Sustainable Water and Wastewater Management for a Circular Economy

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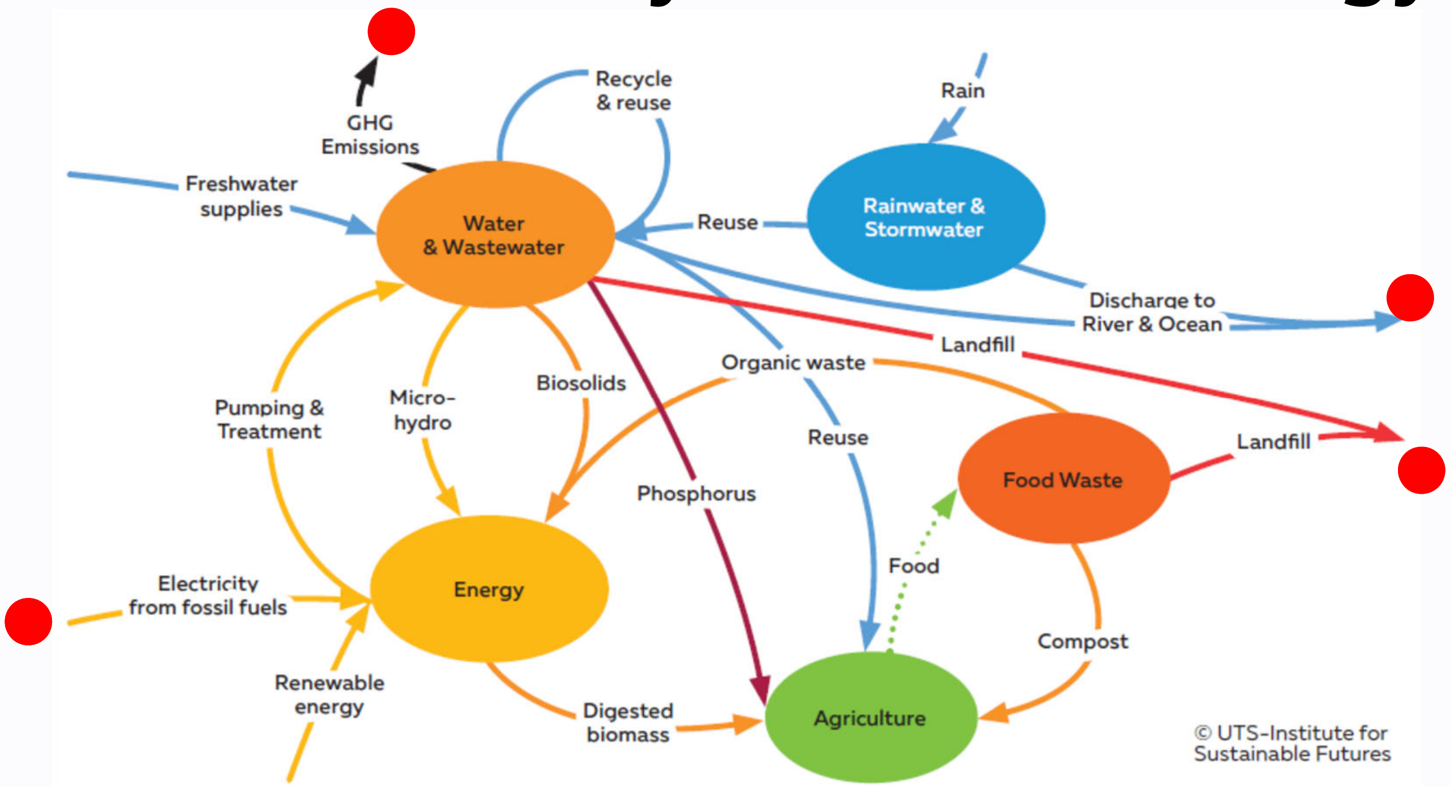
Summary

- Circular economy, SDGs and the water sector
- Renewable energy based water treatment systems
- Case study-1: Illawarra water treatment plant
- Renewable energy potential in water and wastewater treatment.
- Case study-2: Wollongong water reclamation plant
- Case study-3: SBRC water-wastewater management
- Concluding remarks

Circular economy and water-energy-food

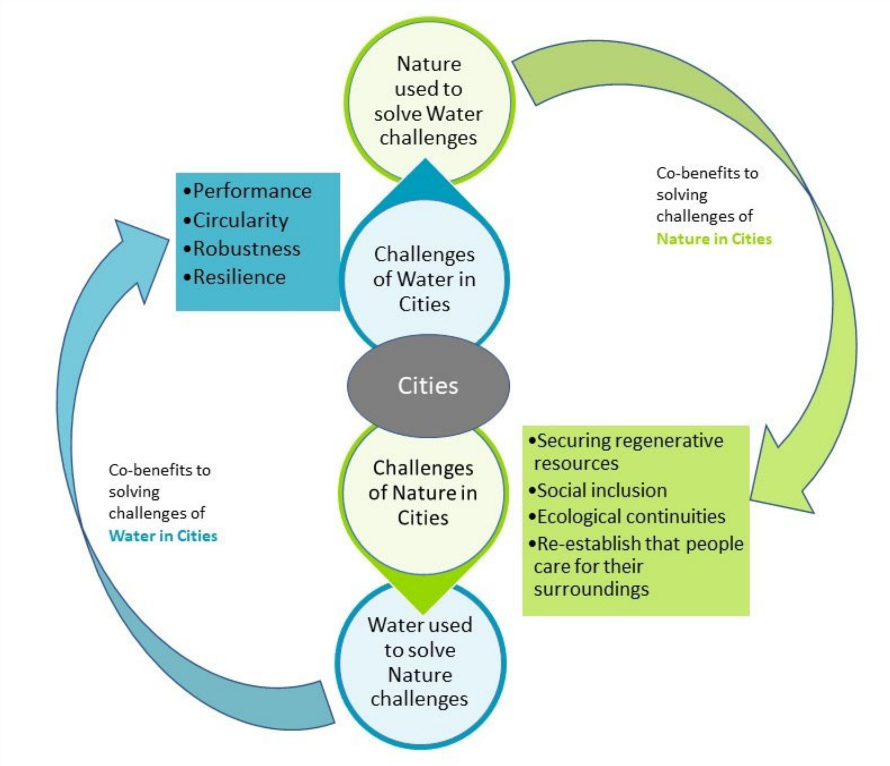


Ref: Jazbec et al (2020) Report for water services association Australia, ISF, UTS, Sydney.

Water Engineering Challenges in Cities

- **Adequate quantity of good water source – rising demand**
- **Water quality (pollution) and treatment for intended purpose including water recycling and reuse.**
- **Construction of new and maintaining existing water infrastructure**
- **Supplementary new water sources**
- **Water sensitive urban design**
- **Water-energy-food nexus**
- **Climate change impact and adaptation**

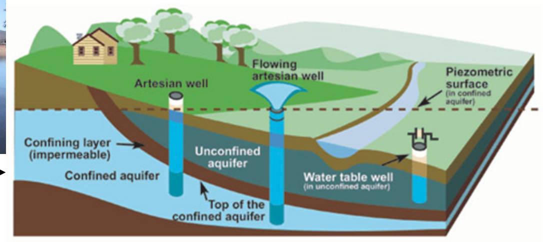
Water and nature challenges in cities: Circular economy and SDGs

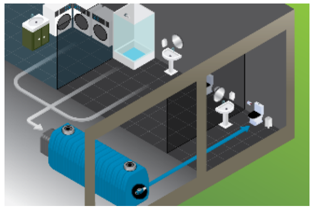


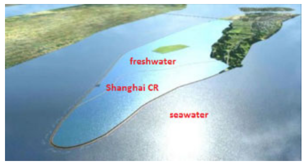
Ref: Trommsdorf, C. (2020) Nature for cities or cities for nature? IWA.

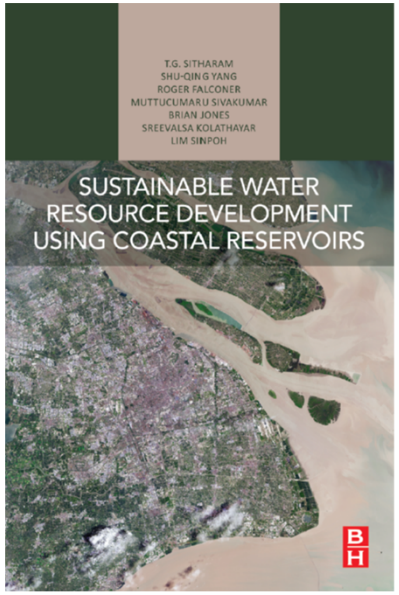
A mix of water sources and treatment technologies

- Rivers
- Reservoirs
- Groundwater
- Rainwater
- Stormwater
- Greywater
- Recycled wastewater
- Desalinated brackish water
- Desalinated seawater
- Coastal Reservoirs



