Nexus Science Event,
University of Southampton
29th November, 2017

The water-energy-climate cycle: from vicious to virtuous?

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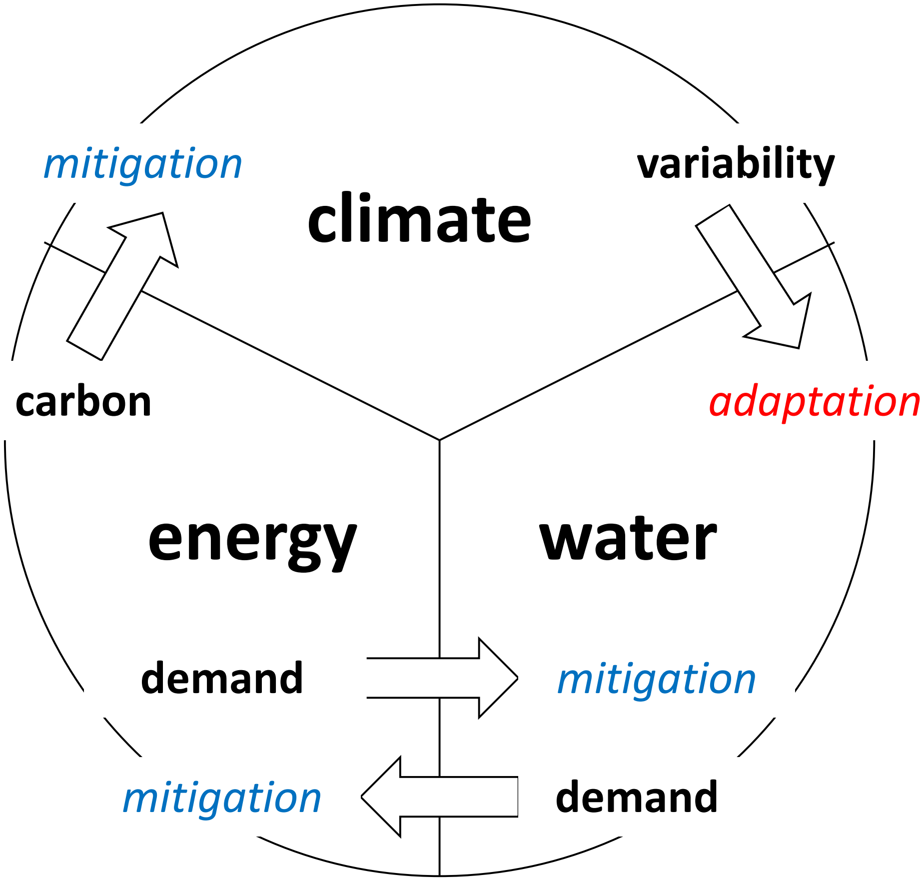
Outline

- **The water-energy-climate cycle**
- **Vicious interactions**
  - Water implications of energy generation
  - Energy/carbon implications of water services
- **Virtuous interventions**
  - Urban systems - energy (& water) saving
  - Appliances, buildings & city-scale systems
- **Conclusions**

Energy-water-climate cycle



mitigation

climate

variability

carbon

adaptation

energy

water

demand

mitigation

mitigation

demand

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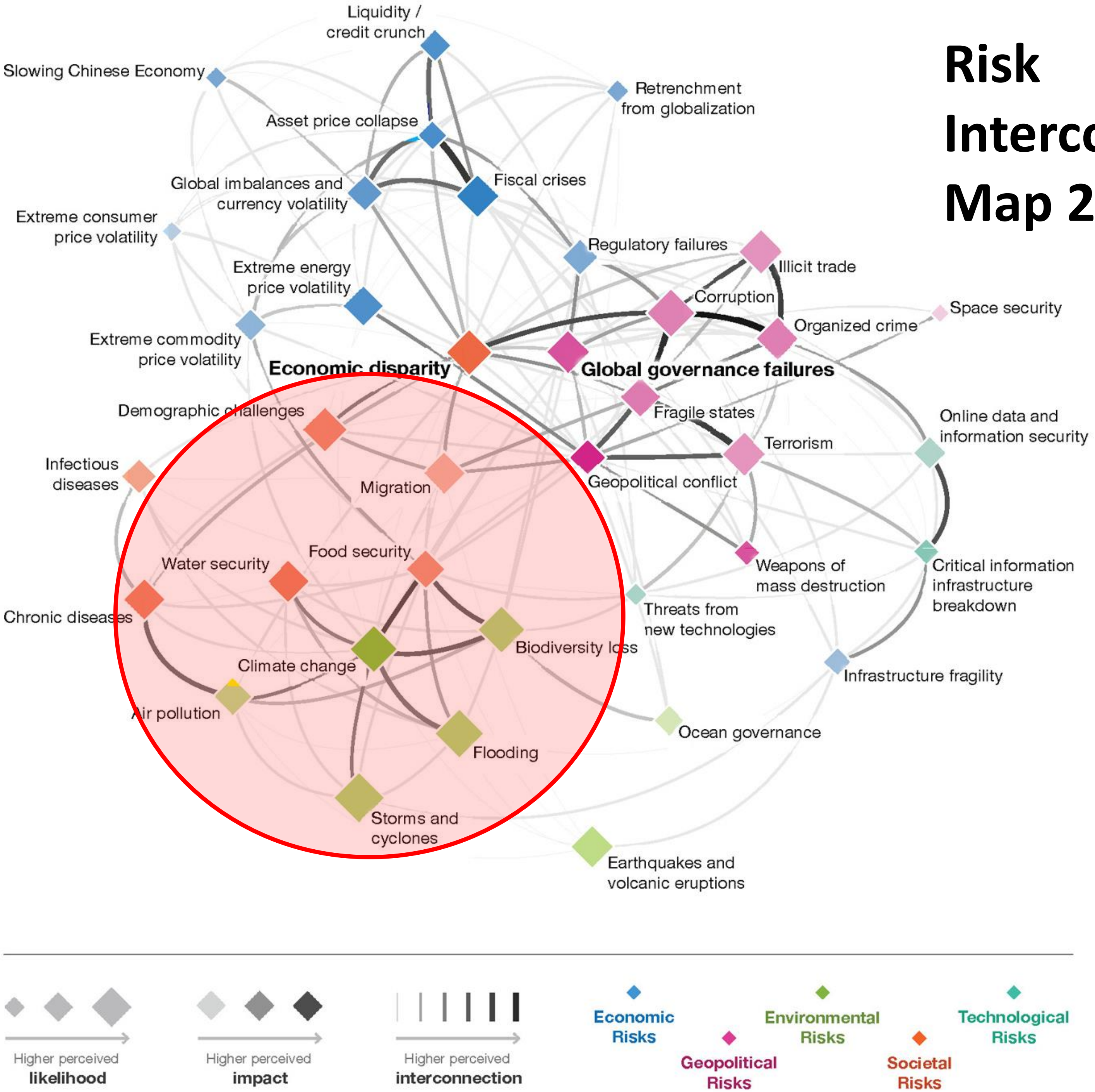
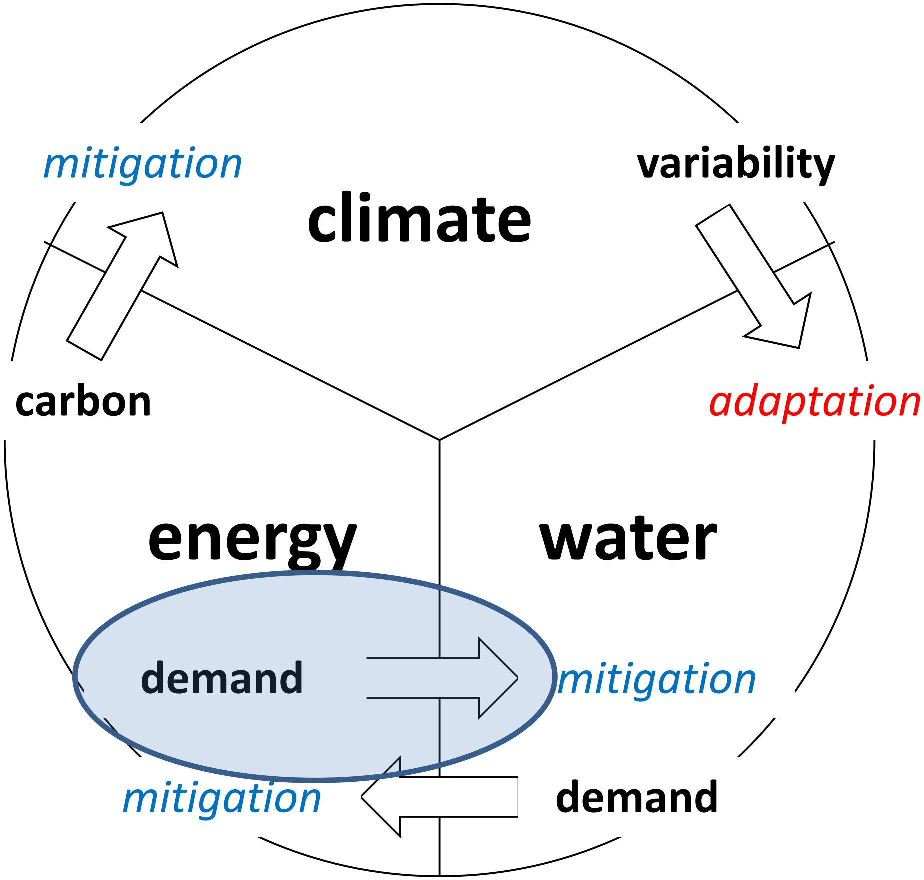
Risk Interconnection Map 2011



WEF (2011)

VICIOUS INTERACTIONS: Water implications of energy generation



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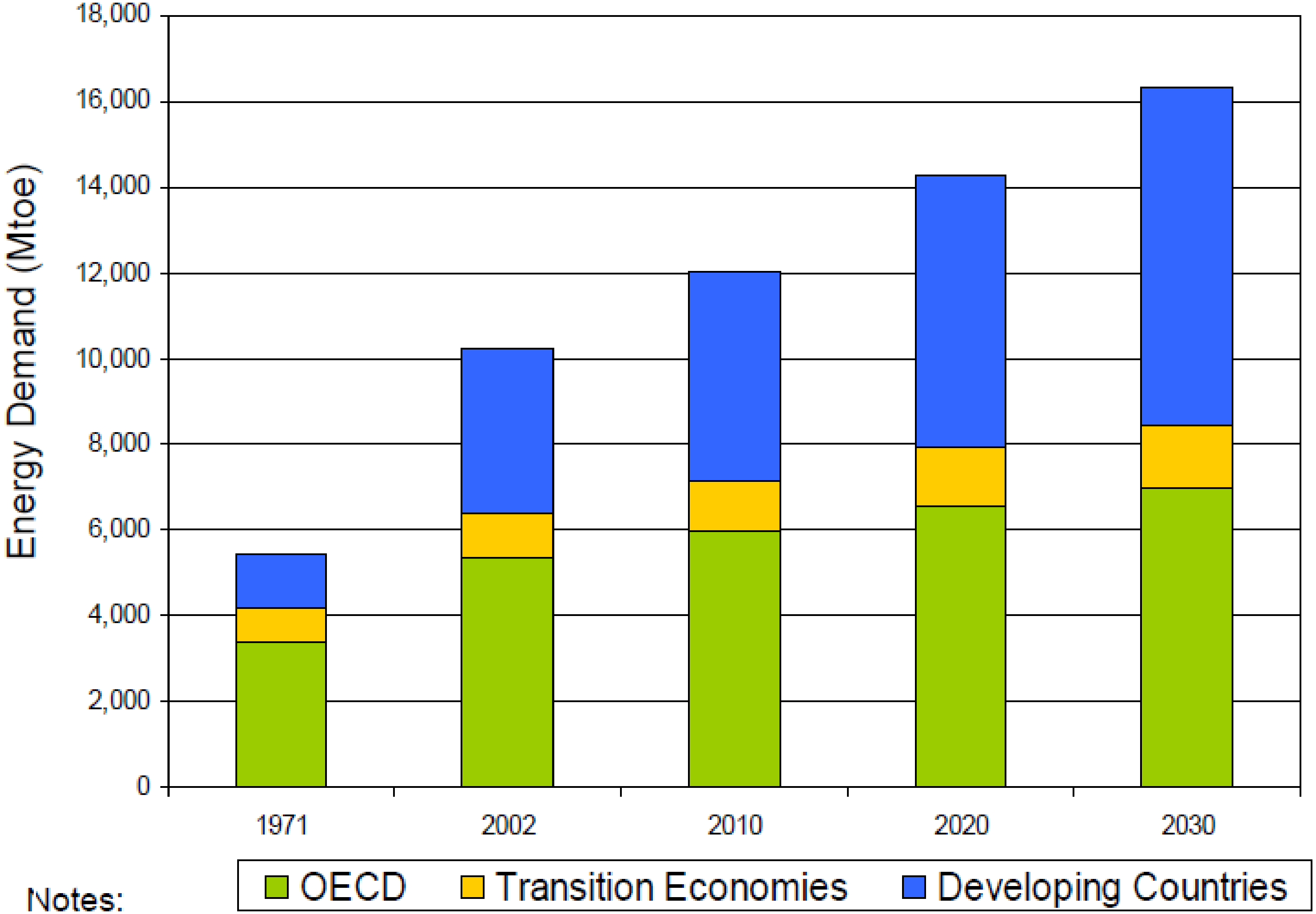
Growth in energy demand

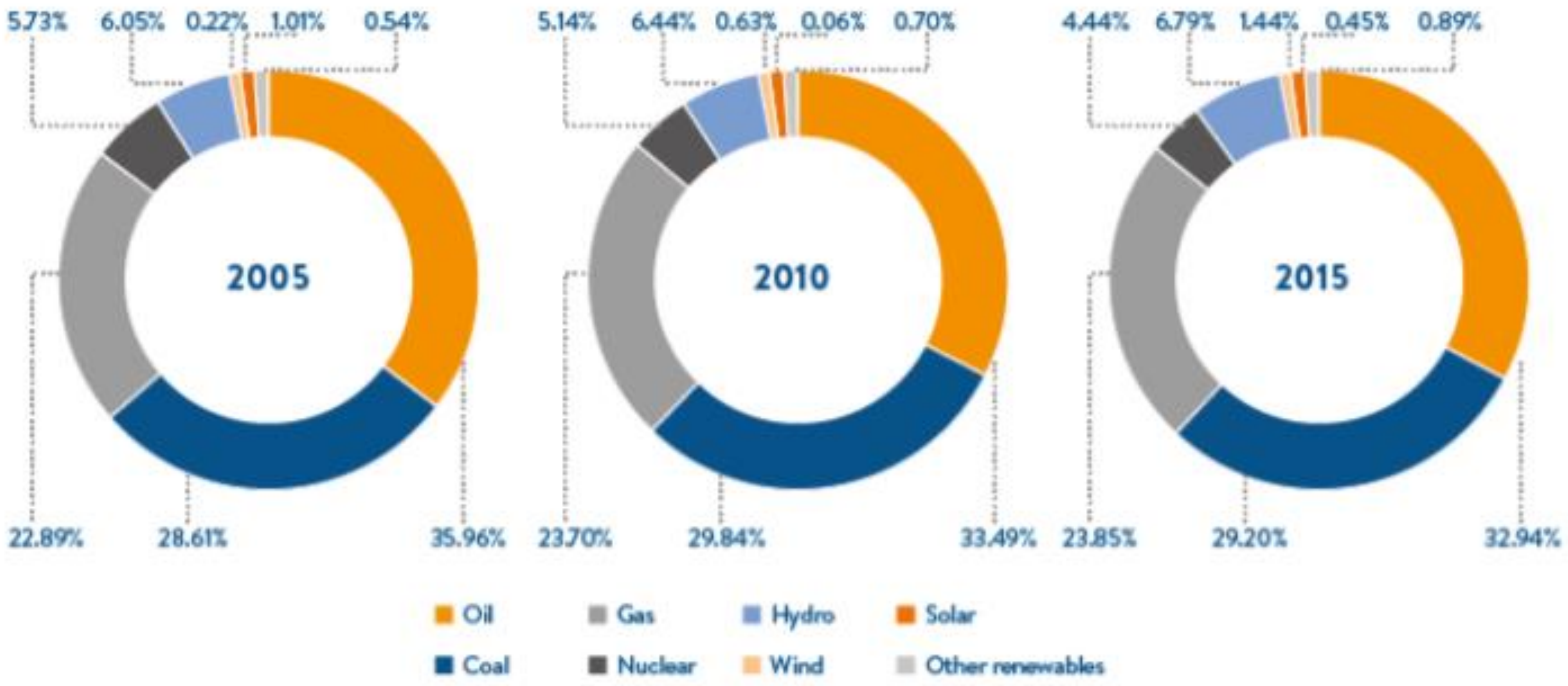


Notes:

1. OECD refers to North America, W. Europe, Japan, Korea, Australia and NZ
2. Transition Economies refers to FSU and Eastern European nations
3. Developing Countries is all other nations including China, India etc.

