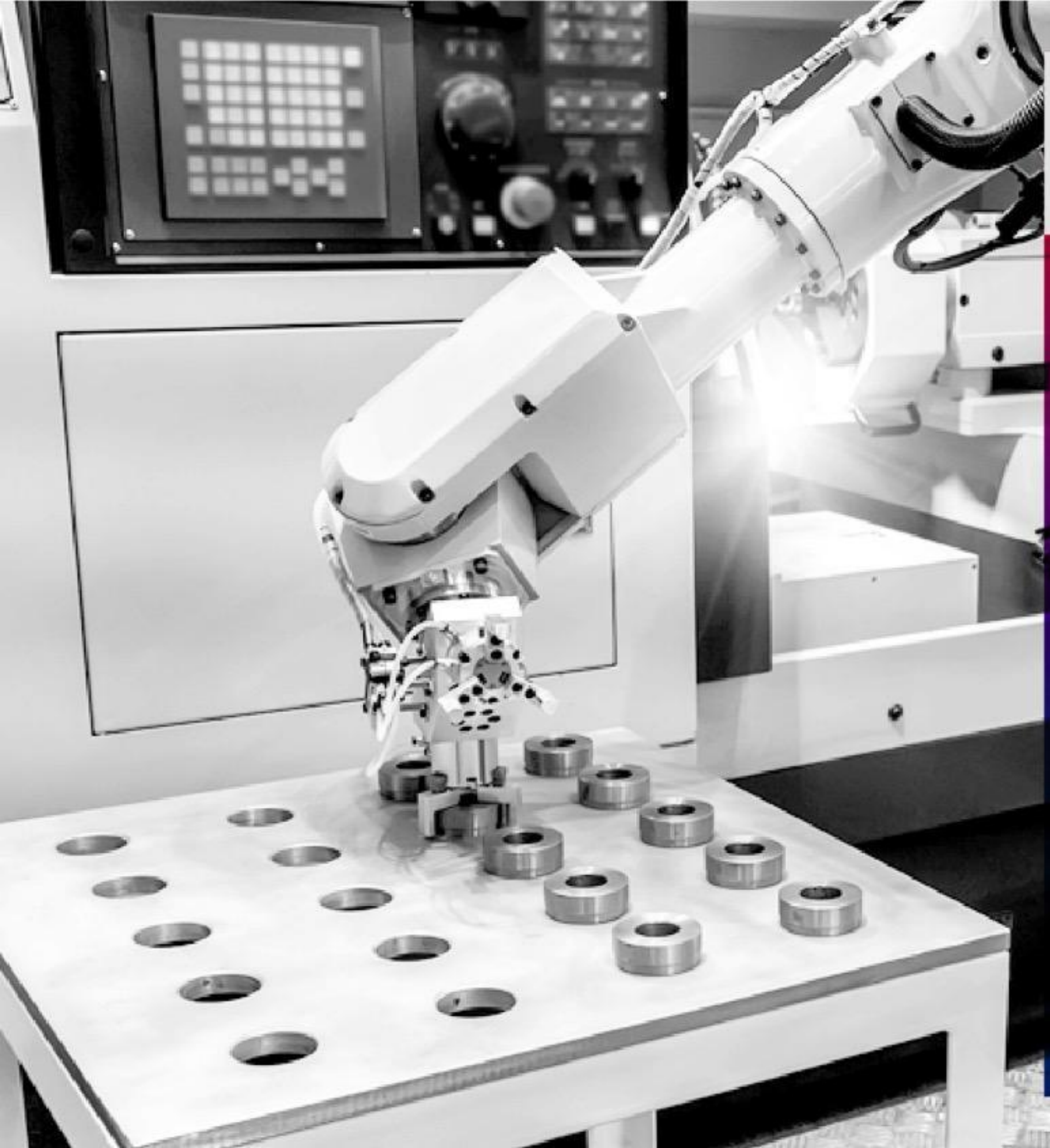

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Measuring Sustainability with Life Cycle Assessment (LCA) and Life Cycle Costing (LCC)

Jonathan S.C. Low, PhD

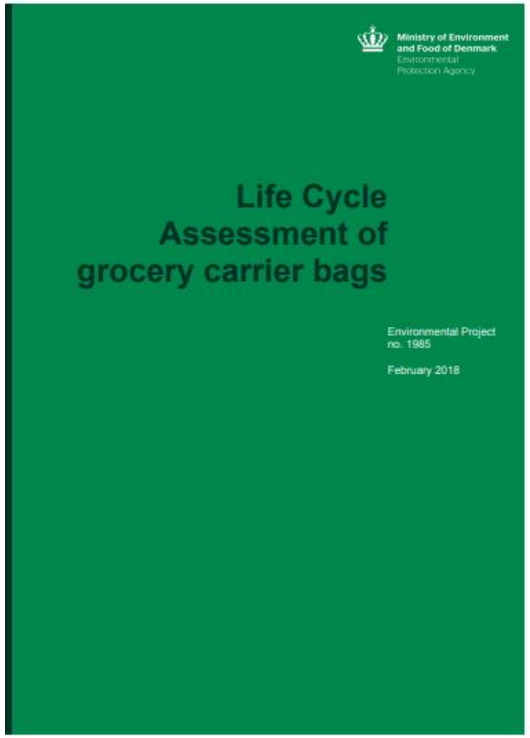
25 May 2021

Life Cycle Thinking to Avoid Problem Shifting

Businesses using paper instead of plastic? Not necessarily better for the environment, experts say

Fast Retailing brands such as Uniqlo and GU will be replacing plastic bags with paper ones. (Photo: Fast Retailing)

Source: CNA, 2020



Lee Hsien Loong
21 July at 03:01

We should all do our part to protect the environment. But we should do it thoughtfully, to make sure that what we are doing will indeed make a difference, and be for the good.

This article explains why banning plastic straws and other single use plastics will likely not help the environment. Using metal straws will actually create more environmental costs than disposable plastic straws. So too reusable shopping bags, which need to be used at least 40 times to "break even" compared to single use shopping bags.

There are no easy ways to deal with climate change. But we must do things which make sense, such as switching to LED light bulbs and encouraging the use of public transport.

There is an ongoing public consultation on how Singapore can become a low-carbon city. You can find out more and share your thoughts here: bit.ly/2JG0Gc0 – LHL

#TowardsZeroWaste #ClimateActionSG

STRAITSTIMES.COM
Ditching plastic straws is not as simple as it looks
Rarely has a minor consumer product received more vilification than the...

According to a **2018 life cycle assessment (LCA) study by the Danish Environmental Protection Agency**, to breakeven against a single-use plastic bag:

- A **polypropylene bag** should be used **37 times**.
- A **paper bag** should be used **43 times**.
- A **cotton bag** should be used **7,100 times**.