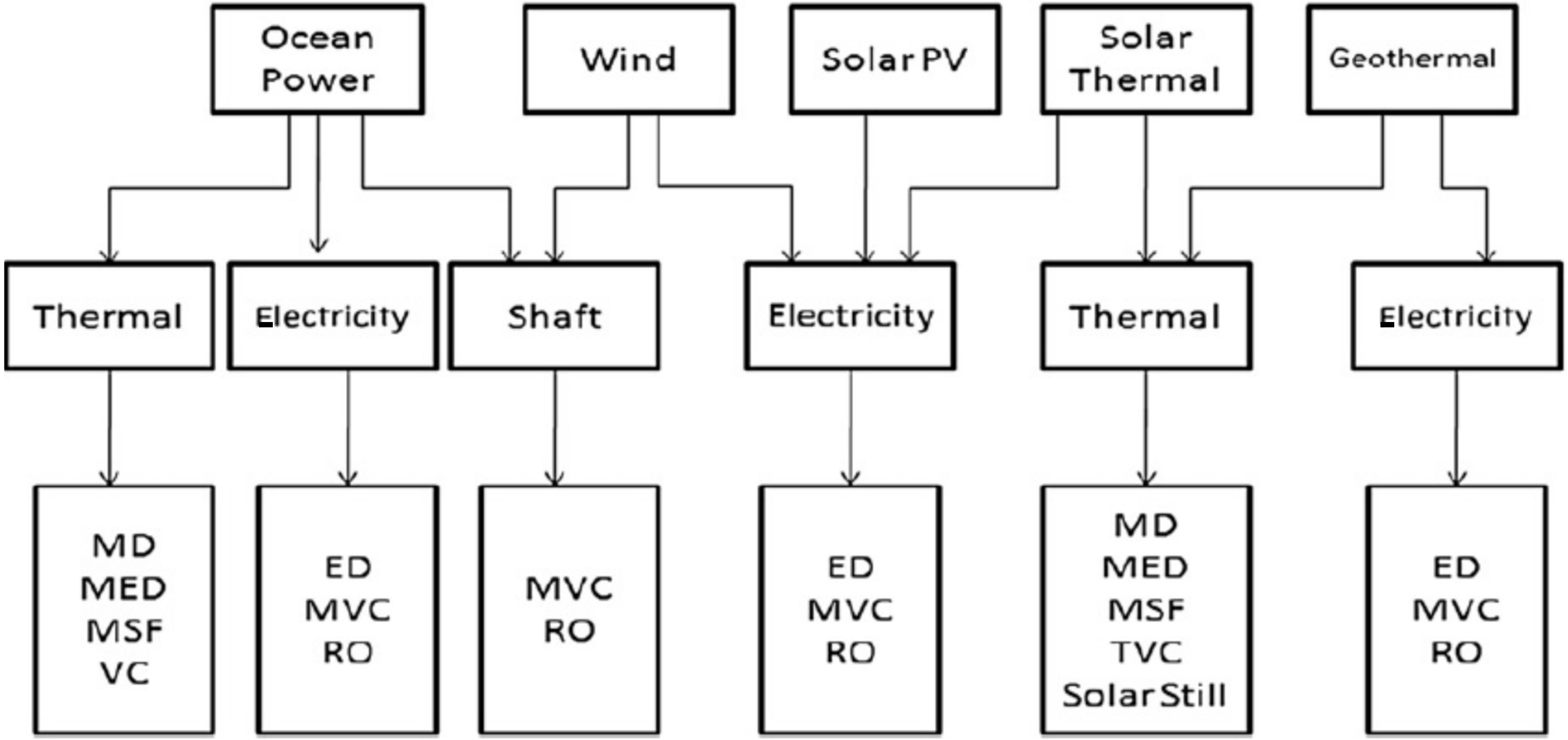






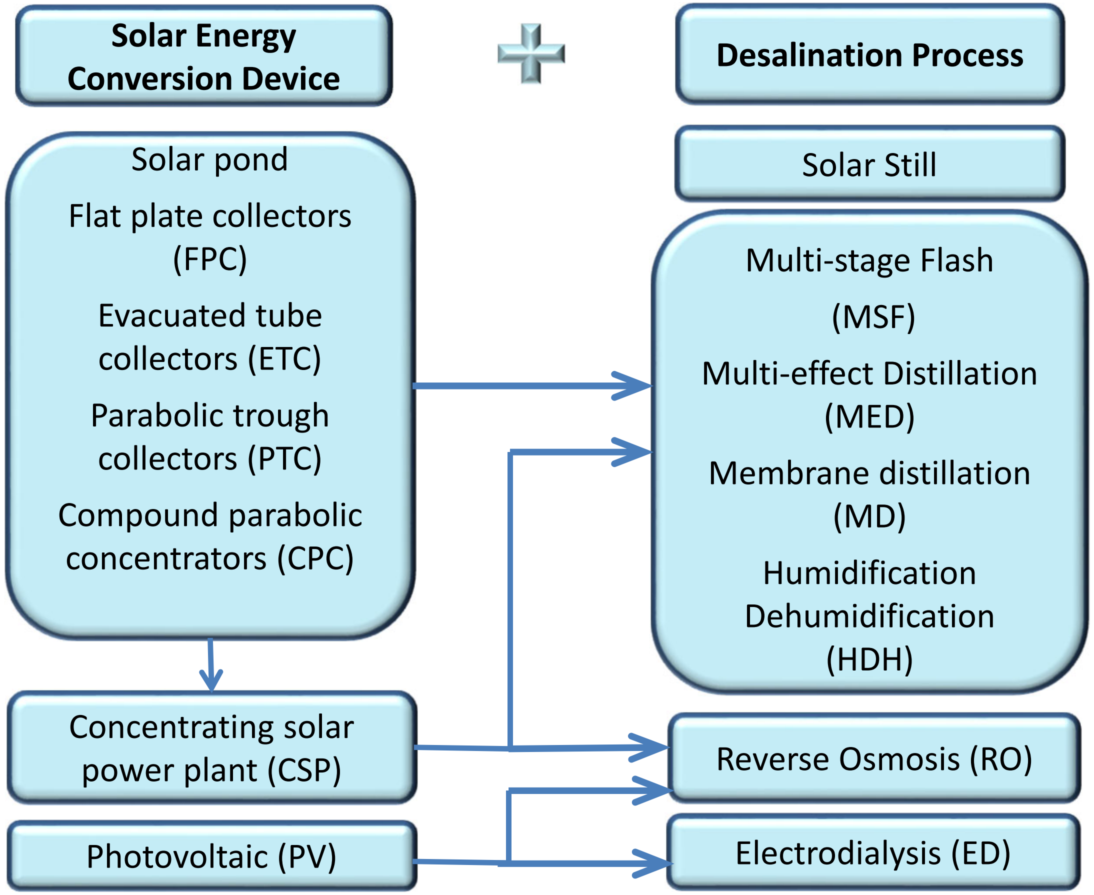
Renewable Energy Based Water Treatment Technologies

Renewable energy powered water treatment options



Ref: K. Jijakli et al. Desalination (2012)

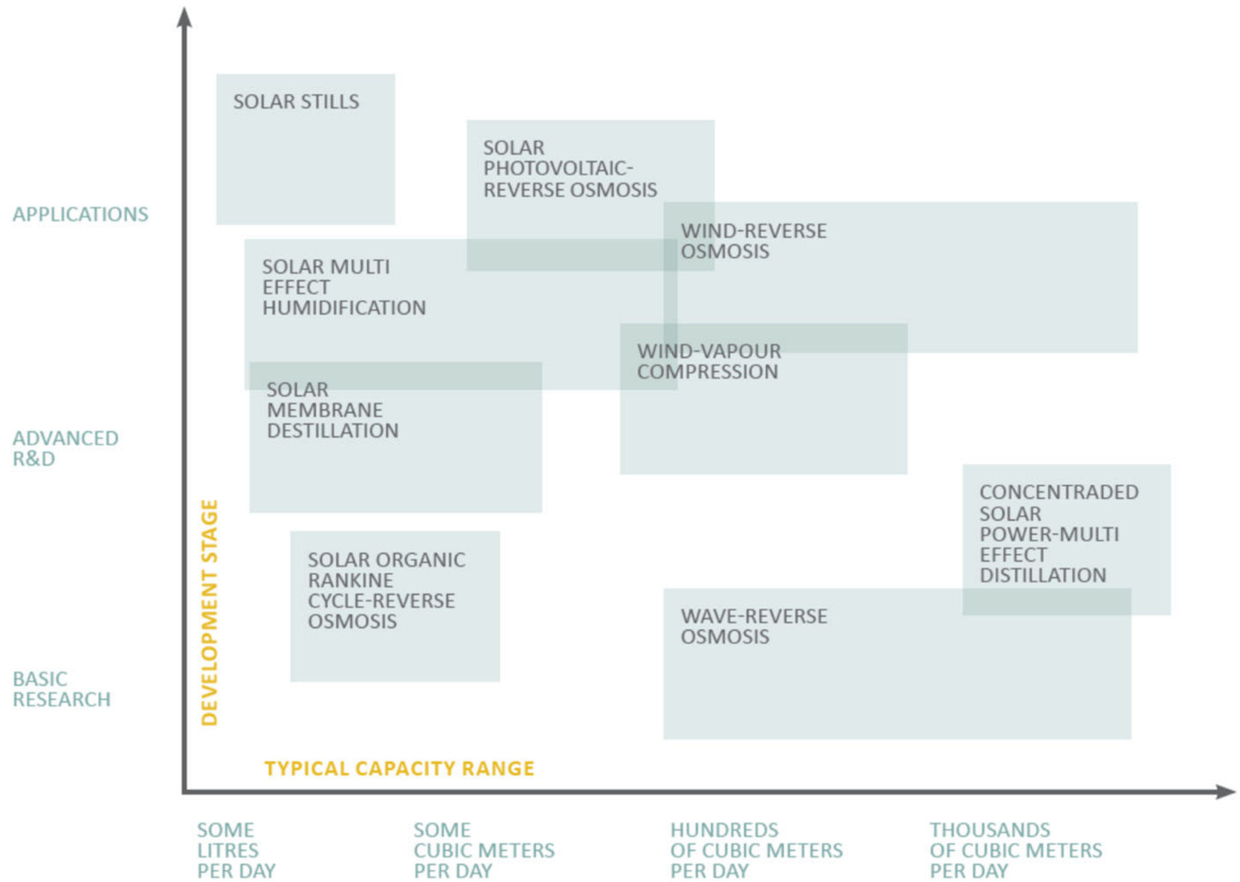
Possible combinations of solar energy with desalination technologies



Major solar desalination technologies and their current status

	Typical Capacity (m^3/d)	Feed water type	Specific energy consumption (kWh/m^3)	Reported Water Cost (USD/m^3)	Technical Development Status
Solar still	< 10	Seawater & brackish water	600-2000 (solar)	6-60	Commercial
Solar HDH	< 100	Seawater & brackish water	140-700 (solar)	3-20	Demonstration /Advanced R&D
Solar MD	< 100	Seawater & brackish water	100-900 (thermal)	12-18	Demonstration /Advanced R&D
PV-RO	<500	Seawater & brackish water	1.2-19 (electric)	0.8-30	Commercial
PV-ED	<500	Brackish water	0.7-4 (electric)	0.3-16	Commercial
Solar MSF	10 -5000	Seawater	50-100 (thermal)	1-5	Demonstration
Solar MED	10- 5000	Seawater	50-100 (thermal)	1-7	Demonstration /Advanced R&D
CSP + MED/RO	>1000	Seawater & brackish water	--	0.9-2	Research & Development

Renewable energy powered water treatment



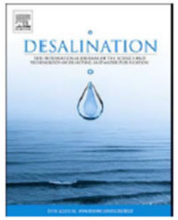
Ref:M. Papapetrau, et al 2009

Desalination 428 (2018) 116–145

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal



Engineering advance

Application of solar energy in water treatment processes: A review

Ying Zhang[a], Muttucumaru Sivakumar[a,*], Shuqing Yang[a], Keith Enever[a], Mohammad Ramezanianpour[b]

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[b] Department of Engineering and Architectural Studies, Ara Institute of Canterbury, Christchurch, New Zealand

Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.21024

85 (2017) 46–54
August

Grey water treatment using a solar powered electro-coagulator and vacuum membrane distillation system

Mohammad Ramezanianpour[a,b], Muttucumaru Sivakumar[a,*], Aleksandar Gocev Stojanovski[a]

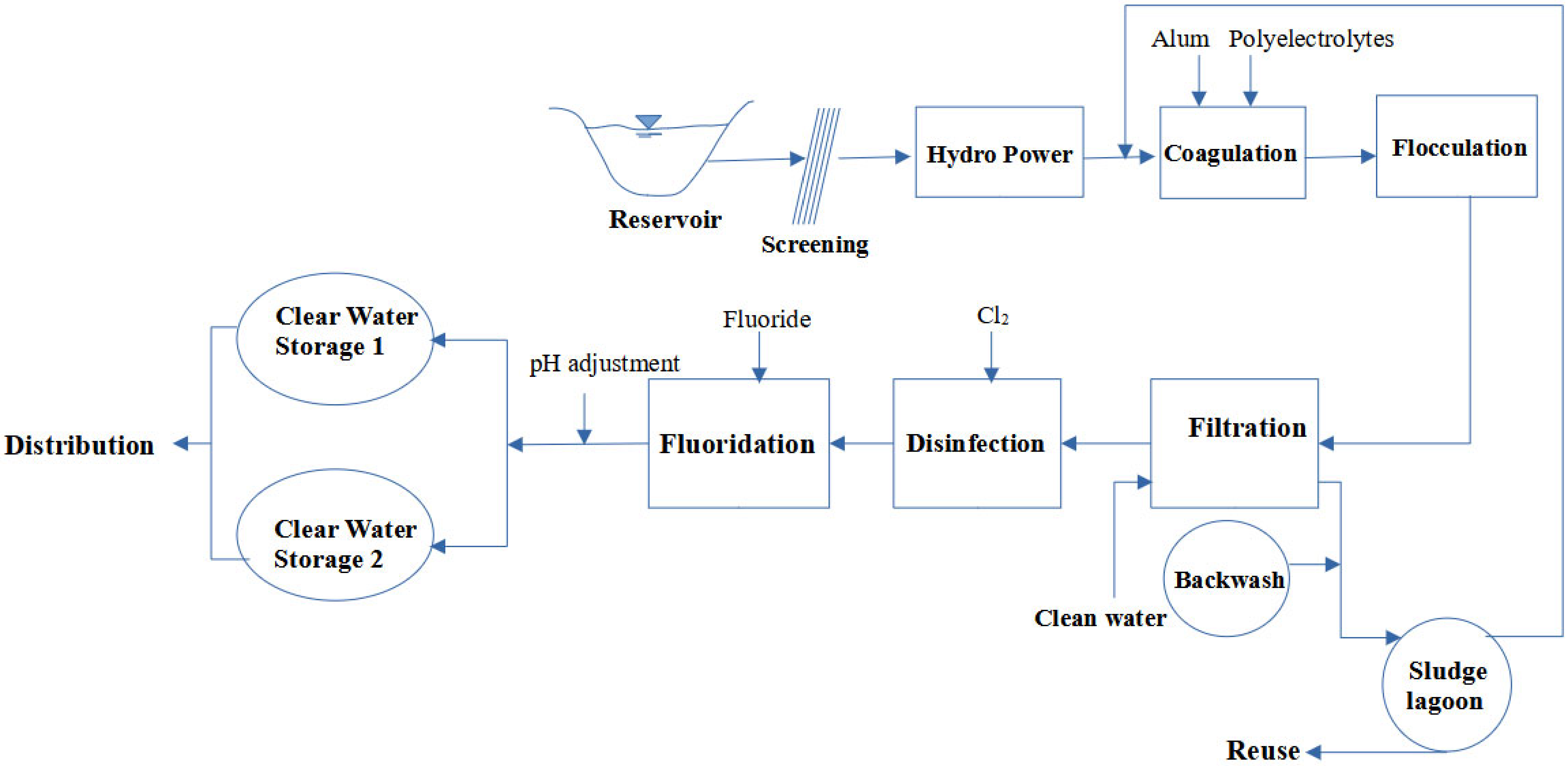
[a]*Sustainable Water and Energy Research Group, GeoQuest Research Centre, School of Civil, Mining and Environmental Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong NSW 2522, Australia, Tel. +(64) 3 940 8023; email: matt.pour@ara.ac.nz (M. Ramezanianpour), Tel. +(61) 2 4221 3055; emails: siva@uow.edu.au (M. Sivakumar), ags616@uowmail.edu.au (A.G. Stojanovski)*
[b]*Department of Civil and Architectural Studies, Ara Institute of Canterbury (Poly Technique), City Campus, Christchurch 8140, New Zealand*

