption in Keelung City may explain why Keelung City receives the lowest PDWM.***

Insert Table 3 about here

The regional comparison indicates that the PDWM is significantly different between urban …the water management policy did not provide sufficient incentives to encourage the water saving and the construction of the sewerage system. ***Theoretically, an economic instrument by varying water price may be a directive tool to encourage water saving. However, the water supply is monopolized by***

Taiwan Water Company owned by the government. The water price adjustment is difficult to be implemented due to political involvements. On the other hand, the construction of the sewerage system seems to lose its attractiveness to the local governments (mayors) as sewerage systems are invisible and difficult to increase the political popularity. Public education by providing the public with more information about the relative advantage of the sewerage system may be an effective option for the increase of sewerage systems.

Insert Table 4 about here

4. Discussions

The model of Eq. (1) presented in this paper integrates the economic and environmental consideration on a multi-objective basis to evaluate the PDWM, and hence the PDWM outcome of each DMU estimated in this paper may be more appropriate than that evaluated by single item of water use efficiency. The environmental impact incorporated in Eq. (2) constitutes two major items: the raw water consumption and the impacts arising from inappropriate treatment of waste water. An effective way to improve the PDWM is either by reducing the raw water consumption or increasing the sewage (waste water) treatment rate. In order to obtain a trade-off between the two objectives, a simple analysis is presented by linking per capita water consumption and the sewage treatment rate that form a two dimensional view about the PDWM improvements, depicted in Figure 2. Two separating lines are selected to divide the matrix into four quadrants: I, II, III, and IV where the separating line for X axis is subjectively selected at the per capita water consumption of 0.47 ton/day per person and the separating line for the sewage treatment rate is determined at the point of 49.97% that was planned as a target of the sewage treatment rate for year 2010 by CAPMI. The number of DMUs falling in each zone is counted and listed in Table 5. The details are discussed below:

Insert Figure 2 about here

(1) Zone I contains 5 DMUs in urban regions. No rural DMUs fall in this zone. The DMUs in Zone I are characterized with high sewage treatment rates and high raw water consumption. And thus, they are required to focus on the improvement of water consumption and to maintain the performance of sewage treatment.

(2) Zone II contains 9 DMUs including 7 DMUs in urban regions and 2 DMUs in rural regions. These DMUs performs well at both water consumption and sewage treatment. In detailed investigation, we find that the 2 DMUs belonging to rural regions are Lienchiang County 2010 and Lienchiang County 2011. Lienchiang County is composed of several small islands, looking like chessboard. It covers 30 sq meter with population of 9,944 persons. It has served as a military base since the Kuomintang government relocated to Taiwan in 1949. Thus, the military structure with accompanied infrastructure like military hospitals and sewerage systems was performed well in the past. In the meantime, water resource is limited and thus the water consumption in this county was also low in the observed years.

(3) Totally 41 DMUs including 9 DMUs in urban regions and 32 DMUs in rural regions fall in Zone III, accounting for 62.12% of total observations. This zone is characterized with acceptable per capita water consumption but the sewage treatment rate is inferior to other zones. This implies that the city/county falling in this zone has to enhance the installation of sewerage systems to improve the sewage treatment rate.

(4) There are 11 DMUs in Zone IV including 9 DMUs in urban regions and 2 in rural regions. These DMUs exhibit inferior in both water consumption and the sewage treatment rate. Hence, they should attempt to reduce water consumption and

enhance the sewage treatment rate by increasing the construction of sewerage systems.

Insert Table 5 about here

Table 5 also indicates that 18 DMUs (60%) of 30 DMUs in urban regions and more than 34 DMUs (94%) of 36 DMUs in rural counties falling in Zone III and Zone IV, that exhibit low sewage treatment rates. The responding strategies for these DMUs to improve PDWM are to construct sewerage systems as well as sewage treatment plants. On the other hand, 14 DMUs (46.67%) of urban counties/cities but only 2 DMUs (5.56%) of rural regions falling in Zone I and IV, exhibiting low performance in water consumption. These DMUs should focus on water saving and conservation. The result of Figure 2 and Table 5 implies that a spatial inequality exists between urban and rural regions. In practice, per capita water consumption not only relies on household's lifestyles and environmental consciousness but also the infrastructure. The drinking water is supplied via the water piping from the government-owned waterworks to each household. Due to better infrastructure in urban regions, more than 95.72% households in urban regions enjoy the supply of running water from waterworks while only 84.82% households in rural regions are equipped with piping systems for the supply of running water (DGBAS, 2012). Table 6 demonstrates that each person in urban regions consume 173.84 tons/year of running water, more than 117.58 tons/year in rural regions. The difference in the construction of piping system for running water may explain the differential in water consumption.

Among these cities/counties, Taipei City has the highest sewage treatment rate of 95.33% while Taitung County ranks the bottom with the treatment rate of 13.05% in 2011. Almost all the sewage generated in Taipei City was discharged to the waste water plants through the sewerage systems by 2011. On the other hand, Keelung City ranks the top for per capita water consumption, consuming 695 Liter/day of water with 22.86% of sewage treatment rates, and thus it falls in Zone IV.

Table 6 also indicates that the sewage generated is almost the same between the two regions. Each person in urban regions generates 44.02 BOD_5 g/day, a little more than 42.67 BOD_5 g/day in rural regions. However, in urban regions about 55.6% of sewage generated was delivered to waste water plants for treatment to remove the possible pollution while in the rural regions the treatment rate is only about 21.3 % only. The lower sewage treatment rate in rural regions may attribute to the insufficient sewerage systems. Without the sewerage systems, households may use the simple septic tanks to treat the sewage. Otherwise, the untreated sewage is discharged directly to the neighboring environment like rivers or lakes and brings about the water pollution.

Insert Table 6 about here

4. Factors affecting performance

The results of the Tobit regression model is listed in Table 7 in which we find that the explanatory variables including the extent rate of sewerage systems (ESS), public participation (PAR), and education (EDU) are found to be significant in affecting PDWM except for the variable of environmental expenditure (EXP). The positive sign of ESS implies that an enhanced extent of sewerage systems may largely improve management performance for domestic water. This implies that there is a necessary and urgent need to improve the extent rate of sewerage systems as well as relevant treatment facilities for municipal sewage.

Similarly, the participation rate and education also provide highly positive impacts on the improved water management. ***In general, stakeholders of***

environmental groups or volunteers form as a monitoring force for the illegal emissions and provide pressure to conserve water resources. Many non governmental organizations of environmental groups that take a major part in environmental governance regimes may behave actively in affecting policy making and engage in issue discussion. The experience shows that the success of policy implementation requires the support of environmental groups. Since the percentage of volunteers in a city/county provides positive impacts on PDWM, the creation of a participation mechanism is demanded to ensure that all stakeholders have the opportunity to access to, and participate in management practices (Griffin, 1999; Hooper et al., 1999). In practice, an effective participatory mechanism may improve the policy conflicts and reduce the efficiency of policy formulation, and consequently affect environmental quality. A structured system seems to be appropriate to motivate the public's effort routinely on a specific issue.

Insert Table 7 about here

On the other hand, environmental expenditure (EXP) is not found significant. This implies that the environmental budget of local governments for environmental protection does not link with water conservation or sewage treatment. The result of Bohringer, et al. (2012) find that a positive impact of environmental investment on production growth by using a panel dataset of German manufacturing sectors, but the result cannot support the positive impacts of environmental expenditure on production growth. The insignificant relationship between environmental expenditure and PDWM implies that the enhancement of environmental budgets for pollution protection is unable to result in an increase in water saving and sewage treatment.

Based on the flowsheet of water usage depicted in Figure 1, this paper suggests that the improvement of PDWM depends on two actors in the society: the government and the public. The sewage treatment rate is, in general, affected by the governmental operations through the support of sound sewerage systems. On the other hand, the public's environmental consciousness may play an important role in affecting per capita water consumption. Therefore, the most direct method to improve PDWM may focus on the construction of sewerage systems. As the coefficient of ESS is 0.0037339, this implied that an increase in the sewerage systems by 1% may increase PDWM by 0.3734%. In the past, Taiwan governments invested a lot on the construction of sewerage systems and thus the extent rate of sewerage systems increased from 3% in 1991 to 10.87% in 2003 and 21.56% in 2009. By end of 2011, the average extent rate of sewerage systems was 26.01% in Taiwan. Taipei ranked the top, attaining 100%, followed by New Taipei City. Ten administrative units had to face the challenge of low extent rates with less than 10%, including 9 rural counties and 1 urban city. Table 8 indicates that the extent rate in urban regions reached to 39.2%, much higher than 15.14 % in rural regions by end of 2011. An ANOVA analysis reveals that the extent rate of sewerage systems in urban regions is significantly higher. The result may explain why urban regions have higher PDWM than rural regions.

The target of the extent rate of sewerage systems established by CPAMI (2006) is also listed in Table 8. CPAMI expected to rise up the extent rate of sewerage systems by 3% each year after 2007. The actual performance, however, seems to fall a little behind the target, shown in Table 8. A gap of 2-3% exists between the target and the performed extent rate of sewerage systems.

Considering the low extent rate of sewerage systems in rural regions, we suggest that some improvement strategies may be adopted to avoid pollution aggravation of rivers and aquifers in rural regions. These improvement strategies

may include: (1) the installation of decentralized wastewater treatment systems (DEWATs), and (2) the construction of artificial wetlands. A reliable, efficient and low-cost wastewater treatment system on site is demanded in rural regions before waste water is discharged or released into the environment and thus a decentralized wastewater treatment system may help improve the environmental quality and public health due to its benefit of low operation and maintenance costs, resource efficiency and non-dependence on energy, and resource recovery through wastewater re-use and biogas generation (Borda, 2013). Artificial wetlands also play important role in the conservation of water resources and are beneficial to the environment. Wetlands can serve as a habitat for wide animals/plants and thus are helpful to conserve endangered species and lead to an increase in biodiversity. Chen (2012) suggests that the increase in recharge area (water infiltration area) and the greenness-covered area (e.g. forestation) are the vital role to conserve the water resources.

Compared to developed countries, Taiwan installed less sewerage systems and thus the sewage treatment rate is much lower. For example, the sewage treatment rate of Holland, UK, Switzerland and Germany had more than 96% in 2009 (CPAMI, 2009) while Taiwan only reached to 40.25% in 2011. According to the “construction of sewerage systems: Phase IV” planned by CPAMI (2009), the extent rate of sewerage systems is planned to reach 38.47% by 2014. If the target is attained, the sewage treatment rate will increase accordingly and the overall performance of domestic water management will rise up.