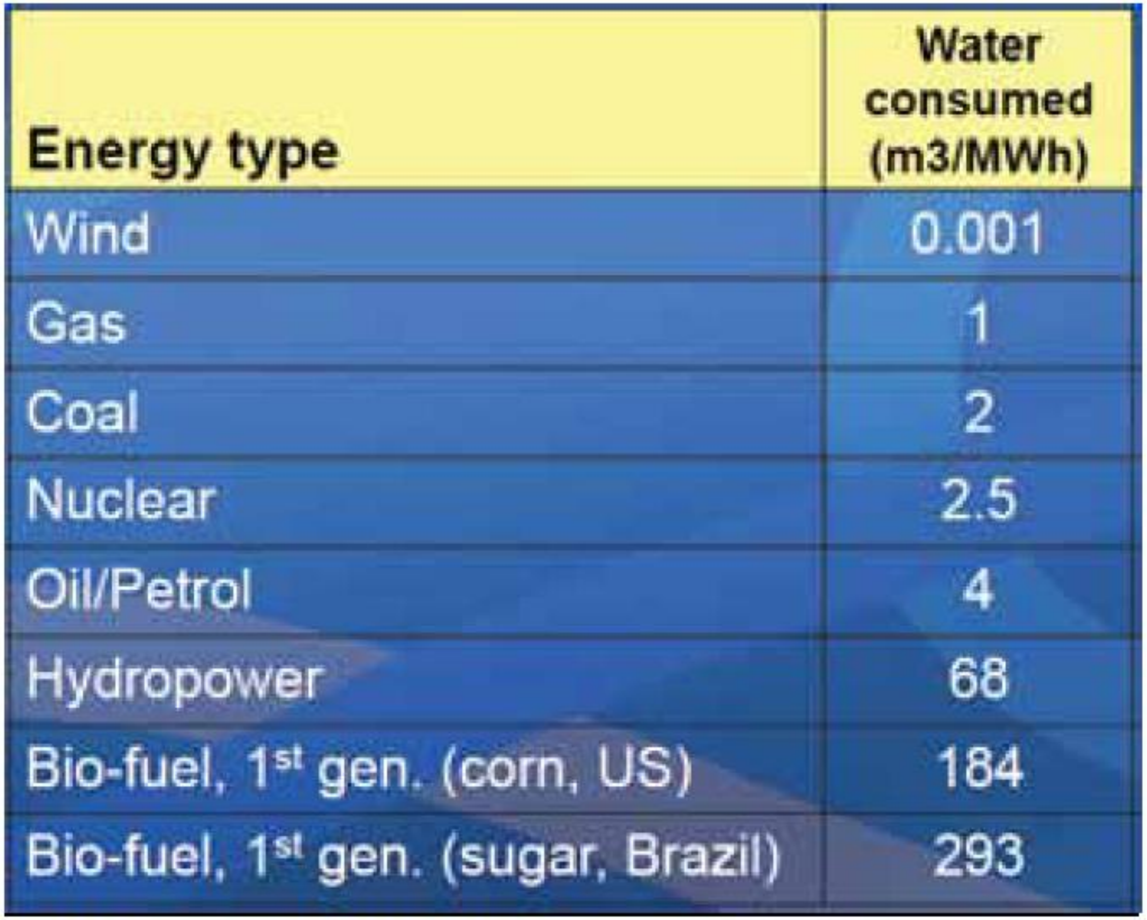
Source: IEA World Energy Outlook 2004

Global electricity generation by resource



Source: World Energy Council (2016)

Water consumption to generate power from different technologies

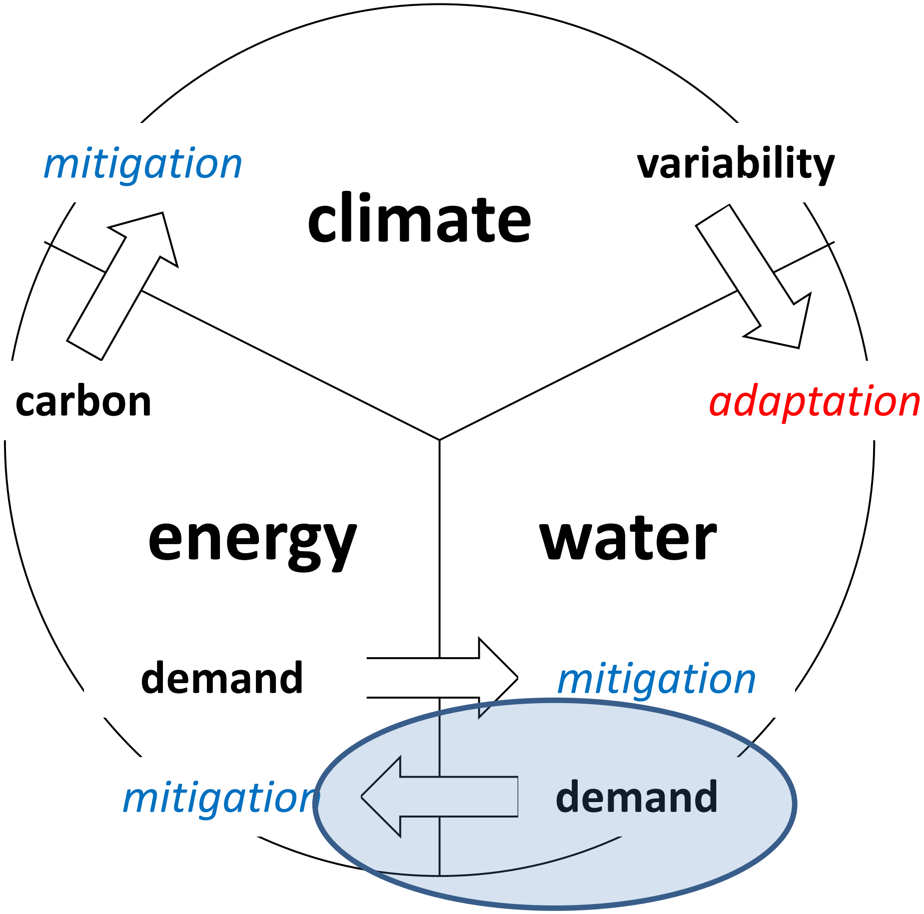


Energy type	Water consumed (m3/MWh)
Wind	0.001
Gas	1
Coal	2
Nuclear	2.5
Oil/Petrol	4
Hydropower	68
Bio-fuel, 1st gen. (corn, US)	184
Bio-fuel, 1st gen. (sugar, Brazil)	293

PV = 0.1

Sources: Henrik Larsen, DHI Water Policy, 2008

VICIOUS INTERACTIONS: Energy implications of water services



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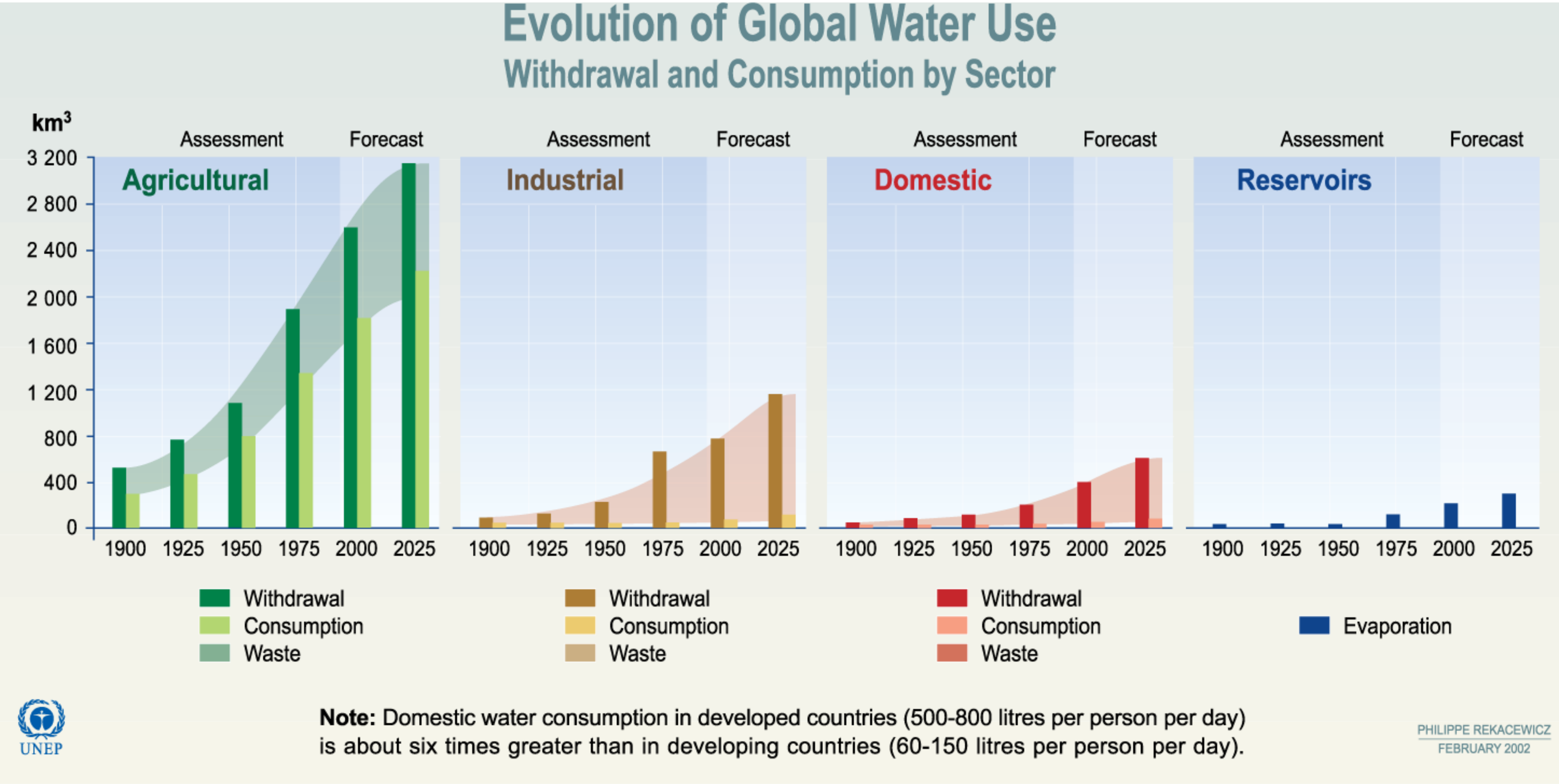
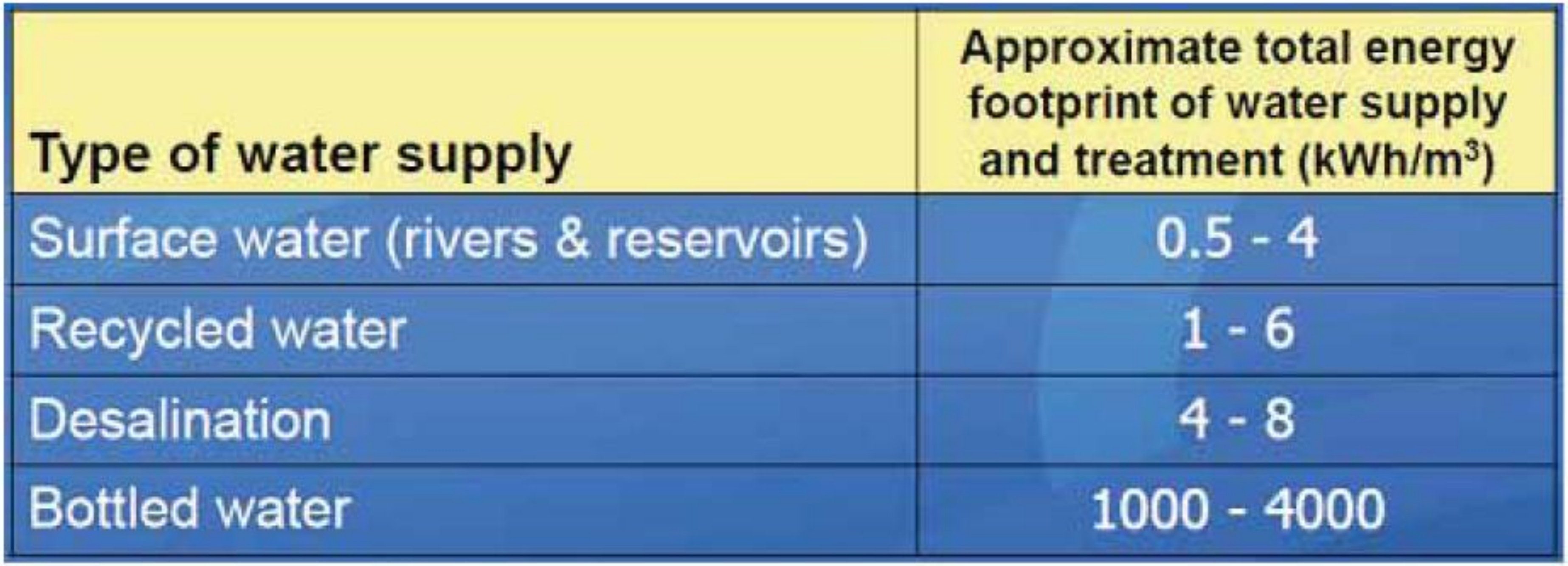
Growth in water demand



Note: Domestic water consumption in developed countries (500-800 litres per person per day) is about six times greater than in developing countries (60-150 litres per person per day).

Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

Energy consumption in water production

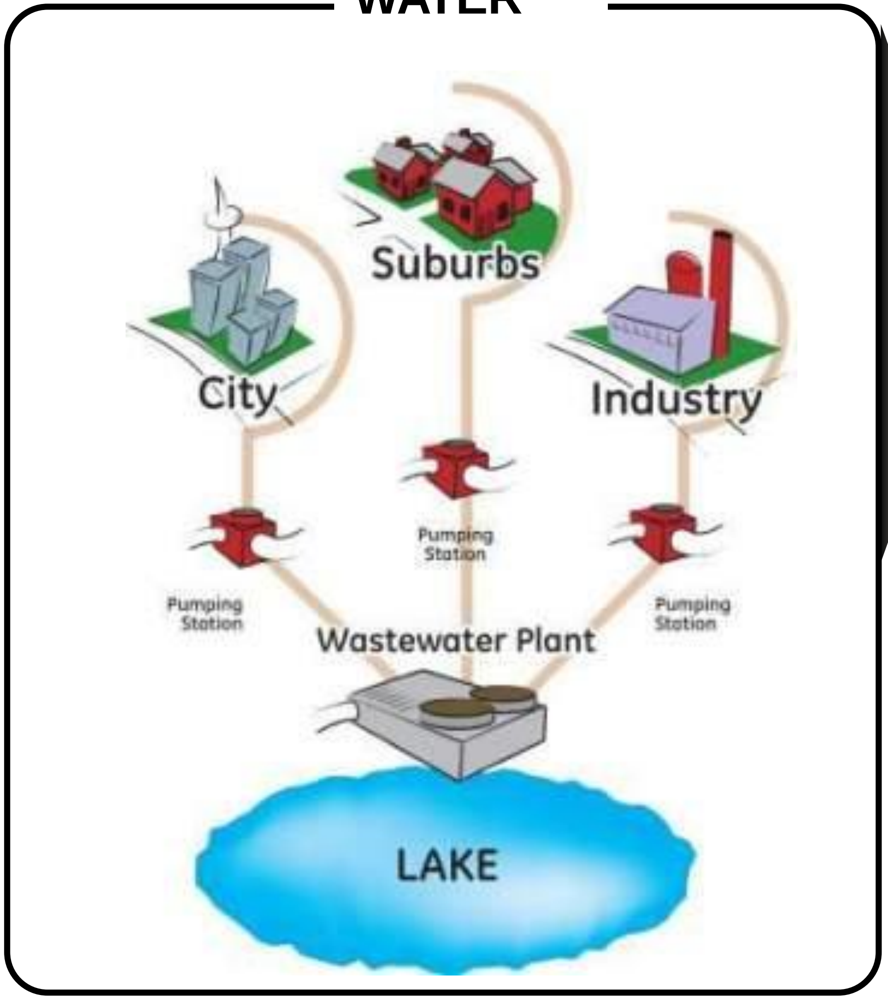


Type of water supply	Approximate total energy footprint of water supply and treatment (kWh/m^3)
Surface water (rivers & reservoirs)	0.5 - 4
Recycled water	1 - 6
Desalination	4 - 8
Bottled water	1000 - 4000