Case studies in Wollongong Region

Well protected Avon water catchment

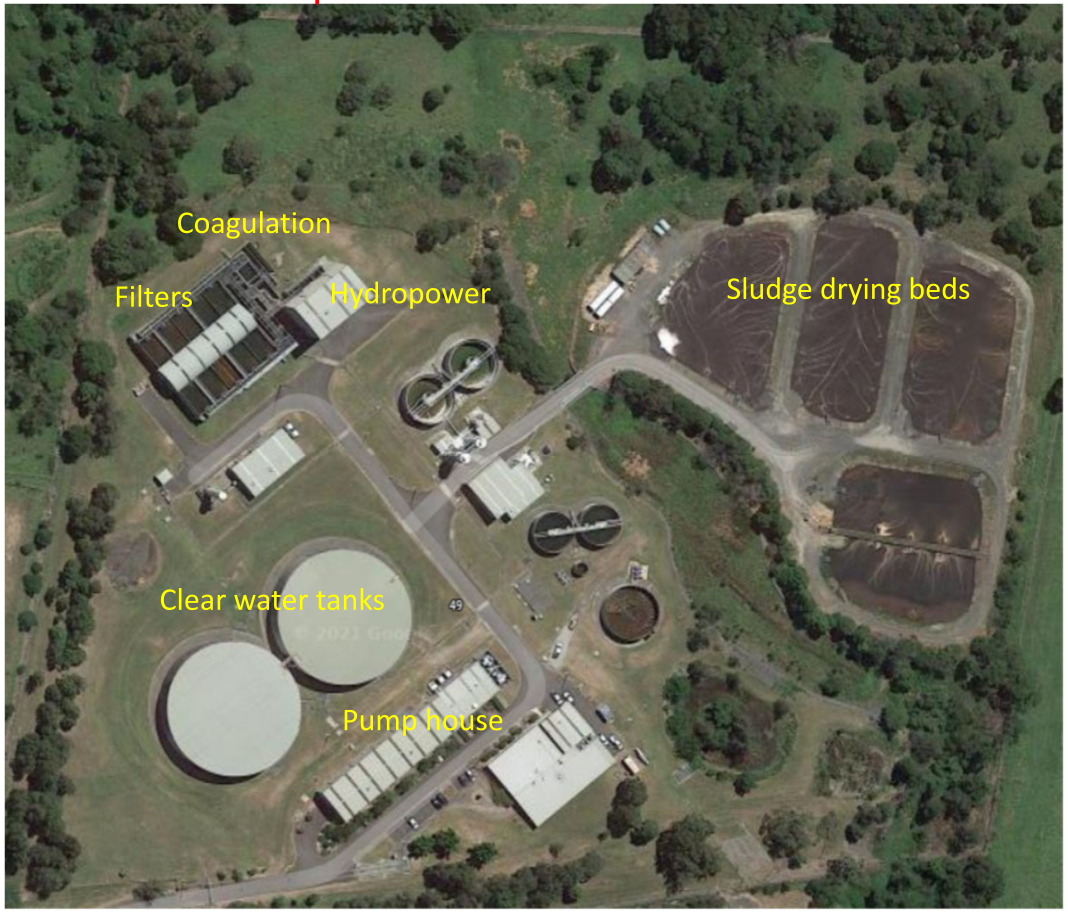
Ref: Google maps

Case study-1: Wollongong water treatment plant



Wollongong Water Treatment Plant

Carbon positive water treatment



Ref: Google images

WTP Elevation 25 m AHD

Population served 300,000

Design Max Flow = 210 ML/d

Operating flow= 72 ML/d

Daily power consumed =32.4 MWh
Pumps – 28.8 MWh
Others - 3.6 MWh

Daily hydropower produced by one Frances turbine = 44.4 MWh

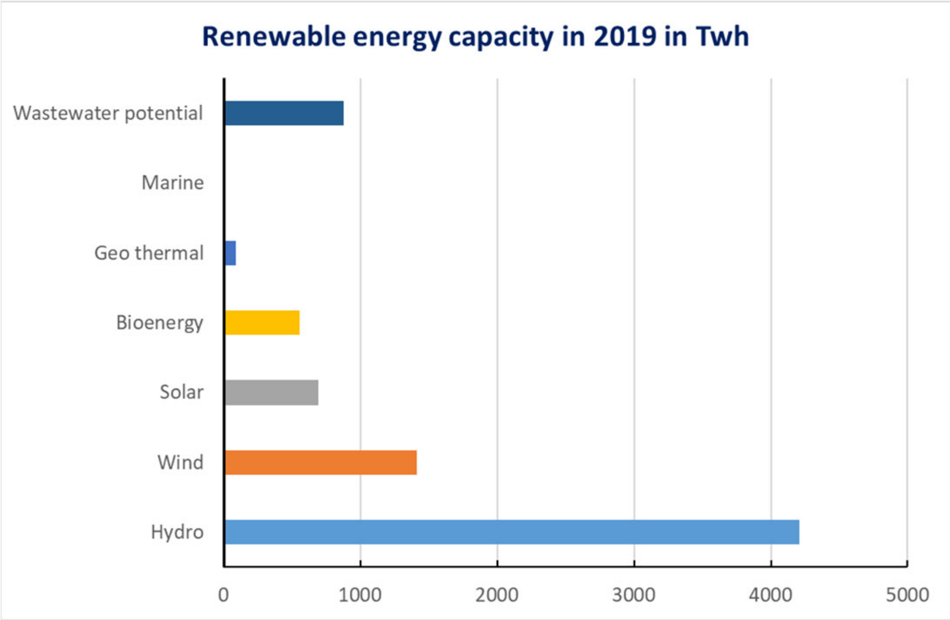
Energy positive by 12.0 MWh per day - exported to grid

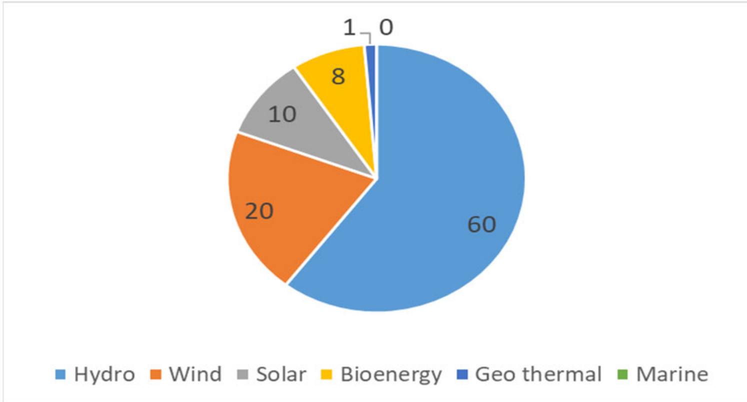
Wastewater Engineering and management

(Treatment, reuse, resource recovery)

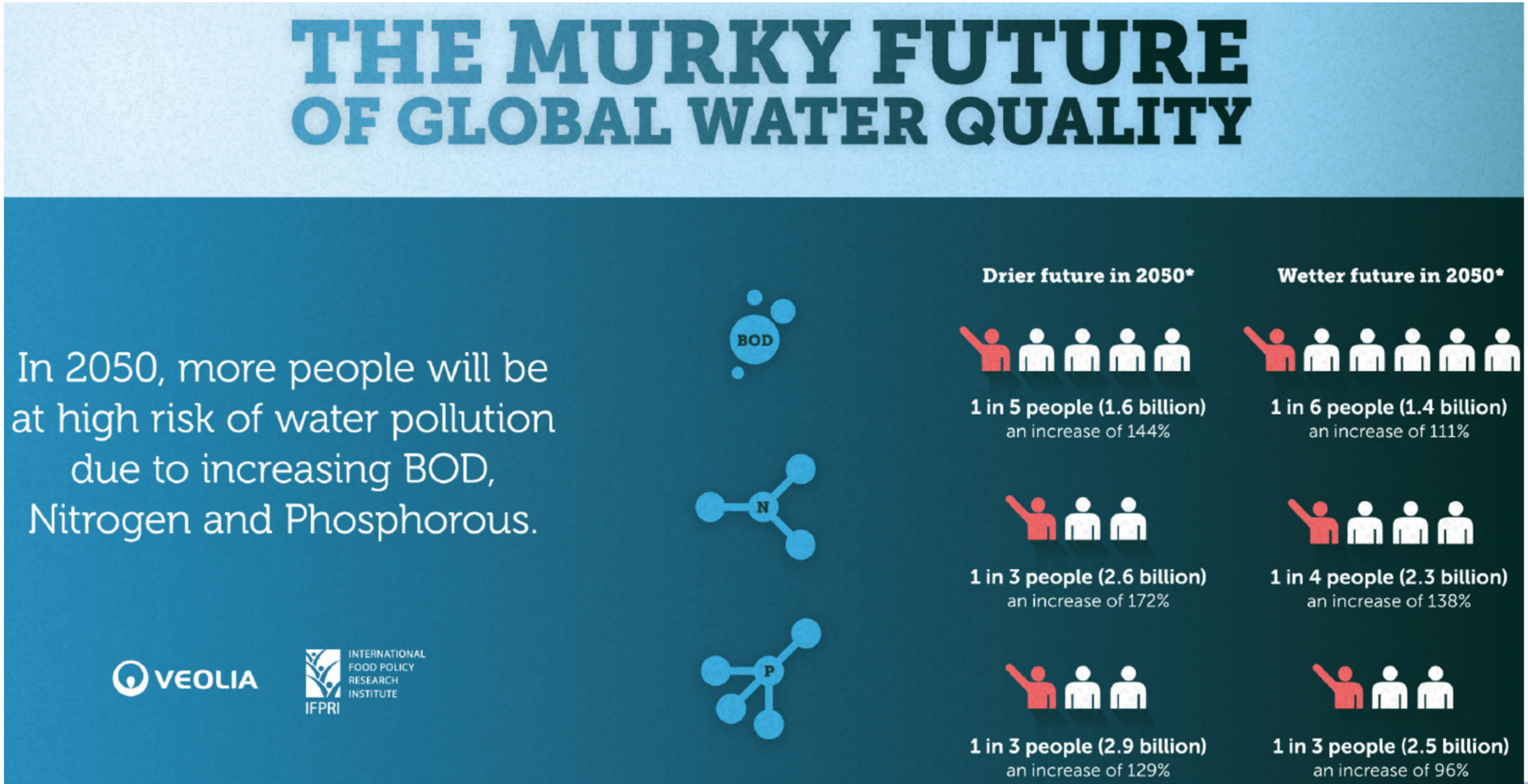
- Wastewater consists of recoverable potable water, energy, nutrients. This means it is not a 'wastewater', it should be viewed as a resource!
- Advanced treatment technologies exist to treat wastewater to potable water standards.
- Depending on the level of treatment, various types of reuse can be practiced.
- Specific unit treatment processes are required for removing emerging pollutants.
- All new treatment plants can be designed with net zero carbon emissions and with full life cycle analysis and sustainability assessment.