Insert Table 8 about here

In contrast, environmental participation and education may provide indirect impacts on PDWM. …Water conservation practices have been implemented in some developed countries to achieve sustainable use of water. ***Technically, ecological sanitation options for toilets including urine diversion dry toilets (UDDT), urine diversion flush toilets (UDFT), low-flush toilets, etc may reduce the wastewater generated. The urine diverting dry toilet (UDDT) is a sanitation system which contains several major functional design including source separation of urine and faeces; waterless operation; and ventilated vaults or containers for faeces storage and treatment (SuSanA, 2013). The advantages of UDFT include (1) less water requirements than a traditional flush toilet and (2) no odor problem if used correctly. However, UDFT also has to face following challenges including (1) limited availability: it can not be built or repaired locally, (2) high capital and low to moderate operating costs, (3) labor-intensive maintenance, and (4) the correct use of UDFT requires education and acceptance (Akvopedia, 2013). The high investment cost for UDFT may be the key barrier to block the widespread use of UDFT. In practice, s***ome measures have been taken to encourage the purchasing and use of water efficient appliances (i.e., showers, toilets, clothes washers) in residential sectors (Millock and Nauges, 2010; Randolph and Troy, 2008). ***On the other hands, the management improvement involving STPs operation may also provide general benefit to the environment through the adoption of some innovative technologies for sewage treatment. For example, some types of micro-organisms have been developed to reduce operating costs and to conserve a sustainable environment (Organic Solution, 20*****13; Clover Organic, 2013).**

5. Conclusions

At first, this paper presents a model for the indicator of PDWM to measure the relative performance of domestic water management performance across counties/cities in Taiwan. This indicator highlights the important role of water consumption and the sewage treatment rate in determining the performance of domestic management.

Secondly, this study employs the DEA technique to calculate the PDWM scores and to examine the factors affecting the performance calculated. As the model employed in this paper incorporates the level of affluence into the model, it reflects the overall performance of the water management system in the society. Results show that urban regions exhibit better performance in domestic water management. The analysis based on the matrix of per capita consumption vs. sewage treatment rates finds that rural regions invest less on the construction of sewerage systems to transfer the sewage from households to sewage treatment plants even though each person in rural regions consumes less fresh water.

Thirdly, the Tobit model is used to examine the factor affecting the PDWM scores and find that the construction of sewerage systems, environmental participation, education and environmental expenditure affect the outcome of PDWM significantly. This study suggests that two roles in the society should be focused and integrated including the government and the public. The construction of sewerage systems should be enhanced and supported by the governments and some measures may be taken to encourage the public for water saving and conservation. Water is seen as a valuable resource. Thus, the water saving and conservation is required but it requires the public involvement. In practice, domestic water management must be holistic and should be based on collective consideration of water consumption, sewage generation and treatment. Without the active involvement of stakeholders, the water management performance improvement plan cannot succeed.

The results derived from the estimation of the Tobit model implies that these factors may in turn determine conditions for improvement of domestic water management performance. We suggest that the explanatory variables in the Tobit model may help local governments to develop their improvement strategies.

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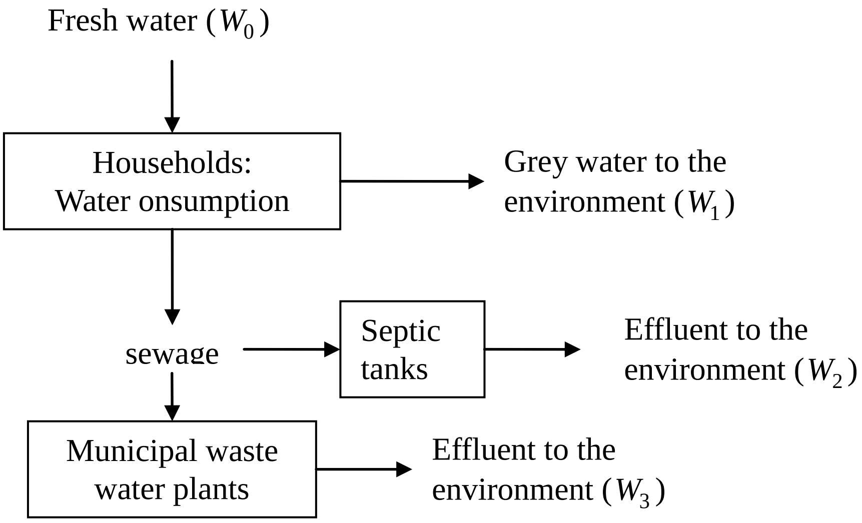

Figure 1: The environmental impact from domestic water consumption

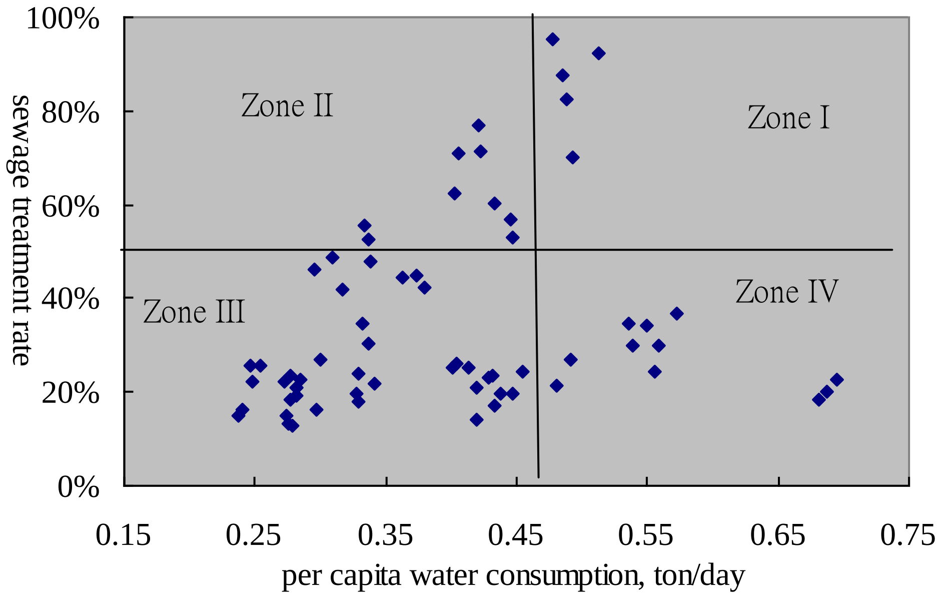

Figure 2. Matrix of water consumption-sewage treatment rate

Table 1. The descriptive statistics

	year	water consump	gray water dischar.	untreated sewage dischar.	sewage treated	sewage genera.	Popu.	income
Urban	2009	3024.25	2471.19	366.67	390.95	757.62	17.33	276.53
	2010	3034.43	2461.65	341.95	442.69	784.64	17.40	284.58
	2011	3015.56	2463.85	310.8	444.97	755.77	17.49	286.64
	Aver.	3024.75	2465.56	339.81	426.20	766.01	17.40	282.58
rural	2009	668.12	488.69	199.42	46.37	245.79	5.79	223.09
	2010	691.76	509.75	194.27	55.05	249.32	5.76	231.82
	2011	675.41	497.65	187.73	55.77	243.5	5.74	231.55
	Aver.	678.43	498.70	193.81	52.40	246.20	5.77	228.82
pooled	2009	3692.37	2959.88	566.09	437.32	1003.41	23.12	249.81
	2010	3726.19	2971.40	536.22	497.74	1033.96	23.16	258.20
	2011	3690.97	2961.50	498.53	500.74	999.27	23.22	259.10
	Aver.	3703.18	2964.26	533.61	478.60	1012.21	23.17	255.70
unit		10^6 m^3/yr	10^6 m^3/yr	BOD_5 ton/day	BOD_5 ton/day	BOD_5 ton/day	10^6	NT\$$10^3$ per capita

Table 2. Descriptive statistics for explanatory variables included in the Tobit regressions

	year	ESS	PAR	EDU	EXP
urban	2009	33.35	4.70	38.92	1.67
	2010	36.31	4.81	40.19	1.71
	2011	39.63	5.33	41.36	1.67
rural	2009	11.83	11.14	25.50	1.53
	2010	13.95	10.92	26.34	1.42
	2011	15.14	11.21	27.04	1.51
pooled	2009	21.61	8.22	31.60	1.59
	2010	24.11	8.14	32.64	1.55
	2011	26.27	8.54	33.55	1.58
average		24.00	8.30	32.59	1.58
unit		%	10^{-5}	%	NT$ 10^3

Table 3. The comparison of PDWM between urban and rural regions

unit name	2009	2010	2011	mean
urban regions				
Chiayi City	66.30%	67.00%	67.80%	67.03%
Hsinchu City	90.60%	100.00%	98.40%	96.33%
Hsinchu County	82.90%	86.10%	92.50%	87.17%
Kaohsiung City	76.40%	81.00%	80.50%	79.30%
Keelung City	41.50%	42.40%	41.20%	41.70%
New Taipei City	84.80%	100.00%	100.00%	94.93%
Taichung City	54.90%	54.60%	61.60%	57.03%
Tainan City	51.70%	43.20%	54.00%	49.63%
Taipei City	99.70%	99.10%	100.00%	99.60%
Taoyuan County	92.60%	100.00%	95.70%	96.10%
average	74.14%	77.34%	79.17%	76.88%
rural regions				
Changhua County	84.50%	86.30%	91.20%	87.33%
Chiayi County	81.10%	79.60%	70.30%	77.00%
Hualien County	44.90%	50.30%	58.00%	51.07%
Kinmen County	56.90%	59.10%	59.40%	58.47%
Lienchiang County	57.50%	57.00%	59.70%	58.07%
Miaoli County	47.10%	49.60%	51.30%	49.33%
Nantou County	52.70%	51.60%	48.60%	50.97%

Penghu County	72.50%	84.40%	76.10%	77.67%
Pingtung County	72.40%	73.90%	79.30%	75.20%
Taitung County	71.80%	50.20%	71.60%	64.53%
Yilan County	66.10%	69.80%	65.40%	67.10%
Yunlin County	73.50%	71.90%	80.70%	75.37%
average	65.08%	65.31%	67.63%	66.01%