Without life cycle thinking, what may seem like a solution, could actually shift or create a new problem.

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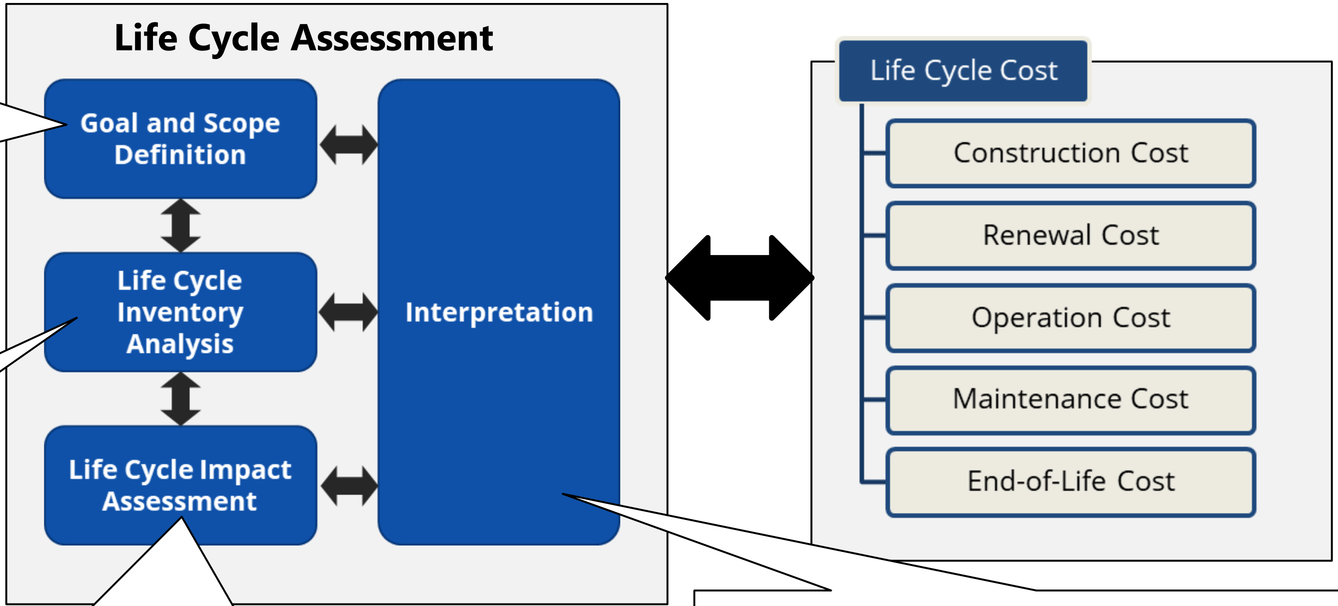
Life Cycle Assessment (LCA) and Life Cycle Costing (LCC)

- LCA is an **evidence-based approach to measure sustainability** of products, services and systems.
- LCC, employed in tandem, **assesses the economic performance** and is able to **internalise environmental impacts** as financial costs.

Step 1: Framing the Study
- Purpose of the study
- Target audience/ stakeholders
- Questions to be answered..?

✓ Define functional unit and system boundary



Step 2: Building the Model

✓ Model and collect data on the flows of resources into, within and out of the system

Step 3: Computing the KPIs

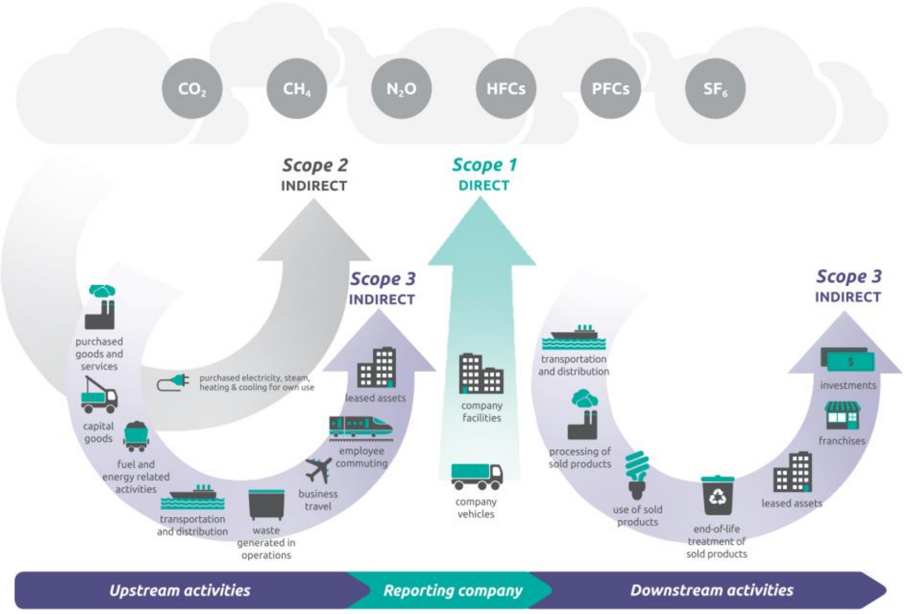
✓ Convert the Life Cycle Inventory Analysis into relevant indicators (e.g. carbon footprint and net present value)

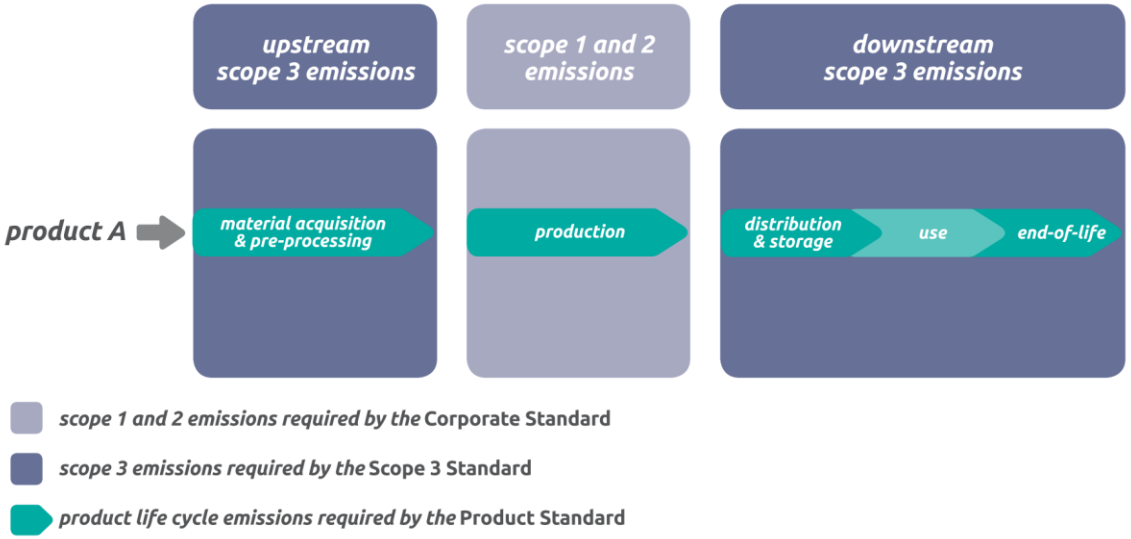
Step 4: Utilising the Findings
- Sensitivity and uncertainty analyses
- Scenario analysis