Worlds renewable energy use and wastewater potential





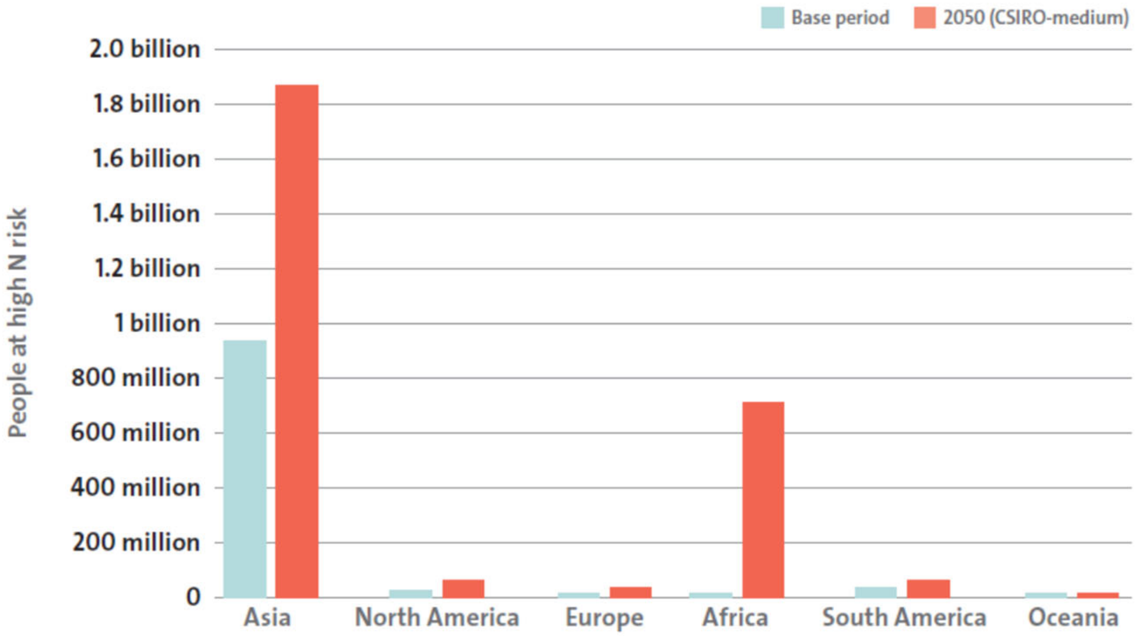
Ref: Data from arena.org



Ref: Veolia- IFPRI, 2015.

Population living in high N risk river basins- an illustrative comparison between base period (2000-2005) and 2050 (under the CSIRO-medium scenario)

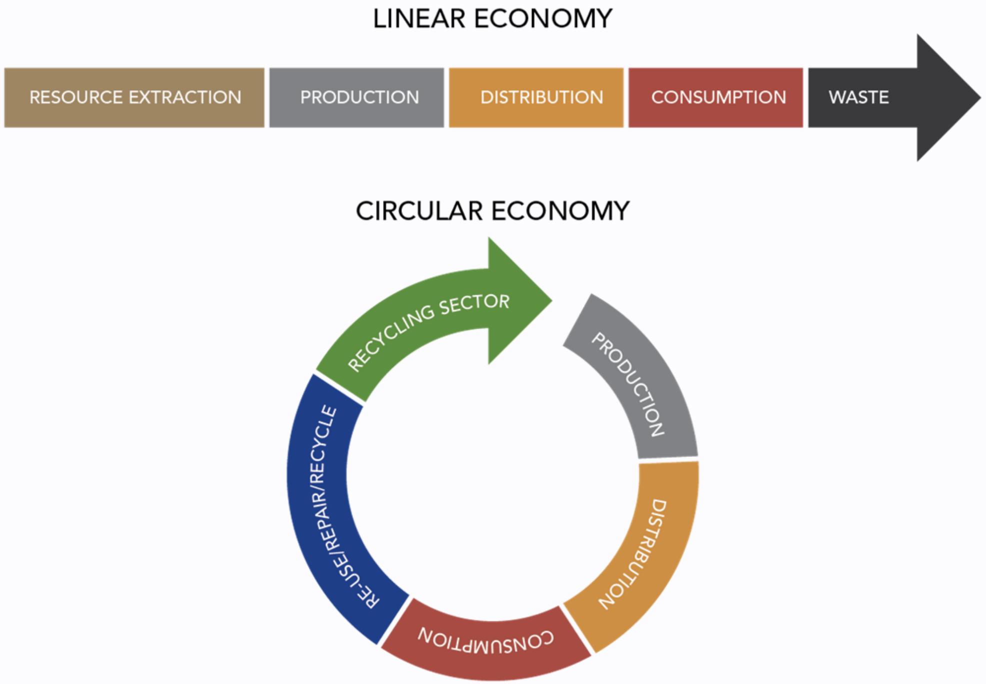
Figure 4



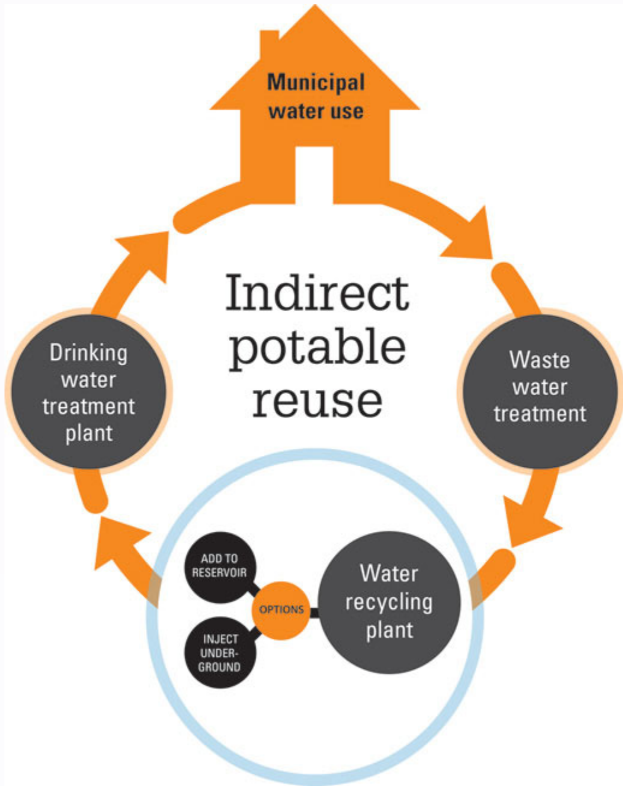
Note: *Population in basins without water quality data is excluded. Data for other regions and scenarios are available upon request.*

Ref: Veolia- IFPRI, 2015.

Wastewater treatment and reuse



https://nerc.org



https://choice.com.au

Floating solar panels in wastewater treatment pond

Floating solar plant at Jamestown, SA, powering the wastewater treatment facility

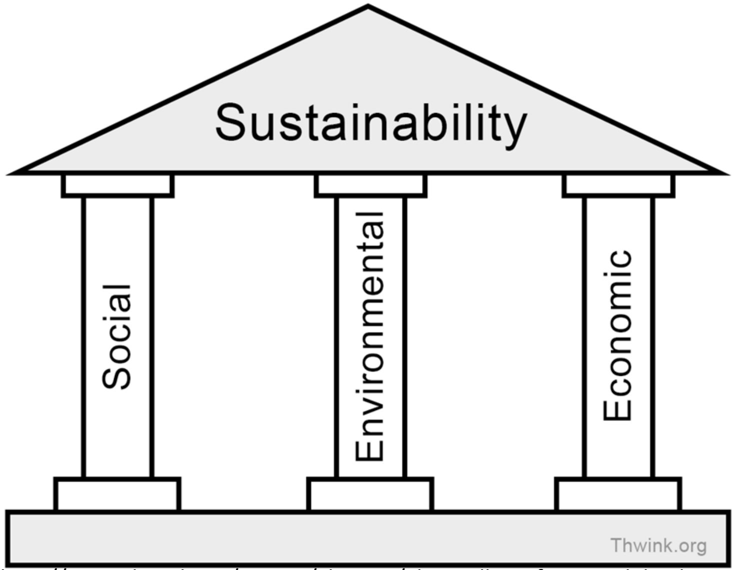
- 3.5 MW panels
- panels follow the sun
- Concentrating mirrors
- 57% more efficient than roof top solar
- Reduce evaporation

Ref: Infratechindustries.com

Is wastewater treatment plant sustainable?

Case study 2:

- Population served- 200,000
- Ave. Flow 50 ML/d
- Final product near drinking water quality
- Over 80% treated water is reused
- 11,000 tonnes of bio-solids and 100% reused