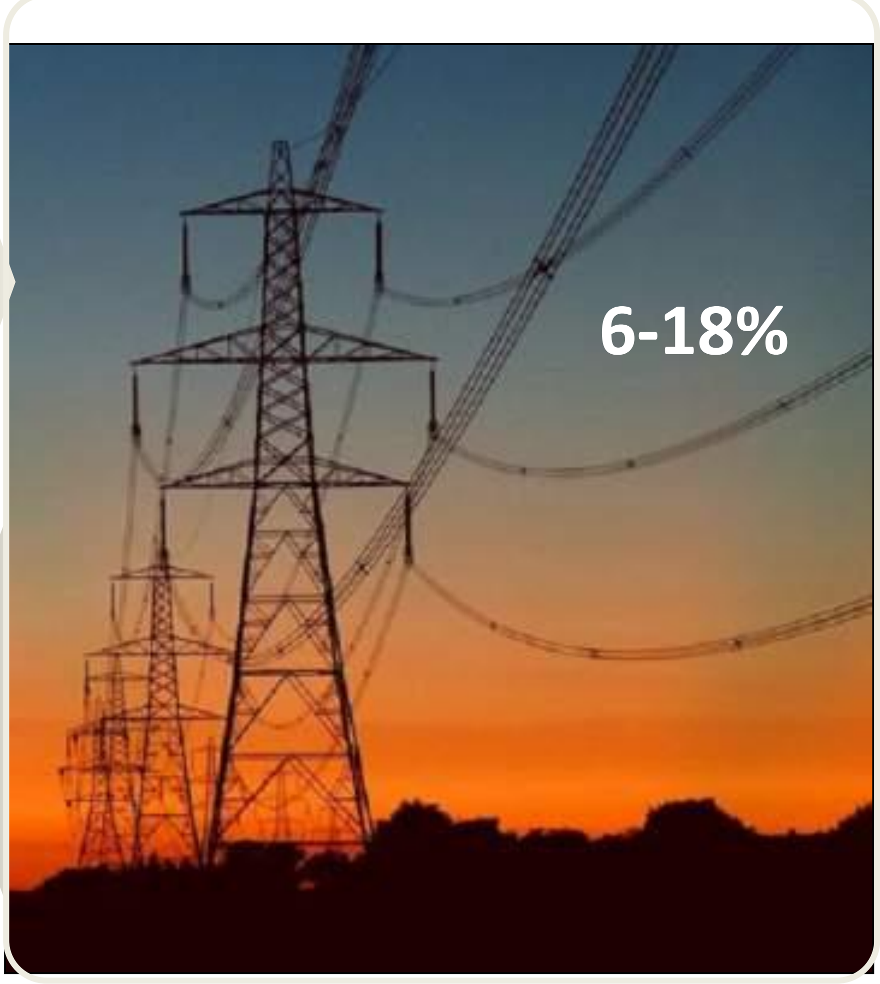
Sources: Henrik Larsen, DHI Water Policy, 2008

City energy demand for water services

WATER



ENERGY



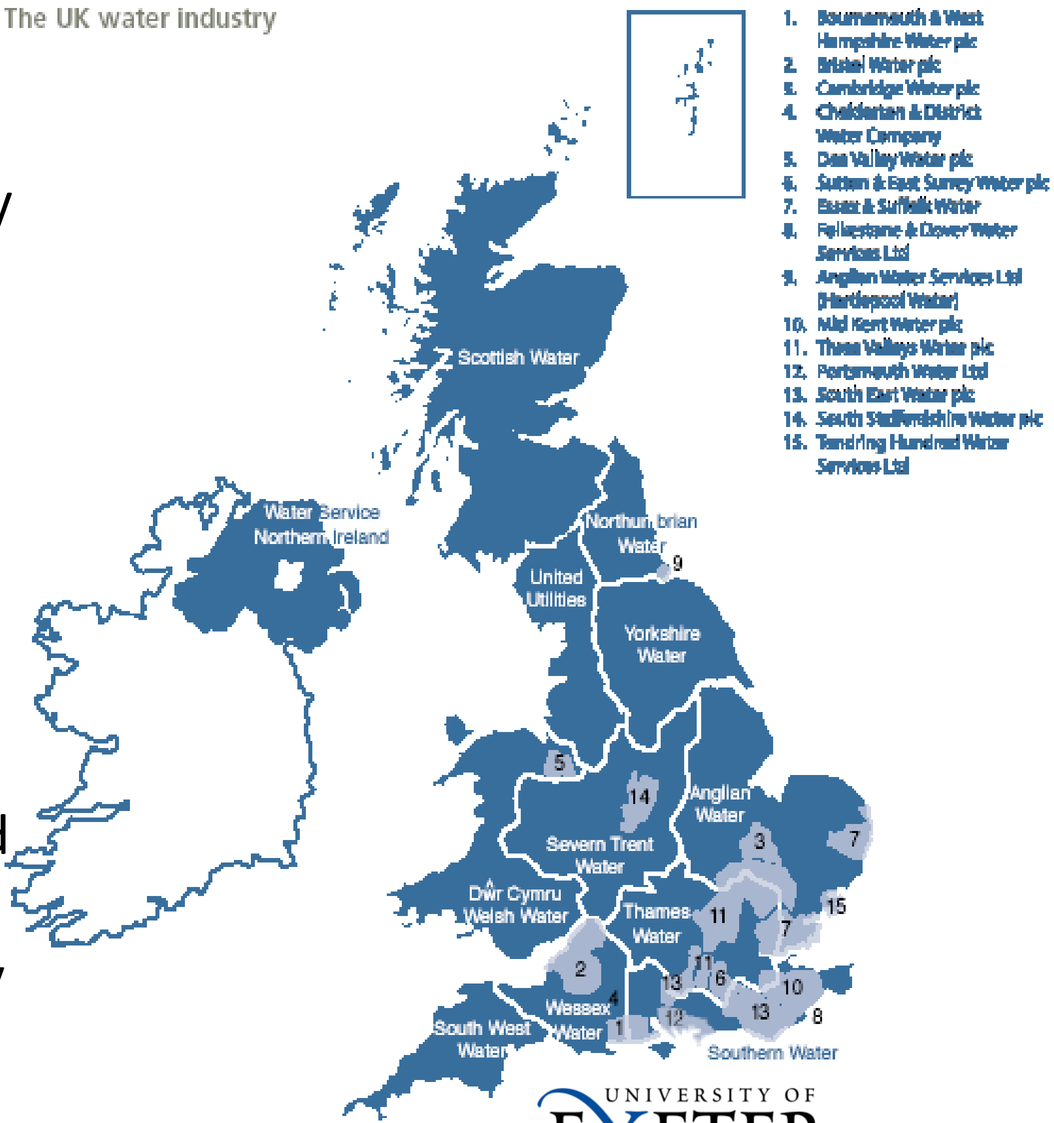
6-18%

Source: General Electric

Energy consumption for UK water services

- **UK** water industry consumes over **8000 GWh** energy annually to produce potable **water and treat wastewater**
- This translates to **over 5 million tonnes of CO_2** equivalent emissions . Of these
  - **56 %** of these emissions derive from wastewater,
  - **39 %** from water supply and
  - **5 %** from administration/transport by the water industry

The UK water industry



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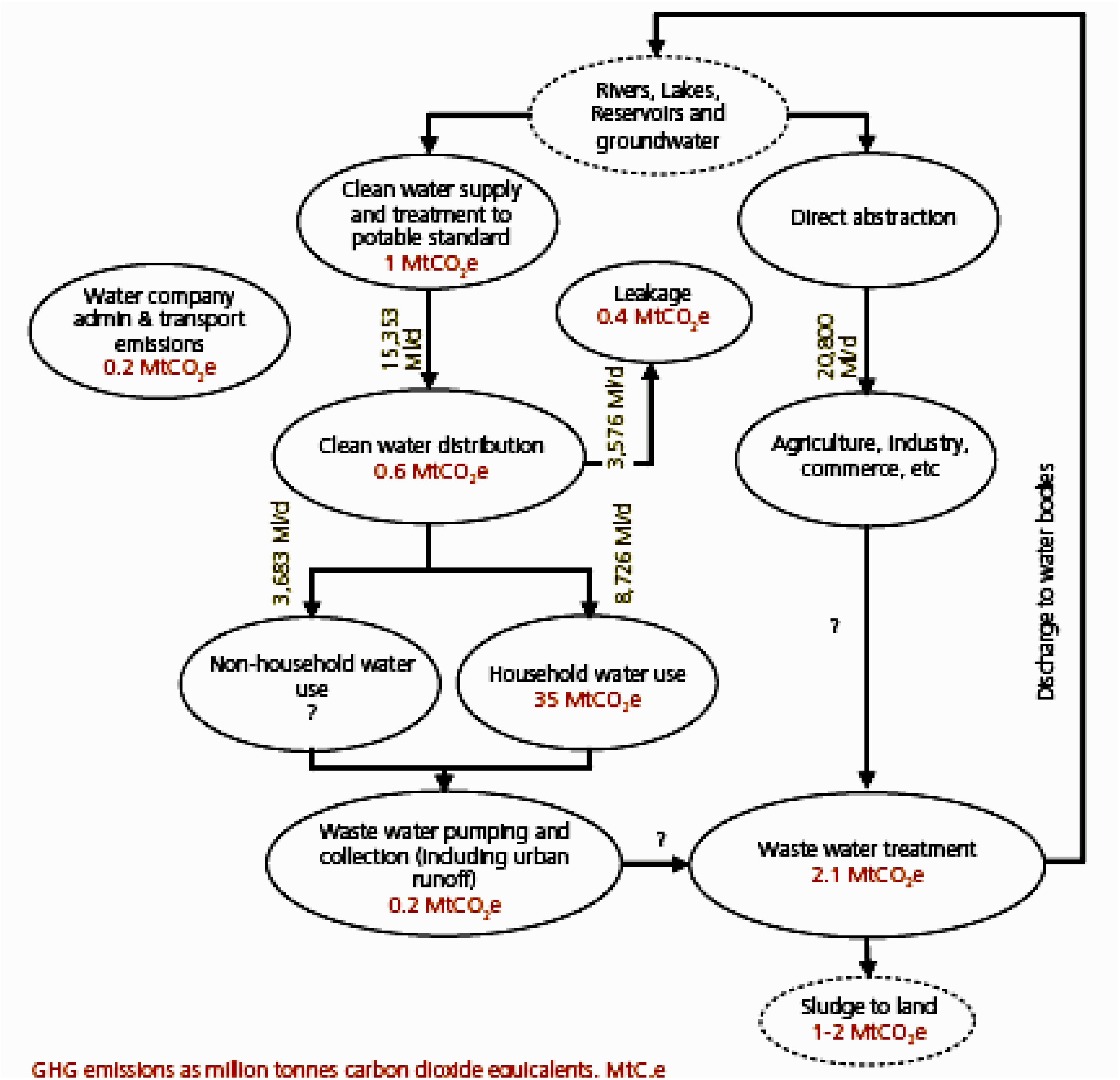
Energy and associated Carbon footprint of water sector in the UK



Rivers, Lakes, Reservoirs and groundwater

Clean water supply and treatment to potable standard
1 MtCO$_2$e

Direct abstraction

Water company admin & transport emissions
0.2 MtCO$_2$e

Leakage
0.4 MtCO$_2$e

15,353 Ml/d

20,800 Ml/d

3,576 Ml/d

Clean water distribution
0.6 MtCO$_2$e

Agriculture, Industry, commerce, etc

3,683 Ml/d

8,726 Ml/d

?

Discharge to water bodies

Non-household water use
?

Household water use
35 MtCO$_2$e

Waste water pumping and collection (including urban runoff)
0.2 MtCO$_2$e

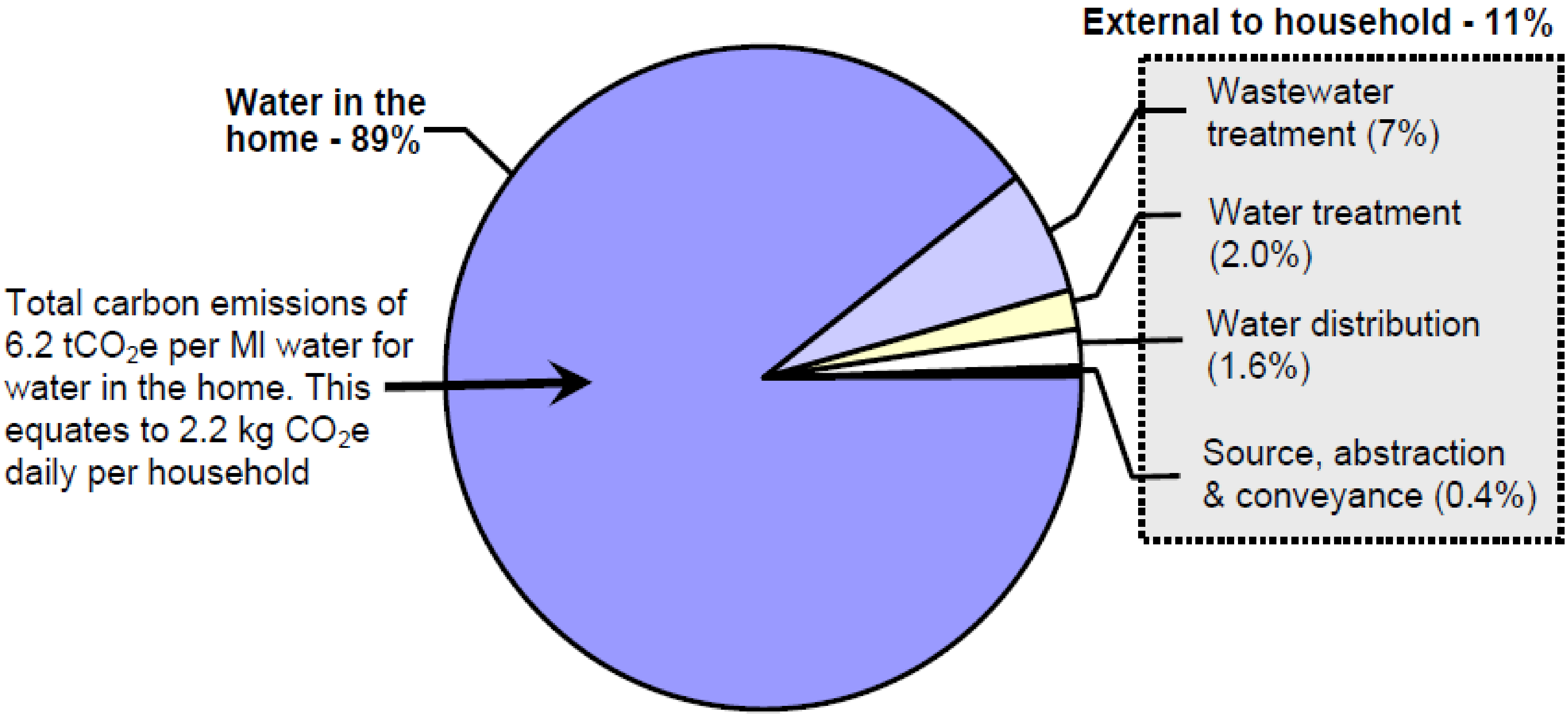
?

Waste water treatment
2.1 MtCO$_2$e

Sludge to land
1-2 MtCO$_2$e

GHG emissions as million tonnes carbon dioxide equivalents. MtC$_2$e

UK average CO_2e emissions for water service and usage in the home



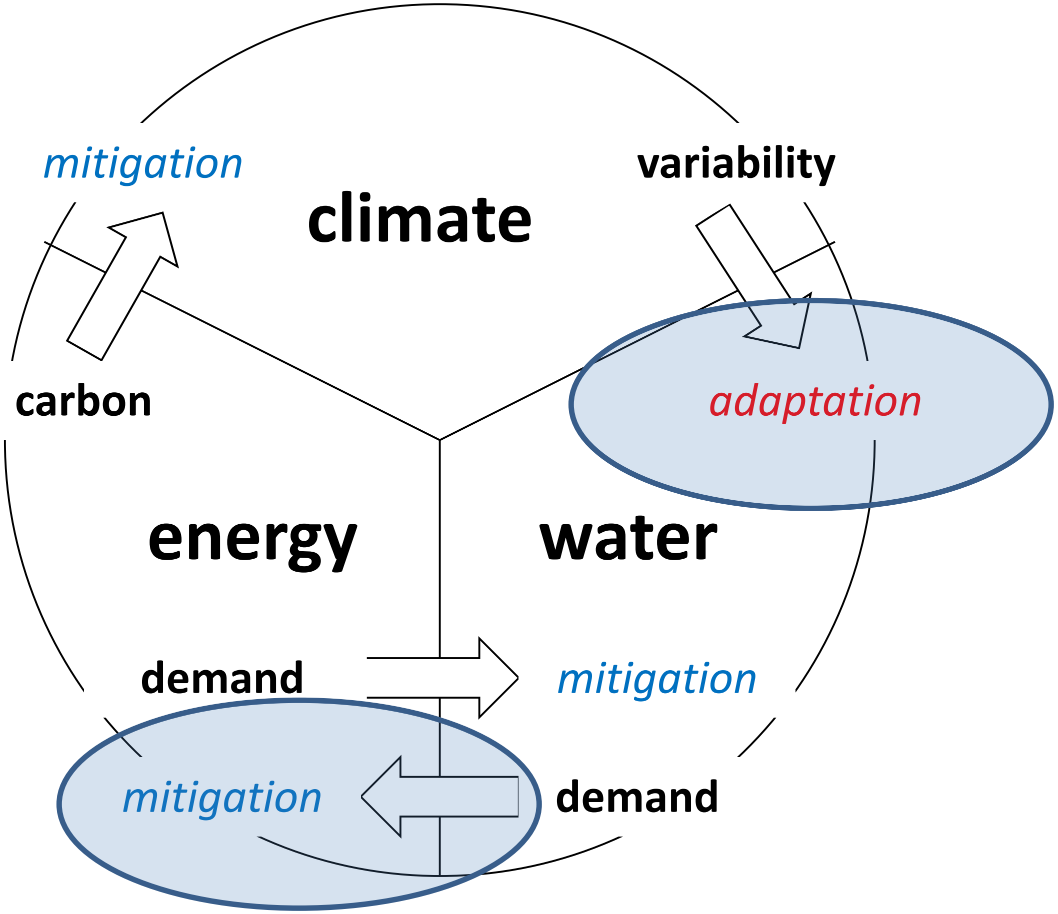
Total carbon emissions of 6.2 tCO_2e per Ml water for water in the home. This equates to 2.2 kg CO_2e daily per household

EA (2008)

What should we prioritise?

- In the UK, we use **8 TWh** electrical energy for water services
- Saving 30% equates to **2.4 TWh** savings
- Water related energy use at home by customers is at least **60 TWh**
- So users saving just **5%** will have the same overall impact!

