

污水下水道全生命週期 減碳管理策略

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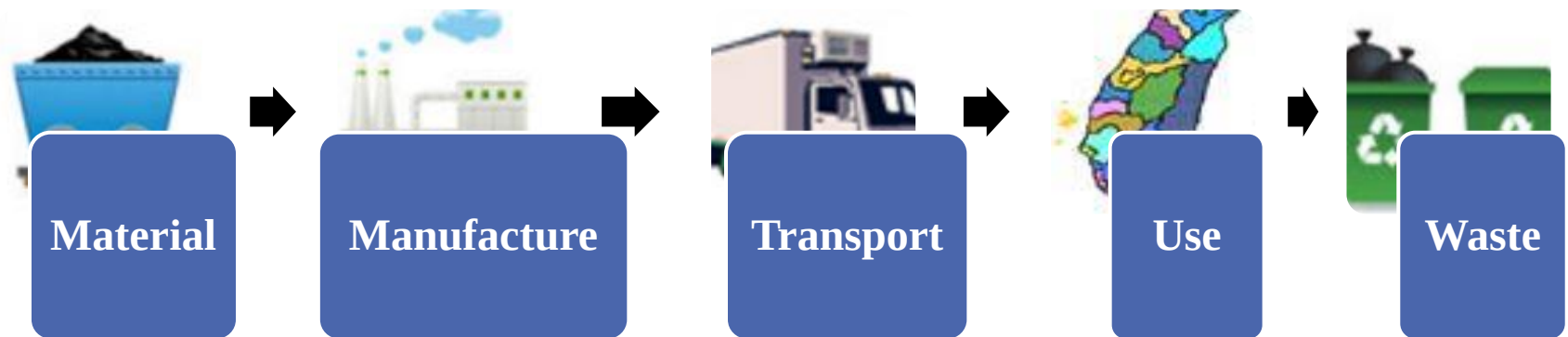
大綱

- 生命週期評估與減碳管理
- 國外下水道全生命週期評估
 - 澳洲城市水處理系統生命週期評估
 - 西班牙城市水處理系統生命週期評估
 - 以色列污水處理與再生利用之生命週期評估
- 國內下水道全生命週期評估發展
- 結語

生命週期評估與減碳管理

- 生命週期評估：

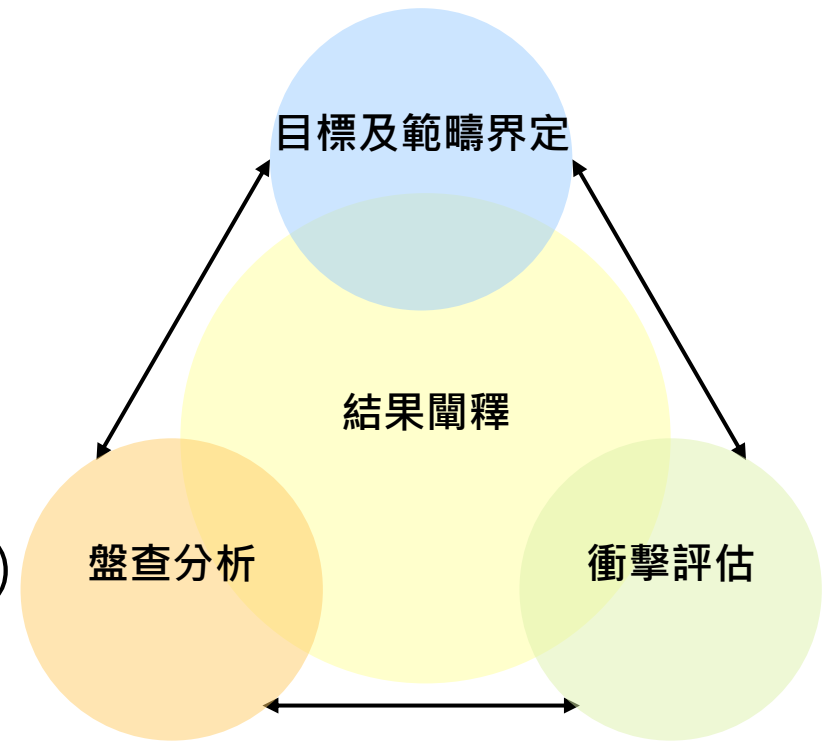
評估產品或服務在生命週期中，從原料的取得、製造、使用和棄置等階段(亦即搖籃至墳墓)整個生命過程中的環境考量面與潛在衝擊



生命週期評估與減碳管理

- ISO14040生命週期評估四個主要步驟：

- 目標及範疇界定
(Goal and Scope Definition)
- 盤查分析
(Life Cycle Inventory)
- 衝擊評估
(Life Cycle Impact Assessment)
- 結果闡釋
(Life Cycle Interpretation)



生命週期評估與減碳管理

- 衝擊評估結果通常包含：

中間點型



- ☐ 酸化
- ☐ 優養化
- ☐ 全球暖化
- ☐ 臭氧層破壞
- ☐ 光化學氧化
- ☐ 生態毒性

終點型



- ☐ 人體健康
- ☐ 生態品質
- ☐ 氣候變遷
- ☐ 天然資源

全球暖化指標：

單位：(kg CO₂ eq)

運用

- 評估工程各階段衝擊熱點
- 做為工程碳管理相關政策之參考指標
 - 策略規劃
 - 優先順序設定
 - 製程設計

生命週期評估與減碳管理

• ISO14064溫室氣體管理標準：

- 詳述溫室氣體盤查設計、發展、管理及報告之**原則**
- 決定溫室氣體排放**盤查邊界**，量化溫室氣體之排放與移除
- 此標準包含盤查之品質管理、報告、內部稽核及**查證工作**

• ISO14064應用與效益：

- 提升溫室氣體量化、監督及報告之可信度、一致性與透明度
- 促進溫室氣體管理策略與規劃之發展
- 促進溫室氣體排放減量與移除增量之績效進展
- 促進溫室氣體減量或移除增量之信用與交易



國外下水道 全生命週期評估

Life Cycle Assessment for Sustainable Metropolitan Water Systems Planning

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significant increase in greenhouse gas emissions due to coal-fired electricity generation for a small increase in water supply. Assessment of a greenfield scenario incorporating water demand management, on-site treatment, local irrigation, and centralized biosolids treatment indicates significant environmental improvements are possible relative to the assessment of a conventional system of corresponding scale.

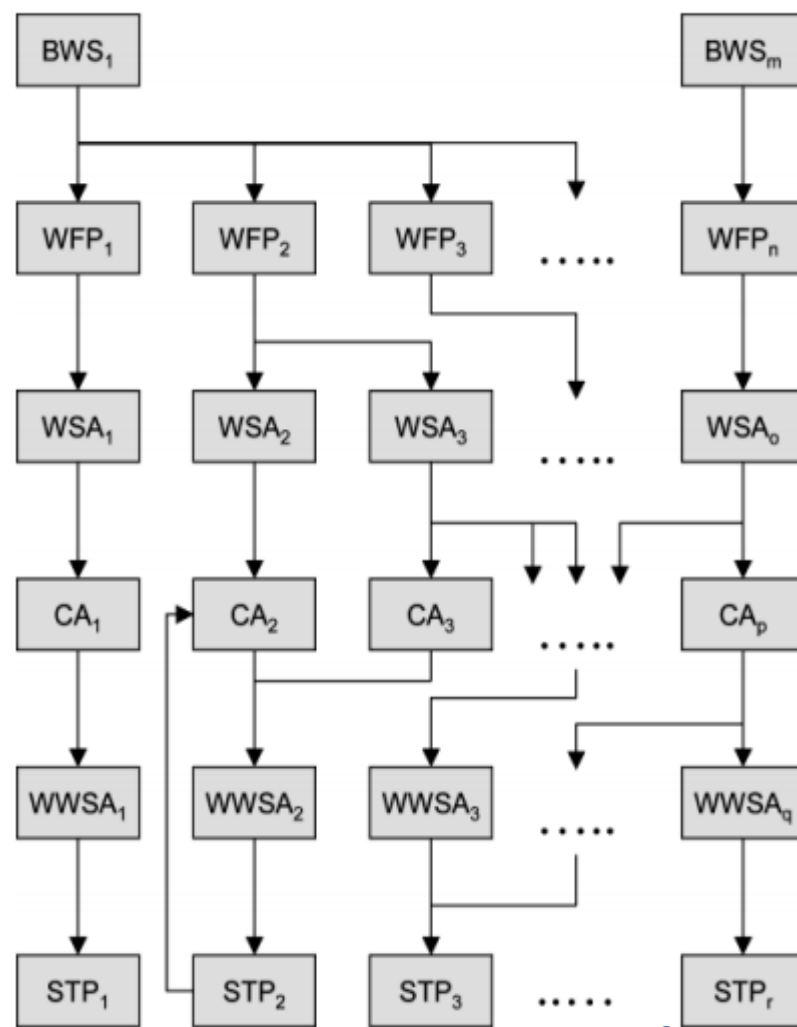
Introduction

Previous LCA studies in the area of water cycle management have mainly addressed specific aspects of wastewater systems, i.e., quantifying environmental loads of wastewater systems (1–5) or biosolids systems (6, 7). Fewer LCA studies of water supply alternatives (8, 9) have been published. LCA has also been used for the definition of environmental sustainability indicators for wastewater systems (10, 11) and more recently for urban water systems (12).