Table 4. The comparison of PDWM between the two regions

source	SS	d.f.	MS	F	P-value	Critical value
between	0.193526	1	0.193526	6.594759	0.012573	3.990924
within	1.878103	64	0.029345			
Total	2.071628	65				

Table 5. The umber of DMUs in each zone

	Urban regions	Rural regions	Total
Zone I	5	0	5
Zone II	7	2	9
Zone IIII	9	32	41
Zone IV	9	2	11
Total	30	36	66

Table6. The descriptive statistics on an individual basis in 2011

	water consump.	**sewage genera.**	**sewage treated**
urban	**173.84**	**44.02**	**24.49**
rural	**117.58**	**42.67**	**9.08**
pooled	**159.83**	**43.69**	**20.66**
unit	**Ton/yr/pers.**	**BOD$_5$ g/day/pers.**	**BOD$_5$ g/day/pers.**

Table 7. The result of the Tobit regression

variables	Coef.	Std. Err.	z	P
Cons.	.5213106	0.141745	3.68	0
ESS	.0037339	0.001375	2.71	0.007
PAR	.0095434	0.005463	1.75	0.081
EDU	.0097564	0.003948	2.47	0.013
EXP	-.018502	0.056323	-0.32	0.749
Log likelihood = 35.859287				
Number of observation = 61				

Table 8. The extent rate of sewerage systems in Taiwan during 2009-2011

	Extent rate of sewerage systems		
	2009	2010	2011
urban	33.24%	35.87%	39.20%
rural	11.83%	13.95%	15.14%
pooled	21.56%	23.91%	26.08%
Target	23.47%	26.47%	29.47%

附件三：The estimation of water shortages through the test of environmental Kuznets curve

Abstract

Considering a gradual shortage of water resources in the world, many researchers estimate waster demand by using a linear model to develop the strategies for water management. Water consumption may provide an adverse impacts on the environment and be seen as a pollution. This paper employs an EKC (environmental Kuznets curve) model that emphasizes the inverted U-shaped relationship between pollution and income, to test whether an environmental Kuznets phenomenon exists or not. Taiwan is selected as an example by forecasting the water demand and supply in 2020, 2030 and 2040 and to project the water shortage. The estimates derived by using EKC and linear models, respectively are employed to predict water demand by considering the change of population and economic growth. The result finds that (1) an environmental Kuznets phenomenon exists for water consumption, (2) water price is not found significantly to affect water consumption and (3) the income elasticity is positive for domestic water consumption by using the linear form of regression models but it is negative for industrial and agricultural water consumption. An increase in per capita GDP by 1% may result in increased domestic water consumption by 0.3609%, but a reduction of industrial water consumption by 0.1127%, and agricultural water consumption by 0.1404%. Based on the water demand predicted and water supply projected, water shortage can be solved autonomously in case of sustainable economic growth by using the EKC form of aggregate forecasting. However, the linear form of sectoral forecasting suggests Taiwan’s water shortage remains existent until 2030 even in base climates.

Keywords: Environmental Kuznets Curve (EKC); income elasticity; water supply; water demand; water shortage

1. Introduction

The Worldwatch Institute suggests that more than two-thirds of the world's population (an estimated 1.8 billion people) may be risky of water shortages due to population growth, human activities and climate change by 2025 (National Geographic, 2014; De Fraiture et al., 2008). In a global perspective, water scarcity seems to be inevitable owing to increasing water demand that is projected to double between 2003 and 2035 (Tidwell et al., 2004) and population growth that also increased to double in the last 60 years. On the contrary, the uneven distribution of rainfalls across regions over time due to climate change aggravates the uncertainty of water supply and may explain the regional or temporal shortage of water supply. Such a conflict between water supply and demand while depleting water resources are accompanied with increasing demand may be one of the major causes leading to scarcity.

Due to climate change, extreme climates such as floods and droughts[2] have increased (Forsee and Ahmad, 2011). Many literature investigate the impact of climate change on water resources (e.g. Arnell, 2004; Bouwer et al., 2010) or focus on the potential impacts of climates on river basins (e.g. Barnett, 2003). The aggravation of climate change may reduce runoff (Christensen et al., 2004), affect the pattern in annual runoff (Milly et al., 2005), influence the volume and timing of river flows and

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[2] Droughts are defined as "a sustained, extended deficiency in precipitation when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems" by Mishra and Singh (2010).

also groundwater recharges (Arnell, 2004) and degrade water quality (Milly et al., 2002; Arnell, 2004). Hence, the priority task is to estimate the water shortage in case of droughts and to develop some strategies to face the challenge of water scarcity.

In order to estimate water demand in the future, many forecasting models employ multivariate regression models and time series analyses by incorporating a variety of factors in association with climate change, economic development, and population growth. In general, log-linear specification is widely employed to estimate the price and income elasticity for water demand (e.g. Polycarpou and Zachariadis, 2013; Rinaudo et al., 2012; Bartczak et al., 2009). Very few employ EKC (Environmental Kuznets Curve) models incorporating the squared term of national incomes to examine the price and income elasticity for water demand.

In reality, most EKC models focus on natural resources consumption or environmental pollution for the test of the inverted U-shaped relationship between industrial pollution and per capita income (e.g. Duarte, et al., 2013; Thompson, 2012; Orubu and Omotor, 2011; He and Richard, 2010; Chen and Chen, 2008; Martinez-Zarzoso and Bengochea-Morancho, 2004; Kander and Lindmark, 2004; Lindmark, 2002) but very few examine the existence of an EKC phenomenon for water consumption. Hettige et al. (2000) conduct an empirical test of an EKC on the industrial pollution and find that the industry share of national output executes a Kuznets-type pattern. Orubu and Omotor (2011) examine the impact of national incomes on water pollution arising from suspended particulate matter and organic water pollutants in Africa by using longitudinal data and investigate the existence of an EKC phenomenon. Duarte, et al. (2013) analyze the relationship between per capita water consumption and per capita income for 65 countries over the period 1962–2008 and find that water withdrawal per person has a peculiar inverted-U relationship with per capita income. The income elasticity of water consumption clearly decreases throughout the whole period. Thompson (2012) examines the effect of water abundance on an EKC for water pollution and finds that water abundance has significant impacts on the turning point of an EKC.

Practically, resource consumption may provide an adverse impact on the environment in addition to pollution, and thus, is seen as an environmental pressure due to population growth, economic development, urbanization and industrialization (Kander and Lindmark, 2004). The hypothesis of an inverted U-shaped relationship between water consumption and national incomes may attribute to the increased living abundance as income grows during the first stages of economic development. After the turning point, water use efficiency increases because of technology improvement for industry and agriculture, and consequently water consumption decreases.

The major purpose of this paper is to verify whether water consumption executes like the pattern of an EKC, increasing to a peak and then decreasing as national incomes increase. Secondly we would like to examine the price and income elasticity of water demand, and thirdly the future water demand is estimated by using Taiwan as a case example by using a log-log specification of regression models incorporating the term of squared national incomes, and linear models. Lastly, the water supply in 2020, 2030, and 2040 is also projected by considering three cases of climates by using the hydrological data and thus water shortages in case of three climates are obtained. In addition, the authors also attempt to discuss and develop some responsive strategies to recover the crisis of water shortages.

2. Research methods

This study outlines two primary methods to forecast Taiwan's future water demand: aggregate forecasting and sectoral forecasting. The former employs the data of water consumption at the aggregate level by using both EKC and linear forms of regression models to predict future water demand while the latter uses the sectoral data of water consumption. A statistical regression method of causal relationship incorporating the variable of squared income is employed to estimate future water demand, expressed as:

$$\ln q_t = \alpha_0 + \alpha_1 \ln y_t + \alpha_2 (\ln y_t)^2 + \alpha_3 \ln p_t + e_t \quad t = 1, 2, \ldots, T \tag{1}$$

where q_t represents per capita water consumption in period t, y_t is per capita income in terms of per capita gross domestic products (GDP), p_t denotes water price, T is the final period of the data set and e_t is random errors. The variation of weather and other seasonal factors is neglected in this paper to affect water demand. Once estimated, the coefficients of Eq. (1) are used to generate per capita water demand in the period of T+n. The corresponding demand $Q_{a,n}$ for total water consumption predicted by aggregate forecasting is

$$Q_{a,n} = P\ q_{t,n} \tag{2}$$

where P is population and $q_{t,n}$ is per capita total water demand in the period of T+n, obtained by aggregate forecasting. The total water demand $Q_{s,n}$ predicted by sectoral forecasting in the period of T+n is:

$$Q_{s,n} = P\ (q_{d,n} + q_{i.n} + q_{a,n}) \tag{3}$$

where $q_{d,n}$ is per capita water demand for domestic uses, $q_{i.n}$ denotes per capita water demand for industrial uses and $q_{a,n}$ is per capita water demand for agricultural uses.

In the second step, water supply is projected based on the historical data of precipitation, fresh water withdrawals, and groundwater harvesting. A number of studies incorporate climate change for estimating future water demand and evaluate the potential impacts (e.g. Groves et al., 2008). Considering the increasing climate extremes like droughts caused by changing climatic conditions (Forsee and Ahmad, 2011; Ahmad et al., 2010; Stephen et al., 2010; Puri et al., 2011ab), this paper presents three scenarios including base climates, drought climates and severe drought climates according to the level of annual precipitation that is assumed to obey a normal distribution function, to evaluate the amount of water supply. Base climates represent a climate as usual and are expected to have a mean precipitation level μ. In contrast, the probability of precipitation in drought climates and severe drought climates is assumed to occur below 5%and 2.5%. And thus, the precipitation R_b, R_d and R_s in base climates, drought climates and severe climates respectively is:

$$R_b = \mu \tag{4}$$

$$R_d = \mu - 1.8\sigma \tag{5}$$

$$R_s = \mu - 2.2\sigma \tag{6}$$

where σ is standard errors.

The historical data reveals that the major water supply source consists of direct intaking from rivers/streams, reservoirs, and groundwater, accounting for more than 99.9% of total water supply. And thus, the water supply projected from other sources like sea water desalination or waste water reclamation is neglected. The extraction rates e_s and e_r from precipitation for rivers/streams and reservoirs supply sources serve as a basis to project water supply in this paper. In general, water supply in case of flooding climates assures of sufficient water supply and thus flooding climates are not discussed in this paper. And thus, the water supply for base climates, drought climates and severe drought climates is

$$W_b = R_b\ (e_s + e_r) + G \tag{7}$$

$$W_d = R_d\ (e_s + e_r) + G \tag{8}$$

$$W_s = R_s\ (e_s + e_r) + G \tag{9}$$

where G represents the water supply of groundwater.