✓ Answer questions asked in step 1

Life Cycle Assessment and GHG Protocol Standards

	Life Cycle Assessment (Consequential Approach)			
	GHG Protocol Corporate Standard			Avoided Impact
	Scope 1	Scope 2	Scope 3	
Emission sources	• Direct on-site greenhouse gas emissions • Direct emissions from on-site stationary combustion • Mobile combustion from company owned vehicles	• Embodied emissions of purchased utilities (electricity, water, steam, heating, and cooling)	• Embodied emissions of purchased goods and services • Upstream and downstream transportation, not controlled by company	• Avoided embodied emissions resulting from displaced activities as a consequence of the existence of the current system under study

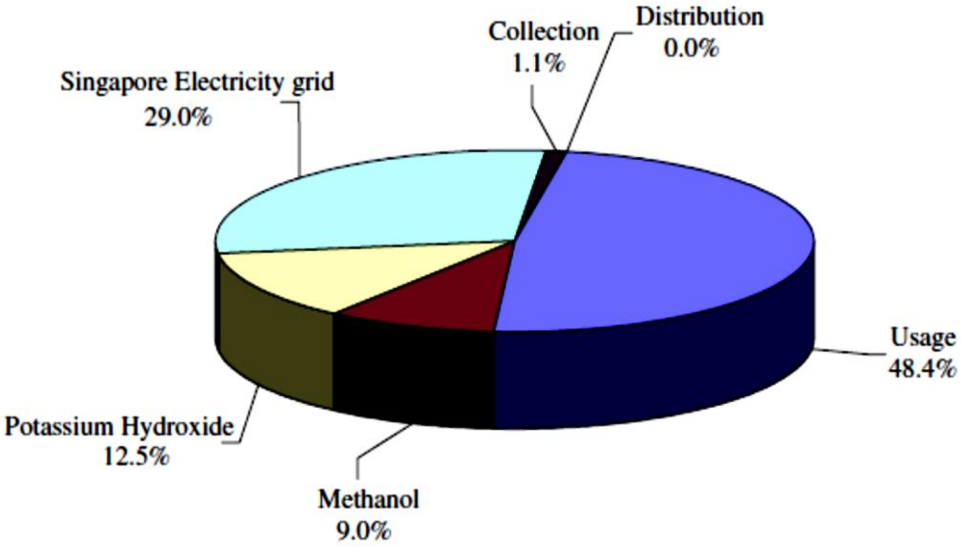




Source: "Corporate Value Chain (Scope 3) Accounting and Reporting Standard, Supplement to the GHG Protocol Corporate Accounting and Reporting Standard", Greenhouse Gas Protocol, World Resource Institute & World Business Council for Sustainable Development

LCA – Environmental Impact of Biodiesel Derived from Used Cooking Oil (UCO) in Singapore

Net life cycle emissions (kg/km)	Diesel	Biodiesel	Percentage change
Net life cycle SO_2	5.01E−01	3.43E−05	−99.99
Net life cycle NO_x	7.99E−02	1.64E−03	−97.95
Net life cycle N_2O	9.02E−06	3.53E−07	−96.08
Net life cycle fossil fuel CO_2	9.41E−01	4.31E−02	−95.42
Net life cycle CO	2.02E−02	1.91E−03	−90.54
Total $PM_{2.5}$ and PM_{10}	1.42E−01	1.35E−05	−99.99
Net life cycle NMVOC	7.23E−03	6.13E−04	−91.52
Net life cycle CH_4	4.28E−03	7.58E−04	−82.28

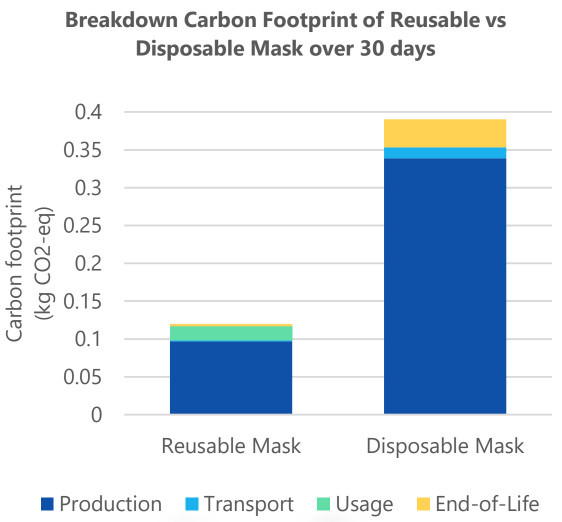


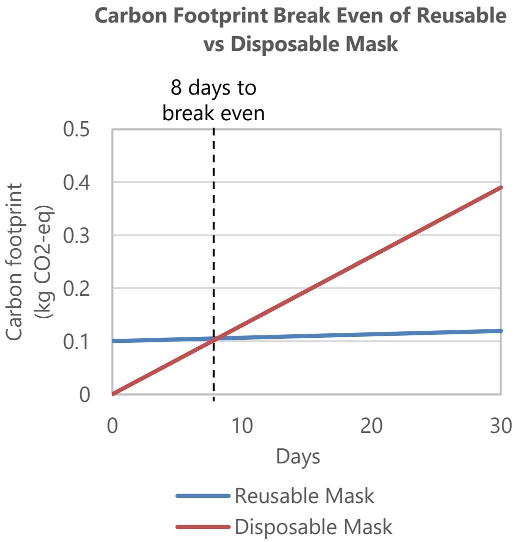
Key findings:

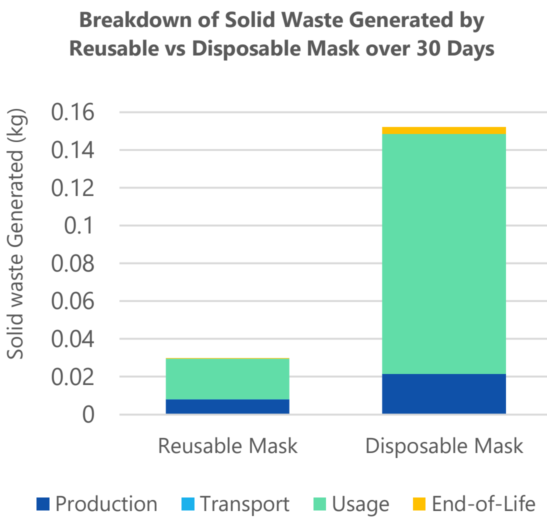
- The **biodiesel has significantly lower environmental impact** than diesel (>82% across the board).
- **Carbon footprint from the use of the biodiesel** is 0.006 kg CO_2-eq per km; which is **180 times less than diesel** at 1.08 kg CO_2-eq per km.