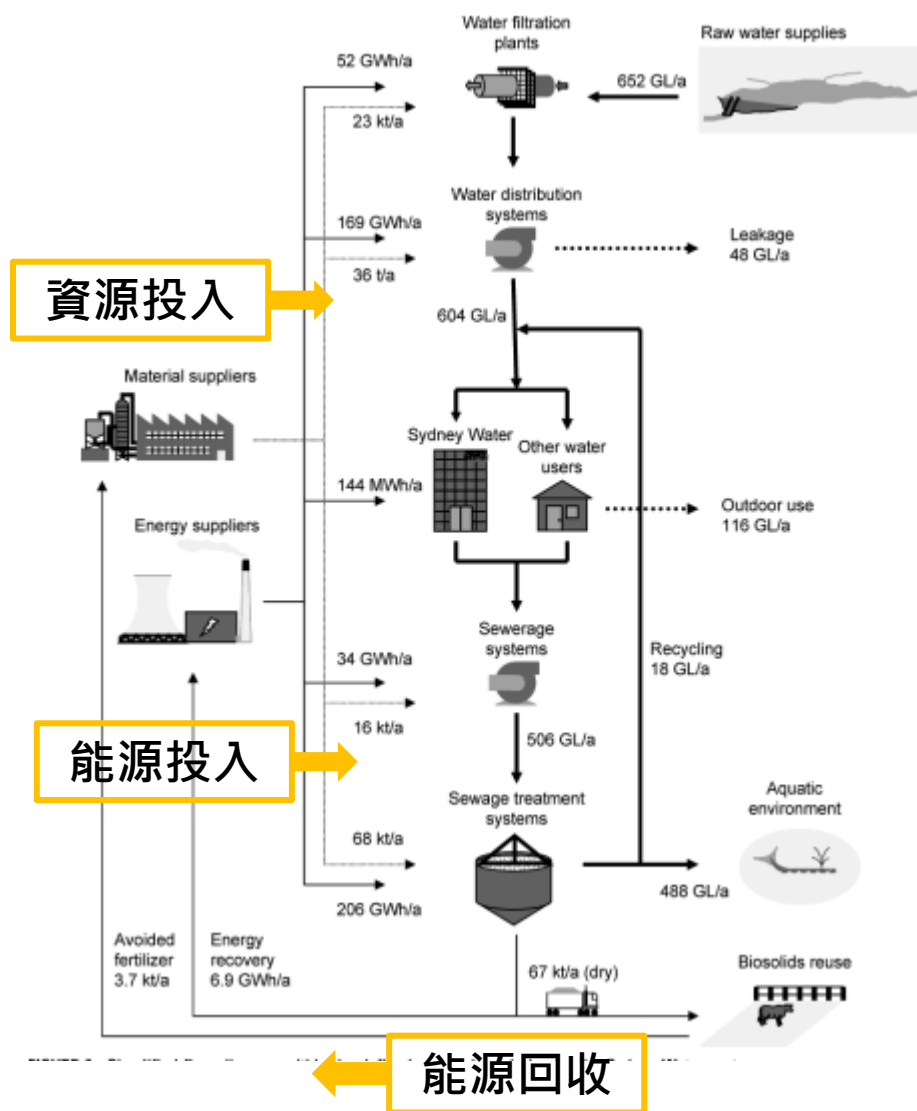
Recent Swedish studies have incorporated some of the most comprehensive LCA system boundaries, including water, sewage, and sludge treatment and avoided fertilizer production (e.g., refs 2 and 4) as have been discussed in greater detail previously (1). These studies developed detailed

澳洲城市水處理系統生命週期評估

- 包含：
 - 9個淨水廠 →
 - 13個供水系統 →
 - 55個需水區 →
 - 蒐集至40個
污水下水道系統 →
 - 由31個污水處理廠
進行處理或再生 →



澳洲城市水處理系統生命週期評估



- 功能單位：1年供水量
- 系統邊界：
 - 邊界包含淨水、供水、用水、污水處理等階段
 - 考量基礎建設、設備 (排除施工階段之能耗)
 - 考量營運階段能資源投入及回收
 - 能源組成包含91%的燃煤、6%的水力發電以及3%的再生能源

澳洲城市水處理系統生命週期評估

TABLE 3. LCIA Results of the Base Case

environmental indicators/ impact categories	resource use		output-related categories			
	total energy use	water use	climate change	eutrophication potential	photochemical oxidant formation potential	human toxicity potential
	TJ/a	GL/a	kt CO ₂ /a	kt O ₂ /a	t ethene/a	kt
total	8110	655	721	231	127	
Percentage Contributions Relative to Sydney Water's Total for Each						
water filtration plants	12%	<1%	11%	1%	9%	
water system areas	28%	8%	24%	1%	5%	
customer areas		92%				
wastewater system areas	8%		7%	<1%	11%	
inland STPs	12%	<1%	20%	16%		
coastal STPs	29%	<1%	29%			
water recycling by STPs	1%		1%			
recycled water distribution	1%		1%			
biosolids system	-1%	<-1%	-1%	1%	7%	
infrastructure	4%		4%	<1%	2%	
nonsystem areas	6%		5%	<1%	23%	
total	100%	100%	100%	100%	100%	100%

城市水處理系統
全生命週期之
二氧化碳排放量

每年 721 千噸 CO₂

熱點
污水處理廠是城市水
處理系統中，衝擊最
大，共佔49%

- 暖化衝擊熱點(污水處理廠)，應優先進行單元操作之排碳分析，進一步執行減碳規劃
- 研究結果指出，能源衝擊高、基礎建設之衝擊較低

澳洲城市水處理系統生命週期評估

TABLE 5. Comparison of Scenarios against the Base Case for Each Environmental Indicator and Impact Category

	total energy (%)	water usage (%)	climate change (%)	eutrophication potential (%)	photochemical oxidant formation potential (%)	human toxicity potential (%)	freshwater aquatic ecotoxicity potential (%)	marine aquatic ecotoxicity potential (%)	terrestrial ecotoxicity potential (%)
desalination	27	0	23	1	5	1	0	1	3
demand management	-4	-6	-4	-6	-6	-6	-6	-6	-6
energy efficiency	-13	0	-11	-1	-6	-1	0	0	-2
energy generation	-8	0	-7	0	-1	0	0	0	-1
energy recovery from 50% biosolids	-4	0	-2	0	-2	-9	-29	0	-39
population +7%	3	7	4	7	6	7	7	7	7
population +16%	8	16	10	16	15	16	16	16	15
population -7%	-4	-6	-5	-6	-6	-6	-6	-6	-6
population -16%	-8	-12	-8	-12	-11	-12	-12	-12	-11
secondary upgrade of major coastal STPs	23	0	21	-8	16	2	2	0	51
secondary & tertiary upgrade of major coastal STPs	26	0	23	-10	17	2	3	0	60

- 該研究針對能源效率管理、需水人口管理、單元操作管理等情境分析，改善廠內設備之能源效率，可以降低11%之暖化衝擊

Environmental assessment of urban water cycle on Mediterranean conditions by LCA approach