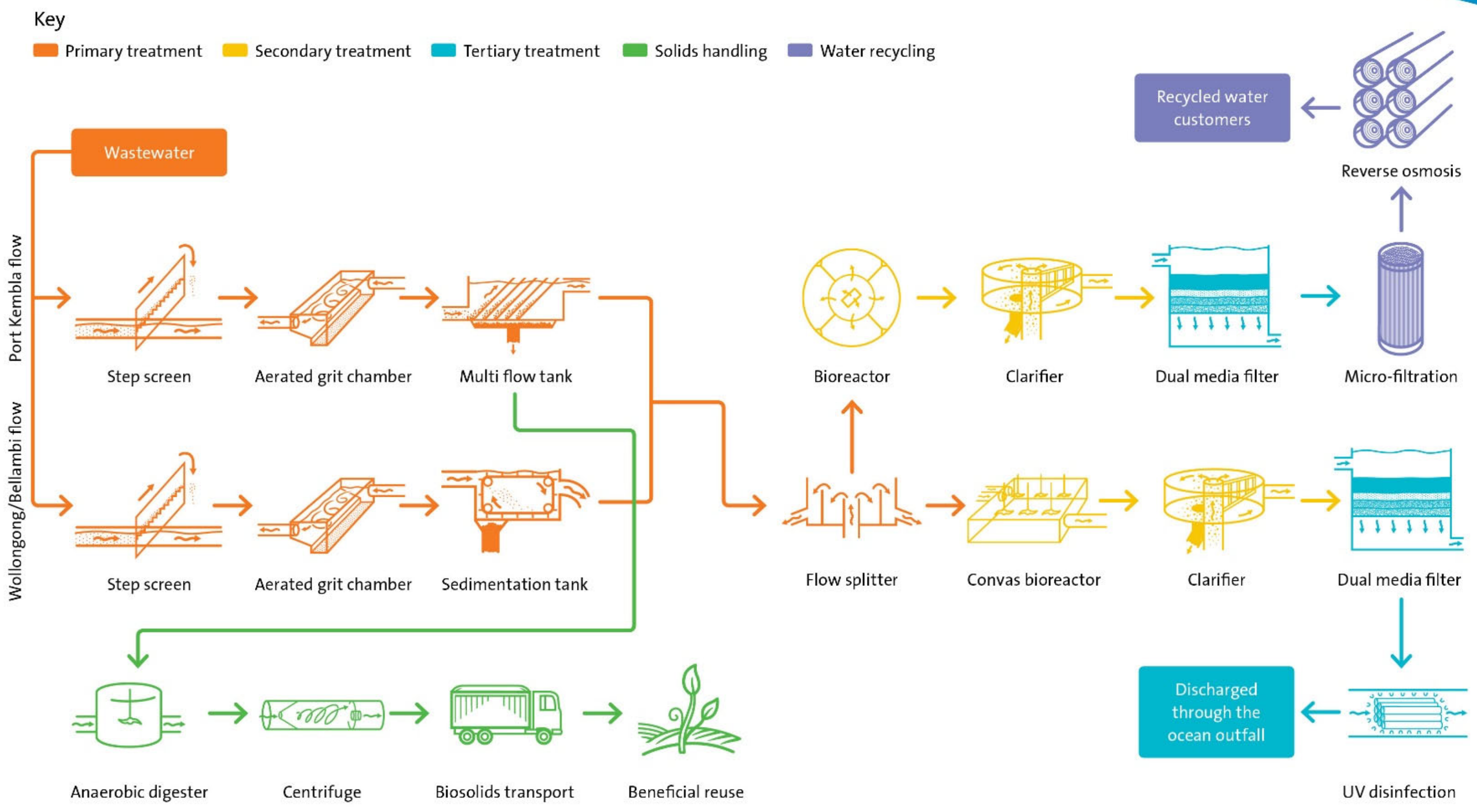


http://www.thwink.org/sustain/glossary/ThreePillarsOfSustainability.htm

Water Supply Option	Energy Use (kWh/kl)
Warragamba and other Water Storages	0.25 (Sydney Water, 2002)
Access “deep storage”	0.4 (Leslie, 2004)
Shoalhaven inter-basin transfer	2.4 (Anderson 2006)
Residential wastewater reuse (greenfields)	1.2 (Anderson, 2006)
Large Scale Indirect Potable Wastewater Recycling	2.8-3.8 (NSW LC, 2006)
Desalination	5.4 (NSW LC, 2006)
Residential Indoor Retrofit (that reduces hot water use)	-32.6 (White, 2006)

Energy intensity of water supply options (Knights, 2007)

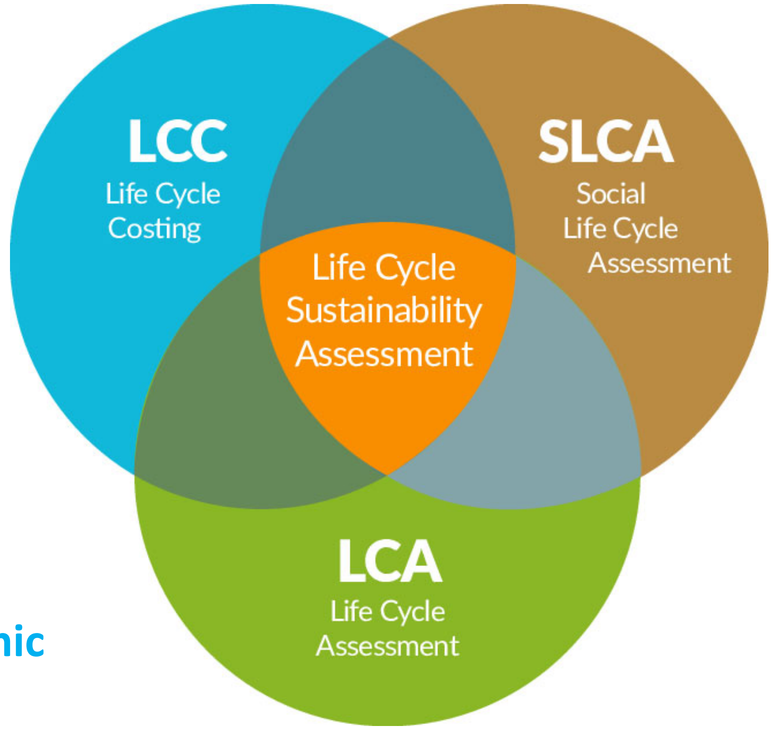
Wollongong Water Recycling Plant



Methodology – Life Cycle Sustainability Assessment

Evolution of environmental protection to the LCSA (Curran, 2015)

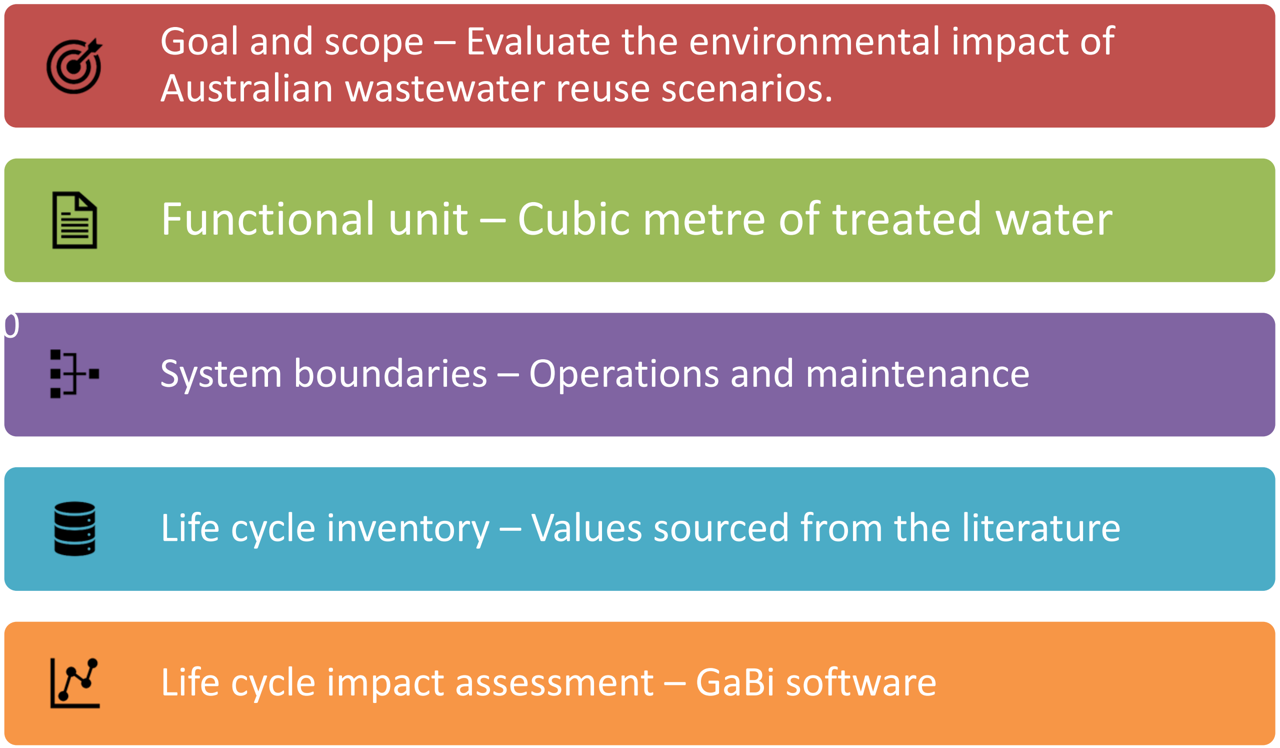
Evolution of Environmental Protection	
Chronology	**Strategy**
1970's to 1980's	End-of-Pipe Treatment
Mid 1980's	Waste Minimization/Reduction
Early 1990's	Pollution Prevention/Cleaner Production
Mid 1990's	ISO Certification/Life Cycle Assessment
2000 and Beyond	Sustainable Development/Life Cycle Sustainability Assessment



LCSA = LCA + SLCA + LCC

Environmental (LCA) Social (SLCA) Economic (LCC)

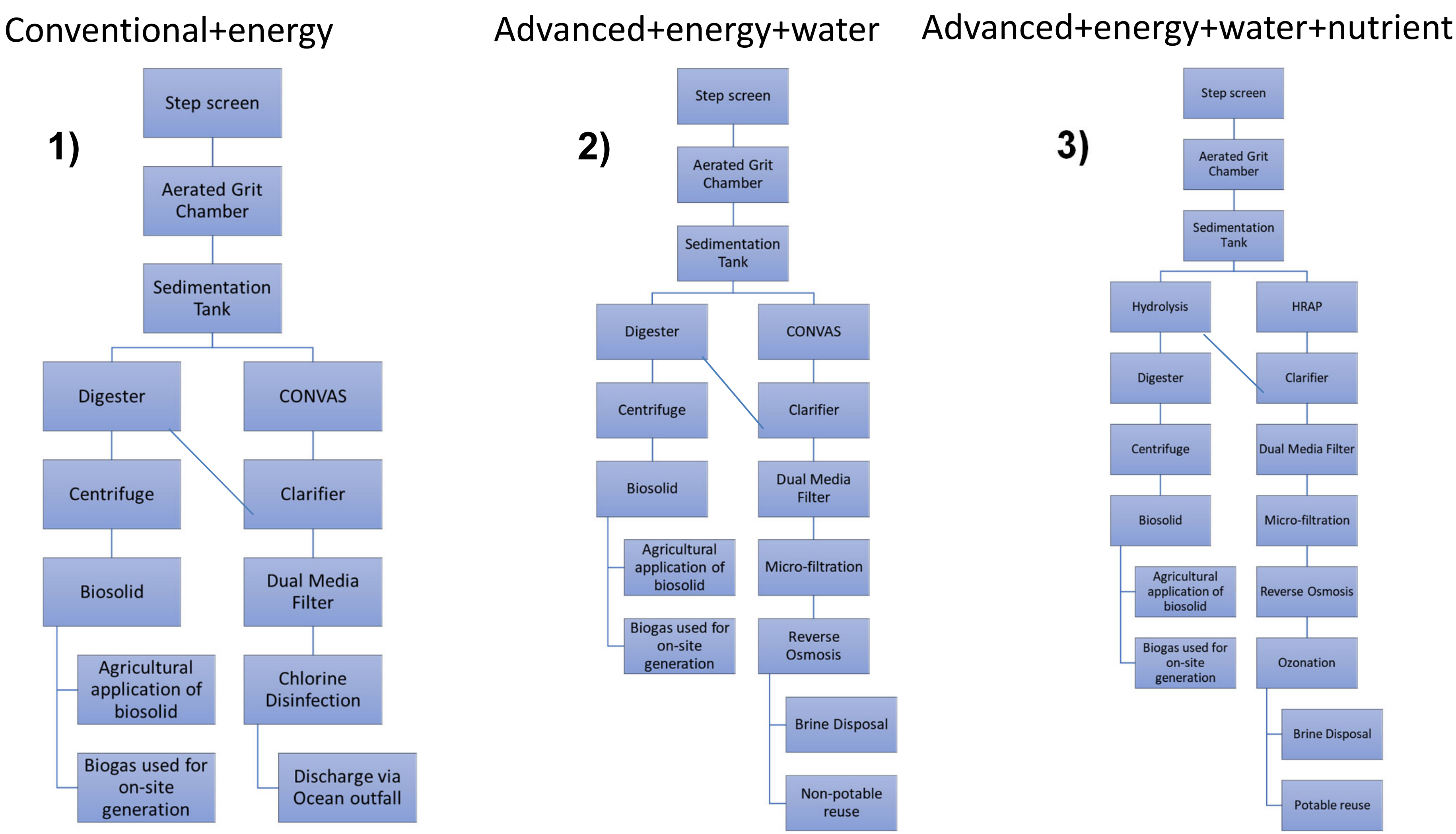
https://www.researchgate.net/figure/The-overlap-between-the-three-pillars-of-sustainability-resulting-in-LCSA_fig1_301823430