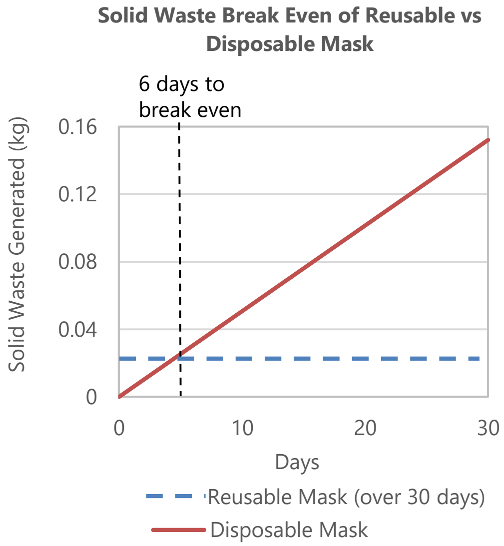
B.H. Chua, H.M. Lee, and J.S.C. Low (2008), "Life cycle emissions and energy study of biodiesel derived from waste cooking oil and diesel in Singapore", International Journal of Life Cycle Assessment, vol. 15, pp. 417-423.

LCA – Environmental Impact of Reusable vs Disposable Masks









Assumptions:

- The masks provide a comparable function, i.e. similar efficacy in reducing the spread of respiratory droplets.
- The disposable mask is used for a day; while the reusable mask is used for 30 days.
- 1/3 of SG population returns to work and school post-circuit breaker.

Key findings of using the **reusable vs disposable mask** (over a 30-day period):

- Has **3.3 times less carbon footprint** and generates **5 times less solid waste**.
- Has a **lower carbon footprint after only 8 days** and generates **less solid waste after only 6 days**.
- Can **avoid a total carbon footprint of 590 tonnes of CO_2-eq** and **220 tonnes of solid waste** over the 30-day period.

A.W.L. Lee, E.R.K. Neo, Z.Y. Khoo, Z.Q. Yeo, Y.S. Tan, S.Y. Chng, W.J. Yan, B.K. Lok, J.S.C. Low (2021), "Life cycle assessment of single-use surgical and embedded filtration layer (EFL) reusable face mask", Resources, Conservation and Recycling, vol. 170, no. 105580, July 2021.

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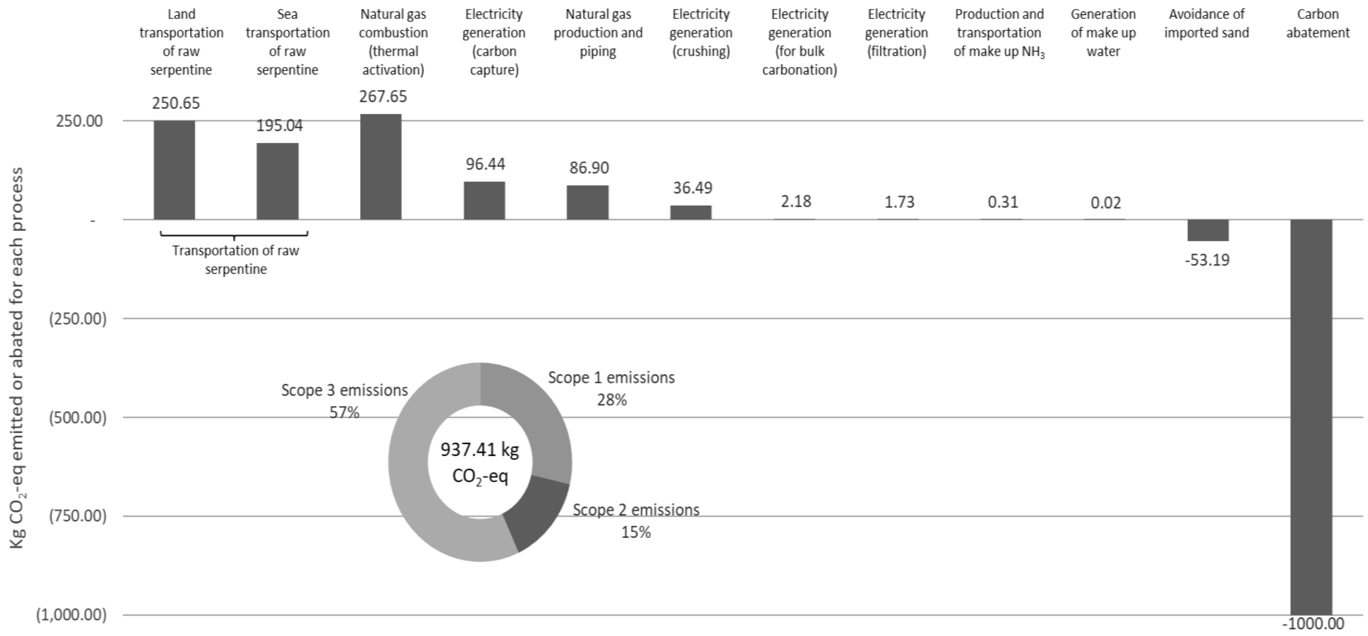
LCA – Carbon Abatement Potential of CO_2 Mineralisation



Effect of shipping distance on life cycle GHG emissions

Key findings:

- Taking into account life cycle GHG emissions and avoidance of import sand, a **net abatement of 115.78 kg CO_2-eq per tonne of CO_2 sequestered** can be achieved when minerals are imported from Australia and heating energy is not optimised.
- **Transportation** (land and sea) of mineral feedstock (raw serpentine) **contributes significantly** (~47%) to life cycle GHG emissions.
- If the **mineral feedstock** can be sourced **from a neighbouring country**, and **industrial waste heat** utilised, the net abatement can **increase up to 903.59 kg CO_2-eq per tonne of CO_2 sequestered**.

Z.Y. Khoo, E.H.Z. Ho, Y.Q. Li, Z.Q. Yeo, J.S.C. Low, J. Bu, L.S.O. Chia (2021), "Life cycle assessment of a CO2 mineralisation technology for carbon capture and utilisation in Singapore", Journal of CO_2 Utilization, vol. 44, 101378.