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ABSTRACT

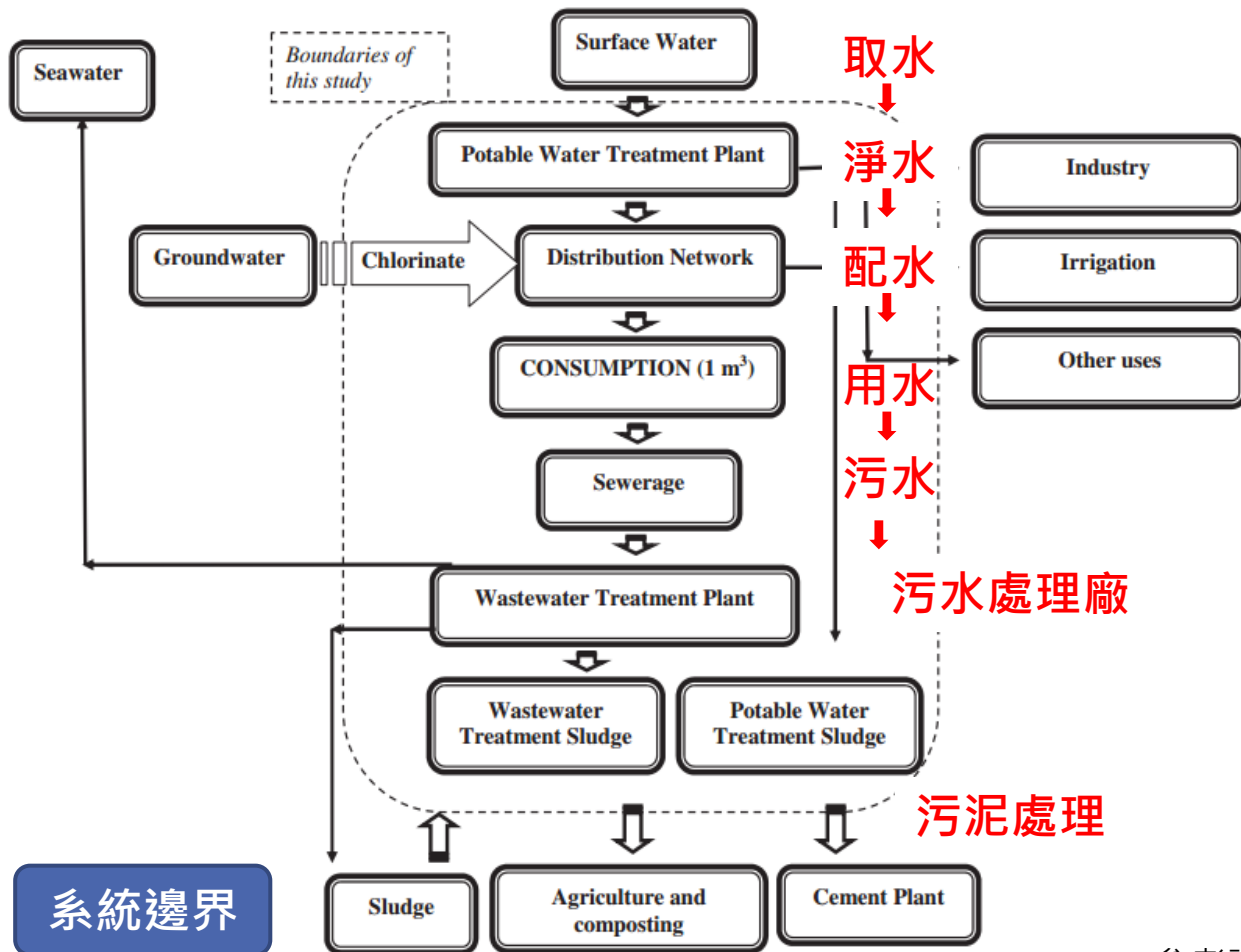
Urban water authorities in many countries are struggling to satisfy the increasing demand for both potable and non-potable water whilst also improving the environmental profile of the urban water system.

The main goal of this study is to use the Life Cycle Assessment methodology to carry out an environmental analysis of every stage of the urban water cycle in Tarragona, a Mediterranean city of Spain (scenario I). These stages are: water abstraction, potable water treatment, intermediate pumping, distribution network, sewage collection and wastewater treatment. This study also proposes possible scenarios for improving the environmental performance reducing the high level of water stress resulting from increasing demand and limited resources: using reclaimed water (scenario II) and using desalination plants and reclaimed water to supply water during a drought (scenario III). Inventory analysis was performed using local operation data.

In the current situation (scenario I) the main environmental impacts on urban water cycle were caused by 35.2% of distribution network, 20.5% of collection pumping and 13.8% of wastewater treatment plant for the Global Warming Potential impact category because these stages have high energy consumption. In Reclaimed water (scenario II), no significant improvement in indicators is observed, because the addition of environmental loads introduced by the tertiary treatment, except for the reduction in

西班牙城市水處理系統生命週期評估

- 供水方案：



- 功能單位：

- 1立方公尺

- 系統邊界：

- 邊界包含取水、淨水、配水、供水、用水、污水處理等階段
- 考量基礎建設、設備，不包含建設階段之消耗
- 考量營運階段能資源投入

- 情境假設：

- 污水再生利用
- 極端缺水情境

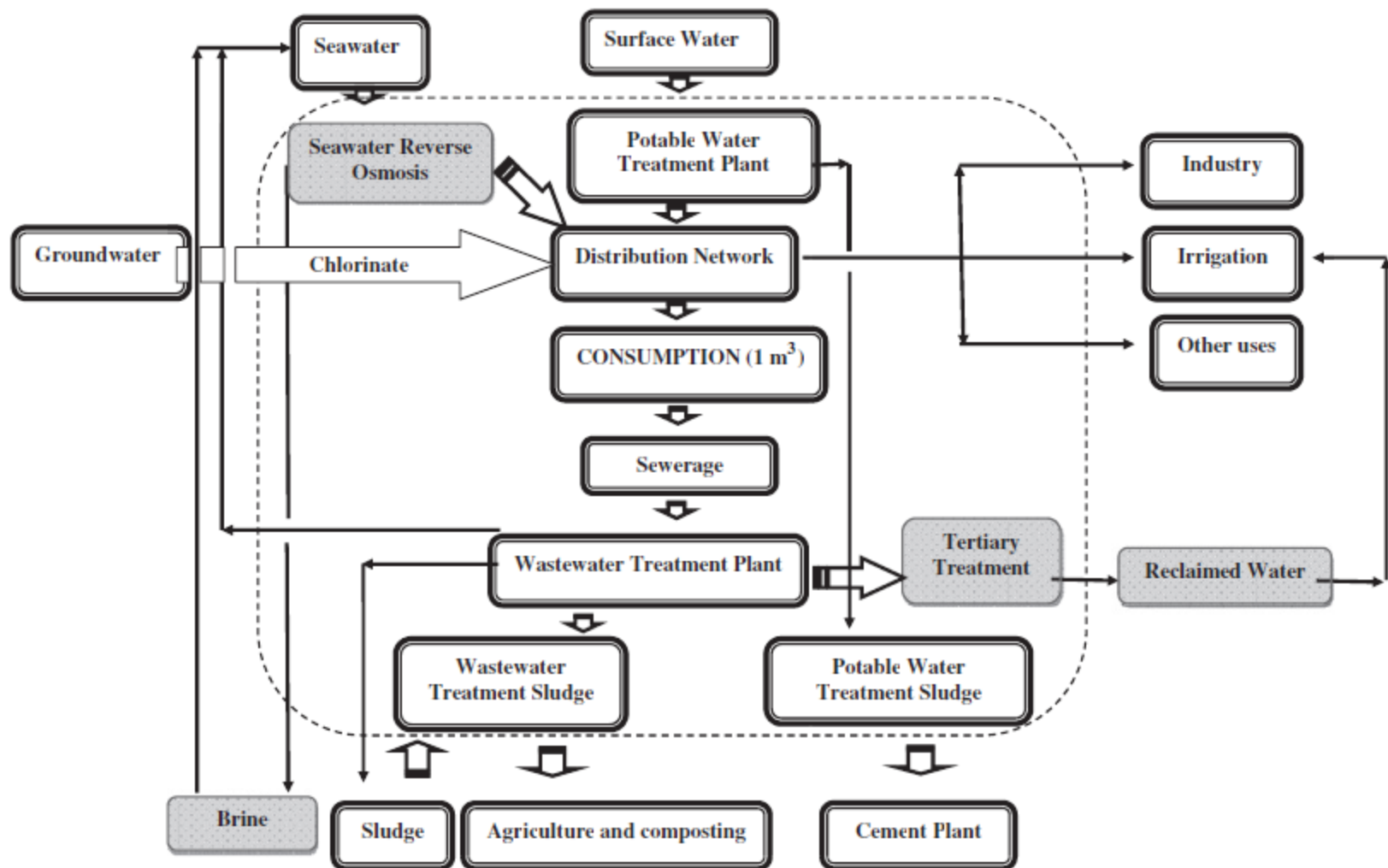


Fig. 2. Urban water cycle with reclaimed water (scenario II) and seawater reverse osmosis (scenario III).