Thirdly, the water shortage is calculated and obtained by comparing Eq. (2)-(3) and Eq. (7)-(9) for 2020, 2030 and 2040 under three cases of climates.

2.2 The data

The data for water consumption employed in this paper is provided by Water Resources Agency (2014) and socio-economics data like GDP and population is obtained from DGBAS (2014). Totally 31 observations of water consumption covering the period between 1980 and 2011 are used to test Eq. (1). Typically, water consumption is categorized into three sectors including domestic, industrial, and agricultural uses that are depicted in Figure 1. The total water consumption increased from 16,173 million m^3 in 1980 to a peak of 18,701 million m^3 in 2002, slightly fluctuating to the second peak of 19,069 million m^3 in 2009 and then decreased to 17,225 million m^3 in 2011. Domestic water consumption increased from 987 million m^3 in 1980 to a peak of 3,734 million m^3 in 2001 and then decreased to 3,238 million m^3 in 2011. The industrial sector reduced its water consumption from 1,667 million m^3 in 2001 to 1,552 million m^3 in 2011. In agricultural sector, water consumption increased from 14,073 million m^3 in 1980 to a peak of 15,932 million m^3 in 1983, after then slightly fluctuating and reducing to 12,435 million m^3 in 2011. The domestic, industrial and agricultural consumption accounted for about 18.80%, 9.01%, and 72.19%, respectively, in 2011.

Insert Figure 1 about here

Per capita water consumption is depicted in Figure 2 in contrast with per capita GDP. Per capita total water consumption reached to a peak of 1,016 m^3 in 1983 and then declined to 744 m^3 in 2011. On the contrary, per capita GDP kept a rising trend, increasing from US$ 2,385 in 1980 to US$ 20,006 in 2011. The pattern of the trend implies that an EKC may exist. The average economic growth rate was 4.18% for the past 10 years (2002-2012) and 4.17% for the past 20 years (1992-2012). Thus, the growth rate of 4.175% is employed to project the future GDP in 2020, 2030 and 2040 respectively. The growth rate of Taiwan's population was 0.64%, 0.42%, and 0.31% for the period between 1990-2012, 2000-2012 and 2008-2012, respectively. According to DGBAS's projection, the population in Taiwan is estimated to be 23.61 million by 2020, 23.55 million by 2030, and 22.71 million by 2040 (DGBAS, 2014). Thus, the population projected by DGBAS is used to estimate water demand for the future in this paper.

Insert Figure 2 about here

3. Analysis of Taiwan's water supply

The analysis framework is depicted in Figure 3 to describe the status of Taiwan's water supply in 2011. The precipitation level in 2011 was 82.8 billion m^3, of which 23.12% was vaporized, 70.78% flew into rivers/streams/lakes, and 6.10% infiltrated into the ground and percolated downward through voids in solid and rock, and eventually formed as a part of groundwater storage. The amount of water runoff flowing into the sea through rivers/streams/lakes was 47.10 billion m^3, accounting for 80.37% of total runoffs in 2011. The balance was captured by reservoirs or directly intaked from the rivers/streams for agricultural or industrial uses, amounting to 11.5 billion m^3.

Insert Figure 3 about here

The most common sources of water supply currently are rivers or streams, accounting for 34.81% of total water supply 17.21 billion m^3 in 2011, followed by the other two major sources of reservoirs/dams and groundwater, amounting to 5.51 and 5.70 billion m^3, accounting for 32.02% and 33.12%, respectively. In order to avoid water shortages, reservoirs and dams were constructed in the upstream of rivers/streams, serving as storage tanks to adjust and increase water supply in the past. Until 2012, totally 102 sets of reservoirs/dams had been completed with total design capacity of 28.56 billion m^3 and effective capacity of 19.07 billion m^3, designed for the purposes of power generation, water supply and flood control. Though the risk of water scarcity was moderated by dams and reservoirs, opposition to the construction of new reservoirs is widely recognized due to their highly adverse impacts on the environment (Vedwan et al., 2008). The water supply through the support of reservoirs/dams seems to have drawn a stop line in Taiwan.

Groundwater has become one of the principal sources in Taiwan, especially for agricultural irrigation to grow crops. In 2011, 5.71 billion m^3 of groundwater was withdrawn, accounting for 33.17% of total water consumption, in excess of the groundwater infiltration rate 5.05 billion (Water Resource Agency, 2014). In the past between 2001 and 2011, an average of 0.59 billion m^3 groundwater was over exploited annually. Such a long-term and continual overexploitation of groundwater may create a groundwater drought[3] (van Lanen and Peters, 2000) and have brought about land subsidence (water table falling) in Taiwan. As a consequence, it results in seawater intrusion in many areas, especially in the west Taiwan along the costal areas. For example, the land subsidence (water table declining) rate for the current time ranges from 1.9 cm to 2.8 cm per year. The accumulated depth of land subsidence has been up to 3.4 m in Pingtung County, 2.50 m in Changhwa County and 2.47 m in Yunlin County by 2012 (Water Resource Agency, 2014). In practice, the groundwater storage serves as a buffer tank, providing insufficient water supply in drought seasons and absorb the emergently heavy rainfalls in flooding seasons. The over-exploitation of groundwater may become a consumption pattern in Taiwan and decrease the use of surface water supply. Very few of water supply sources come from desalination plants or waste recycling plants in Taiwan. By 2011, totally 20 desalination plants had been installed and operated with intaking sea water capacity of 21.14 million m^3 to produce 7.55 million m^3, accounting for 0.04% of total water supply (Water Resource Agency, 2014).

4. Results and discussions

The estimation results for Eq. (1) are listed in Table 1, showing that the inverted U-shaped curve exists for the cases of per capita total water consumption, per capita domestic water consumption, and per capita agricultural water consumption as the coefficient for the term of squared national incomes is significantly negative, equivalent to -0.0961, -0.1975 and -0.1074, respectively. The results reveal that water demand decreases as economic growth surpasses the turning point of the curve. Such

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[3] Ground water drought is defined as the decrease of groundwater level (Eltahir and Yeh, 1999). The occurrence of ground water drought depends on groundwater recharge or discharge.

a result implies that income growth may autonomously slow down the water consumption for domestic and agricultural uses in the future while national incomes keep an increasing trend, and eventually reduce the level of total water consumption.

On the contrary, no significant evidence is found that national economic expansion affects water demand for the production of industrial products. This insignificant relationship may be explained by the characteristics of derived demand for industrial water. As water for industrial use in general is seen as an input into a production process, its demand is derived from the production function and dependent on the price of all inputs and the outputs produced from it. Furthermore, the low share of water cost for total production costs of industrial outputs, accounting for about 0.5% only, is another reason (Water Resource Agency, 2013) to explain the lacking of motives for industrial water saving and conservation. Such a result coincides with the suggestion of Alcamo et al. (2007). They provide a pessimistic perspective for future industrial water demand that may increase dramatically in developing countries.

Insert Table 1about here

On the other hand, the linear form of regression models in Table 1 shows that national incomes have significant impacts on total and all three sectoral water consumption. The income elasticity is -0.0824, 0.3609, -0.1127 and -0.1404 for total, domestic, industrial and agricultural consumption, respectively. The negative sign of the income elasticity implies that water consumption may decline accompanied with income growth. The results indicate that an increase in per capita GDP by 1% is beneficial to a reduction of total water consumption by 0.0824%, industrial water consumption by 0.1127%, and agricultural water consumption by 0.1404%. In contrast, the positive sign of the income elasticity for domestic water consumption indicates that an increase in per capita GDP by 1% may result in increased domestic water consumption by 0.3609%. Such a result may attribute to the changed living styles and increasing level of affluence. The finding corresponds to the studies of Postel et al. (1996). In reality, if some measures are taken to encourage efficient use of water in households, water may be saved and/or supply water to other sectors.

As to the price elasticity of water demand, no significant evidence is found for the impact of water price on water consumption for each sector. A great deal of literature examines the price elasticity of water demand and most of them find that the price elasticity is very low (e.g. Polycarpou and Zachariadis 2013; Rinaudo et al 2012; Arbues et al., 2003; Bartczak et al., 2009; Nauges and Strand, 2007). For example, Polycarpou and Zachariadis (2013) evaluate the price elasticity of water demand using quarterly household level data for the period between 2001 and 2009. They find that the price elasticity takes values between 0.25 and 0.45, and the income elasticity ranges between 0.53 and 0.75. The empirical study of Rinaudo et al (2012) finds that the price elasticity for water demand is 0.2 through an econometric analysis of a cross-sectional data set. The empirical study of Bartczak et al. (2009) find price and income elasticities are 0.22 and 0.12, respectively based on the data provided from Poland between 2001 and 2005 by employing a static random effect model. The study of Nauges and Strand (2007) find that the demand elasticity of non-tap water with respect to total water cost ranges between 0.4 and 0.7 by using sample survey carried out in 1995-1997.

This paper finds that Taiwan’s per capita water consumption is insensitive to water price, but affected by per capita income. The lacking of evidence to support the relationship of water price with water consumption may attribute to low water rates and the inflexible price adjustment. Currently, the water production and supply are monopolized by two administrative units: one is Water Department of Taipei Municipality that is responsible for the water supply in Taipei Municipality and the other is Taiwan Water Corp., a water utility for non-Taipei regions in Taiwan. Table 2 reveals the historical water rate conducted by the two administrative units from 1975. In practice, the adjustment of water rates requires political negotiation and takes a long time and thus the water rate has been adjusted just for very few times in the past four decades shown in Table 2.

Insert Table 2 about here

5. Projected water demand and supply

Since no evidence is found to support the significant role of water price in affecting water consumption, the explanatory variable of water price is removed from Eq. (1) and the revised model expressed below incorporates the variables of income and squared income only.

$$\ln q_t = \alpha_0 + \alpha_1 \ln y_t + \alpha_2 (\ln y_t)^2 + e_t \quad t = 1, 2, \ldots, t, \tag{10}$$

The estimation results for Eq. (10) are listed in Table 3. The coefficient for squared GDP is found to be significant for total, domestic and agriculture uses, equivalent to -0.0913, -0.1355 and -0.1136, respectively while the industrial water consumption is not found to have an EKC phenomenon. As to the linear model of Eq. (10), the sign of the income elasticity for domestic water consumption is positive but negative for the other sectors. The results are completely identical to the estimates of Eq. (1) that incorporates the variable of water price.