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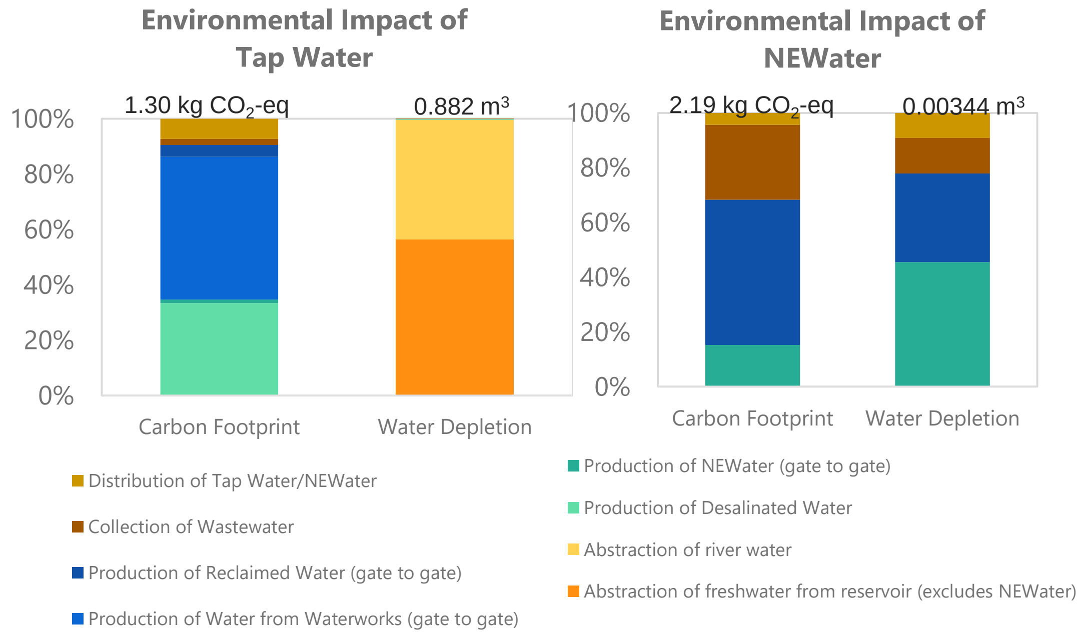
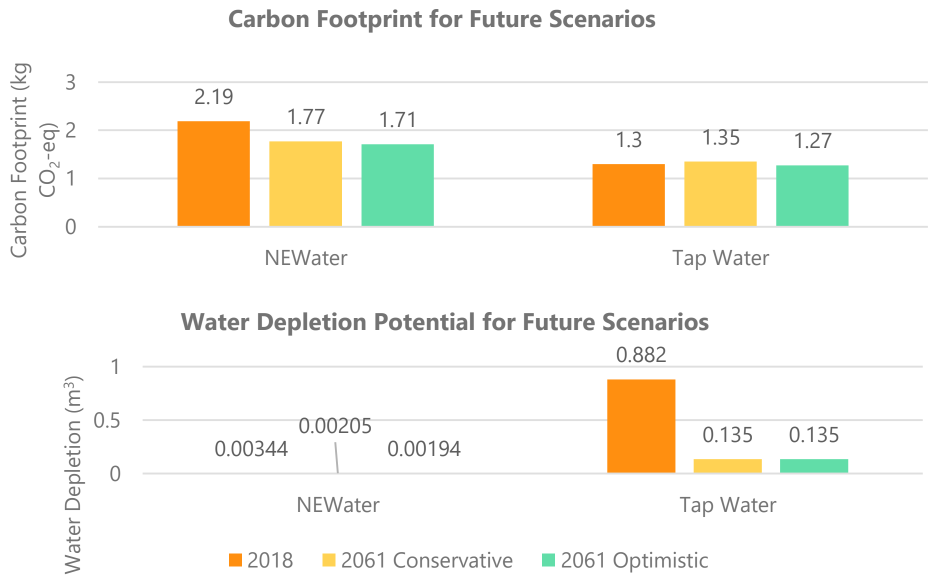
LCA – Environmental Impact of Singapore's Water System