西班牙城市水處理系統生命週期評估

- 主要的衝擊在於水配送階段，地形與距離造成的能源消耗是衝擊的主要原因
- 污水與污泥再利用於農業可以減少肥料施用、減少優養化衝擊，每立方公尺水於暖化衝擊可減少 $2.99 \times 10^{-03} \text{ kg CO}_2 \text{ eq}$
- 水再生利用可減少淡水資源壓力
- 極端缺水情境下，海水淡化之各面向皆高度衝擊，儘管高耗能、高衝擊，然而在乾旱情境下是難避免的



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Research article

Comparative LCA of decentralized wastewater treatment alternatives for non-potable urban reuse



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ABSTRACT

Municipal wastewater (WW) effluent represents a reliable and significant source for reclaimed water, very much needed nowadays. Water reclamation and reuse has become an attractive option for conserving and extending available water sources. The decentralized approach to domestic WW treatment benefits from the advantages of source separation, which makes available simple small-scale systems and on-site reuse, which can be constructed on a short time schedule and occasionally upgraded with new technological developments.

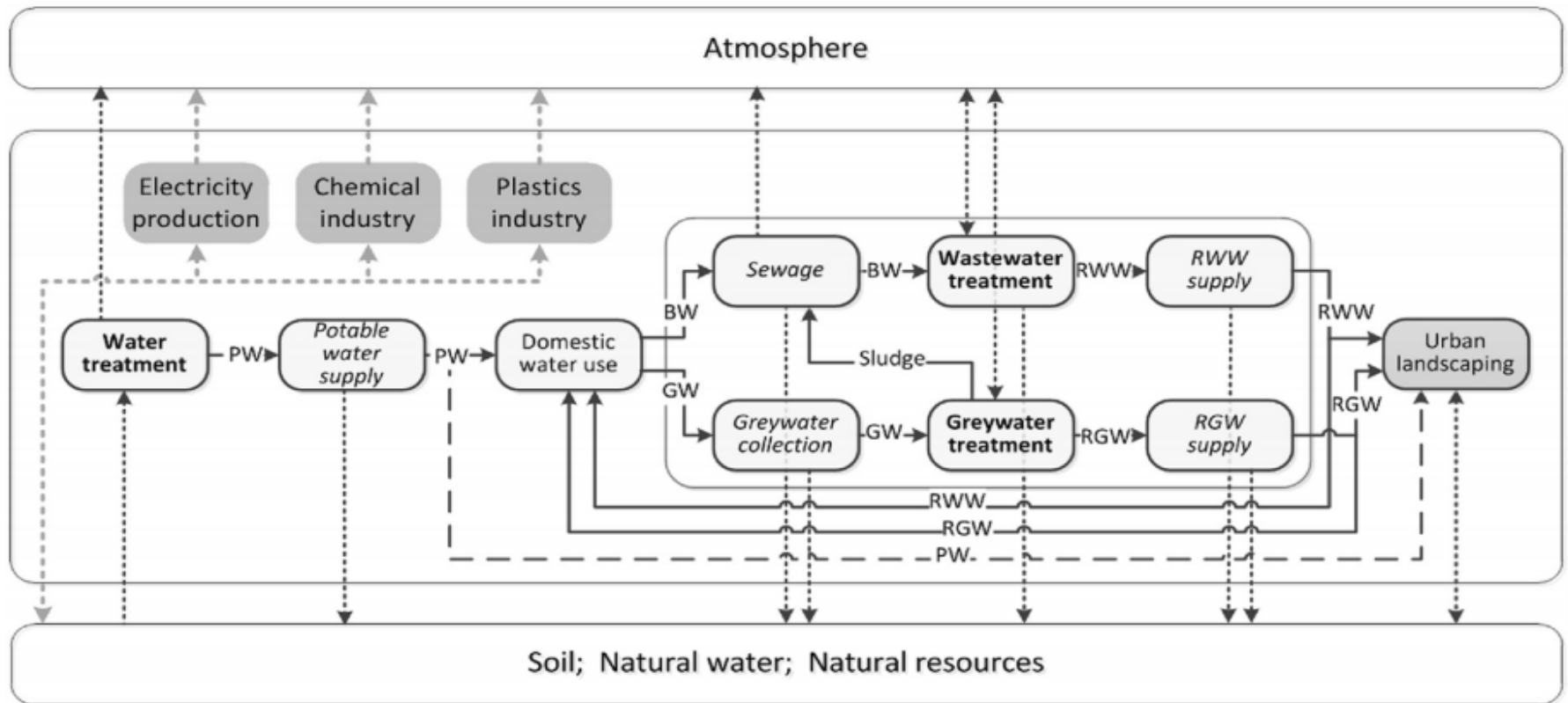
In this study we perform a Life Cycle Assessment to compare between the environmental impacts of four alternatives for a hypothetical city's water-wastewater service system. The baseline alternative is the most common, centralized approach for WW treatment, in which WW is conveyed to and treated in a large wastewater treatment plant (WWTP) and is then discharged to a stream. The three alternatives represent different scales of distribution of the WW treatment phase, along with urban irrigation and domestic non-potable water reuse (toilet flushing). The first alternative includes centralized treatment at a WWTP, with part of the reclaimed WW (RWW) supplied back to the urban consumers. The second and third alternatives implement de-centralized greywater (GW) treatment with local reuse, one at cluster level (320 households) and one at building level (40 households).

以色列污水處理與再生利用 之生命週期評估

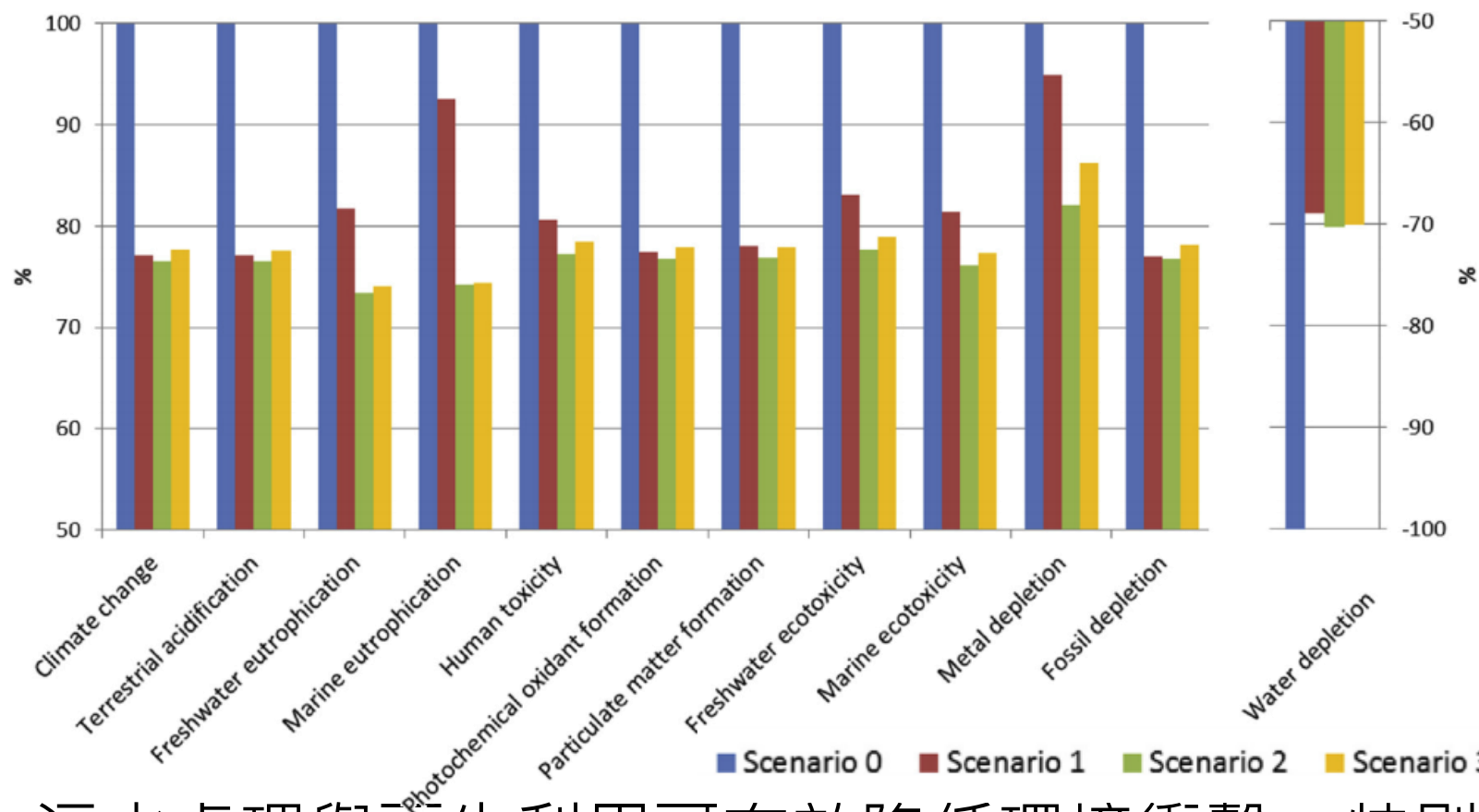
- 過去多以海水淡化為供水水源，因此欲透過污水再生開發新的水資源
 - 情境零**：基礎方案，無城市再利用
 - 情境一**：由集中式污水廠產出再生水，利用於沖廁、澆灌、非飲用水
 - 情境二**：將灰水(生活污水)、黑水(排泄水)分離，由集中式污水廠將灰水再生利用於沖廁、澆灌、非飲用水
 - 情境三**：將灰水(生活污水)、黑水(排泄水)分離，由分散式污水廠將灰水再生利用於沖廁、澆灌、非飲用水