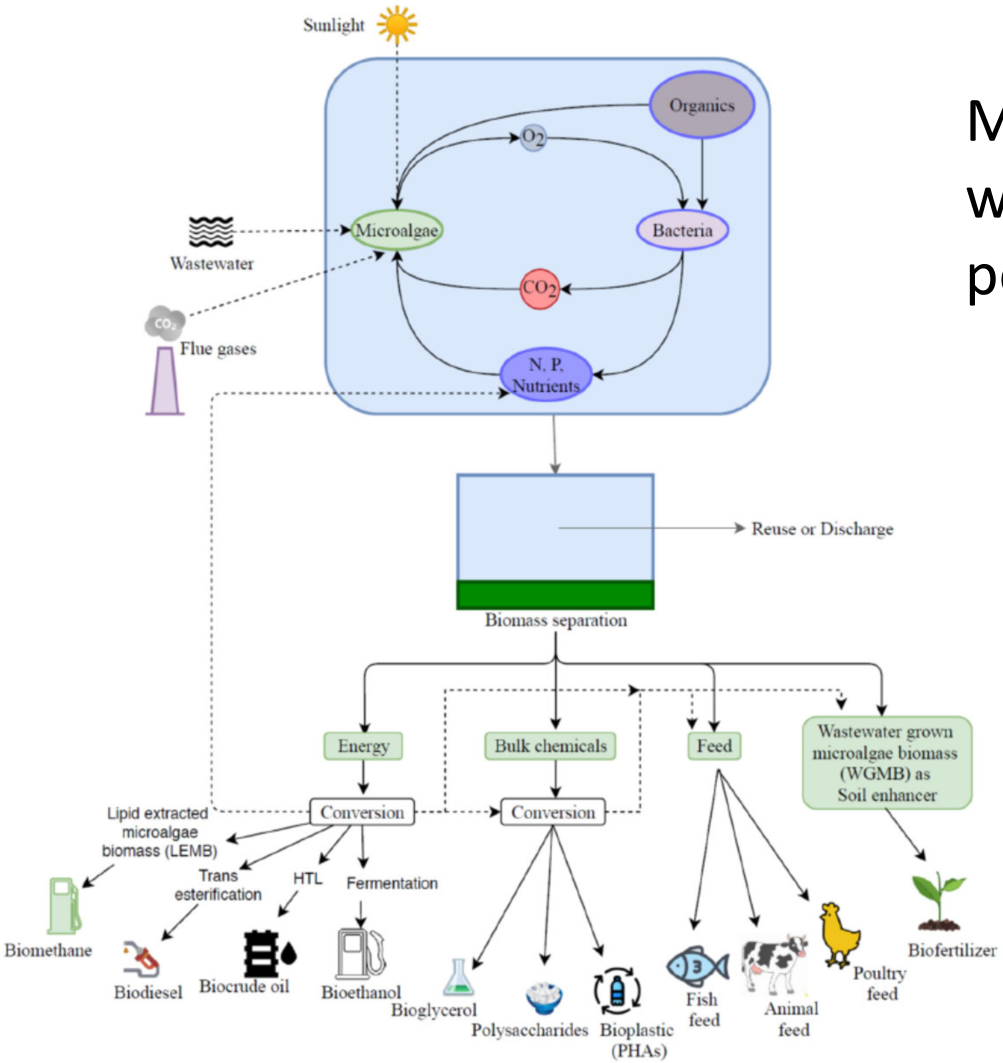

Goal and scope – Evaluate the environmental impact of Australian wastewater reuse scenarios.
Functional unit – Cubic metre of treated water
System boundaries – Operations and maintenance
Life cycle inventory – Values sourced from the literature
Life cycle impact assessment – GaBi software

Life Cycle Inventory

3 scenarios

- Selecting sustainable technology to be used in each scenario
- Gathering inventory data for scenarios


Conventional+energy
Advanced+energy+water
Advanced+energy+water+nutrient
1)
Step screen
Aerated Grit Chamber
Sedimentation Tank
Digester
CONVAS
Centrifuge
Clarifier
Biosolid
Dual Media Filter
Agricultural application of biosolid
Chlorine Disinfection
Biogas used for on-site generation
Discharge via Ocean outfall
2)
Step screen
Aerated Grit Chamber
Sedimentation Tank
Digester
CONVAS
Centrifuge
Clarifier
Biosolid
Dual Media Filter
Agricultural application of biosolid
Micro-filtration
Biogas used for on-site generation
Reverse Osmosis
Brine Disposal
Non-potable reuse
3)
Step screen
Aerated Grit Chamber
Sedimentation Tank
Hydrolysis
HRAP
Digester
Clarifier
Centrifuge
Dual Media Filter
Biosolid
Micro-filtration
Agricultural application of biosolid
Reverse Osmosis
Biogas used for on-site generation
Ozonation
Brine Disposal
Potable reuse

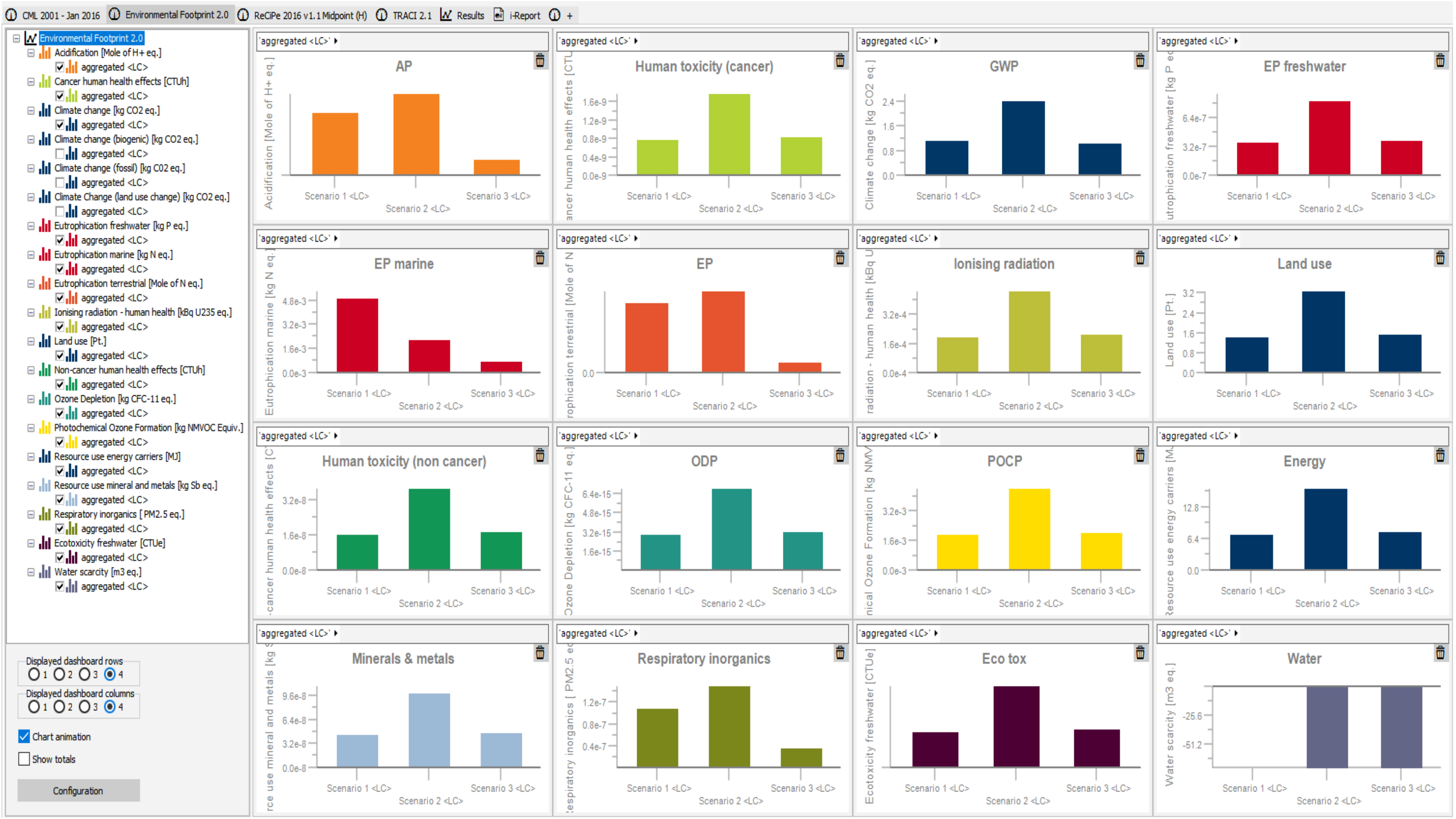


Micro-algae based wastewater treatment and potential applications

Key benefits for circular economy

- Less energy requirement
- Utilisation of flue gases (CO_2)
- Increase bioenergy production
- Nutrient recovery

Ref: Al-Jabri et al 2021, Water **2021**, 13, 27. https://doi.org/10.3390/w13010027