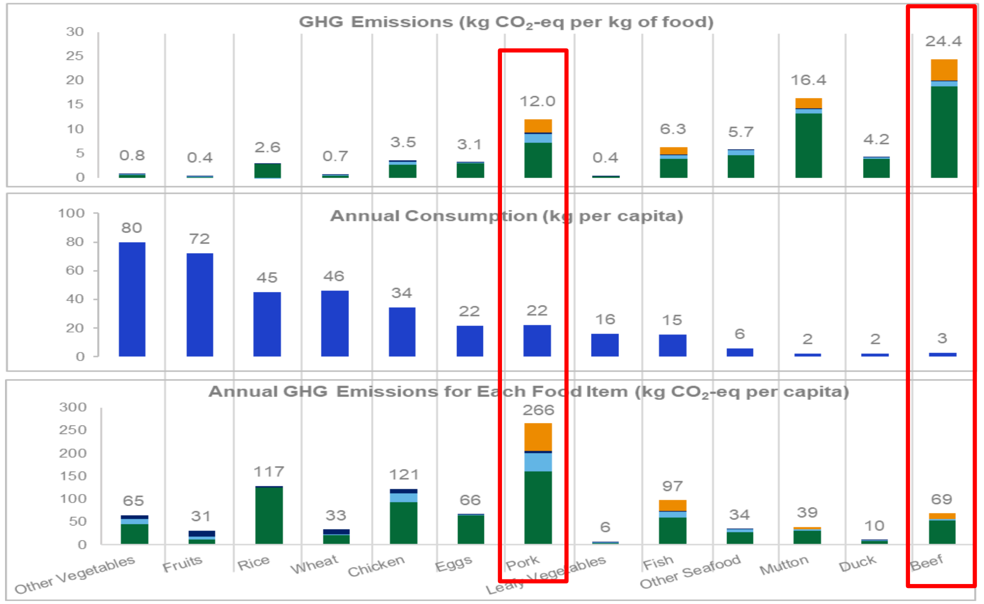


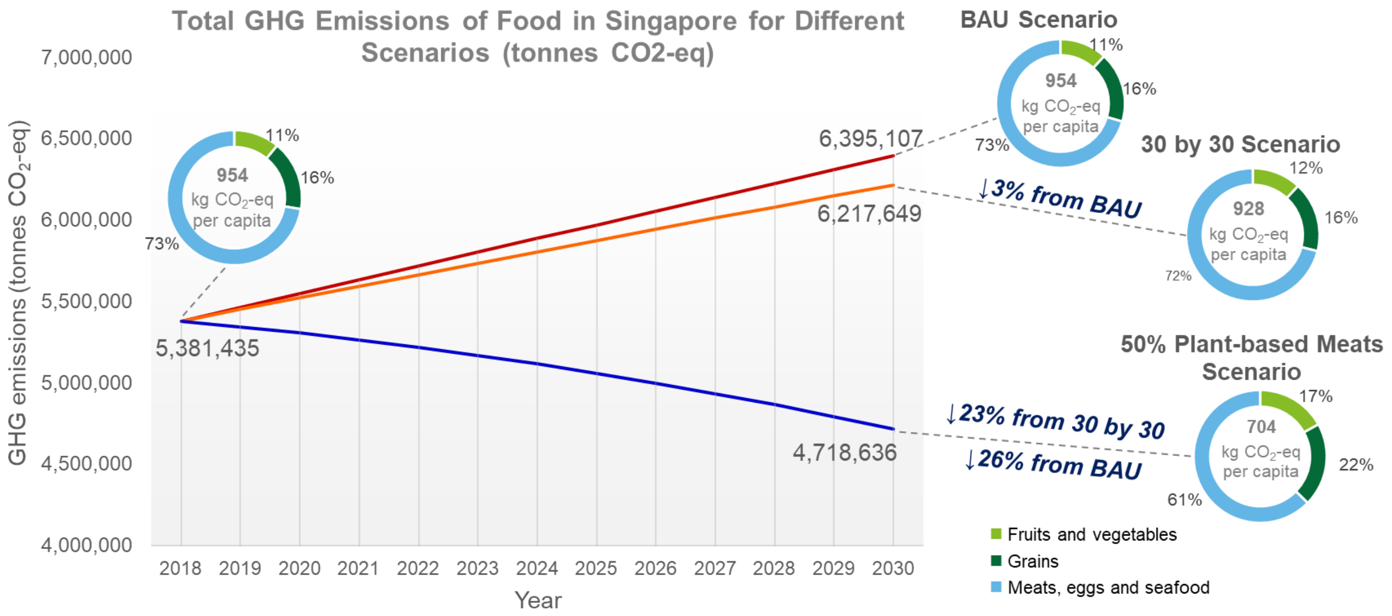
Key findings:

- **Carbon footprint of tap water is only about 60% that of NEWater** as tap water has a large mix of local catchment and imported water.
- Conversely, piped **NEWater has significantly lower water depletion potential** as it virtually does not abstract water from freshwater bodies.
- In water-scarce Singapore, this is a **trade-off in moving towards water self-sufficiency**.

C. Hsien, J.S.C. Low, S.F. Chan, and W.H. Tan (2019), "Life cycle assessment of water supply in Singapore — A water-scarce urban city with multiple water sources", Resources, Conservation and Recycling, vol. 151, 104476.

LCA – Environmental Impact of Food Consumed in Singapore





Key findings:

- GHG emissions of **beef is the highest** on a **per kg** basis while **pork is the highest** based on a **per capita consumption**.
- **Increasing local food production** (i.e. 30 by 30) can **offset GHG emissions** from the **transportation** of food over longer distances.
- However, to more meaningfully **reduce total GHG emissions** of food consumed in Singapore, **local diet** needs to shift to one which is **more plant-based**.

Full report downloadable at: https://www.ecosperity.sg/content/dam/ecosperity/en/reports/Environmental-Impact-of-Key-Food-Items-in-Singapore_Oct2019.pdf

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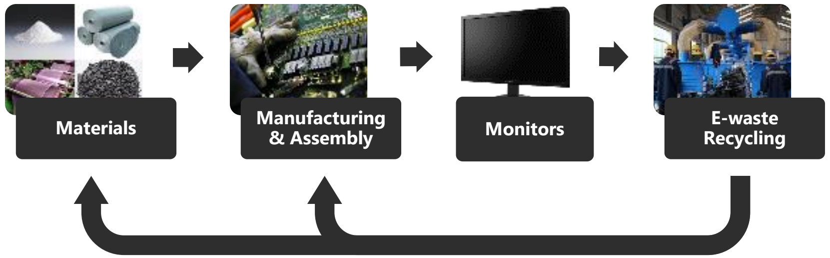
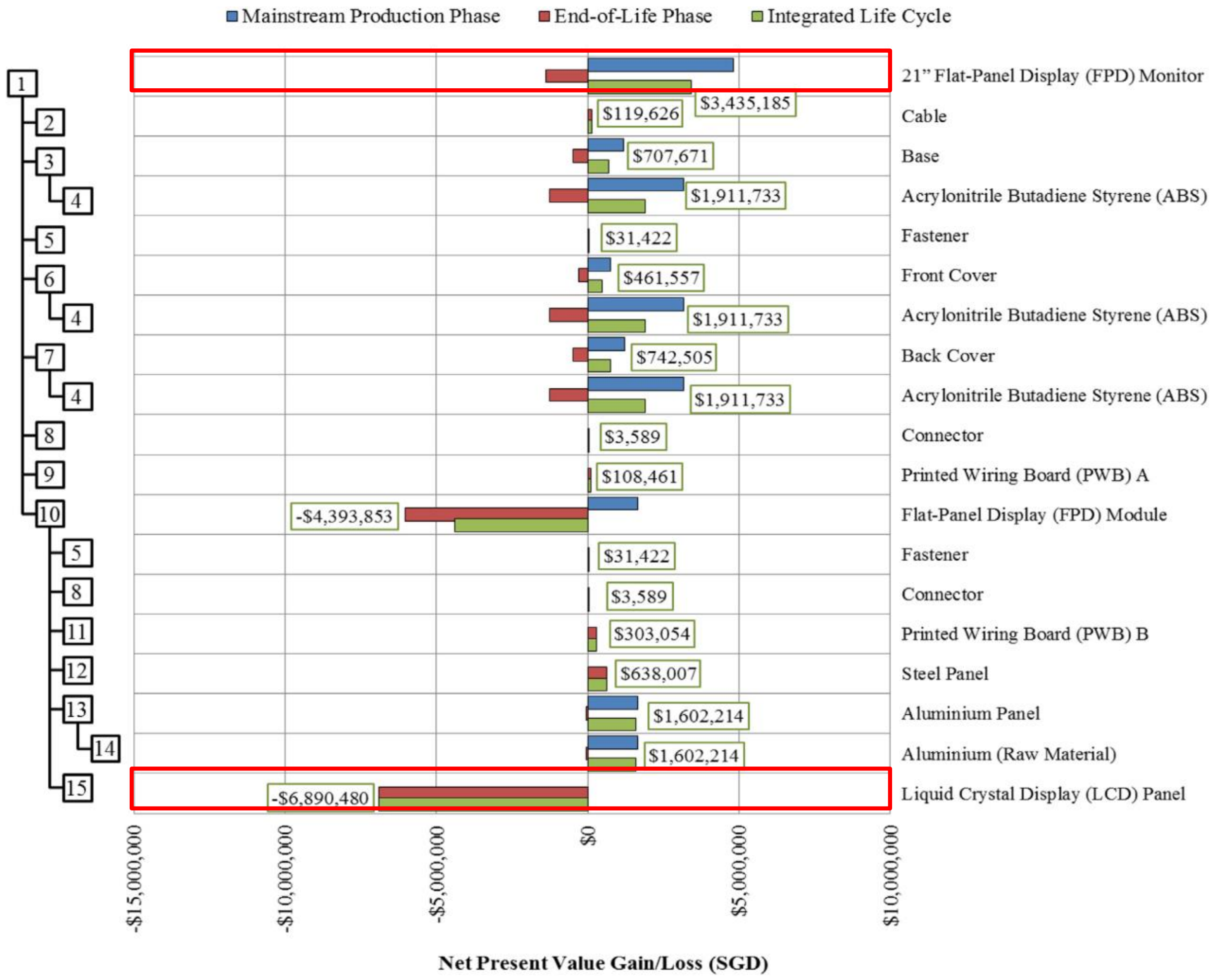
LCC – Cost-Benefit Analysis of Circular Production/Recycling of Flat Panel Display (FPD) Monitors