以色列污水處理與再生利用 之生命週期評估

- 功能單位：1年之再生水供給量
- 系統邊界：包含污水處理和再生水流佈



以色列污水處理與再生利用 之生命週期評估



- 污水處理與再生利用可有效降低環境衝擊，特別是以海水淡化為水源之區域

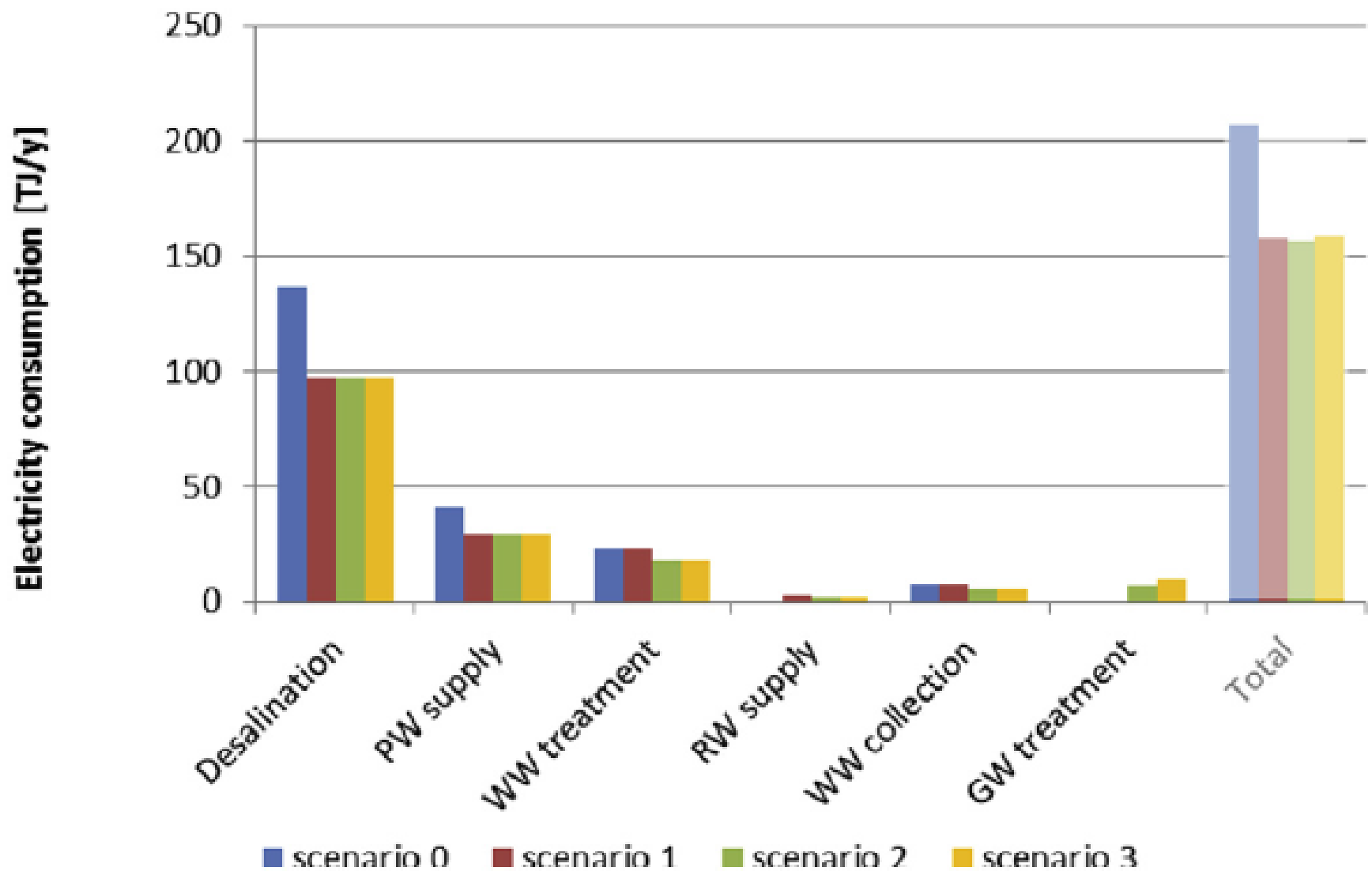
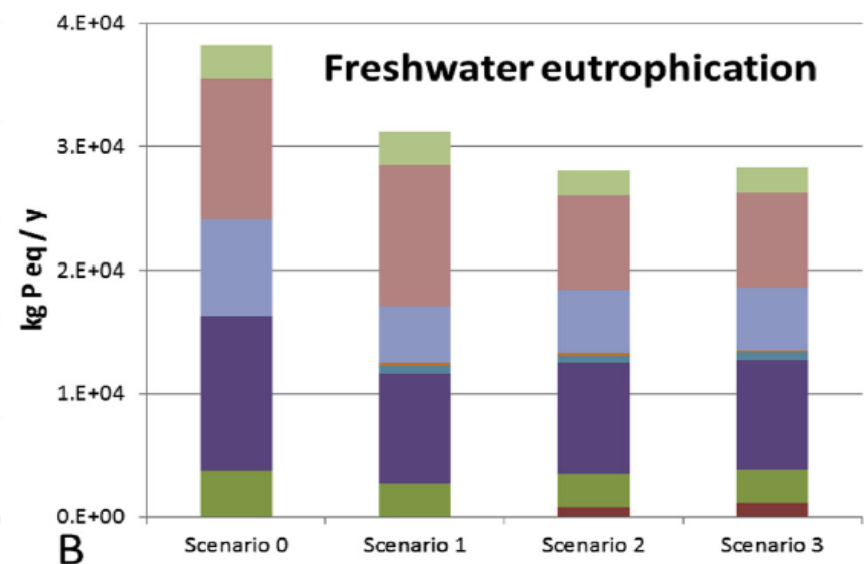
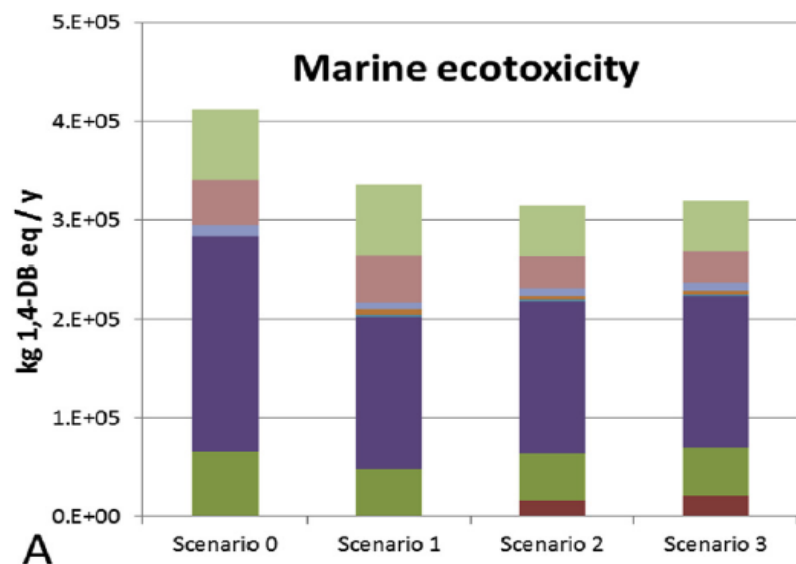