VIRTUOUS INTERVENTIONS: Appliances



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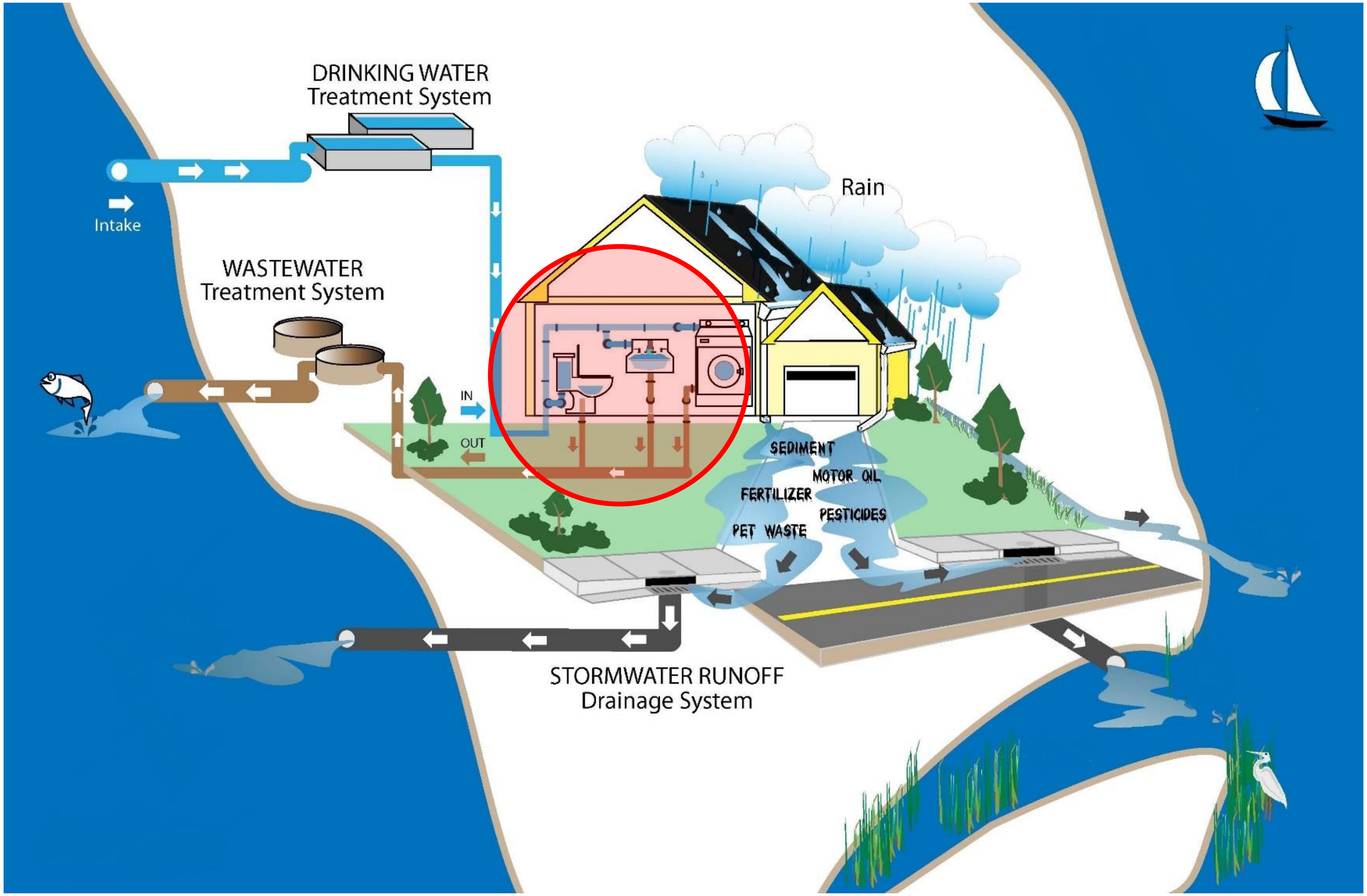
Household appliances



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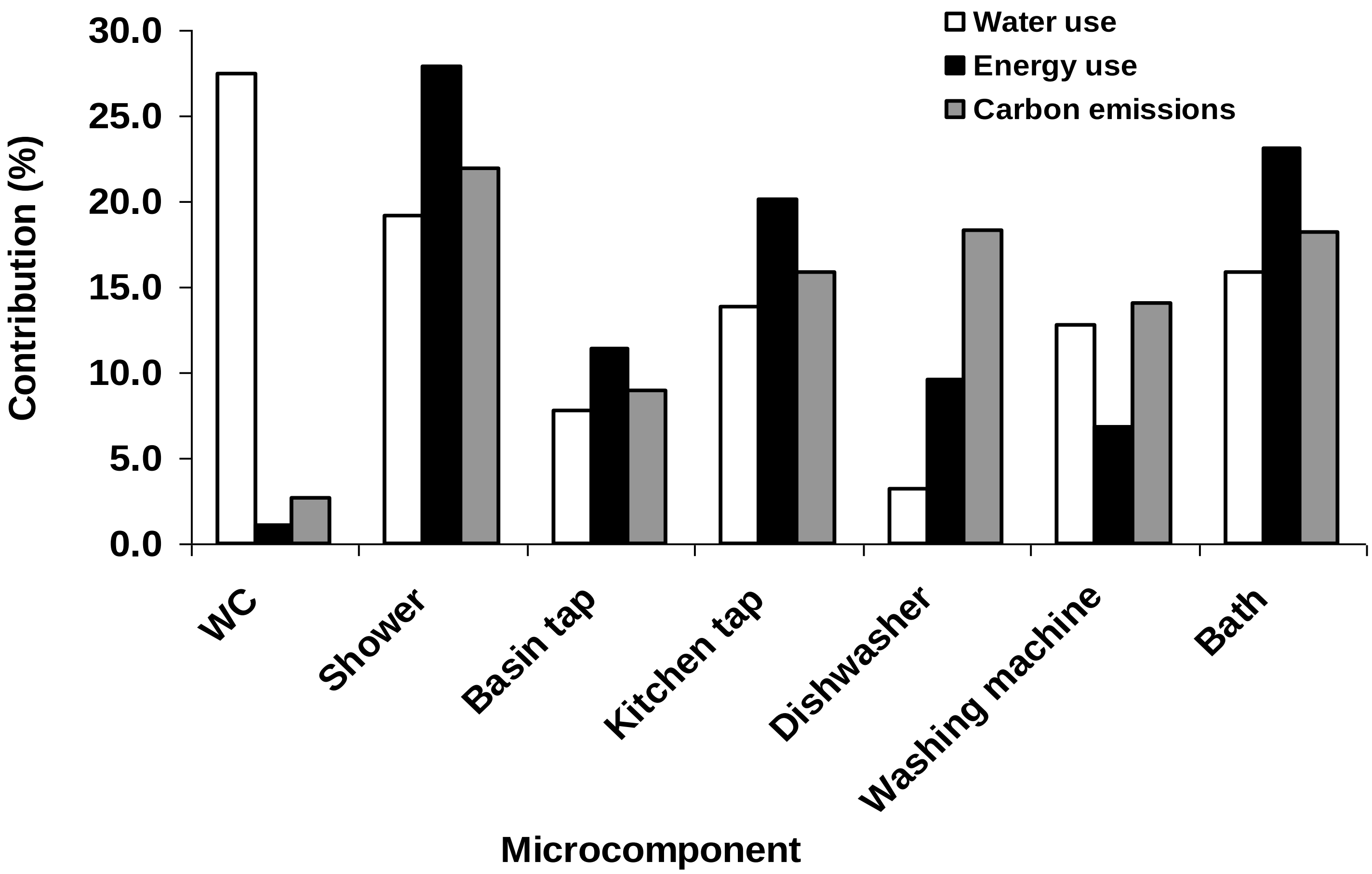
Micro-component based contributions to energy, water and CO_2e emissions



FIDAR, A., MEMON, F.A. & BUTLER, D. (2010). Environmental implications of water efficient microcomponents in residential buildings, *Science of the Total Environment*, 408 (23), 5828 – 583.

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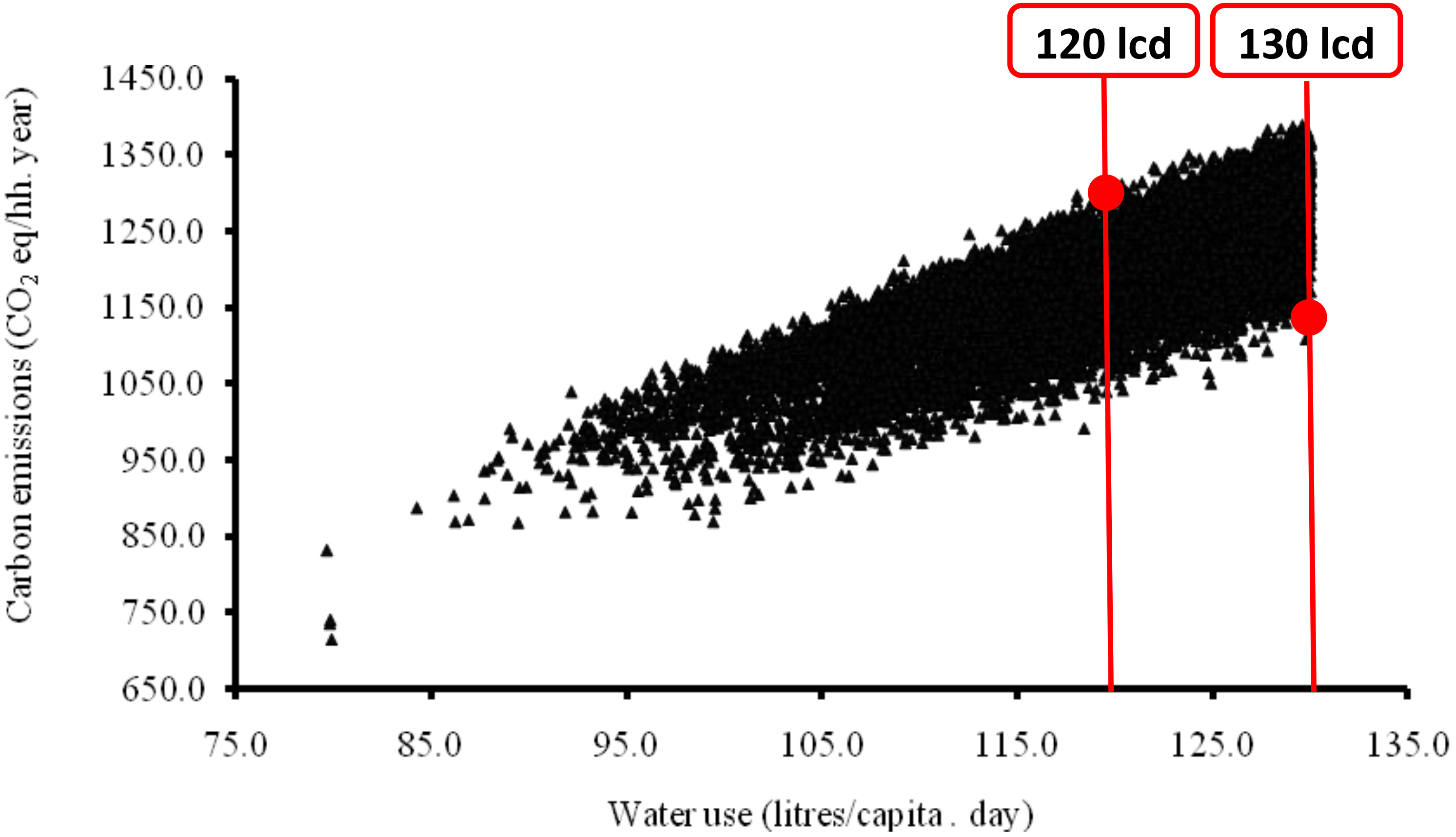
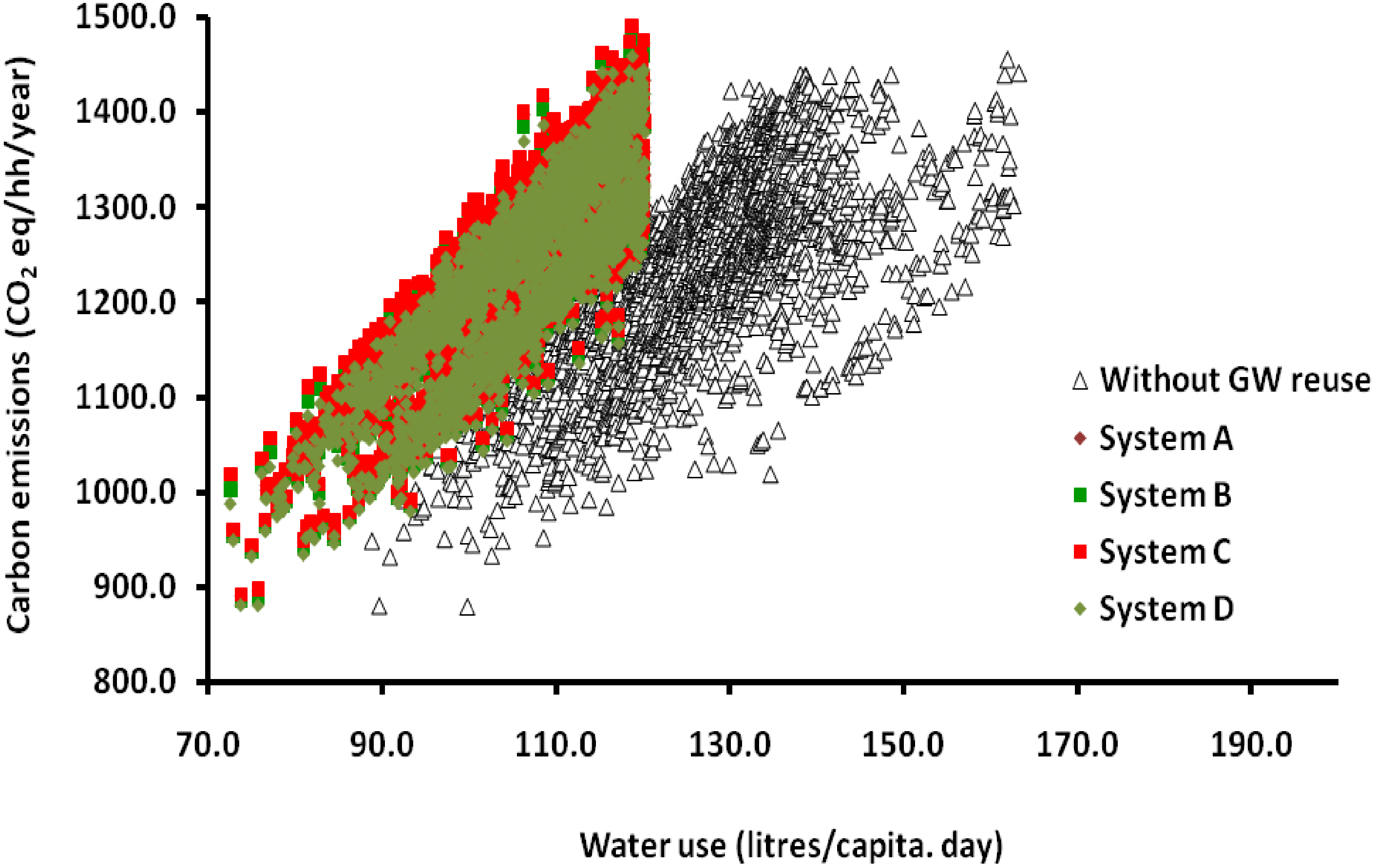
Water use & CO_2e emissions of household micro-components



FIDAR, A., MEMON, F.A. & BUTLER, D. (2010). Environmental implications of water efficient microcomponents in residential buildings, *Science of the Total Environment,* 408 (23), 5828 – 583.

Water use & CO_2e emissions including greywater reuse



MEMON, F.A., FIDAR, A.F., WARD, S., BUTLER, D. & ALSHARIF, K. (2014). Energy and carbon implications of water saving micro-components and grey water reuse systems. In *Alternative Water Supply Systems* (Eds. Memon, F.A. & Ward, S.), IWA Publishing, 265-285.

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Ultralow flush toilet (ULFT)

A pneumatic flush WC that uses a displaced air principle to operate.