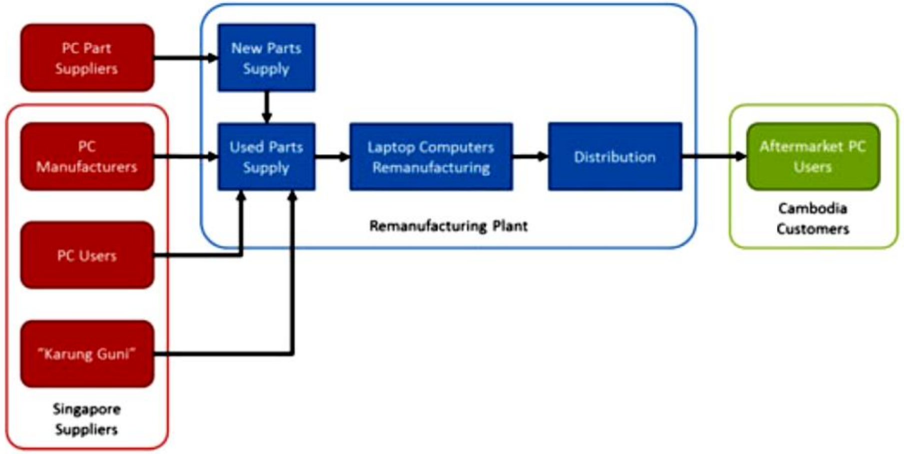


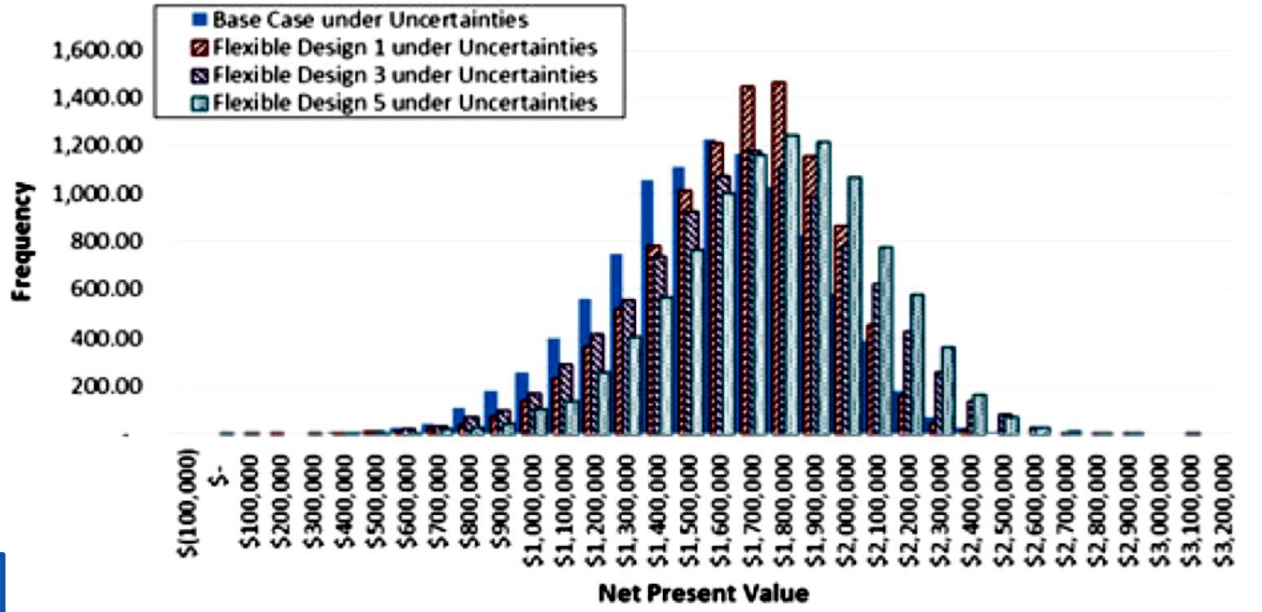
Key findings:

- Closed-loop recycling of end-of-life (EoL) FPD monitors will be a **cost incurring activity** despite recovery of some valuable metals (e.g. aluminium, silver and gold).
- However, the **circular production system will still be profitable** (i.e. positive NPV) as a whole.
- The **major cost driver is the treatment of the LCD panel** containing mercury in the backlights, which is hazardous and laborious to handle.

J.S.C. Low, W.F. Lu, and B. Song (2014), "Product Structure-Based Integrated Life Cycle Analysis (PSILA): a technique for cost modelling and analysis of closed-loop production systems", Journal of Cleaner Production, vol. 70, pp. 105-117.

LCC – Designing a Remanufacturing System for Used PC for the Cambodian Market





Metrics	Base case design under uncertainties	Flexible Design 1 under uncertainties	Flexible Design 3 under uncertainties	Flexible Design 5 under uncertainties	Best design?
Initial CAPEX	$180 000	$120 000	$180 000	$120 000	Flexible Designs 1 & 5
Total CAPEX	$180 000	$150 000	$180 000	$150 000	Flexible Designs 1 & 5
Mean NPV	$1 524 519	$1 611 286	$1 640 028	$1 725 505	Flexible Design 5
Standard deviation	$328 919	$286 848	$353 159	$324 936	Flexible Design 1
P95	$2 035 699	$2 026 187	$2 202 531	$2 233 989	Flexible Design 5
P5	$950 119	$1 093 909	$1 038 790	$1 164 845	Flexible Design 5

Key findings to optimise system:

- Despite the risks, the **benefits of setting up the main remanufacturing activity in Cambodia outweigh the costs** due to much lower CAPEX and OPEX in the long-term.
- A system designed with **lower initial capacity** –but with allowance to expand – **will be effective in mitigating market risks**.
- Implementing a **flexible shift policy** will further enhance the system's ability in **mitigating such risks** as well as agility in **capturing the upsides** of market volatility.