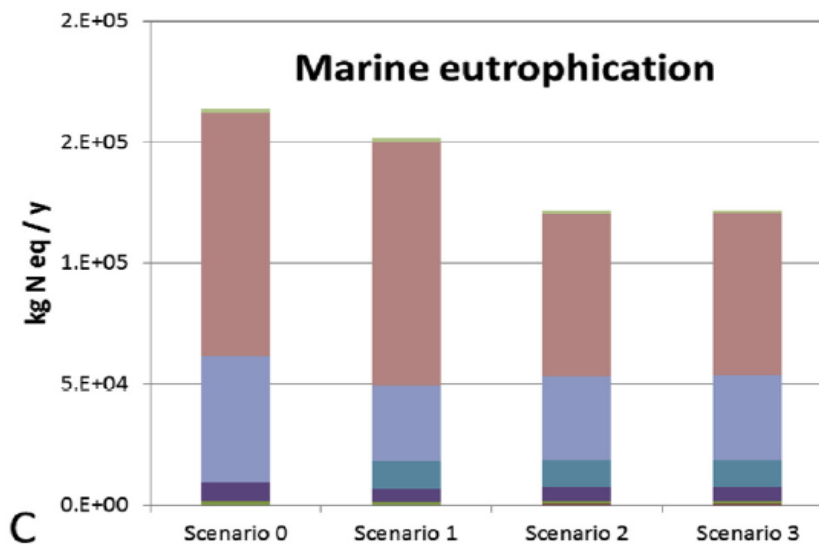
Fig. 3. Annual electricity consumption of each of the main foreground sub-systems.

以色列污水處理與再生利用 之生命週期評估

- 暖化衝擊來自於海水淡化之能源耗用(65%，每年貢獻 4.9×10^4 噸 CO_2 -eq/y)
- 基礎情境衝擊最高，分散式灰水處理再生利用為最佳情境(情境三)



■ GW collection
 ■ GW treatment
 ■ PW supply
 ■ SW desalination
 ■ RW irrigation
■ RW supply
■ RWW discharge
■ WW collection
■ WW treatment



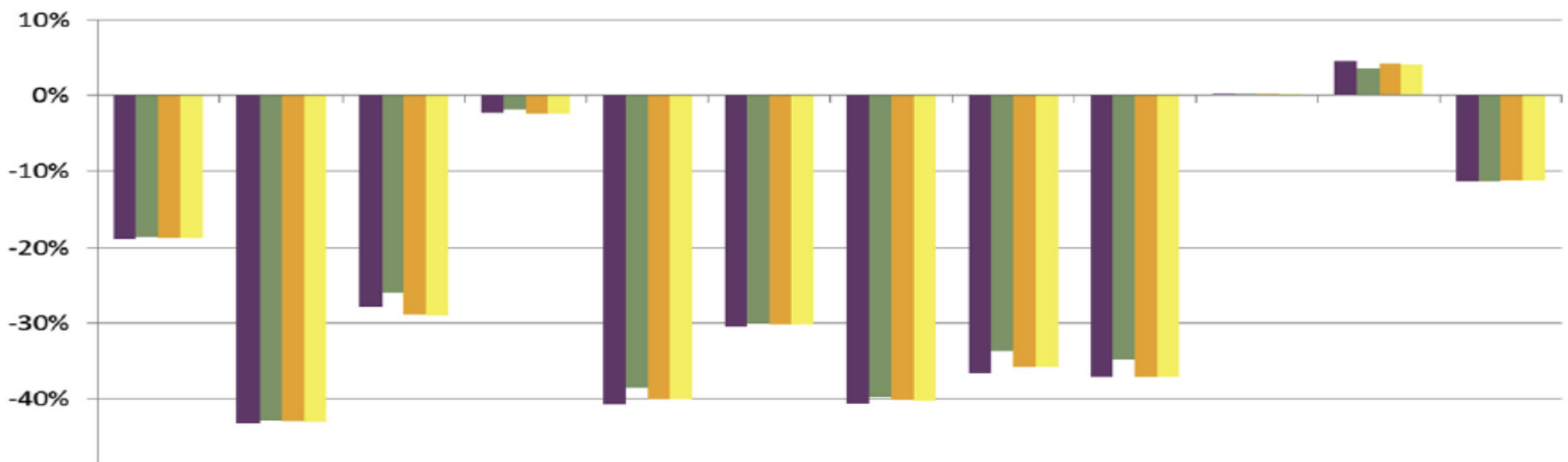
4. Subsystem contribution in the three top impact categories (ReCiPe H World): A – marine ecotoxicity, B – freshwater eutrophication, C – marine eutrophication.

以色列污水處理與再生利用 之生命週期評估

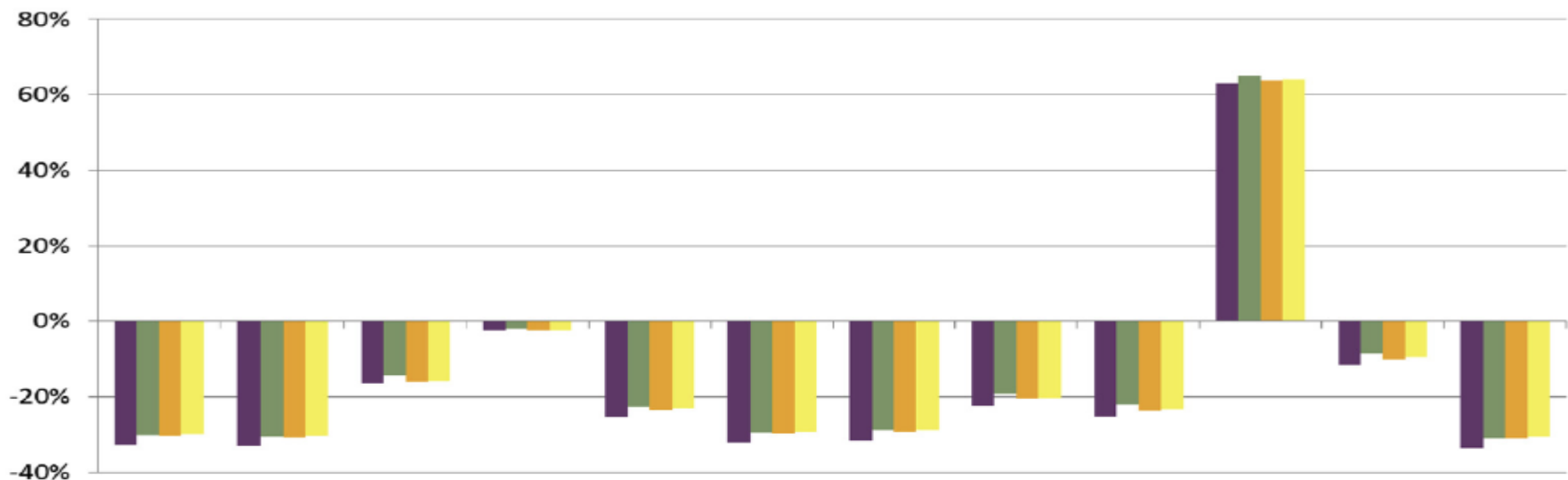
- 電力結構為40%燃煤、50%燃天然氣、10%太陽能發電，若電力結構改善有助於降低海水淡化、水再生利用之環境衝擊：

15%燃煤、65%燃天然氣、13%太陽能、7%風力發電 (2030)