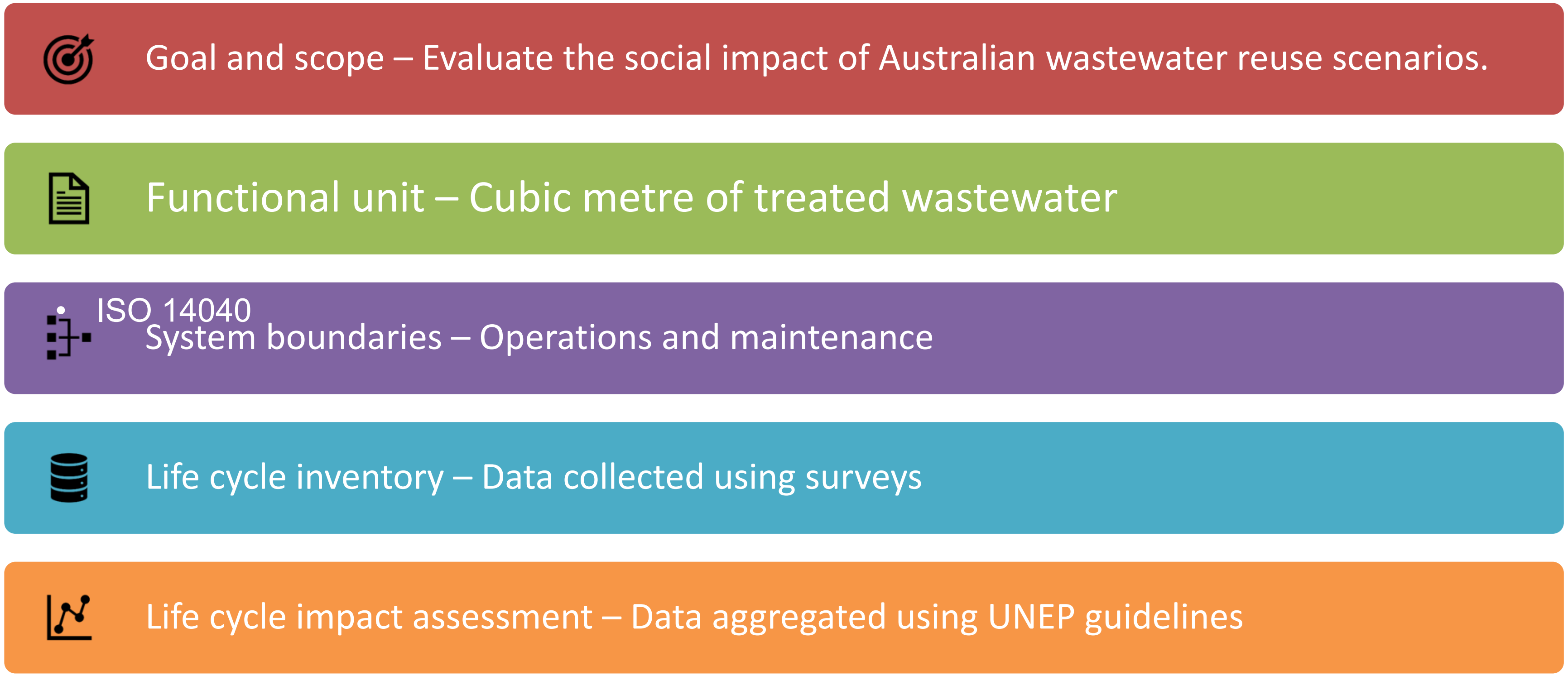

CML 2001 - Jan 2016
Environmental Footprint 2.0
ReCiPe 2016 v1.1 Midpoint (H)
TRACI 2.1
Results
i-Report
Environmental Footprint 2.0
Acidification [Mole of H+ eq.]
aggregated <LC>
Cancer human health effects [CTUh]
aggregated <LC>
Climate change [kg CO2 eq.]
aggregated <LC>
Climate change (biogenic) [kg CO2 eq.]
aggregated <LC>
Climate change (fossil) [kg CO2 eq.]
aggregated <LC>
Climate Change (land use change) [kg CO2 eq.]
aggregated <LC>
Eutrophication freshwater [kg P eq.]
aggregated <LC>
Eutrophication marine [kg N eq.]
aggregated <LC>
Eutrophication terrestrial [Mole of N eq.]
aggregated <LC>
Ionising radiation - human health [kBq U235 eq.]
aggregated <LC>
Land use [Pt.]
aggregated <LC>
Non-cancer human health effects [CTUh]
aggregated <LC>
Ozone Depletion [kg CFC-11 eq.]
aggregated <LC>
Photochemical Ozone Formation [kg NMVOC Equiv.]
aggregated <LC>
Resource use energy carriers [MJ]
aggregated <LC>
Resource use mineral and metals [kg Sb eq.]
aggregated <LC>
Respiratory inorganics [PM2.5 eq.]
aggregated <LC>
Ecotoxicity freshwater [CTUe]
aggregated <LC>
Water scarcity [m3 eq.]
aggregated <LC>
Displayed dashboard rows
1 2 3 4
Displayed dashboard columns
1 2 3 4
Chart animation
Show totals
Configuration
AP
Human toxicity (cancer)
GWP
EP freshwater
EP marine
EP
Ionising radiation
Land use
Human toxicity (non cancer)
ODP
POCP
Energy
Minerals & metals
Respiratory inorganics
Eco tox
Water
Scenario 1 <LC>
Scenario 2 <LC>
Scenario 3 <LC>

LCIA Results

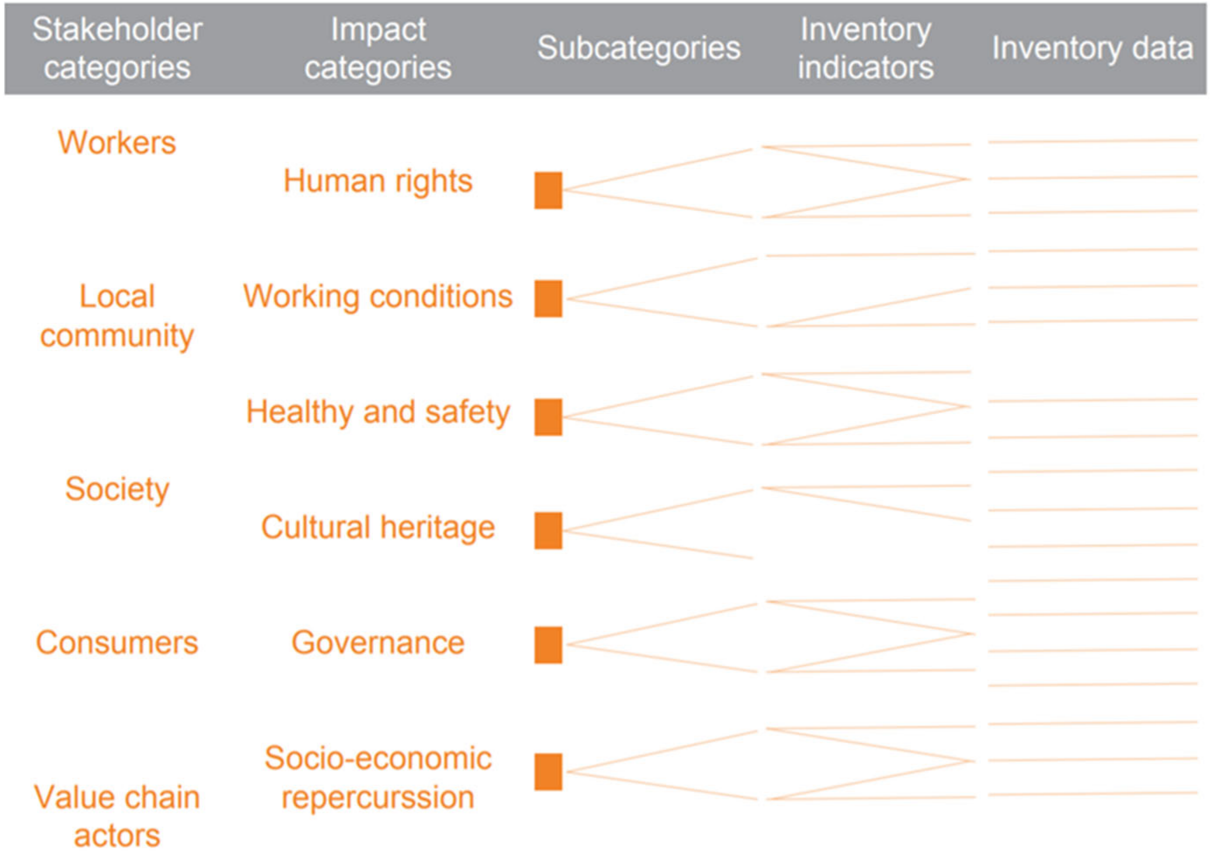
Scenario	Scenario 1	Scenario 2	Scenario 3
LCA Score	0.70	0.42	0.96

Impact Category	Scenario 1	Scenario 2	Scenario 3
AP (mole of H+ eq.)	0.014	0.0181	0.0034
Human toxicity (cancer) (CTUh)	7.67E-10	1.76E-09	8.18E-10
GWP (kg CO2 eq.)	1.12	2.38	1.01
EP freshwater (kg P eq.)	3.54E-07	8.15E-07	3.78E-07
EP marine (kg N eq.)	4.88E-03	2.13E-03	6.96E-04
EP terrestrial (mole of N eq.)	5.51E-02	6.44E-02	7.61E-03
Human toxicity (non-cancer) (CTUh)	1.61E-08	3.71E-08	1.72E-08
ODP (kg CFC-11 eq.)	2.95E-15	6.79E-15	3.15E-15
POCP (kg MWVOC eq.)	1.88E-03	4.37E-03	1.97E-03
Energy (MJ)	7.12	16.40	7.60
Ecotoxicity (CTUe)	3.03E-02	6.97E-02	3.24E-02
Water scarcity (m^3 eq.)	0.00	-71.60	-71.60

Impact Category	Scenario 1	Scenario 2	Scenario 3
AP (mole of H+ eq.)	0.24	0.19	1.00
Human toxicity (cancer) (CTUh)	1.00	0.44	0.94
GWP (kg CO2 eq.)	0.90	0.42	1.00
EP freshwater (kg P eq.)	1.00	0.43	0.94
EP marine (kg N eq.)	0.14	0.33	1.00
EP terrestrial (mole of N eq.)	0.14	0.12	1.00
Human toxicity (non-cancer) (CTUh)	1.00	0.43	0.94
ODP (kg CFC-11 eq.)	1.00	0.43	0.94
POCP (kg MWVOC eq.)	1.00	0.43	0.95
Energy (MJ)	1.00	0.43	0.94
Ecotoxicity (CTUe)	1.00	0.43	0.94
Water scarcity (m^3 eq.)	0.00	1.00	1.00
Total	**8.43**	**5.09**	**11.57**

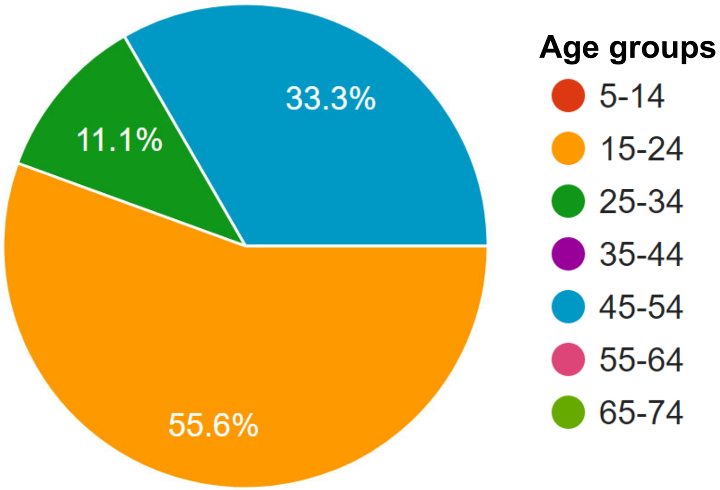

Goal and scope – Evaluate the social impact of Australian wastewater reuse scenarios.
Functional unit – Cubic metre of treated wastewater
ISO 14040
System boundaries – Operations and maintenance
Life cycle inventory – Data collected using surveys
Life cycle impact assessment – Data aggregated using UNEP guidelines

Social Life Cycle Inventory



Social life cycle impact assessment methodology (UNEP/SETAC, 2011)

Building the Life Cycle Inventory



Occupations

- Marketing
- Librarian
- Law Graduate
- Project Engineer (Civil)
- Travel agent
- Environmental Engineering Student
- Regional Manager - Veolia Australia & New Zealand

Social Life Cycle Impact Assessment

Stakeholder (level 2)	Category (level 3)	Sub-category (level 4)	Weight (%)	Indicator	Type of indicator[a]
Public	Water saving		29.6	Water saved	N
	Equity/fairness		9.3	Water supply equivalence	Q
Community	Community engagement		12.0	Reclamation system scale	Q
	Local employment		3.4	Maintenance work hours	N
	Urban landscape		12.6	RW availability	Q
Consumer	Health concerns	Level of contact with RW	6.5	Types of reuse	Q
		Source of RW	4.6	Type and origin of RW	Q
		Trust in supplier and technology	4.9	Type of operating company	Q
	Finance		9.2	Household water expenses	N
	Convenience	Supply reliability	5.2	Pipeline length	N
		Consumption habits	2.7	Required precautions	Q
			100.0		

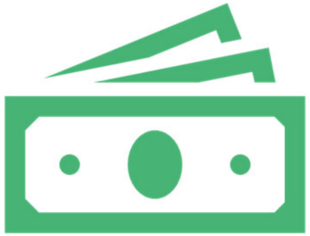
[a] *N* quantitative, *Q* qualitative

Ref: Opher et al (2018) A comparative social life cycle assessment of urban domestic water reuse alternatives. *International Journal of Life Cycle Assessment,* 23**,** 1315-1330.