- A sealable lid allows air to force waste from the bowl
- Requires only **1.5 litres** per flush and gives improved flushing and drainage performance.
- Looks and is used in the same way as a conventional WC
- Generates its own air and requires no ancillary equipment
- Is very low maintenance

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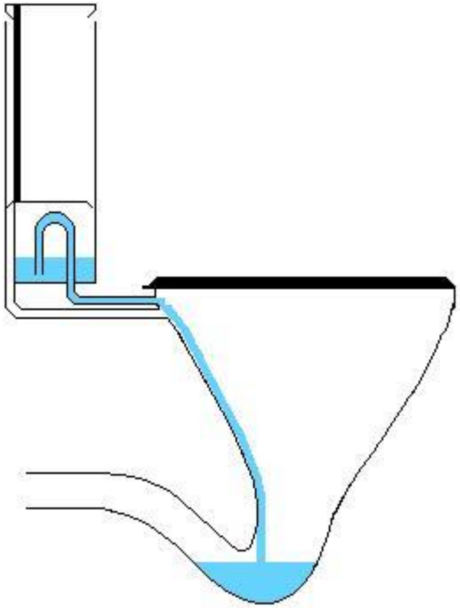
Operation



Test rig experiments

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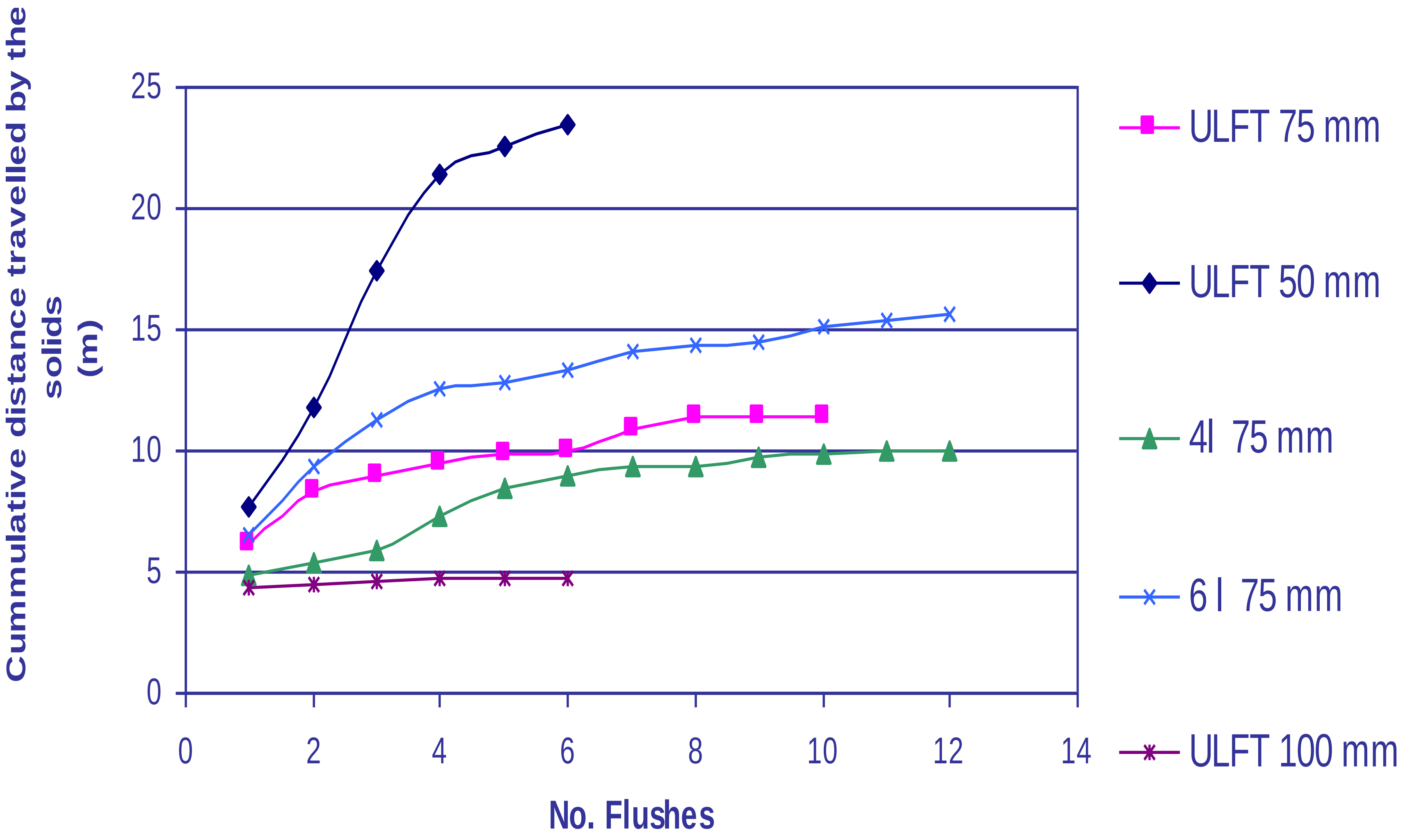
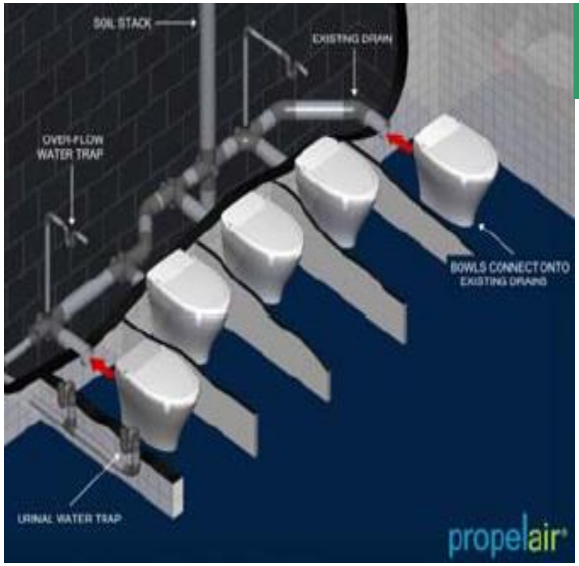
Test rig experiments



LITTLEWOOD, K., MEMON, F.A. & BUTLER, D. (2007). Downstream implications of ultra-low flush WCs. *Water Practice and Technology,* 2, 2, doi10.2166/wpt.2007.037.

In-situ trials

- In situ trials extended over 8 months at WRc
- The purpose was to record water saved and ‘real world performance’
- 2 ULFT tested (1 ladies, 1 in gents)



Results

- No reported blockages even after 5000 flushes
- No impact on the water seal traps of the other connected appliances
- 58% of users thought ULFT was easy to use
- Concern of hygiene of touching lid

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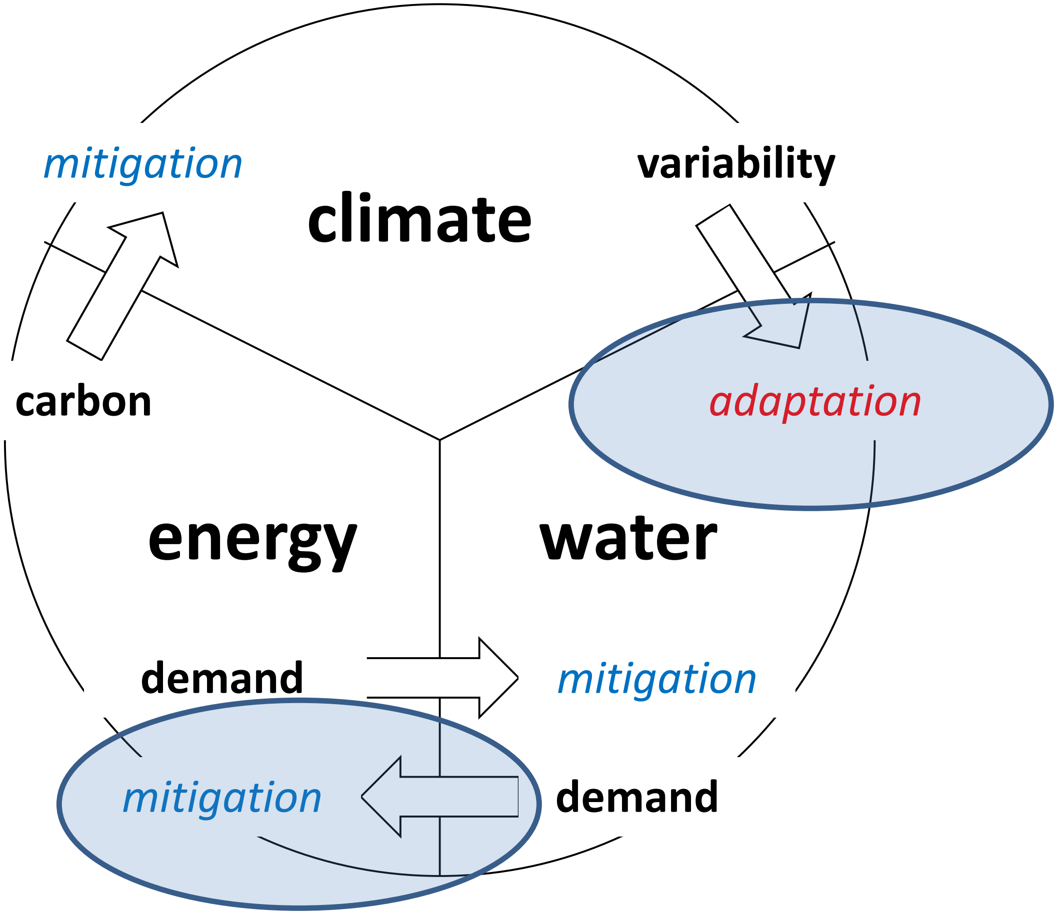
Resource saving potential

- Average volume of WCs at WRc: ~ 9 litres
- Average volume of ULFT: 1.3 litres

- **Water saving: 86%**
- Each ULFT flush (1.3 l) requires 500 J
- Each litre of water delivered requires 3200 J
- **Net energy (and carbon) saving: 84%**
- **Net energy (and carbon) saving: 76% (c.f. 6 l WC)**

VIRTUOUS INTERVENTIONS: Buildings



mitigation

climate

variability

carbon

adaptation

energy

water

demand

mitigation

mitigation

demand

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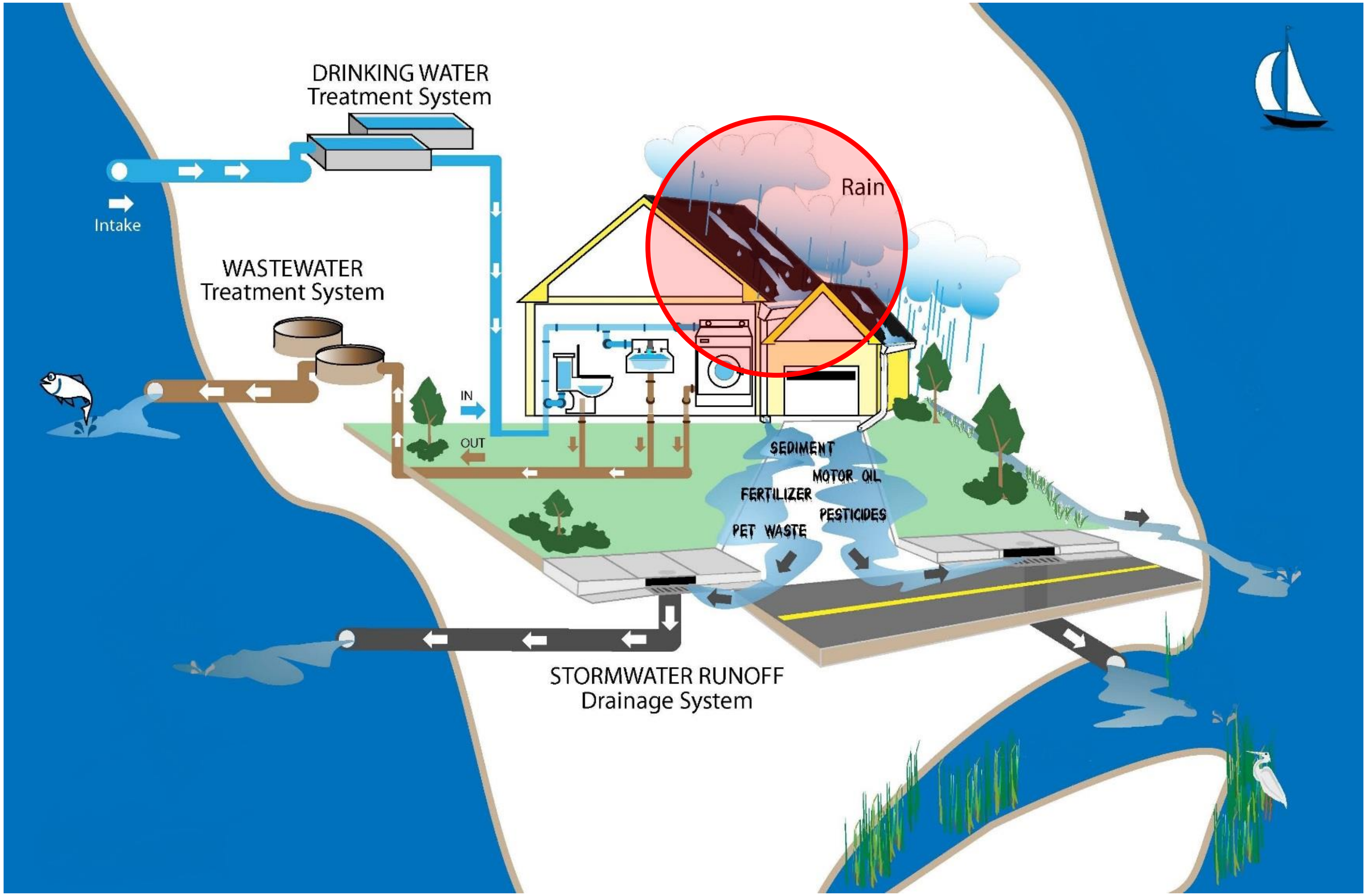
Rainwater harvesting



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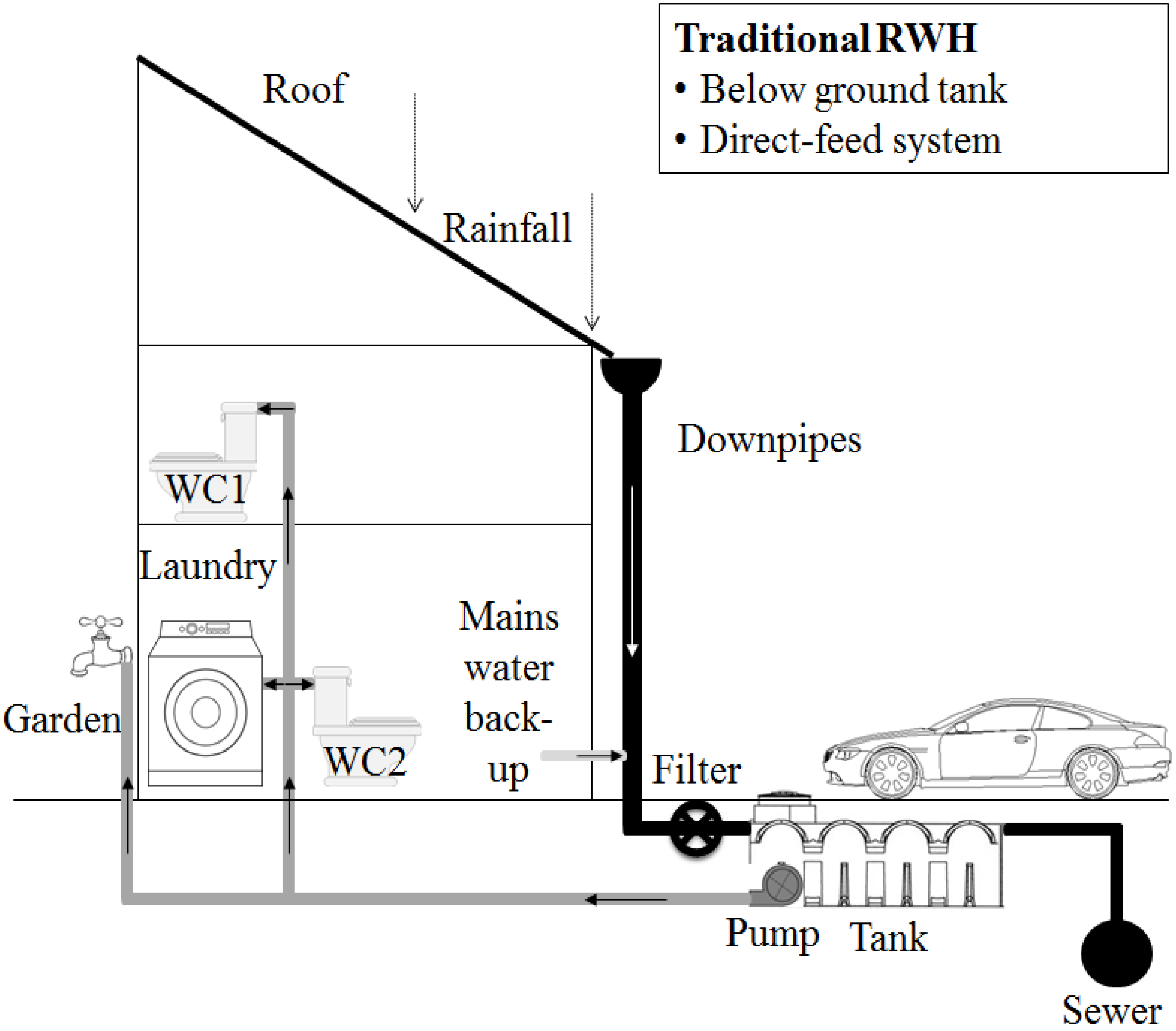
Rainwater harvesting



Traditional RWH
- Below ground tank
- Direct-feed system

MELVILLE-SHREEVE, F., WARD, S., & BUTLER, D. (2016). Rainwater Harvesting Typologies for UK Houses: A Multi Criteria Analysis of System Configurations, *Water*, 8, 129; DOI:10.3390/w8040129.