Insert Table 3 about here

Using the estimates of α_0, α_1 and α_2 listed in Table 3, following equations are employed to predict the total water demand in the future by the aggregate data of total water consumption.

$$\ln q_s = 0.6654 + 1.5037 \ln y_n - 0.0913 \ (\ln y_n)^2 \qquad (11)$$

$$\ln q_l = 7.752 - 0.1105 \ln y_n \qquad (12)$$

where q_s and q_l represent per capita water demand for total water consumption by using square form and linear form of GDP, respectively.

The future demand predicted by sectoral forecasting is to aggregate the water demand estimated for each sector. Since the industrial water consumption is not found to have an EKC phenomenon, the water demand for each sector is predicted by linear forms only, listed below:

$$\ln q_d = 1.2168 + 0.3926 \ln y \qquad (13)$$

$$\ln q_i = 5.4825 - 0.1227 \ln y \qquad (14)$$

$$\ln q_a = 8.2133 - 0.1918 \ln y \qquad (15)$$

where q_d, q_i and q_a represent per capita water demand for domestic, industrial and agricultural uses.

The per capita water demand in 2020, 2030, and 2040 is predicted based on Eq. (11)-(15) and total water consumption is obtained according to Eq. (2) and (3) for aggregate and sectoral forecasting respectively. The water demand predicted by the EKC form and linear form of aggregate forecasting and by the linear form of sectoral forecasting is depicted in Figure 4. The total water demand in Taiwan estimated by the EKC form of Eq. (11) is 15.65, 13.25 and 10.52 billion m^3 for 2020, 2030, and 2040, respectively while that estimated by the linear form of aggregate forecasting (Eq. 12) is 17.80, 16.93, and 15.61 billion m^3. In contrast, the water demand estimated by sectoral forecasting that aggregates water demand of each sector is 18.29, 18.00, and 17.34 billion m^3 for 2020, 2030, and 2040, respectively, higher than the other two aggregate forecasts.

Insert Figure 4 about here

Among the three forecasts, the EKC form (Eq. 11) of aggregate forecasting provides the most optimistic projection on future water demand due to the existence of inverted U-shaped relationship between income and water demand. The income turning point ($\hat{q}_t$, $\hat{y}_t$) of the fitted regression function is calculated by

$$\ln \hat{y}_t = \frac{-\alpha_1}{2\alpha_2} \tag{16}$$

$$\ln \hat{q}_t = \alpha_0 - \frac{\alpha_1^2}{4\alpha_2} \tag{17}$$

Substituting the estimates of α_0, α_1 and α_2 listed in Table 3 into Eq. (16) and (17), we obtain the turning point falling at per capita total water consumption of 950 m^3/year and per capita GDP of US$ 3,769 that occurred in the year between 1986 and 1990. This result provides an optimistic perspective for water demand in the future in response to the gradual exhaustion of water resources if economic development keeps continuous progress.

In contrast, the water demand estimated by sectoral forecasting of Eq. (13)-(15) and Eq. (3) is the most pessimistic. Thanks to decreased population and economic growth, the water demand estimated has a decreasing trend over time. However, the gap between the EKC form of aggregate forecasting and the linear form of sectoral forecasting enlarges over time, amounting to 15.21%, 27.22% and 40.17% for the estimates in 2020, 2030 and 2040.

On the other side, the projected water supply is completely dependent on the level of precipitation. The average and minimum level of annual precipitation were

94.08 and 56.59 billion m^3 with standard errors of 22.36 billion m^3 while the average and maximum values of total water supply were 18.00 and 17.06 billion m^3 with standard errors of 0.64 billion m^3, respectively, between 2001 and 2011 (Water Resource Agency, 2014). And thus, the precipitation R_b, R_d and R_s in base climates, drought climates and severe climates is 94.08, 53.83 and 44.89 billion m^3, respectively, calculated by Eq. (4)-(6).

The average extraction rates e_s and e_r from precipitation for rivers/streams and reservoirs supply sources is 8.53% and 4.60% during the period 2001-2011. According to Eq. (7)-(9), the water supply in base, drought and severe drought climates is estimated to be 17.41, 12.12 and 10.95 billion m^3, respectively, shown in Table 4. Water supply from rivers/streams accounts for 46.14% of total water supply in base climates, but decreases to 35.01% in serious drought climates. This result implies that water supply in more drought climates depend more on groundwater.

Insert Table 4 about here

Based on the water demand estimated shown in Figure 4 and the projected water supply for three climates in Table 4, the water shortage is obtained and listed in Table 5. The resulting projection suggests that the risk of water shortages will, in general, decrease after 2040 even in case of drought climates and severe drought climates by using the optimistic estimation method of EKC regression models. The characteristics of EKC regression models suggests that water demand may decrease over time after it reaches to a peak. This result indicates that water shortage can be solved autonomously in case of sustainable economic growth by using the EKC form of aggregate forecasting. However, the linear form of sectoral forecasting suggests that Taiwan's water shortage remains existent until 2030 even in base climates.

Insert Table 5 about here

5. Discussions and Conclusions

Based on the sectoral forecasting, this paper finds that domestic water consumption keeps an increasing trend while water consumption in the other two sectors decreases as time goes. In this case, we suggest that the government should take some measures to encourage households for water saving and conservation. Currently, Taiwan’s household expenditure for water is about NT$ 4,000 annually, accounting for about 0.5 % of disposable income, much lower than that in developed countries. And thus such a water rate seems to provide little impact on the water-saving behavior of households. Some researchers suggest that incentives for water-saving appliance may be more effective than the water management policy of water price increase (Millock and Nauges, 2010; Randolph and Troy, 2008) and directly contribute to water saving.

On the water supply side, appropriate management is required to develop new technology for water supply from additional water sources. In practice, desalination of brackish water or sea water, recycling of waste water, harvesting of rain water and the construction of wetlands are suggested to bridge the gap of water shortages in the future. The desalination of brackish water or sea water is, in general, considered an effective alternative source for water supply (Khawaji et al., 2008; Jaber & Ahmed, 2004) since the current technology shows that desalination can yield water of potable quality (Karagiannis & Soldatos, 2008).

The reclaimed water from wastewater plants may become a sustainable and practical source to solve water shortages (Chen and Chen, 2014; Kalavrouziotis & Apostolopoulos, 2007). Most researchers suggest that reclaimed water can be used in non-potable urban, industrial and agricultural applications (Karagiannis & Soldatos, 2008). Gikas and Tchobanoglous (2009) suggest that Reclaimed water can be used in a variety of fields including agricultural irrigation, landscape irrigation, industrial applications, urban non-irrigation applications, environmental and recreational applications, groundwater recharge (indirect potable reuse), surface water augmentation (indirect potable reuse), and direct potable uses.

Rainwater harvesting and wetlands are traditionally an effective water supply source for irrigation and the vehicle washing and toilet flushing of domestic water consumption. In order to recover the risk of water shortages stemming from severe droughts, rainwater harvesting has been encouraged in augmentation of water supply. However, the deployment of rainwater harvesting is neglected in Taiwan due to its low economic benefits or implicit advantage. It is widely recognized that wetlands can reduce disaster hazards and improve the conservation of water resources (Chen, 2012). In general, wetlands are used as a natural storage tank for surface water and as a recharging tool for groundwater. and thus they may provide more flexibility for water supply. In case of storming, wetlands can capture storm water runoff before it flow into rivers and sea. Additionally, the wetland may lead to an increase in biodiversity as it can serve as a habitat for wide animals/plants and thus helpful to conservation of endangered species.

In this paper, we develop a novel method by using EKC models in addition to the traditional method of linear models to predict the future water demand, and to estimate the future water shortage by integrating both water demand and supply. The resulting conclusion for the test of the EKC phenomenon for Taiwan’s water consumption is significant and provides an optimistic perspective about future water shortages. On the other side, the linear form either by aggregate forecasting and sectoral forecasting is more pessimistic perspective for the future demand. Since we can not control and adjust the water supply relating to global climate change, Taiwan government has to increase the amount of water supply from other sources. Additional desalination plants and water reclamation from waste water treatment plants should be required. However, the construction of infrastructure for alternative water supply sources may crowd out the economic resources and block the socio-economic development. A water conservation policy may be more appropriate to encourage households, industries and agricultures to engage in water saving programs. The comparison of water use efficiency among the domestic, industrial and agricultural uses may be an important issue for the future study.

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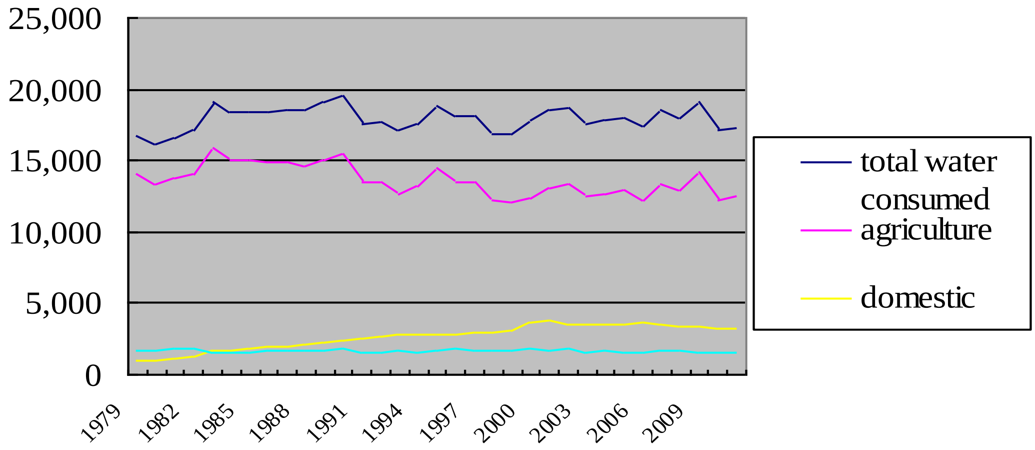

Figure 1. Water consumption in Taiwan during 1979-2011

Table 1. Estimation of EKC curves for water consumption

		intercept	Water price	gdp	Square gdp
Total water consumption	Linear form	7.7592 (0.1160)	-0.1400 (0.1075)	-0.0824*** (0.0251)	
	Square form	0.2892 (1.9455)	0.0412 (0.1003)	1.5806*** (0.4331)	-0.0961*** (0.0250)
Domestic water consumption	Linear form	1.2095 (0.2426)	0.1576 (0.2248)	0.3609*** (0.0524)	
	Square form	-14.1406*** (4.1035)	0.5298 (0.2516)	3.7783*** (0.9135)	-0.1975*** (0.0527)
Industry water consumption	Linear form	5.4848*** (0.1575)	-0.0497 (0.1460)	-0.1127*** (0.0340)	
	Square form	1.6396 (3.1814)	0.0435 (0.1640)	0.7433 (0.7082)	-0.0495 (0.0409)
agriculture water consumption	Linear form	8.2251*** (0.1532)	-0.2553* (0.1420)	-0.1404*** (0.0331)	
	Square form	-0.1172 (2.7548)	-0.0530 (0.1420)	1.7168*** (0.6133)	-0.1074*** (0.0354)

The parentheses represents standard errors.