J.S.C. Low and Y.T. Ng (2018), "Improving the Economic Performance of Remanufacturing Systems through Flexible Design Strategies: A Case Study Based on Remanufacturing Laptop Computers for the Cambodian Market", Business Strategy and the Environment, vol. 27, no. 4, pp. 503-527.

Enabling Quantitative Measurements in the Green Compass

Taking the **value chain** or **life cycle perspective**, the **Green Compass** aims to enable businesses and industries to **transition towards low-carbon and circular economy**.

Operations	Product Life Cycle	Supply Network

Carbon | Energy | Water | Material & Waste

Businesses are assessed **qualitatively** and **quantitatively**.

Tools implemented aim to achieve **tangible improvements**

Tools for sustainability improvement

QUALITATIVE MEASUREMENTS

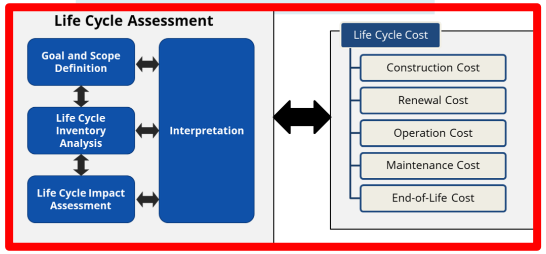
LEVEL	Energy Management in Operations	Water Management in Operations	Material Management in Operations	Carbon Management in Operations
5	The organisation is involved in setting new industry standards and is known for innovations related to energy efficiency and/or energy consumption reduction.	The organisation is involved in setting new industry standards and is known for innovations related to water usage efficiency, recycling of water, and/or water consumption reduction.	The organisation is involved in setting new industry standards and is known for innovations related to material usage efficiency, recycling of material and material consumption reduction.	The organisation is involved in setting new industry standards and is known for innovations related to carbon emissions reduction. T
4	An energy management system is in place to continually and methodically reduce absolute energy consumption and/or improve energy efficiency within the organisation.	A water management system is in place to reduce methodically and continually absolute water consumption within the organisation.	A material and waste management system is in place to methodically and continually reduce absolute material consumption and waste generation within the organisation.	A carbon management system/programme is in place to continually and methodically reduce absolute carbon emissions (scope 1, 2, and 3) within the organisation.
3	The breakdown of energy consumption is done throughout the organisation, beyond known hotspots.	The breakdown of water consumption is done throughout the organisation, beyond known hotspots.	The breakdown of material consumption and waste generation are done throughout the organisation, beyond known hotspots.	The concept of indirect carbon emission along the value chain (scope 3 of GHG protocol) is known and indirect emissions along the value chain's up- and downstream are tracked.
2	Energy consumption is monitored within the organisation.	Water consumption and effluent discharge are monitored within the organisation.	Material consumption and waste generation are monitored within the organisation.	Carbon emissions based on Scope 1 & 2 in GHG protocol are monitored within the organisation. Key areas/facilities/processes that contribute to carbon emissions have been identified.
1	Energy consumption is tracked as part of operational costs.	Water consumption and effluent discharge are tracked as part of operational costs.	Material consumption and waste generation are tracked as part of operational costs and compliance. Waste reduction plan is prepared as part of compliance.	Carbon emissions are monitored within the organisation.
0	Energy management is not considered within the organisation.	Water management is not considered within the organisation.	Material management is not considered within the organisation.	Carbon management is not considered within the organisation.

Tangible Improvements

QUANTITATIVE MEASUREMENTS

Absolute
Energy
Water
Waste
Carbon

Intensity
Energy
Water
Waste
Carbon



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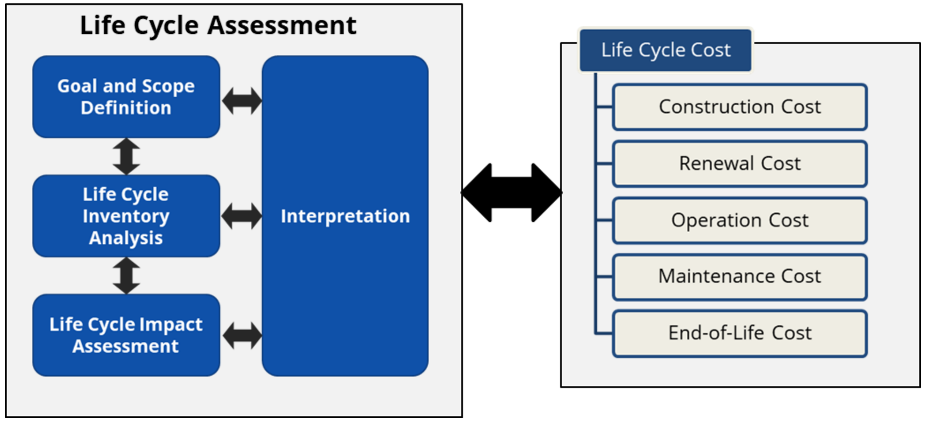
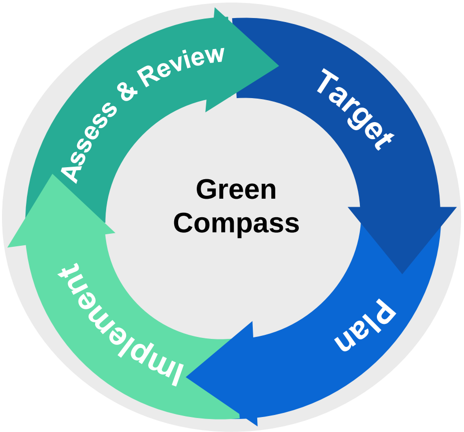
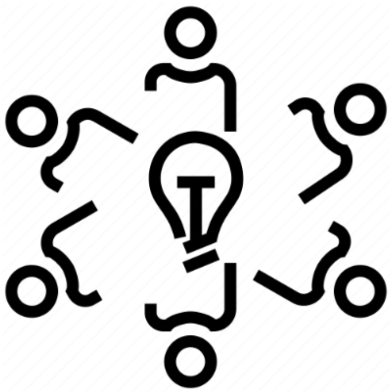
Summary







Without **life cycle thinking**, what may seem like a solution, could actually shift or create a new problem.

Life Cycle Assessment (LCA) and **Life Cycle Costing (LCC)** incorporates life cycle thinking to measure sustainability of products, services and entire ecosystems.

Applied systematically, they can **support collective and decisive action** towards green transformation.

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