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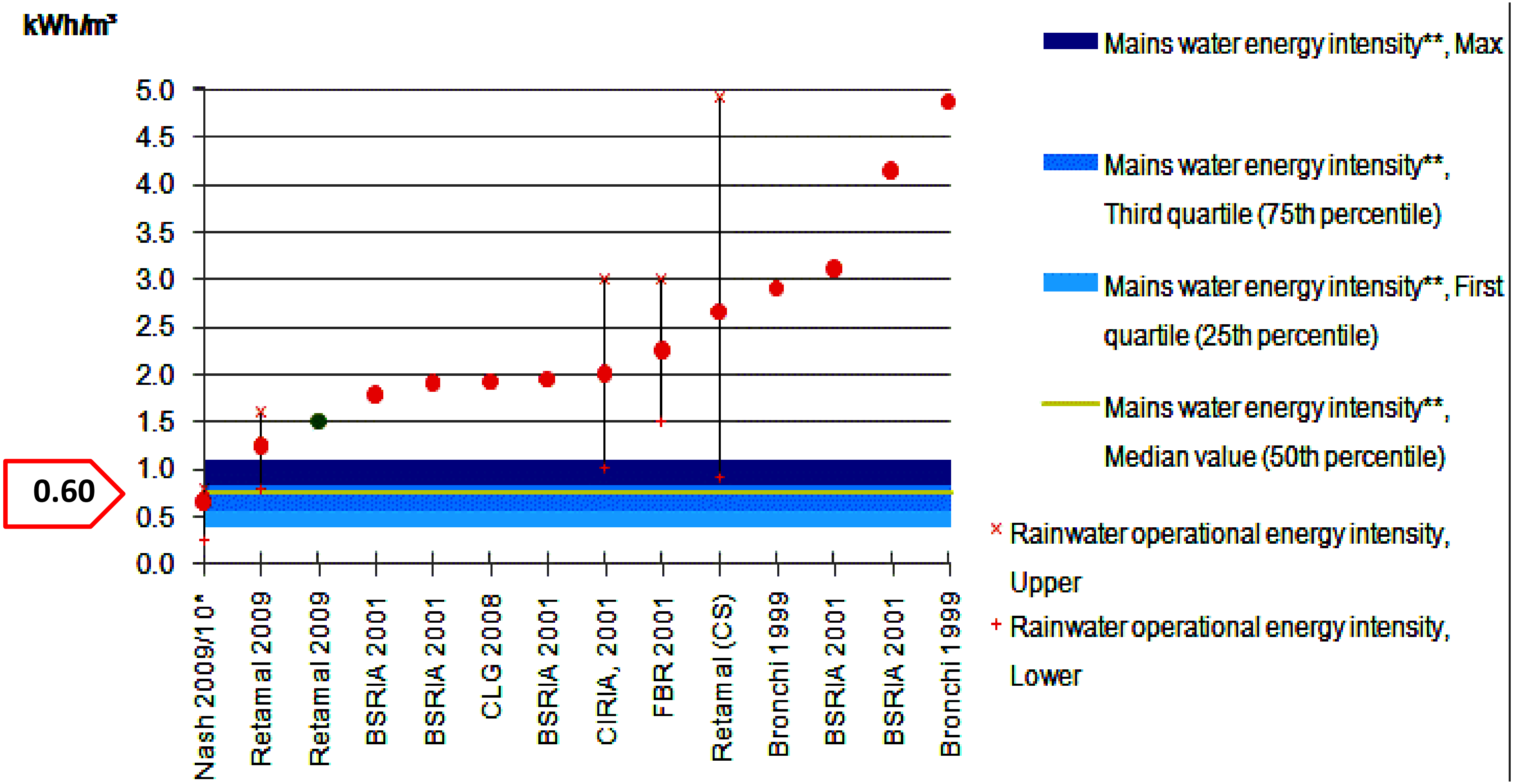
Rainwater harvesting

- **Benefits:**
  - Saves **potable water** (by displacing non-potable water use)
  - Saves **energy/carbon** (at least that associated with the displaced water)
  - Reduces **flood risk** (especially summer storms & can be enhanced by better design)
  - Reduces **load** on regional water resources and central water infrastructure (and potentially delays/limits expansion)

Rainwater harvesting

- **Drawbacks:**
  - Requires **maintenance** (to ensure reliability)
  - Requires **energy/carbon** to *construct* and *operate* (at least most current systems)
  - Has potential **water quality** issues (although these are minimised by careful design/installation)
  - **Payback** period depends on scale of provision (shorter in bigger buildings)
  - **Owners** may be unfamiliar and misuse or remove system

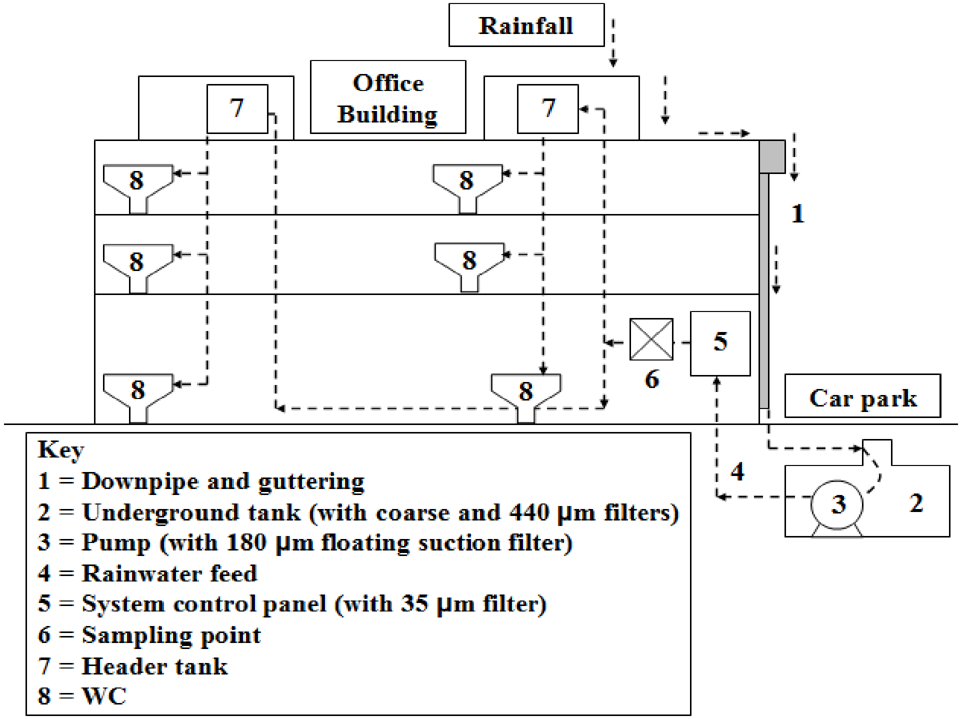
RWH energy consumption



0.60

EA (2010) and Ward S., Butler D. & Memon F.A. (2012), Benchmarking energy consumption and CO2 emissions from rainwater-harvesting systems: an improved method by proxy. *Water and Environment Journal*, 26: 184 –190, and

RWH energy use – office building



Key
1 = Downpipe and guttering
2 = Underground tank (with coarse and 440 μm filters)
3 = Pump (with 180 μm floating suction filter)
4 = Rainwater feed
5 = System control panel (with 35 μm filter)
6 = Sampling point
7 = Header tank
8 = WC

WARD, S., MEMON, F.A. & BUTLER, D. (2012). Operational energy consumption and carbon dioxide emissions from rainwater harvesting systems. Chapter 19 in *Water-Energy Interactions in Water Reuse* (Eds. V. Lazaravo, K-H Choo, P. Cornel), IWA Publishing

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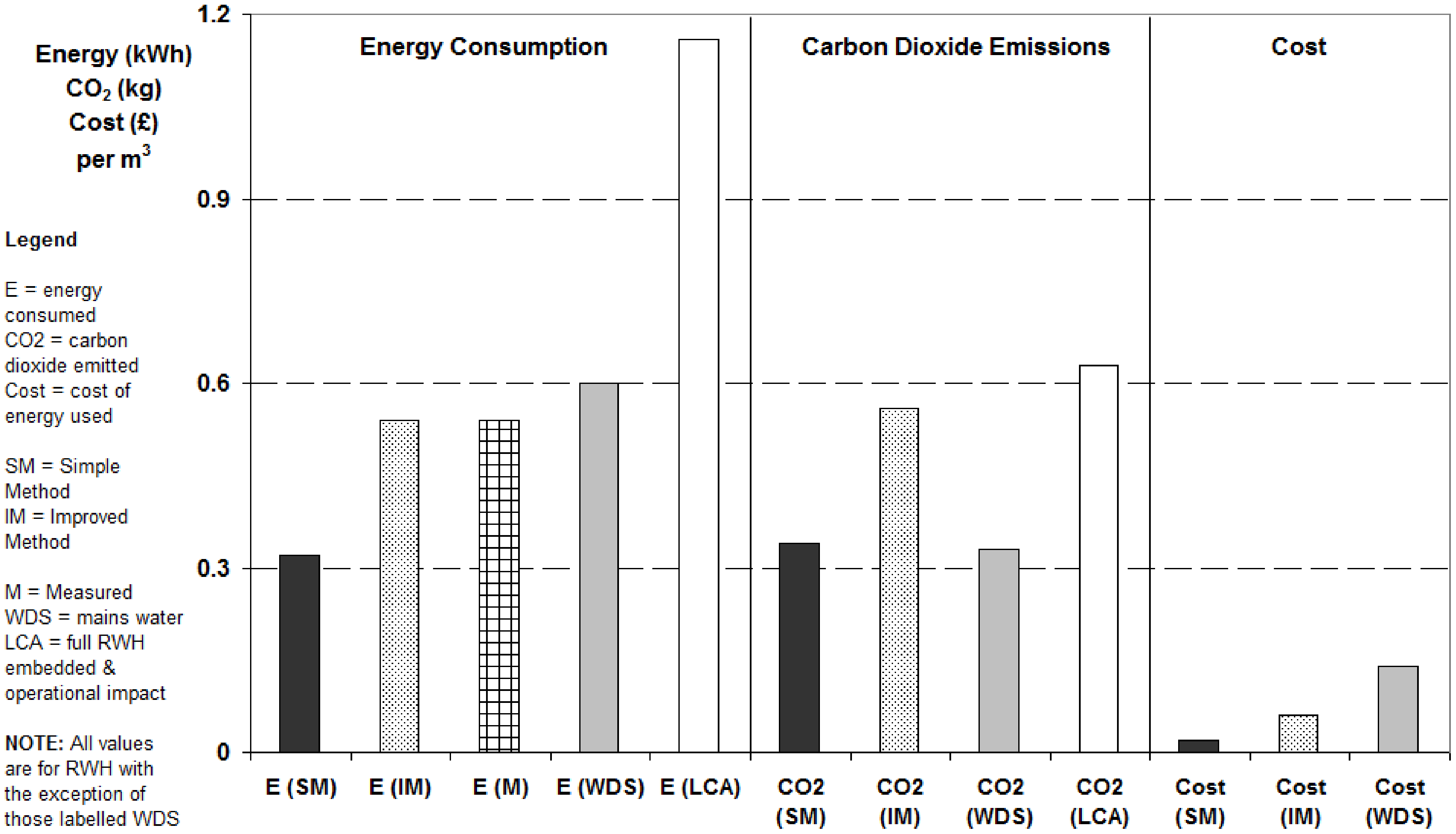
RWH energy use – office building



Legend

E = energy consumed
CO2 = carbon dioxide emitted
Cost = cost of energy used

SM = Simple Method
IM = Improved Method

M = Measured
WDS = mains water
LCA = full RWH embedded & operational impact

NOTE: All values are for RWH with the exception of those labelled WDS

WARD, S., MEMON, F.A. & BUTLER, D. (2012). Operational energy consumption and carbon dioxide emissions from rainwater harvesting systems. Chapter 19 in *Water-Energy Interactions in Water Reuse* (Eds. V. Lazaravo, K-H Choo, P. Cornel), IWA Publishing

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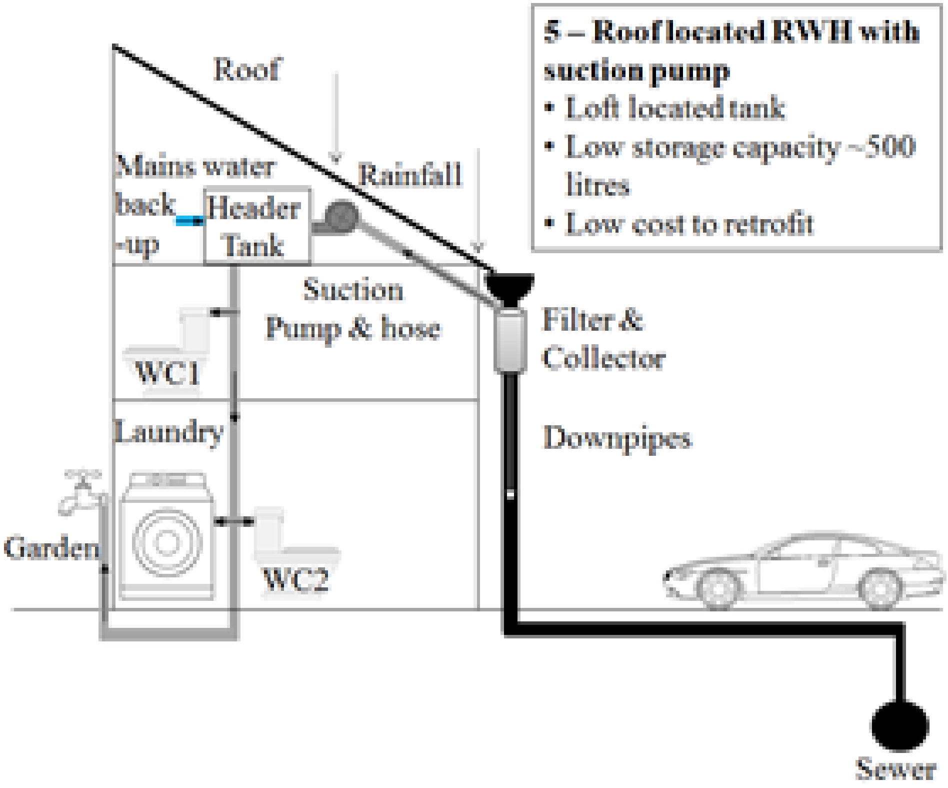
Low energy RWH

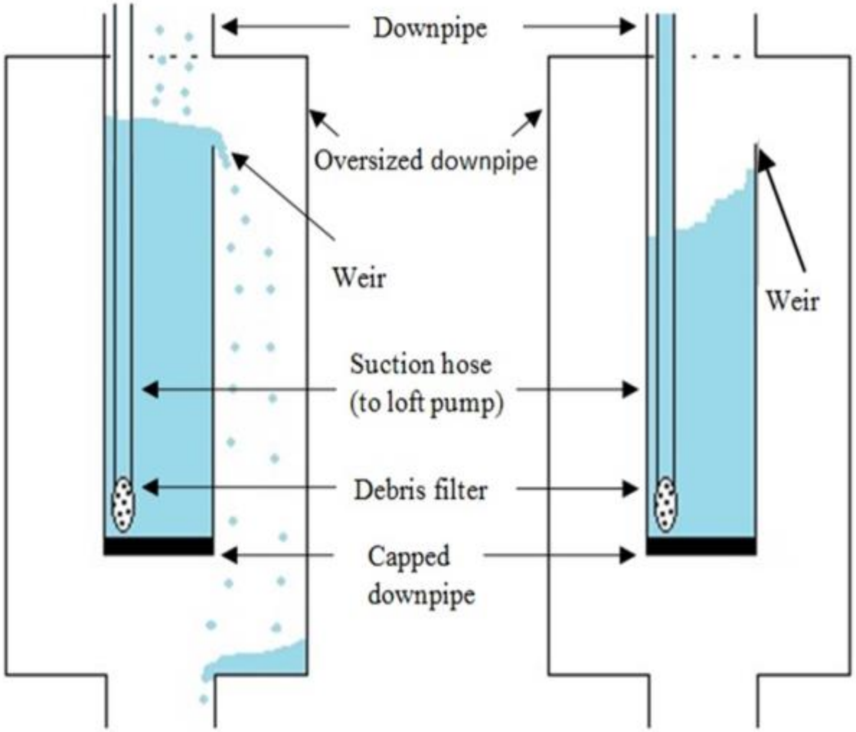


5 – Roof located RWH with suction pump
- Loft located tank
- Low storage capacity ~500 litres
- Low cost to retrofit

MELVILLE-SHREEVE, F., HORSTMAN, C., WARD, S., MEMON, F.A., & BUTLER, D. (2016). A Laboratory Study into a Novel, Retrofittable Rainwater Harvesting System. British Journal of Environment and Climate Change, 6(2): 128-137, DOI: 10.9734/BJECC/2016/23724..