Table 2. The historical water rates in Taiwan (unit: NT$/ m^3)

Periods	Taiwan Water Corp.	Water Department of Taipei Municipality
1975/Jan.	3.30	-
1975/June	3.30	3.00
1979/July	4.95	3.00
1980/July	4.95	5.60
1982/Jan.	6.60	5.60
1991/Aug.	8.25	5.60
1994/March	8.25	7.50
1994/July	9.0	7.50

Table 3. Estimation results of Eq. (10)

		intercept	gdp	Square gdp
Total	Linear form	7.752*** (0.1172)	-0.1105*** (0.0128)	
	Square form	0.6654 (1.6913)	1.5037*** (0.3848)	-0.0913*** (0.0218)
Domestic	Linear form	1.2168*** (0.2403)	0.3926*** (0.0263)	
	Square form	-9.2998** (3.9350)	2.7878*** (0.8952)	-0.1355** (0.0506)
Industry	Linear form	5.4825*** (0.1550)	-0.1227*** (0.0169)	
	Square form	2.0375 (2.7610)	0.6619 (0.6281)	-0.0444 (0.0355)
agriculture	Linear form	8.2133*** (0.1587)	-0.1918*** (0.0173)	
	Square form	-0.6016 (2.3937)	1.8159** (0.5445)	-0.1136*** (0.0308)

The parentheses represents standard errors.

Table 4. Projected water supply, unit: 10^9 m^3

	Amount, unit: 10^9 m^3			Composition		
	B	D	SD	B	D	SD
Rivers/streams	8.03	4.60	3.83	46.14%	37.92%	35.01%
reservoirs	4.33	2.48	2.06	24.85%	20.42%	18.86%
groundwater	5.05	5.05	5.05	29.01%	41.66%	46.13%
total water supply	17.41	12.12	10.95	100.00%	100.00%	100.00%

Table 5. Water shortage projected for 2020, 2030, and 2040, unit: 10^9 m^3

Estimation methods	2020			2030			2040		
	B	D	SD	B	D	SD	B	D	SD
Ekc (Eq. 5)	(1.92)	3.36	4.54	(4.32)	0.97	2.15	(7.03)	(1.74)	(0.57)
Linear (Eq. 6)	0.30	5.58	6.76	(0.53)	4.76	5.93	(1.85)	3.44	4.61
Aggregation (Eq. 7-9)	0.86	6.15	7.32	0.59	5.88	7.05	(0.06)	5.23	6.40

B: Base climates, D: drought climates, SD: severe drought climates

附件四：A performance comparison of waste water treatment plants

Abstract

In consideration of the growing importance of resource recovery from waste, this paper employs the DEA technique to analyze the operating efficiency of municipal waste water plants in Taiwan. Totally 51 plants are investigated and the technical efficiency of each plant is evaluated. The results find that the size, technology, age of plants, and operating modes play important roles in affecting the operating performance. The larger plants run more efficiently than smaller plants. In general, secondary process is less efficient than tertiary process in case recycling behavior is incorporated into the model.

Keywords: DEA; Efficiency; Wastewater; Water reuse; sewage

1. Introduction

Waste water recycling is recognized as an effective strategy in addressing the waster scarcity and become an alternative source of water resources. Water recycling of municipal waste water plants is believed an effective method to achieve the sustainable use of water resource. It has emerged as a realistic option for new sources of water in case of water shortage. Due to potential health risks and environmental impacts resulting from the use of reclaimed water, the wastewater disposal standards aimed at protecting the environment and public health should be regulated. Water contamination from inadequate treatment of industrial waste water may contaminate the ground water. And the depletion and contamination of groundwater may compel industries to relocate as polluted water has high costs for human health.

In recently years, sewage treatment rate in Taiwan have increased, but very few researches focus on the operating efficiency of sewage treatment plants. Many researchers have employed DEA to analyze the water use efficiency at regional level (Hu, et al., 2006). Some empirical studies focus on productivity changes of a series of water plants or analyze the privatization effects of public utilities for efficiency comparison. The purpose of this paper is to measure the technical water use efficiencies in each administrative unit and investigate the factor affecting the variation of technical water use efficiencies across regions. This paper employs the DEA technique to examine the operating efficiency of Taiwan's sewage treatment plants. The results show that factors affecting the cost efficiency of sewage treatment plants can be explained by the plant size, operating technology adopted by the plant, and operating modes. The operating mode of private-firm seeking the maximization of profit has better efficiency. Additionally, this paper also discusses the problems involving the operation and maintenance of wastewater treatment plants examined in this study and links with water resource policies by examining whether it is feasible to regulate the recycling rate of municipal waste water. This paper highlights the need for the amendments of the water policy in Taiwan by integrating the administrative powers among different departments of the government.

2. Research methods

This paper measures the operating efficiency by the ratio of desired outputs to the inputs by using the Data Envelopment Analysis (DEA), a method of linear programming techniques to analyze the relative efficiency of each decision making unit (DMU) for MSTPs in Taiwan based on a constant returns to scale. It is associated with the optimal use of the input resources in a production process based on the existing technology. The DEA was pioneered by Charnes et al. (1978) based on the theoretical concept of frontier production developed by Farrell (1957). Until now, many researchers have employed it to evaluate the relative efficiency in various applications and proved to be an effective approach in identifying the best practice frontiers. For example, a great number of literature employ DEA to calculate the technical efficiency and scale efficiency in power generation plants or energy industries (e.g. Pombo and Taborda (2006) and Vaninsky, 2006). Vaninsky (2006) estimates the efficiency of electric power generation in the United States by using the data during 1991-2004. Avkiran (2014) analyze the profit efficiency of domestic commercial banks and their divisions in the United Arab Emirates by using DEA models. Ohsato and Takahashi (2015) also employ the DEA technique to evaluate the overall and division efficiency of the regional bank's management efficiency in Japan.

In the field of wastewater management, the relevant research by using the DEA technique for the analysis of operating efficiency remains scarce. Hu et al. (2006) analyze the water efficiency at regional level by using the DEA technique and find a U-shape relation between the total-factor water efficiency and per capita real income. Hernández-Sancho and Sala-Garrido (2009) analyze the efficiency of wastewater treatment plants by using the data of 338 plants located in the Valencia Region (Spain). They find that the largest plants are more efficiently operated than smaller plants and maintenance and waste management costs play a vital role in affecting the variation of efficiency across plants.

The service of municipal sewage treatment management is executed by a technology whereby N DMUs transform multiple inputs $x \equiv (x_1, \ldots, x_m) \in \Re_+^m$ into multiple outputs $y \equiv (y_1, \ldots, y_s) \in \Re_+^s$. This paper employs the basic DEA model of CCR (Charnes, Coopers, Rhodes) to calculate the efficiency of municipal sewage treatment. The CCR model, under the hypothesis of constant returns to scale, is expressed as follows:

$$
\begin{aligned}
& Min \quad \theta \\
& s.t. \quad \theta x_0 - X\lambda \geq 0 \\
& \qquad\quad Y\lambda \geq y_0 \qquad\qquad (1) \\
& \qquad\quad \lambda \geq 0
\end{aligned}
$$

where y_0 is output, x_0 is the input, X, Y is the data sets in matrices, λ is a semipositive vector, θ represents the technical efficiency.

In practice, raw wastewater is comprised of approximately 99% water and a small percentage of pollutants including suspended solids, which contain soluble and insoluble substances such as nitrates, phosphorous and heavy metals presenting in varying concentrations, and bacteria, viruses and other microorganisms. Basically, the sewage treatment plant involves three major processes including physical treatments, biochemical treatments, dewatering for sludge treatment and final disposal in order to remove contaminants in raw wastewater. And thus, the waste water treated is designated as the output variable. On the other hand, land costs (x_1), labor costs (x_2), energy consumption (x_3), operating and maintenance (O&M) costs (x_4) are selected as input variables. Land costs (x_1) are measured in terms of the area covered by the MRTP. O&M costs are obtained by summing up the relevant items of materials and supplies for repairs and maintenances excluding energy consumption. As the cost for chemicals and material, sludge disposal, and external service accounts for a relatively low percentage of total treatment costs and thus included in the O&M costs. Thus, the operating efficiency is measured by

$$\eta = \frac{\mu_1 y_1 + \mu_2 y_2 + \mu_3 y_3}{v_1 x_1 + v_2 x_2 + v_3 x_3 + v_4 x_4}$$

where y_1, y_2 represent the effluent output, and contaminants concentration, and x_1, x_2, x_3 and x_4 denotes the input variables of land costs, labor costs, energy consumption, and operating costs.

The cost for the wastewater sewer system and the conveyance channel are not included in the efficiency analysis as the construction and maintenance and management is conducted by another department of governmental administrations separating from MWTPs.

2.2 data collection

By 2014, totally 51 municipal sewage treatment plants (MSTPs) have been constructed and operated with designed capacity ranging from 10 CMD to 1,530,000 CMD including 17 plants in north Taiwan, 11 in middle Taiwan, 13 in south Taiwan, 4 in eastern Taiwan, and 6 in isolated islands (Taiwan EPA, 2014). Currently all these MSTPs are owned by the governments but operated by private contractors. Totally 23 MSTPs locates in north, 9 in middle Taiwan, and 14 in south Taiwan, 3 in East Taiwan and 13 in isolated islands.

The required data for this study is provided by CAPMI (Construction and Planning Agency Ministry of Interior, 2014). Due to missing values occurred in some plants, three plants are omitted. And thus, totally 49 MWTPs are selected for efficiency comparisons, among which 44 MWTPs are operated by the secondary treatment process, two by the primary process and three by the tertiary treatment process.

