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Incorporation of LCA into the Systematic Synthesis of Wastewater Treatment Plants

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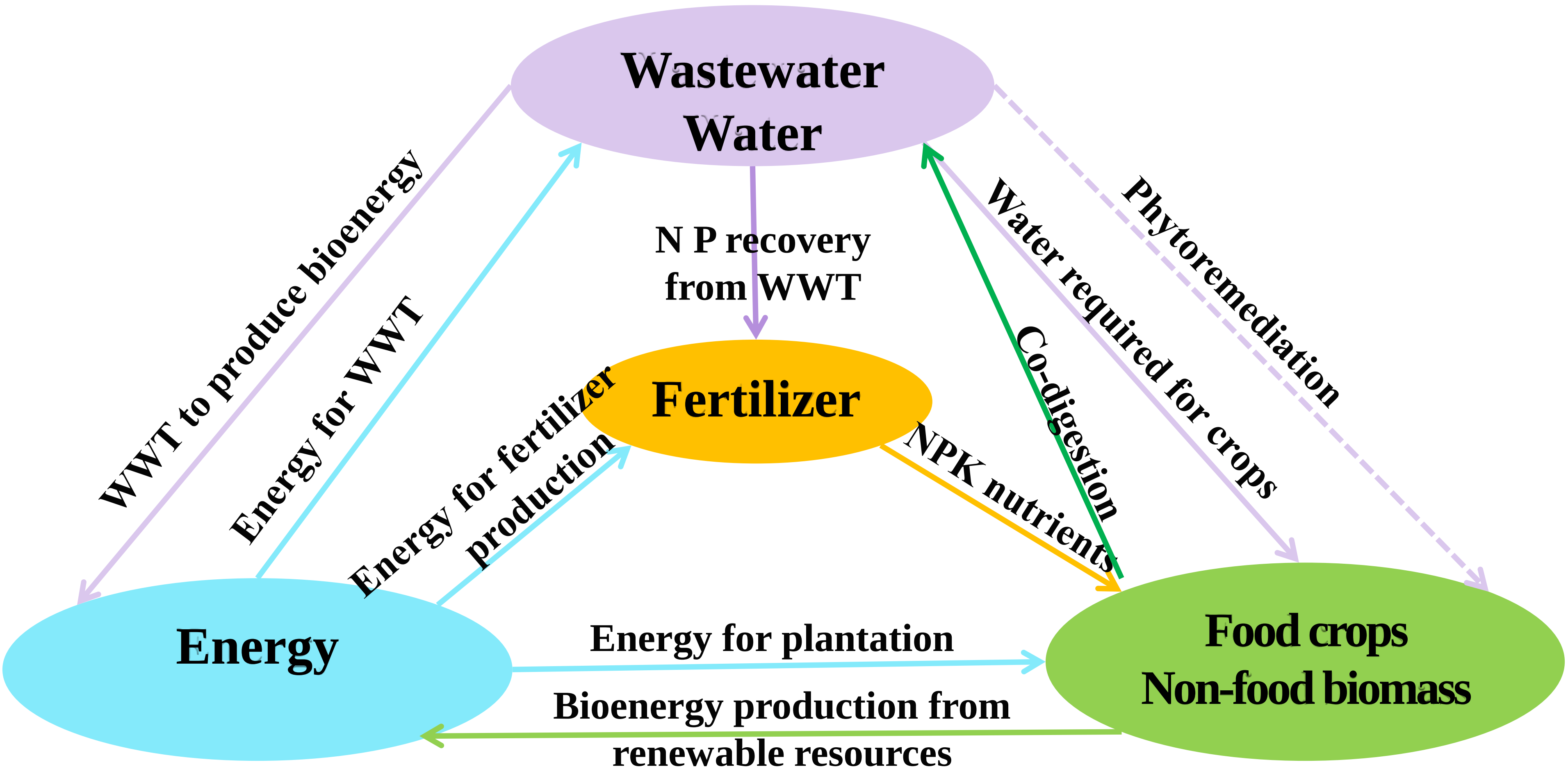
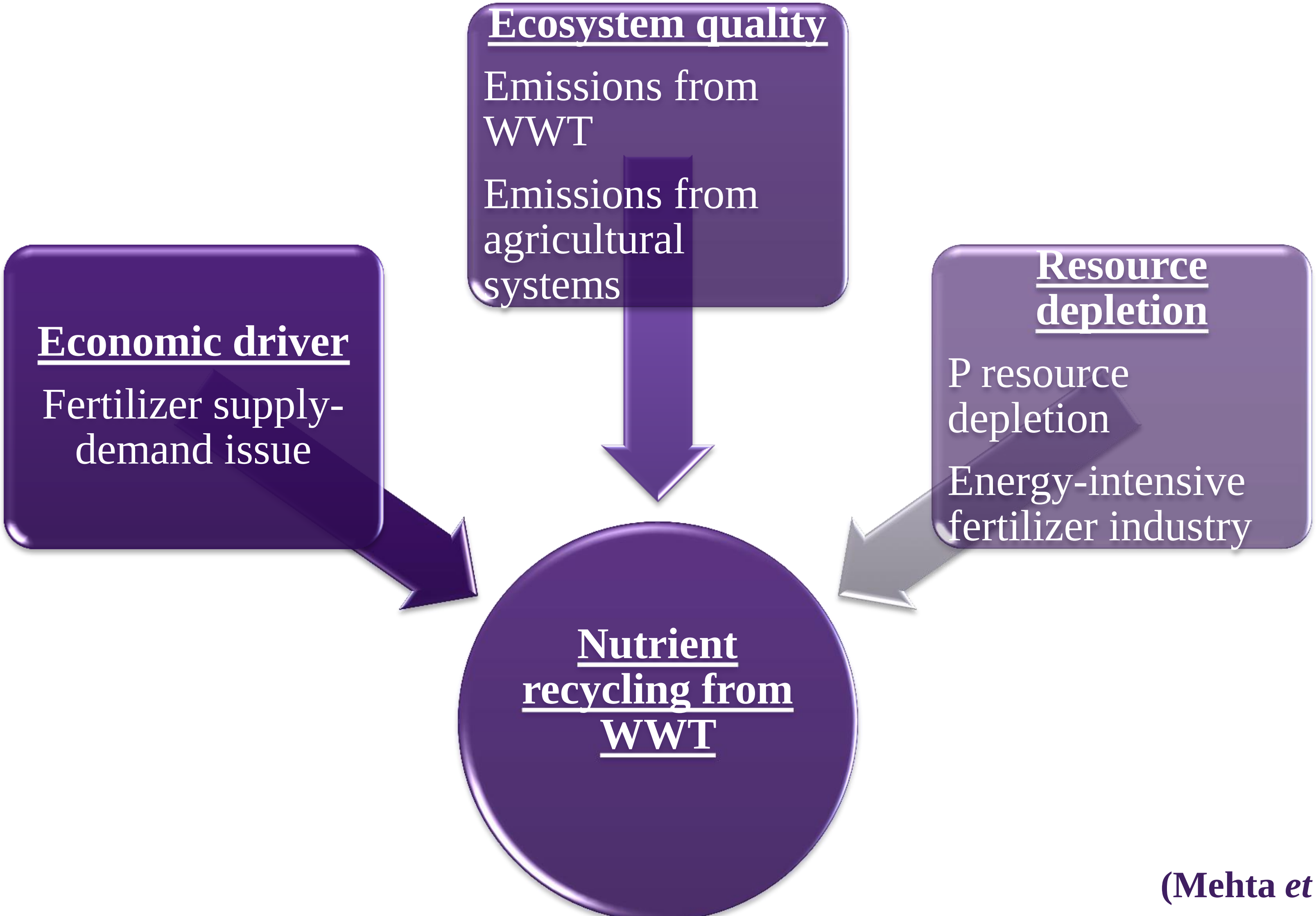
Water, energy and food security nexus