Low energy RWH

A) Chamber connected to downpipe

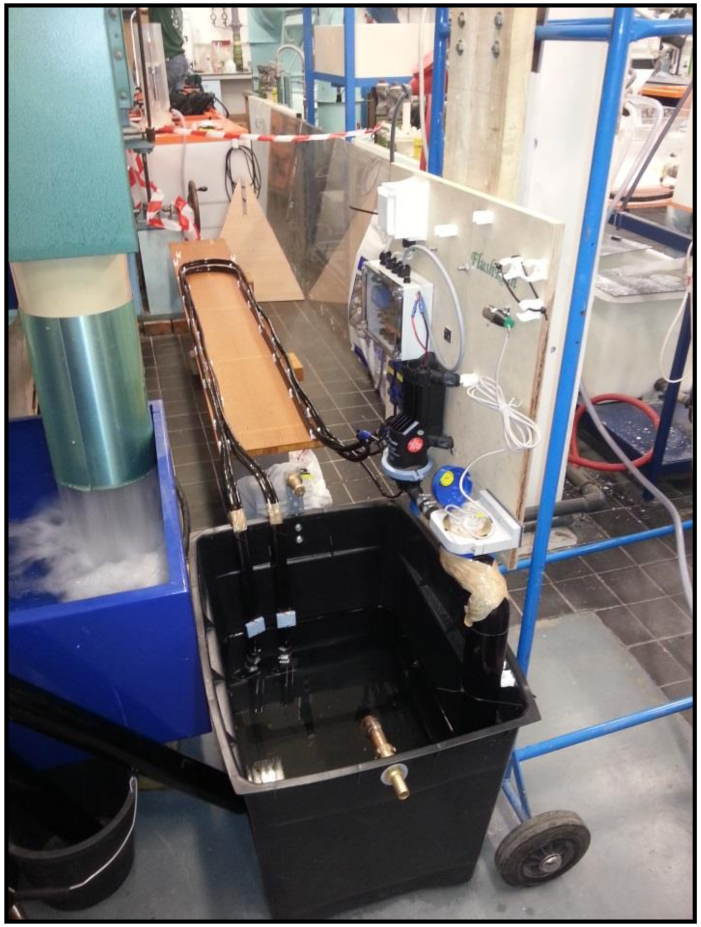


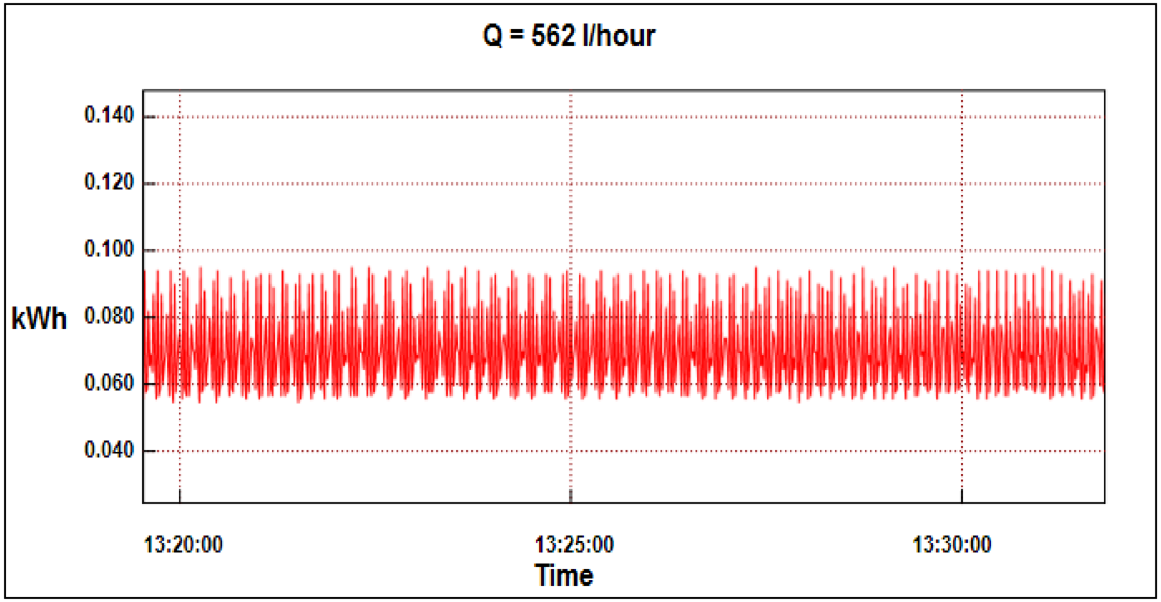
B) Illustration of chamber discharging to downpipe

C) Illustration of chamber being pumped empty

Low energy RWH – lab testing I

Low energy RWH – lab testing II





Laboratory energy use:
0.12-0.18 kWh/m^3

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Low energy RWH – field trials

MELVILLE-SHREEVE P., WARD S.L, & BUTLER D (2016). “Evaluating FlushRain retrofittable rainwater harvesting: a pilot study, *WATEF 2016 conference*, Coventry, September

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Zero energy RWH – lab testing

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The ultimate zero-energy system?

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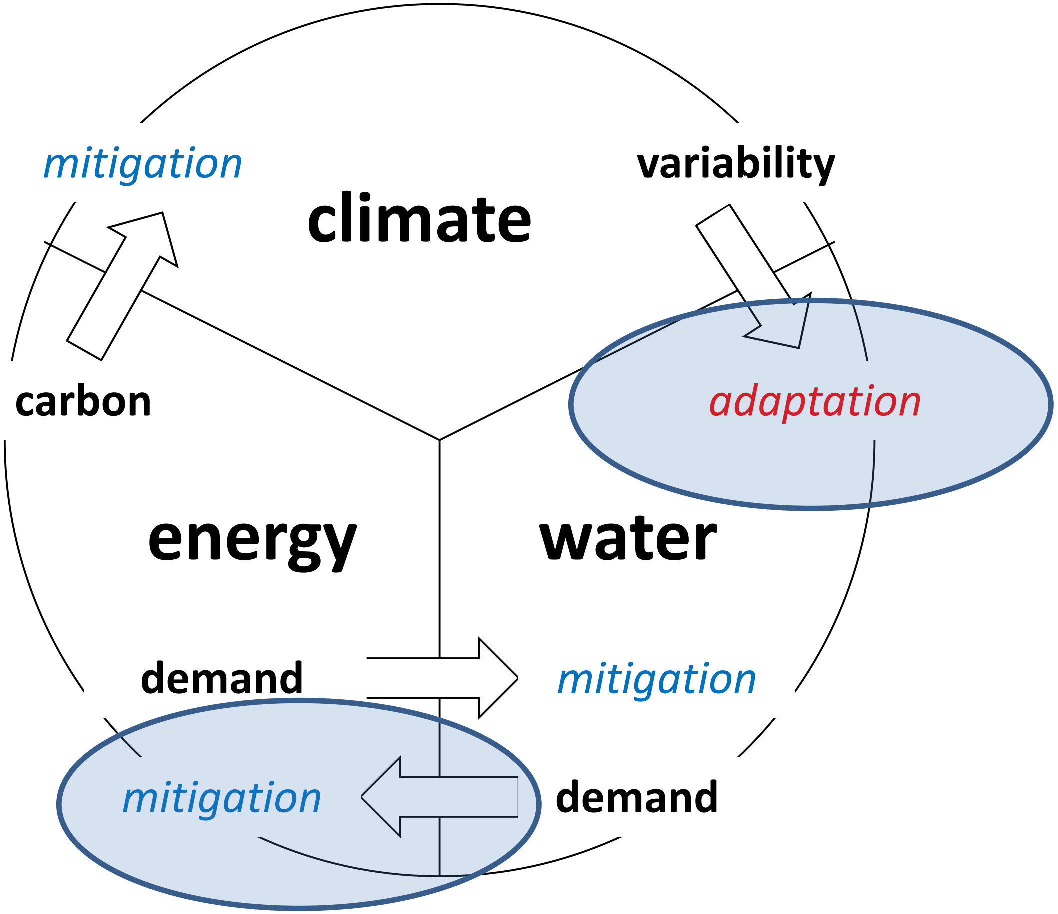
VIRTUOUS INTERVENTIONS:
Cities



mitigation

variability

climate

carbon

adaptation

energy

water

demand

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mitigation

demand

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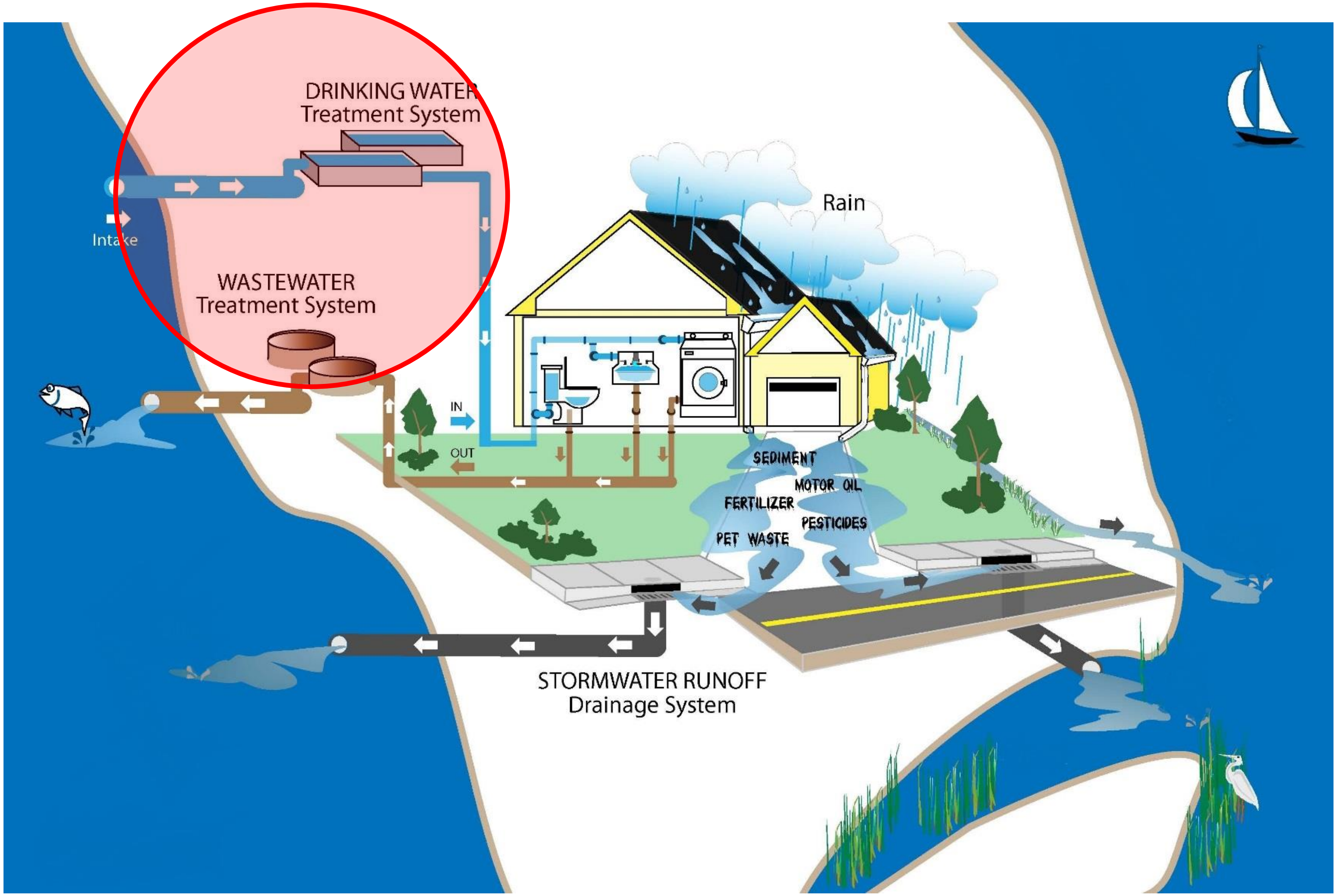
Water supply



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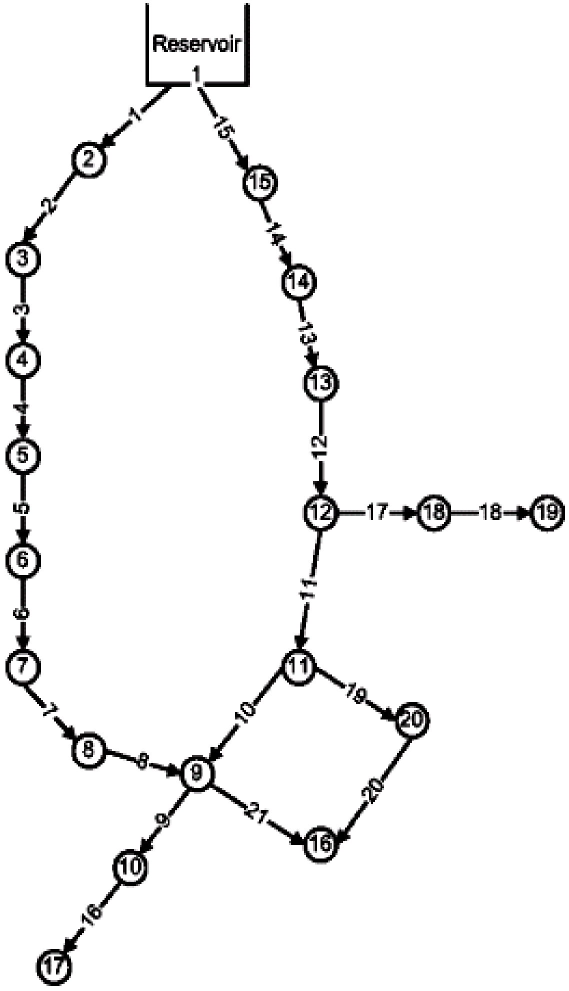
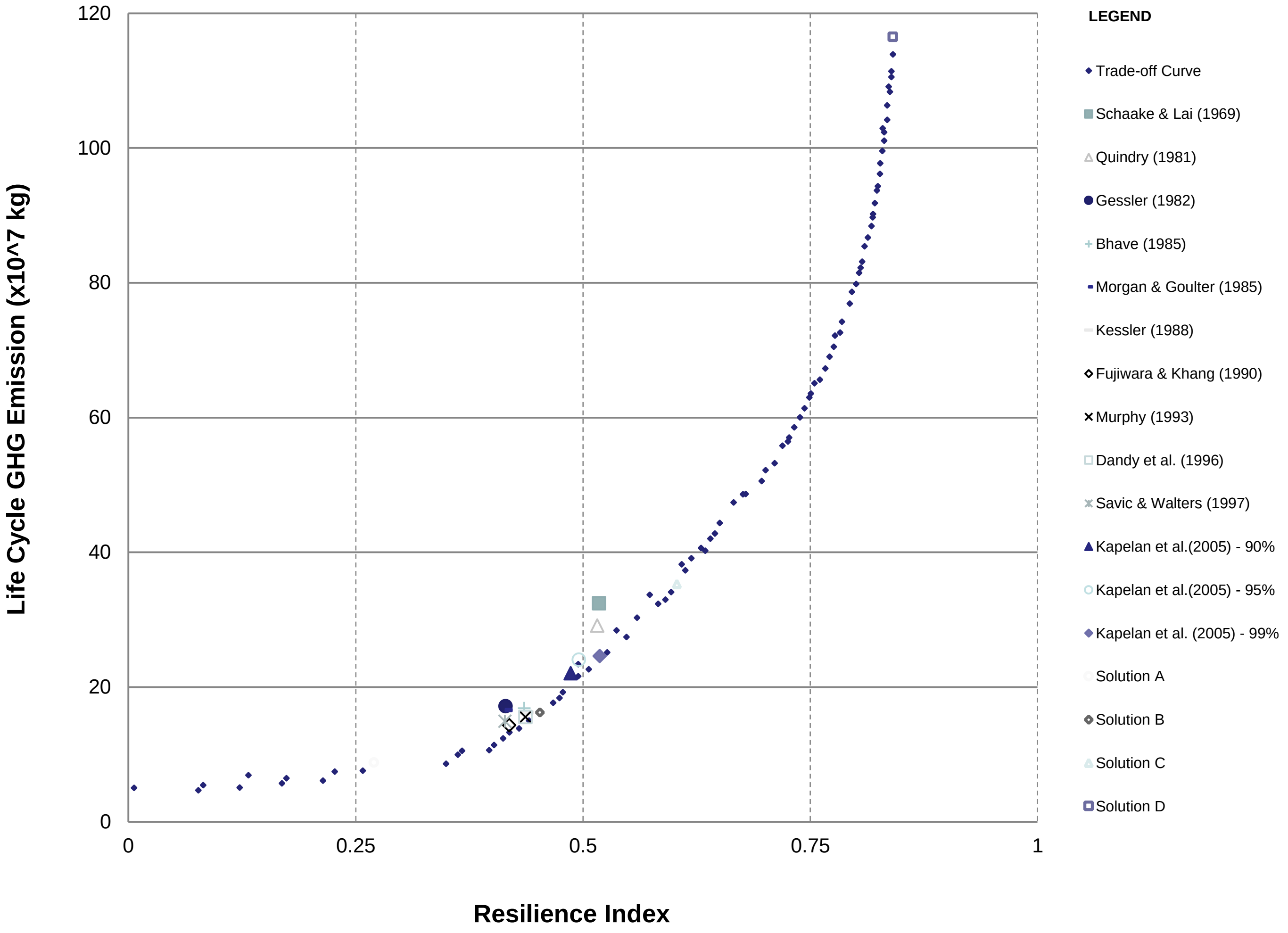
Water supply system

- The **New York Tunnel** has been largely studied as a single objective optimisation problem.
- The network has a single source (i.e. reservoir), 19 demand nodes and 21 pipes.
- Only pipe duplication is considered (15 possible pipe diameters + do nothing).
- Design space = 16^{21} possible solutions



Resilience vs GHG emissions



BASUPI, I, KAPELAN, Z & BUTLER, D. (2013). Reducing life-cycle carbon footprints in the redesign of water distribution systems, *Journal of Water & Climate Change*, 4, 3, 176–192.