- 水源改為42%海水淡化、58%處理之再生水(2050)
，也有助於改善環境衝擊：



Scenario 0 Scenario 1 Scenario 2 Scenario 3



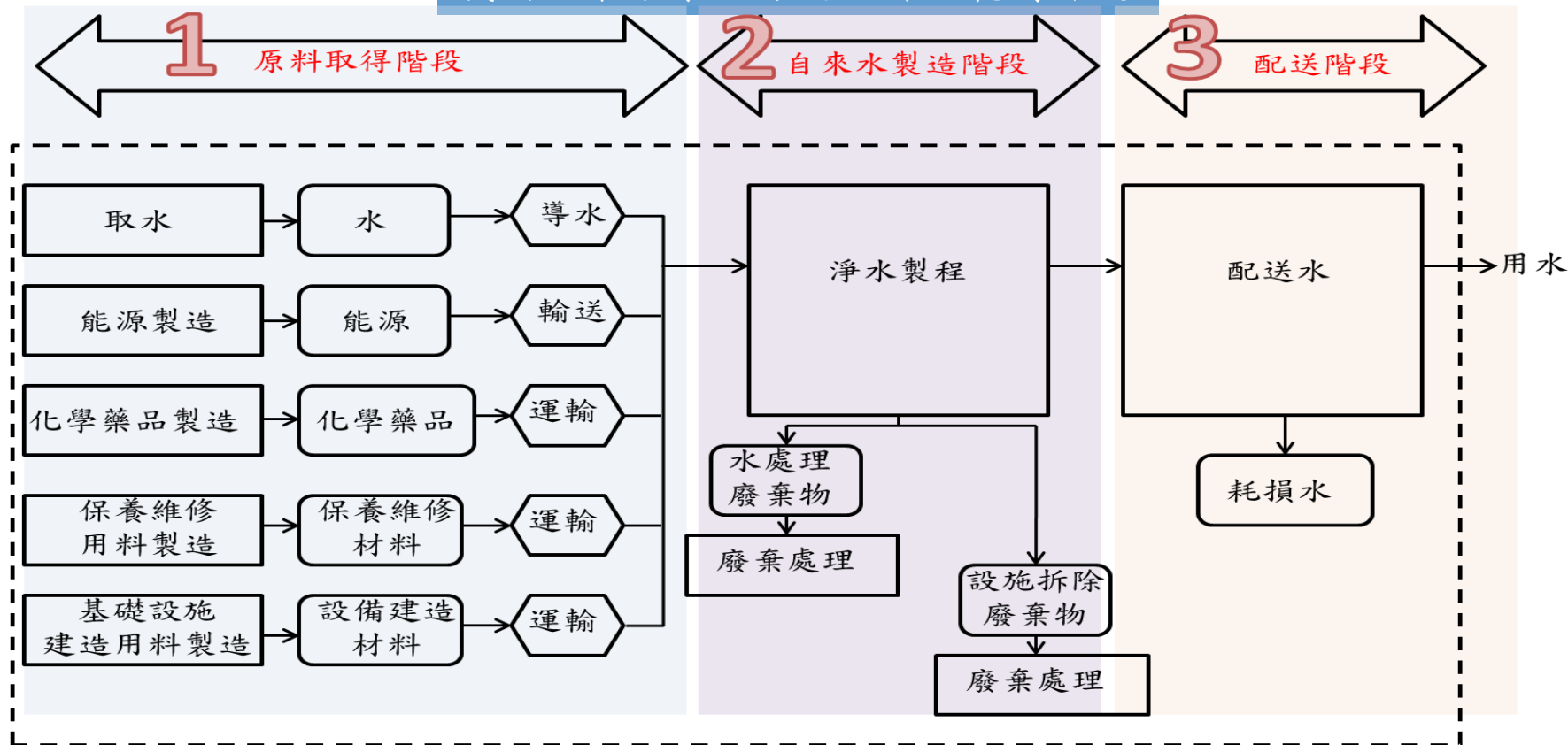
Climate change
Terrestrial acidification
Freshwater eutrophication
Marine eutrophication
Human toxicity
Photochemical oxidant formation
Particulate matter formation
Freshwater ecotoxicity
Marine ecotoxicity
Water depletion
Metal depletion
Fossil depletion

國內下水道 全生命週期評估發展

自來水事業碳足跡評估 與減碳策略之先期研究

水利署(2010)

我國自來水系統探足跡評估範疇界定



- 實際盤查且量化部分淨水場基礎設施、操作單元等，全生命週期之碳排放衝擊

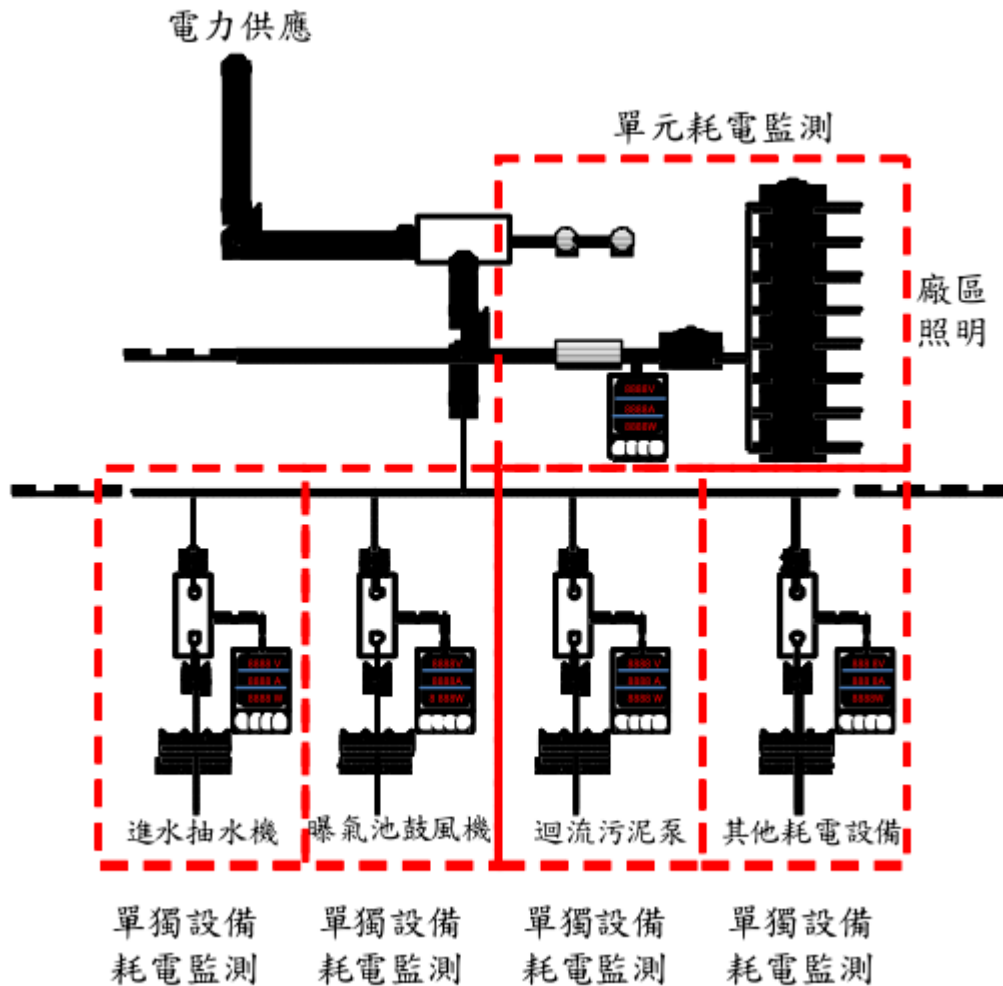
自來水事業碳足跡評估 與減碳策略之先期研究

水利署(2010)

碳排放衝擊：	取水	淨水+廢水	輸配水	主要排碳來源
公館 淨水場	0.00% 用電:0%	32.91% • 用電:5.17% • 用藥:27.57% • 耗材:0% • 柴油:0.16% • 廢棄處理:0%	67.09% • 用電:67.09% • 耗材:0%	用電 (共占用72.27%)
板新 給水廠	8.07% 用電:8.07%	24.97% • 用電:3.96% • 用藥:20.99% • 耗材:0% • 柴油:0% • 廢棄處理:0.01%	66.97% • 用電:66.97% • 耗材:0%	用電 (共占用79.03%)
豐原 給水廠	21.45% 用電:21.45%	59.13% • 用電:21.79% • 用藥:37.18% • 耗材:0.06% • 柴油:0.10% • 廢棄處理:0.01%	19.42% • 用電:19.42% • 耗材:0%	用電 (共占用62.66%)
金門 海水 淡化廠	5.00% 用電:5.00%	92.43% • 用電:92.19% • 用藥:0.16% • 耗材:0.03% • 柴油:0.04% • 廢棄處理:0.01%	2.57% • 用電:2.57% • 耗材:0%	用電 (共占用99.76%)
澄清湖 給水廠	9.34% 用電:9.34%	42.61% • 用電:13.81% • 用藥:27.78% • 耗材:0.01% • 柴油:0.02% • 廢棄處理:0%	48.05% • 用電:48.05% • 耗材:0%	用電 (共占用71.19%)