Table 1 illustrates the mean and variance of flow rates, capital costs, land costs, labor costs and operating costs associated with these municipal sewage treatment plants in 2012. The average flow rate of waste water for these MWTPs is 48,860 cubic meter per day (CMD). The Pali MWTP is the largest plant in Taiwan with designed capacity of 1,530,000 CMD, but the waste water treated is 795,547 CMD, accounting for 52% of the designed capacity. The Chinsa MWTP is the smallest, located in an isolated island in Kimmen County with sewage treated of 2.09 CMD under a designed capacity of 10 CMD.

Table 1. The descriptive variables for flow rate, land cost, labor cost, electricity cost and operating costs

	flow rate	land cost	labor cost	Energy cost	Operating cost
Unit	CMD	hectare	NT$ 1000	NT$ 1000	NT$ 1000
Mean	48860	3.95	6577.49	8816.88	17197.57
variance	2.69E+10	27.36	9.99E+07	6.95E+08	2.69E+09
Max.	795547	25.27	41721	147960	278980
Min.	2.09	0.0039	48.75	47.72	63.33

3.3 The preliminary cost analysis

In this paper, the costs are differentiated as as personnel costs, O&M costs, and energy costs but the land cost is excluded for comparison. The unit treatment costs are defined as the sum of personnel costs, O&M costs, and energy costs for each cubic meter of waste water treated in this paper. The composition of unit treatment costs for MSTPs among the three groups is depicted in Table 2. The personnel cost for group B and C rank the top, up to 45.89% and 48.91% of total unit treatment costs. For Group A operating at higher flow rate has relatively lower personnel costs, only amounting to 30.24% of the total.

In contrast, the O&M costs for maintenance of waste water treatment plants, chemicals consumptions, sludge disposal and others amount up to 41.98% of the total treatment costs for Group A, followed by Group B 37.61% and Group C 21.09%. In practice, the major factors for O&M costs may attribute to the regualr maintennace and replacement on mechanical, electrical, electronic and civil parts.

Electricity costs also play an important contribution to the treatment cost of sewage treatment, amounting up to 16.51-30% of total treatment costs. Aeration for biological reactors adopted in secondary treatment is considered to be the main consumption point in the wastewater treatment process.

Table 2. Unit treatment costs among three groups of MSTPs

	personnel cost	electricity	O&M	Unit total cost	designed capacity (CMD)
Group A	1.13 (30.24%)	1.04 (27.78%)	1.57 (41.98%)	3.74 (100%)	323,554
Group B	9.65 (45.89%)	3.47 (16.51%)	7.91 (37.61%)	21.03 (100%)	12,178
Group C	64.64 (48.91%)	39.64 (30.00%)	27.87 (21.09%)	132.15 (100%)	983

Table 2 implies that Group A has relative advantage in cost sides due to larger flow rates and plant sizes (designed capacity). A plot of flow rate v.s. unit treatment costs is conducted. As the flow rate of the sample MSTPs varies too much, ranging from 2.09 CMD to 797,550 CMD. It is intutive that the unit treatment cost has negative relationship with flow rate. The unit treatment costs ranges from NT$ 1.01/M3 to NT$ 256/m3. The lowest treatment cost may attribute to the high flow rate (744,924 CMD) and low technology level (primary treatment), executed by Pali MWTP. In contrast, the unit treatment cost in Chinsa MWTP is the highest, due to the smallest plant size (10 CMD) and flow rate (2.09 CMD).

The concentration of BOD, SS and COD in raw waste water and effluent is listed in Table 3. On an average, the inflow of waste water contains 181.01 mg/l COD (chemical oxygen demand), 74.11 mg/l SS (suspended solids), and 72.82 mg/l BOD (biological oxygen demand) while the average concentration of COD, SS and BOD is 29.09 mg/l, 10.79 mg/l and 10.26 mg/l, respectively. All the effluent discharged to the river by these MSTPs meets the regulated standard, i.e. 100 mg/l, 30 mg/l, 30 mg/l for COD, SS, and BOD respectively.

Table 3 The quality of inflow waste water and effluent

	pollutants	Average	st. dev.	Max.	Min.

		mg/l		mg/l	mg/l
inflow	COD	181.01	129.20	555.00	25.00
	SS	74.11	53.57	254.80	21.00
	BOD	72.82	62.40	284.00	10.21
effluent	COD	29.09	24.85	155.00	0.00
	SS	10.79	12.17	78.00	2.00
	BOD	10.26	8.63	50.00	1.50
Pollutants removal rate	COD	0.76	0.25	1.00	0.07
	SS	0.80	0.20	0.98	0.16
	BOD	0.78	0.23	0.99	0.02

3. Results

The results obtained by the DEA analysis find that the mean efficinecy is 45.13% with standard error of 0.3215. Figure 1 shows the efficinecy score distribution for the sample waste water plants. It is noticed that eight MSTPs are efficient, accounting for 16.32% of the total sample. The number of nearly efficient plants (efficiency scores between 81% and 99%) is only four, accounting for 8.16% of the total. In contrast, more than 50% of the plants executes in significantly inefficiney with efficiency scores under 50%. These results implies that a wide space remains to improve the operaitng efficiency for these MSTPs. We suggest that the plant size, the operating technology level, and the pollutant removal rate may provide the vital impacts on the performance of these MSTPs. An advanced analysis is undertaken to examine the relationship between efficinecy scores and the the plant size, the operating technology level, and the pollutant removal rate.

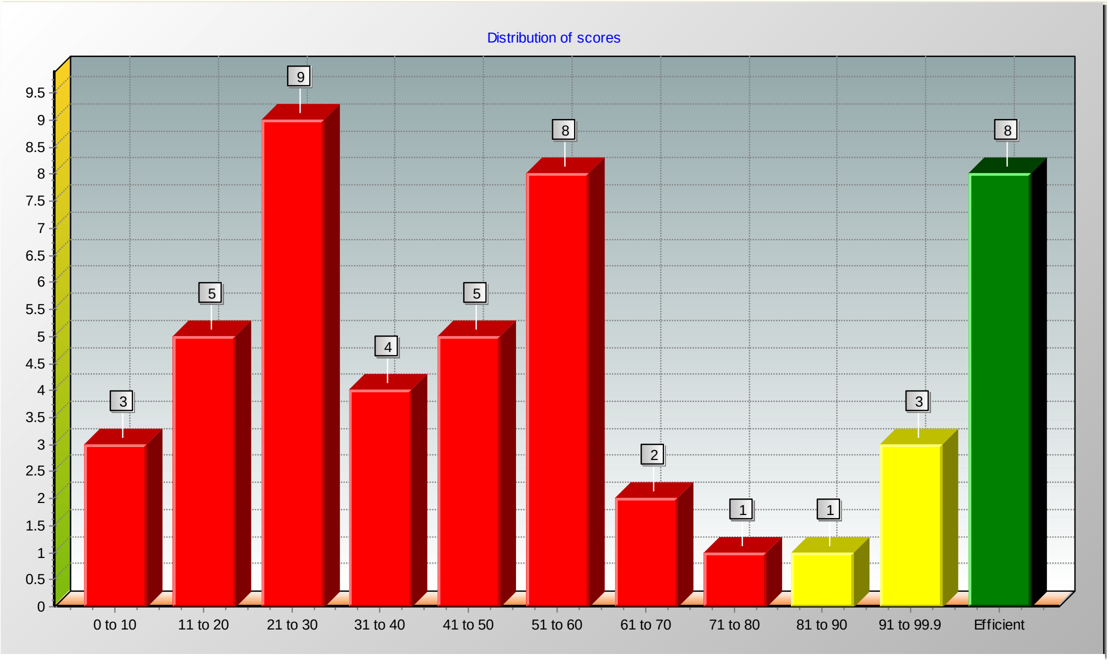

Figure 1. The distribution of efficiency scores

3.1 The impact of plant sizes on the performance

According to the guidelines for the construction of sewerage systems planned by CAMPI, the old MWTPs that has been equipped with sewerage systems is categorized into Class I containing 25 MWTPs including 12 large plants located in urban regions and 13 very small plants in isolated islands (Kimmen County and Lienchian County). In contrast, the newly constructed MWTPs for cities/towns with population more than 100,000 are classified into Class II (Tseng, 2014).

The designed capacity varies very much across these 49 MWTPs, ranging from 10 CMD to 1,530,000 CMD. Considering the high variation of designed capacity in Class I, we categoruize the 12 larger plants in urban regions is termed as Group A and the small MSTPs in isolated islands are categorized as Group C. Class II containing the remaining 24 plants, is called Group B. The MSTPs in Group B is small and mid-scale with designed capacity ranged from 1,200 CMD to 65,000 CMD. All the plants of Group B locate in the small cities of rural regions in Taiwan while Group C is located in isolated islands including Kimmen County and Lienchiang County. The mean of designed capacity, flow rate and efficiency for each group is listed in Table 4. The average designed capacity of MWTPs for Group A, B, and C is 323,554 CMD , 194,463 CMD, and 983 CMD, respectively. Due to less population in isolated islands outside Taiwan, each MSTP in Group C is designed for small capacity, ranging from 10 CMD to 6008 CMD.

The MSTPs in Group B execute at the highest efficiency of 70.71%, ahead of Group C 47.59% and Group B 30.53%. The better efficiency for Group C than Group B implies that the plant size (designed capacity) is not the major factor to affect the outcome of operating efficiency. The possible cause for the low efficiency of Group B may attributes to their low operating rate due to insufficient supply of waste water input. The operating rate for Group C is 0.4362, much higher than Group B, where operating rate is defiend as the ratio between waste water flow rate and designed capacity. In practice, the operating rate is affected by the sewerage installation rate. The MSTPs in Group A, in general, locate in urban regions with high population density and is equipped with high connection rate of sewerage systems. Group C also owns high connection rate of sewerage systems even though they are located in isolated islands. The MSTP in Group B (Class II) was constructed to avoid the pollution to water protection areas (water reservoirs/dams) and thus the connection rate is not high due to insufficient sewerage system.