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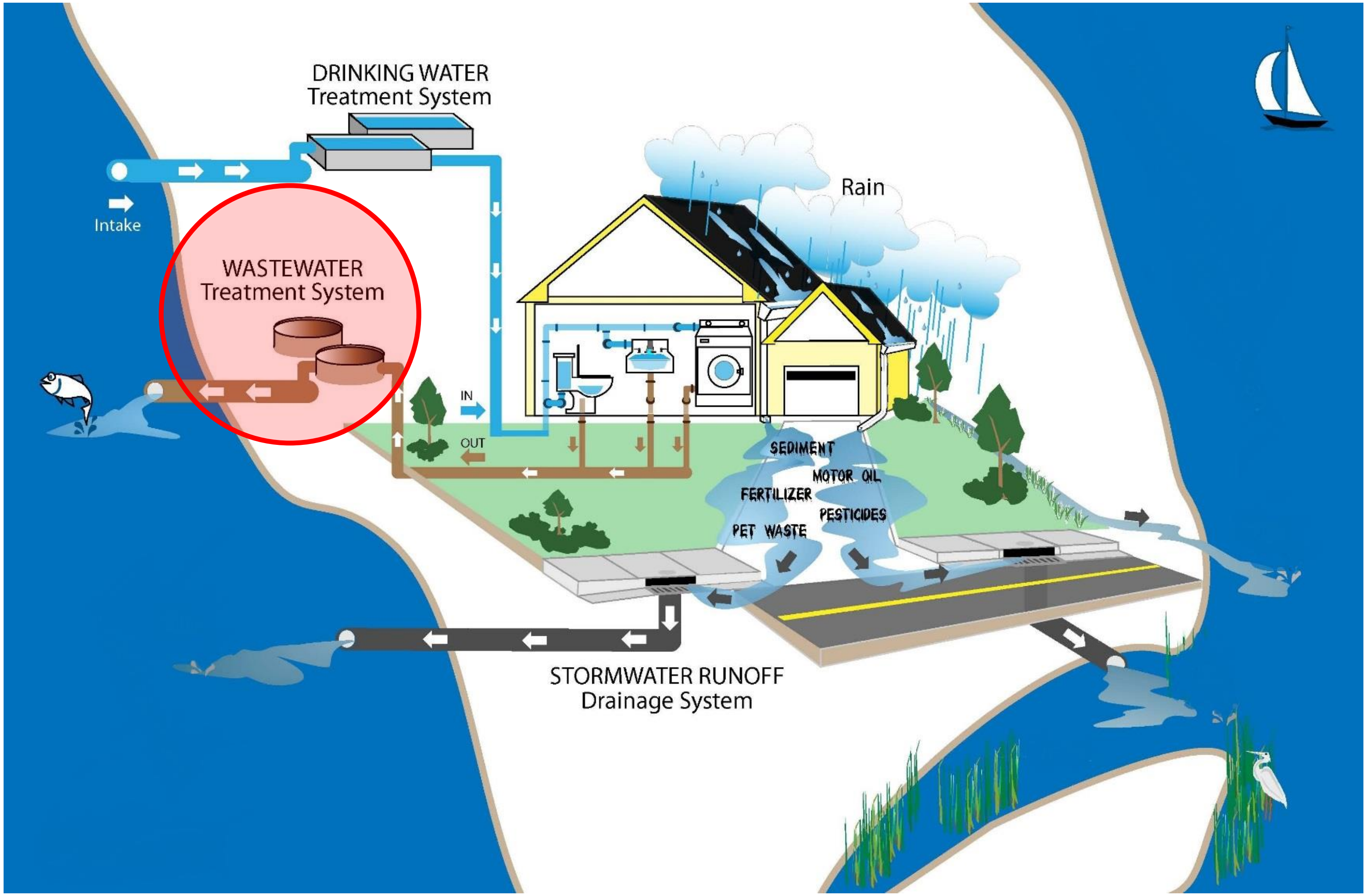
Wastewater treatment



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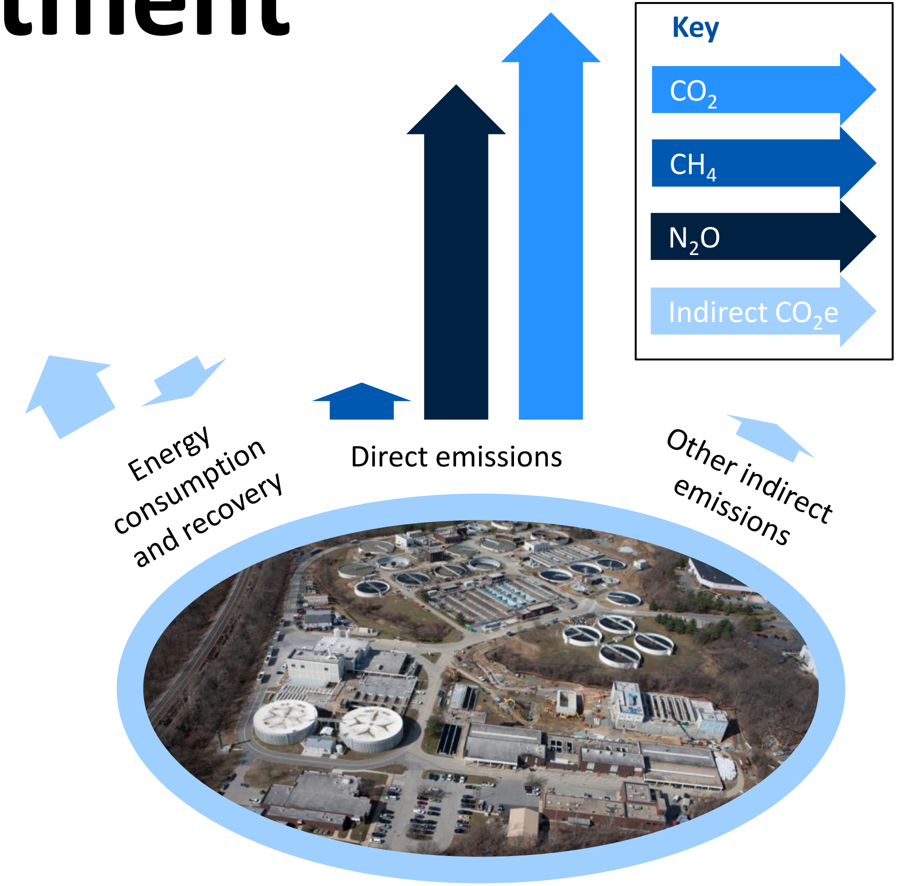
Energy and GHGs in wastewater treatment

- High energy use in wastewater treatment
  ↓
  Carbon emissons
- Wastewater also a source of energy
- Significant direct emissions of CO_2, CH_4 and N_2O



GHGs from a conventional activated sludge wastewater treatment plant (arrow height proportional to CO_2e of emissions)

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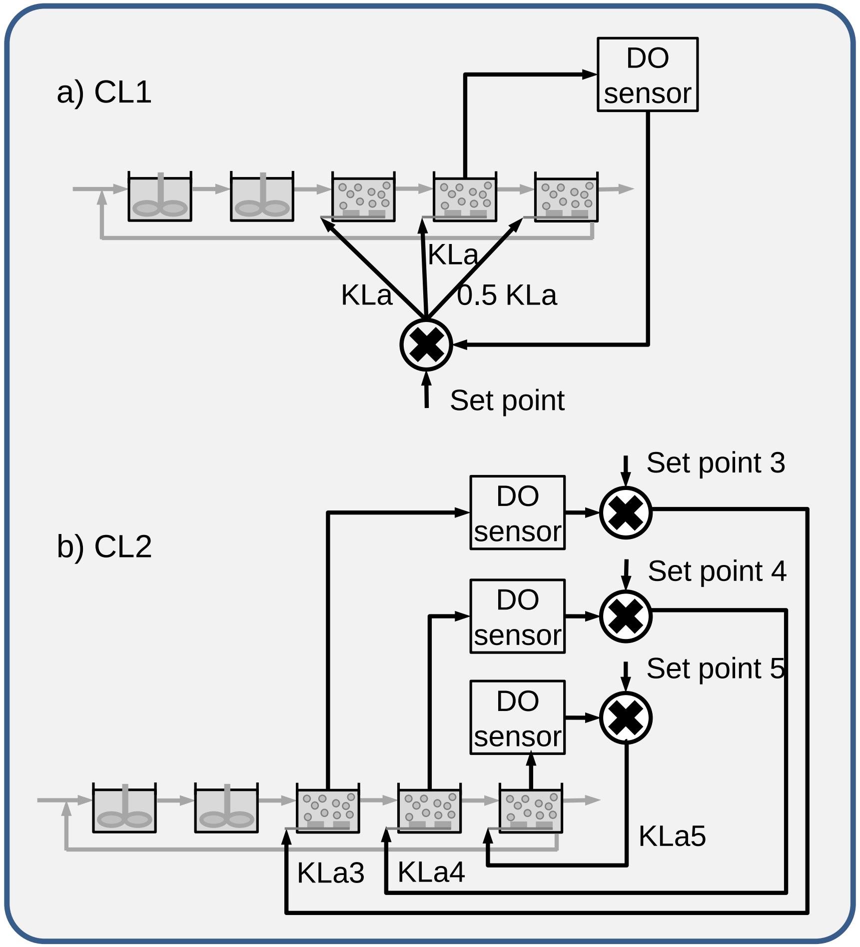
Energy and GHG reduction

- Study of an activated sludge wastewater treatment plant
- Investigate effects of modifying control
  - Flow rate adjustments
  - Choice of dissolved oxygen (DO) control strategy
  - Selection of DO setpoints
- 315 options evaluated



Based on IWA WWTP Benchmark Simulation Model (BSM2) + GHG emission extensions

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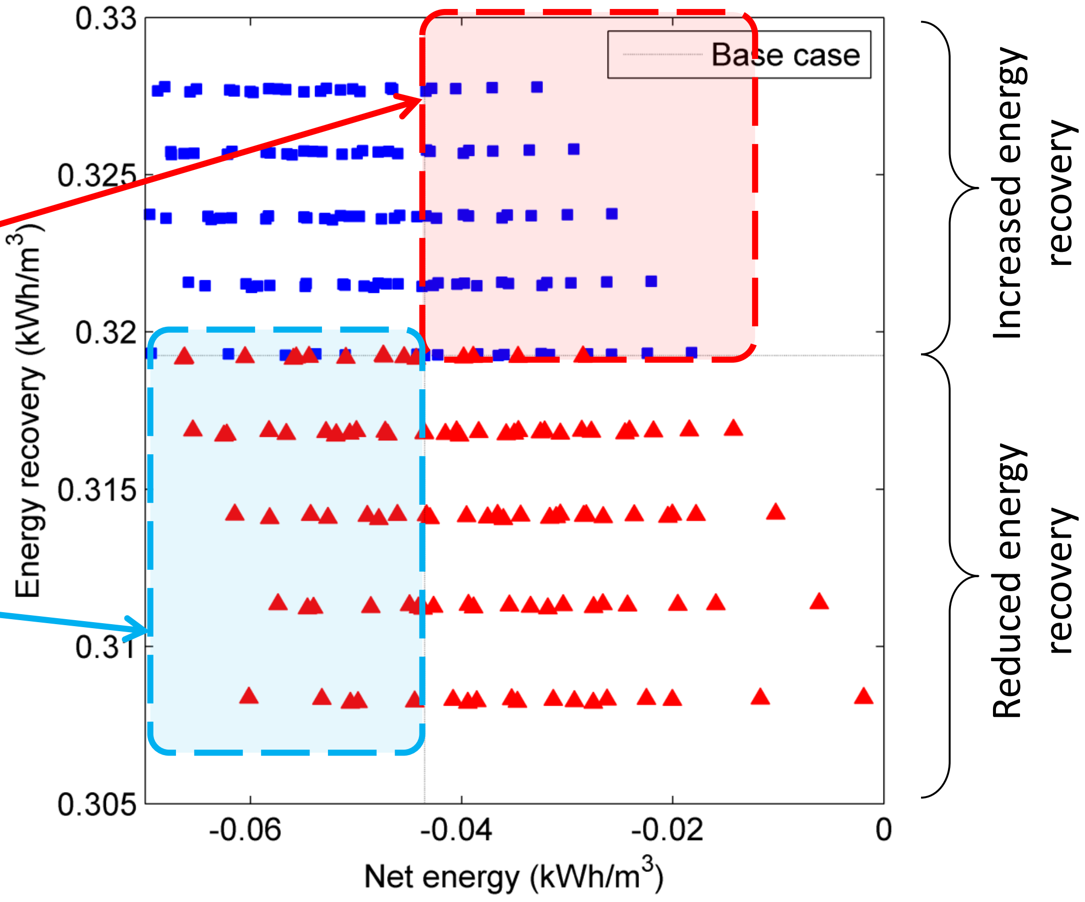
Minimising net energy imported

Increase energy recovery to reduce carbon footprint?

Increasing energy recovery may increase net energy

Net energy may be reduced with a reduction in energy recovery

Don’t focus only on energy recovery!



Relationship between net energy imported and energy recovery

SWEETAPPLE, C., FU, G., & BUTLER, D. (2015). Does carbon reduction increase sustainability? A study in wastewater treatment, *Water Research*, DOI:10.1016/j.watres.2015.06.047

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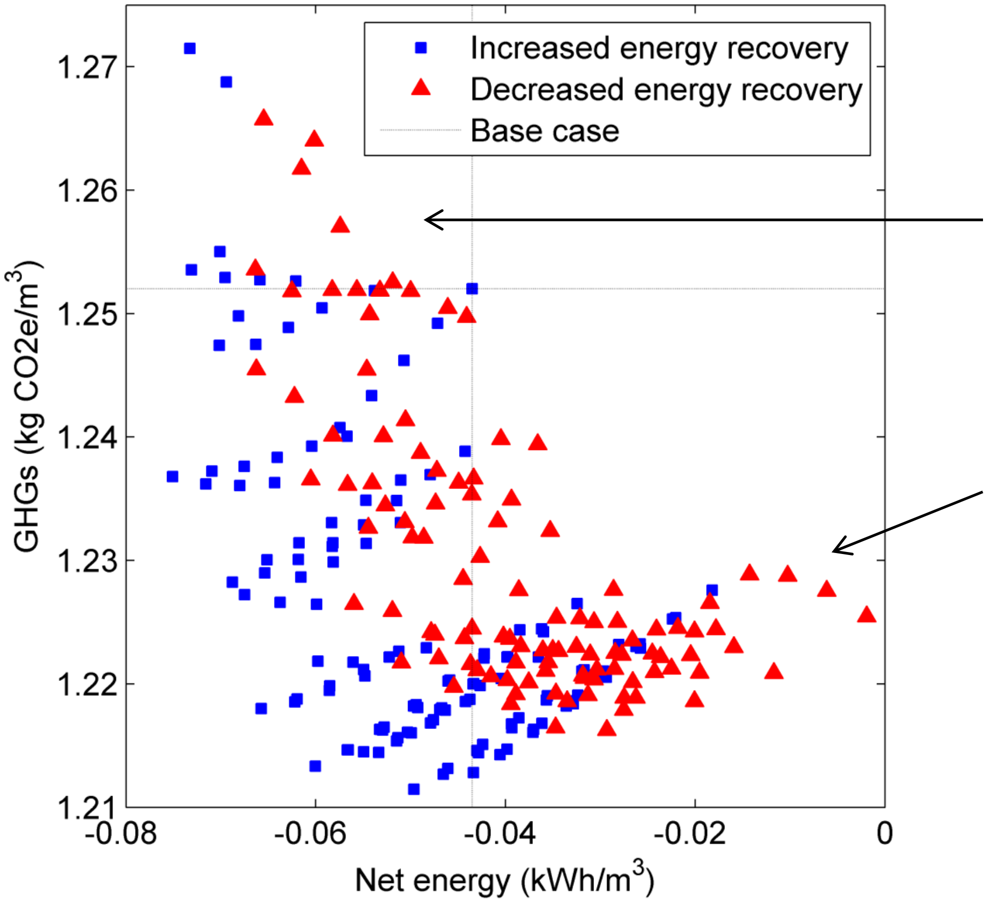
Effects of energy reduction on GHGs



Relationship between net energy imported and GHG emissions

Energy reduction may increase total GHG emissions

GHGs may be reduced without reducing energy use

SWEETAPPLE, C., FU, G., & BUTLER, D. (2015). Does carbon reduction increase sustainability? A study in wastewater treatment, *Water Research*, DOI:10.1016/j.watres.2015.06.047

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Conclusions

Household appliances:

- Key energy user in urban water cycle.
- Avoid unintended energy consequences of reduced household water consumption.

Rainwater harvesting:

- Not as energy consuming as first thought.
- Potential to save water and energy.

Water supply:

- Significant mitigation – adaptation trade-off.

Conclusions

Wastewater treatment

- Energy reduction achievable with improved control.
- Increased energy recovery does not necessarily reduce carbon footprint
- Reducing the carbon footprint may increase GHG emissions.
- Must consider energy use, energy recovery and GHG emissions in combination.

Conclusions

- Balance between **top down** and **bottom up , plus small** and **large-scale** solutions.
- Need a system wide, **integrated approach.**
- Prioritise **combined mitigation & adaptation** solutions (win-win).
- Engage & influence **users.**
- **Encourage innovation** – including in the house.
- **Act now and work together to ensure that the vicious cycle of today becomes the virtuous cycle of tomorrow.**

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University of Southampton
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The water-energy-climate cycle: from vicious to virtuous?

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