污水處理廠節能計畫

營建署(2010)



- 能源管理系統：
 - 逐一監測與量測污水廠之能源耗用，並提出節能改善計畫
- 監測單元項目：
 - 總功率
 - 實功、虛功
 - 電壓、電流
 - 功率因數
- 節能模式分析

污水處理廠節能計畫

營建署(2010)

• 污水處理廠導入生命週期估算排碳量之規劃

鑑別溫室氣體排放原

選擇排放量計算方式

1. 直接監測法
2. 質量平衡法
3. 排放係數法

優先選用順序：

1. 連續監測數據
2. 定期量測數據
3. 自行估算數據

活動數據蒐集

排放係數選用

優先選用順序

1. 自廠發展係數
2. 同業使用係數
3. 設備提供係數
4. 區域公告係數
5. 國家公告係數
6. 國際公告係數

彙整溫室氣體排放量

國內下水道建設生命週期評估

- 下水道建設屬於公共工程之生命週期評估，施工階段之資料盤查，為生命週期評估之寶貴盤查資料
 - 工程碳足跡盤查程序與方法的建立
 - 盤查輔導的落實與碳足跡盤查資料庫系統建置
 - 碳足跡係數資料的蒐集與工程碳足跡係數資料庫系統建置
 - 碳足跡計算分析及減碳策略與成效研析



金門污水處理廠全生命週期評估

污水處理：

Normalization/m ³	金城	太湖	榮湖	擎天	東林
藥品	8.11E-15	3.81E-15	3.81E-15	2.14E-14	1.11E-14
	16%	7%	5%	16%	9%
鋼筋	2.41E-15	8.96E-15	2.24E-14	-	-
	5%	15%	30%	-	-
混凝土	5.33E-16	1.82E-15	4.49E-15	-	-
	1%	3%	6%	-	-
能源	4.05E-14	4.34E-14	4.34E-14	1.13E-13	1.15E-13
	78%	74%	58%	84%	91%
廢水	4.08E-16	4.69E-16	4.96E-16	1.73E-16	1.56E-16
	1%	1%	1%	0%	0%
處理水量(CMD)	4447	1525	610	135	264

子計畫：

榮湖淨水場及遮光板設備

遮光板遮光50%，在環境衝擊上增加1.8倍。若將遮光板增加至遮光100%，環境衝擊上增加2.7倍。

太湖淨水場前加氯及混凝加藥

前加氯及混凝加藥在環境衝擊上增加4.98倍，高級氧化結合吸附單元環境衝擊上增加18.45倍

金城污水廠增加電混凝浮除

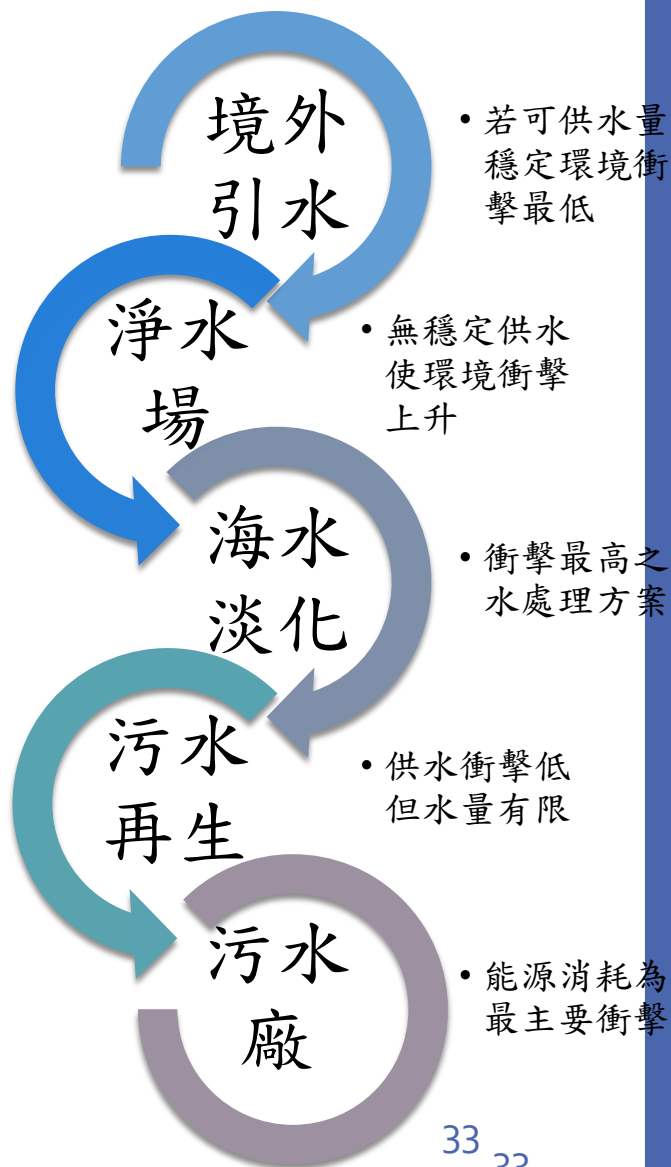
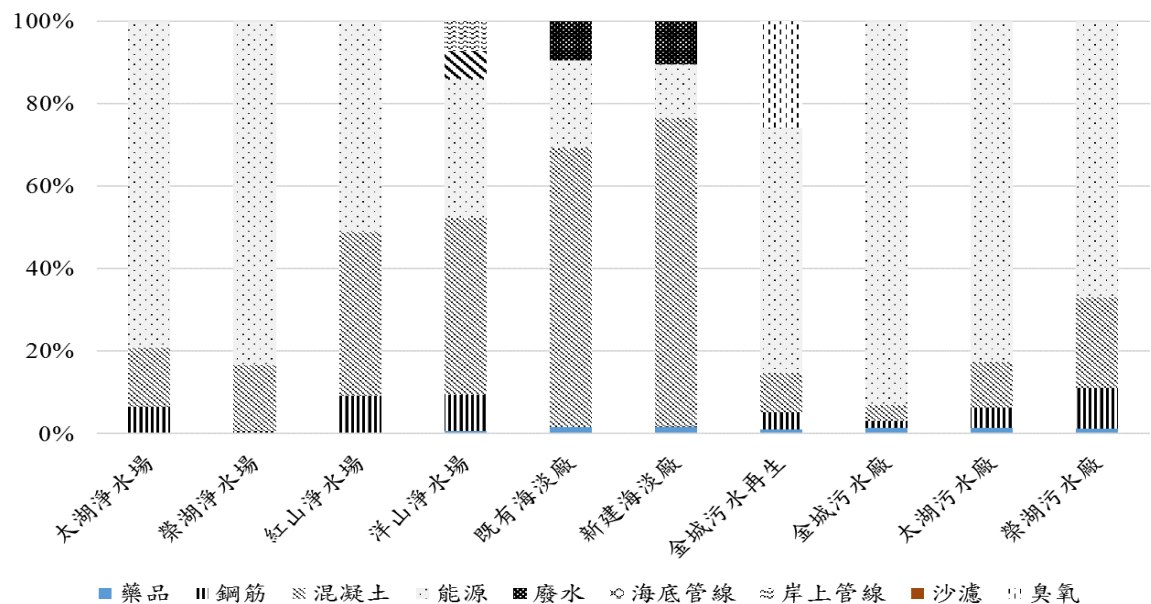
環境衝擊是原本的250倍，最主要衝擊來自鋁板占63.41%，其次是壓克力材料占9.58%

● 能源消耗為最主要衝擊

● 處理水量差異大，若處理水量多衝擊就能夠被分攤而降低

● 擎天與東林污水廠處理水量少，無建造資料的情況下衝擊值仍比三個主要污水廠高

金門各情境碳排放評估結果



- 碳排放結果與環境衝擊結果有相同趨勢，**能源消耗為最主要衝擊**，改善能源供給方式為最有效之減碳方案
- 次要之碳排放源為基礎建設中混凝土使用

結語

污水下水道全生命週期 減碳管理策略

- 各縣市污水下水道系統總戶數接管普及率63% (累計至2012年)，申報運轉之污水處理廠共47廠(2009申報資料)，平均每噸水之耗電量為0.28度電
- 根據國外之生命週期評估結果，污水處理廠為水管理措施中碳排放衝擊熱點，更應執行污水廠之全生命週期評估
- 熱點篩選後，經由處理設備之能源效率改善，可有效降低碳排放衝擊