Table 4. The comparison of efficiency among different plant sizes

	Mean designed capacity (CMD)	Mean flow rate (CMD)	Operating rate	Mean efficiency
Group A	323,554	194,463	0.4962	70.71%
Group B	12,178	2,305	0.2547	30.53%
Group C	983	404	0.4362	47.59%

3.2 The compariosn of pollutants remvoal

Basically, the major purpose of MSTPs is to remove pollutants for the protection of human health and extended to protect downstream users by mitigating health risks that arises from the adverse impacts of pollutants in raw wastewater (Wilsenach et al., 2003). The primary treatment aims to remove coarse solids, settleable organic and inorganic solids while the scoendary treatment is designed to remove the residual organics and suspended solids (biodegradable dissolved and colloidal organic matter) ramained in the flow. At the stage of primary treatment, approximately 25 to 50% of the incoming biochemical oxygen demand (BOD_5), 50 to 70% of the total suspended solids (SS), and 65% of the oil and grease can be removed. In combination with primary sedimentation, the secondary treatment typically remove 85 % of the BOD_5 and SS originally present in the raw wastewater. In order to meet higher water quality standard for particular use rather than discharges into the environment, an advanced treatment should be conducted through tertiary treatment process to remove polluatns that cannot be removed at secondary treatment. And the removal rate RR is calculated based on

$$RR = \frac{x_f - x_0}{x_0}$$

where x_f denotes the pollutant concentration in the effluent, and x_0 represents the pollutant concentration in the inflow waste water. The average removal rate for COD, SS and BOD is 76.29%, 80.02, and 77.55% respectuively.

The relationship between removal rate and efficiency scores for each MSTP is plotted in Figure 2, 3, and 4 for COD, SS, and BOD respectively. It seems that higher removal rates have a negative relationship with efficiency scores. A relationship test finds that the relationship coefficients are – 0.23, - 0.33 and – 0.27

for COD, SS, and BOD respectively.

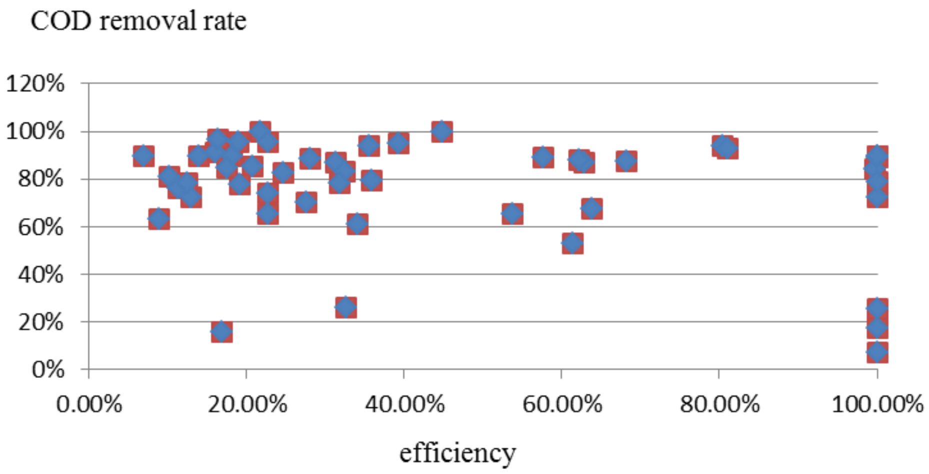

Figure 2. The plot of COD removal rate v.s. operating efficiency

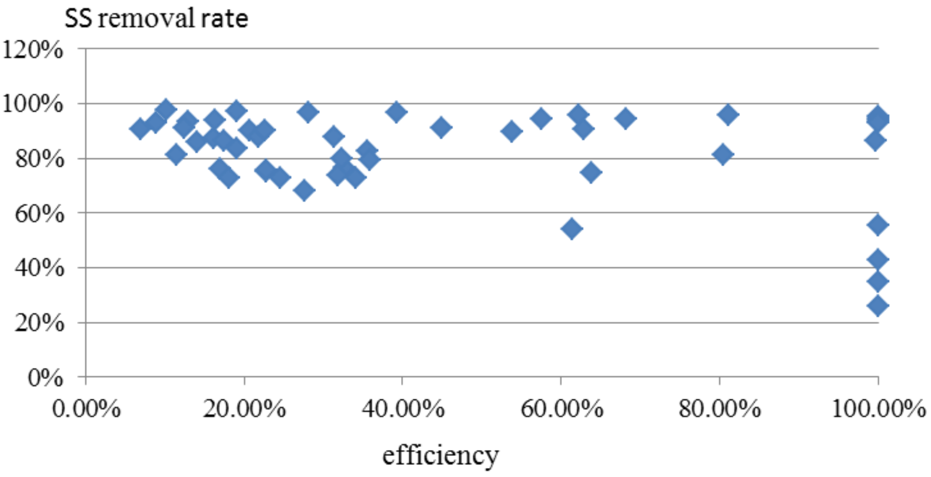

Figure 3. The plot of SS removal rate v.s. operating efficinecy

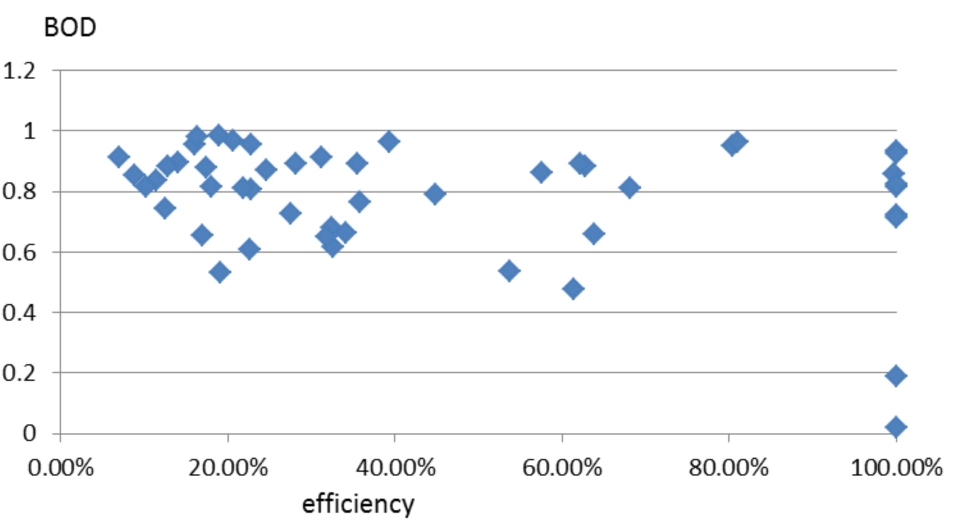

Figure 4. The plot of BOD removal rate v.s. operating efficiency

3.3 The impact of technology level on the performance

In general, the waste water treatment process is categorized into three levels: the primary treatment is applied directly to the raw wastewater and produces a carbon-rich primary sludge, while the secondary treatment process is applied to separate the biomass produced in the Activated Sludge reactors from the water. Theoretically, the treatment cost is the lowest for the primary treatment process, and then followed by secondary and tertiary process. The results illustrated in Table 5 demonstrates that the efficiency of MWTPs operated by primary process has average efficiency of 100%, and the technical efficiency for MWTPs with secondary and tertiary treatment process is 42.83% and 35.63% respectively.

Table 5. Comparison of technical efficiency among various technologies

Technology level	mean	variance
Primary treatment	100%	0
Secondary treatment	43.07%	0.0949
Tertiary treatment	35.63%	0.0758

According to the experience of Carollo (2008), the O&M cost for a tertiary treatment plant consists of 18.6% for primary treatment, 22.3% for secondary treatment, 32.1% for tertiary treatment, and 27.5% for solids treatment respcetively. In order to make a comparison on the same basis of a secondary treatment, the O&M cost is added by 32.8% for the primary treatment plants, and substracted by 32.1 % for the tertiary treatment plants according to the suggestion of Carollo (2008). Using the revised data, the operating efficiency for these MSTPs is obtained. The performance compaprison across the three levels of technology is compared and this paper find that the efficiency of these three primary plants are still leading and ranking the top. This result implies that other factor except technology level may also impact operating efficiency.

4. Discussion

The previous results indicated in Section 3 implies that several factors may affect unit treatment costs, inclduing the size and the load of the plant, the technology level selected by MSTPs, and the pollutant removal rate. The results demonstrates that larger plant sizes are significantly more efficient due to scale economies. The cost increase is not linarly proportional to the flow rate increase. In this paper, the plant area is used to measure the land cost rather than the money paid for the acquisition of the land. In practice, the land price is more expensive in municipality then rural regions.

According to CPAMI (2015), totally 204,056 CMD reclaimed water is produced by these MSTPs in 2015, accounting for the 8.52% of waste water treated. Considering the low recycling rate of municipal waste water in Taiwan and the feasibility of reclaimed water for reuse, the government plans to rise up the recycling rate to 20% in 2030 (Water Resource Agency, 2013). The reclaimed water produced by these MSTPs currently is used internally in the MSTP for the cleaning of filtering clothes, gardening, and fire protection use. Even though the government encourage the private paprty or individual to apply for the free acquirement of the reclaimed water, the consumption of reclaimed water is not popular and thus the cosnumption rate of the reclaimed water is still very low, less than 10%.

In brief, the reuse of reclaimed water depends on many factors inclduing technical possibility, socio-economic factors, and institutional factors. The major barriers involves the perceived risk of reclaimed water quality. A regulation should be made to warranty the water quality of reclaimed water to avoid the negative effect on health. The main potential pollutants in reclaimed water such as BOD5, COD, TP, NH4–N, and pathogens that particularly restrict water quality should be minimized. If the reclaimed water is used for industrial process, chlorine contamination should be avoided as it may lead to corrosion and scaling formation inside the piping systems (Chang and Ma, 2012).

However, Taiwan has not yet established any regulation to support waste water reclamation. In practice, Taiwan’s water policy is flawed as it sees the effluent from municipal sewage treatment plants as a “bad” and a municipal sewage treatment plant is used as a tool for end-of-pipe treatment to avoid the environmental and health impacts. Almost all the effluent is dumped into the sea or rivers. Only a small portion of effluent is reclaimed for internal use in the municipal sewage treatment plant through advanced treatments. In 2011, the effluent discharged from the municipal sewage treatment plant including primary, secondary and tertiary plants reached 2,350,000 CMD, among which 1,589,000 CMD of effluent was produced from the secondary and tertiary sewage treatment plant. If all the secondary and tertiary effluent is recycled and reused, it can reduce the environmental pressure arising from water resoruce scarcity.

5. conclusions

To mitigate the exhaustion of water resources, the integration is required at all levels of the government as well as the stakeholders and the people at the lowest appropriate level concerning planning and decision making. Water resource is a public good, and the sufficient supply of water in proper quantity and safe quality is a basic human right for the citizens.

This paper argues that adequate investments in water management, infrastructure and services can yield a high economic return when facing water shortage.

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