Final Social Life Cycle Assessment Scores

Scenario	Scenario 1	Scenario 2	Scenario 3
SLCA Score	0.40	0.71	0.80

Life Cycle Costing



Scenario	Scenario 1	Scenario 2	Scenario 3
LCC score	1.00	0.57	0.77

Final Weighting

Index	Environment	Economy	Society
FEEM SI[a]	35.7	25.7	38.6
EPI[b]	50.0	–	50.0
De Luca et al. (2015)	19.9	9.3	70.8
Wolfslehner et al. (2012)	33.3	33.3	33.3
Current study	*61.0*	*17.0*	*22.0*

Weighted Method	Scenario 1	Scenario 2	Scenario 3
FEEM SI	0.66	0.57	0.85
EPI	0.55	0.57	0.88
De Luca (2015)	0.52	0.64	0.83
Wolfslehner (2012)	0.70	0.57	0.84
Current study	0.72	0.50	0.89

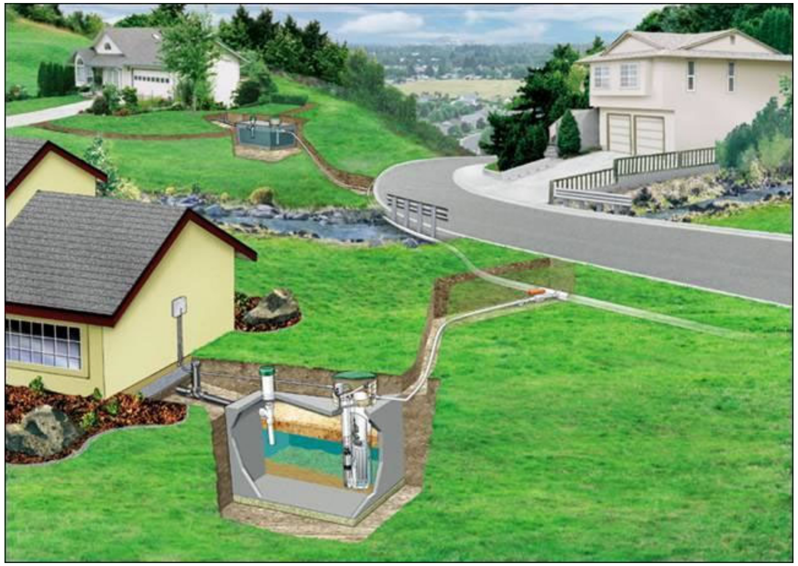
Scenario 3 most preferred by all weighting methodologies

Shows that reuse is sustainable but only if resource recovery is implemented as well

Standardise Social Life Cycle Assessment

Improve inventory – i.e actual plant data and implementation of Ecoinvent databases

Centralised vs de-centralized systems



Comparison of wastewater treatment technologies

FIGURE 3.5: GLOBAL WARMING IMPACTS EXPRESSED AS EQUIVALENT CARBON EMISSIONS FROM PASSENGER VEHICLES ON THE ROAD

Ref: Cascadia green building council, 2011)

Life Cycle Analysis (Cradle to point of use)

IMPACT	UNITS	COMP TOILETS	MEMBRANE BIOREACTOR	RECIRC BIOFILTER	CONSTRUCTED TREATMENT WETLAND
Acidification	kg SO2-Eq.	-55%	1160%	88%	-43%
Aq. Ecotoxicity	Kg TEG Eq.	-62%	1190%	92%	-43%
Eutrophication	kg PO4-Eq.	-58%	1098%	76%	-48%
Respiratory Effects	kg PM2.5-Eq.	-33%	1083%	79%	-36%
Global Warming	kg CO_2-Eq	-44%	1113%	85%	-40%
Ozone Depletion	kg CFC 11-Eq	221%	942%	81%	-6%
Smog Air	kg NOx-Eq	-29%	887%	52%	-41%

Ref: Cascadia green building council, 2011)

Optimal solutions would be to build decentralized systems that are passive, low-energy and gravity-fed conveyance.

Case study 3:

Water and wastewater management at

Sustainable Buildings Research Centre (SBRC) at UOW

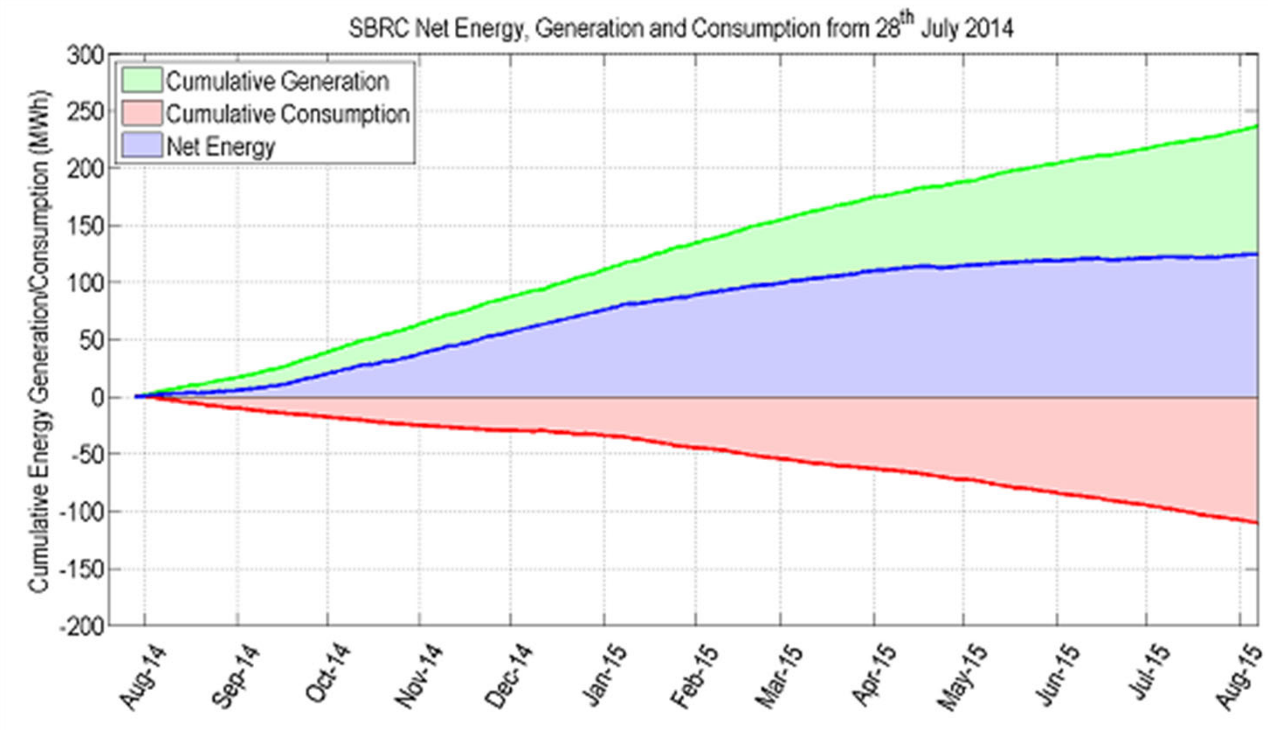
Building area: 2600 m^2 ; Land area: 7500 m^2

Living Building Challenge (LBC) certified

- 1st Living Certified Building in Australia
- 24th Living Certified project in the world
- 3rd Living Certified project outside the United States
- 1st project in Australia to achieve any level of LBC certification.

https://www.uow.edu.au/media/2019/uow-home-to-australias-most-sustainable-building.php

SBRC's Areas of Performance



Net +ve energy

SBRC's Green Features and Water Sustainability

LAND AND ECOLOGY

Green roof and green wall have been integrated. The wider landscape requires minimal irrigation and contain a permaculture and native urban garden.

L1 Green wall
L2 Green roof with testing beds
L3 Native agriculture garden
L4 Permaculture Garden

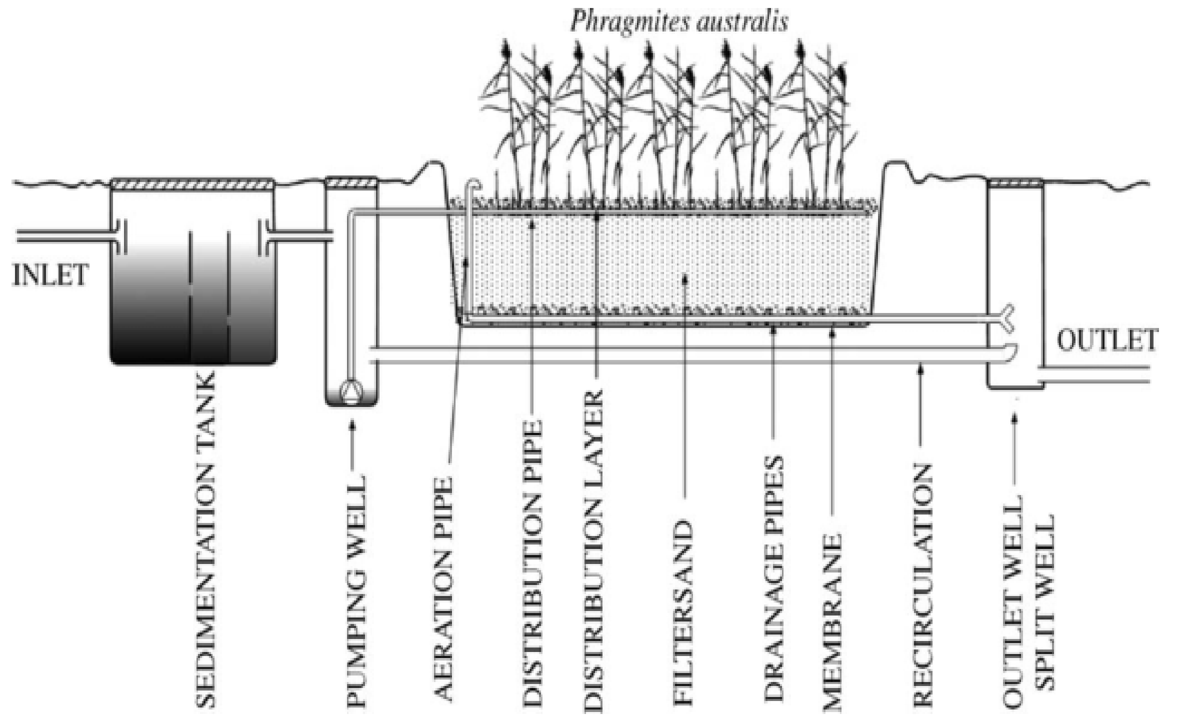
WATER

SBRC is a net exporter of water. All non-harvested stormwater is treated in the site-wide detention basins and swales before leaving the site. All wastewater is treated through the blackwater system and used for irrigation.

W1 Rainwater collection tank (65 kL - Net +ve)
W2 Rainwater treatment (Filter, UV)
W3 Onsite detention of stormwater
W4 Green roof water quality testing
W5 Black water treatment (**Constructed Wetland**)

Sub-Surface Constructed Wetlands (CW's)

Vertical Flow



SBRC wetland performance

Parameter	Removal rate
TSS	89%
BOD5	95%
NH3-N	71%
TN	22%
TP	56%
TOC	52%
FC (CFU/100mL)	2.4 (log)

Good removal of solids, organics and also supports nitrification and phosphorus removal.

UNIVERSITY OF WOLLONGONG AUSTRALIA

SBRC (innovation campus) vs. UOW (main Campus)

SBRC	UOW
Water use = 6.6 L/EP/d (net zero from Sydney Water)	Water use = 16.4 L/EP/d (no water saving devices)
Energy use = 10.0 kWh/EP/d (0 from grid)	Energy use = 12.7 kWh/EP/d (all from the grid)
Advanced Building Management System (HVAC control, water/wastewater monitoring, meteorological monitoring, self-automated comfort control)	No management system (minimal monitoring and control)
Integrates recycled materials in building (e.g. recycled railway structure)	Beginning to implement recycled materials construction projects

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A taxonomy of design factors in constructed wetland-microbial fuel cell performance: A review

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Review

A critical review of the symbiotic relationship between constructed wetland and microbial fuel cell for enhancing pollutant removal and energy generation

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Concluding remarks

- ✓ Circular economy, ecological cycles and SDGs.
- ✓ Renewable based energy sources and full life cycle analysis must underpin all treatment system design.
- ✓ Decentralized nature based system such as constructed wetlands are more sustainable.
- ✓ Wastewater treatment systems can be designed for carbon neutrality.
- ✓ Wastewater is a resource: water, energy and nutrients can all can be recovered by sustainable engineering practices.

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