Why nutrient recovery from wastewater treatment (WWT)?



(Mehta *et al.*, 2015)

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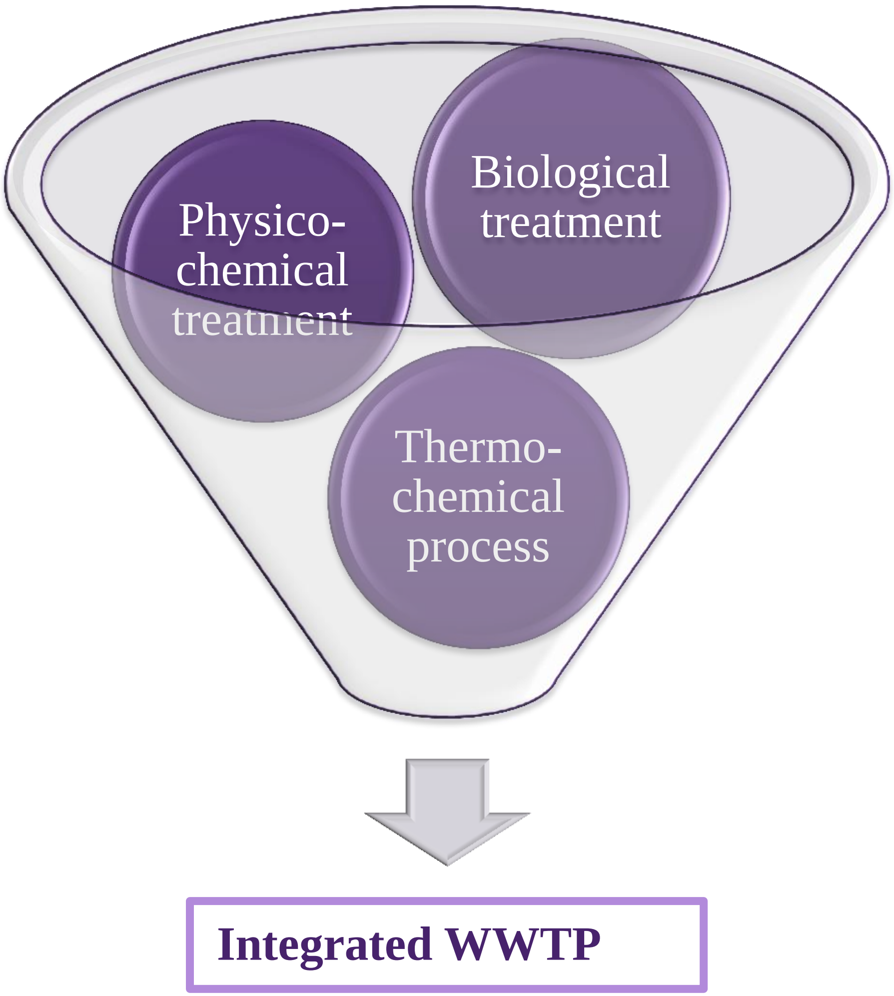
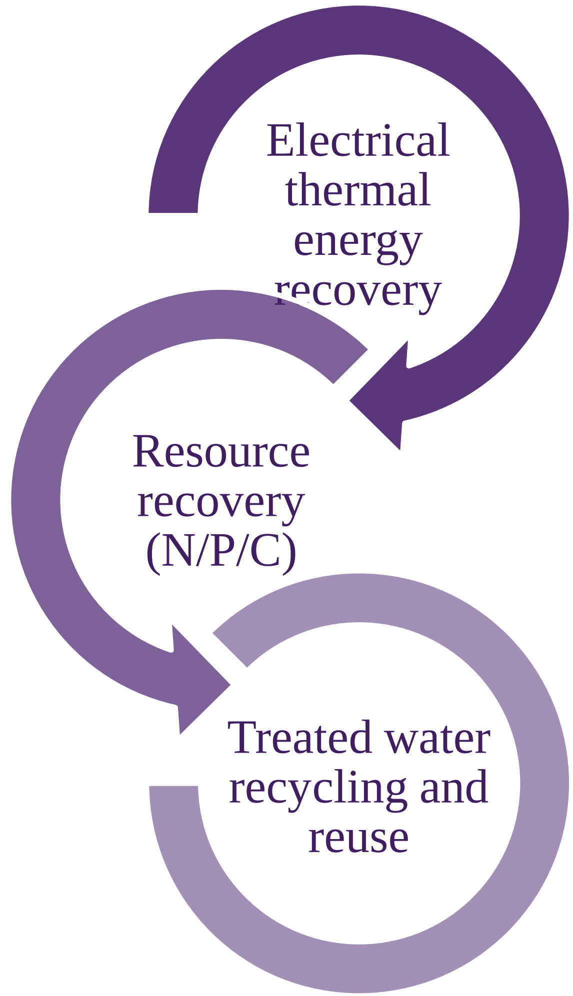
An integrated WWT concept





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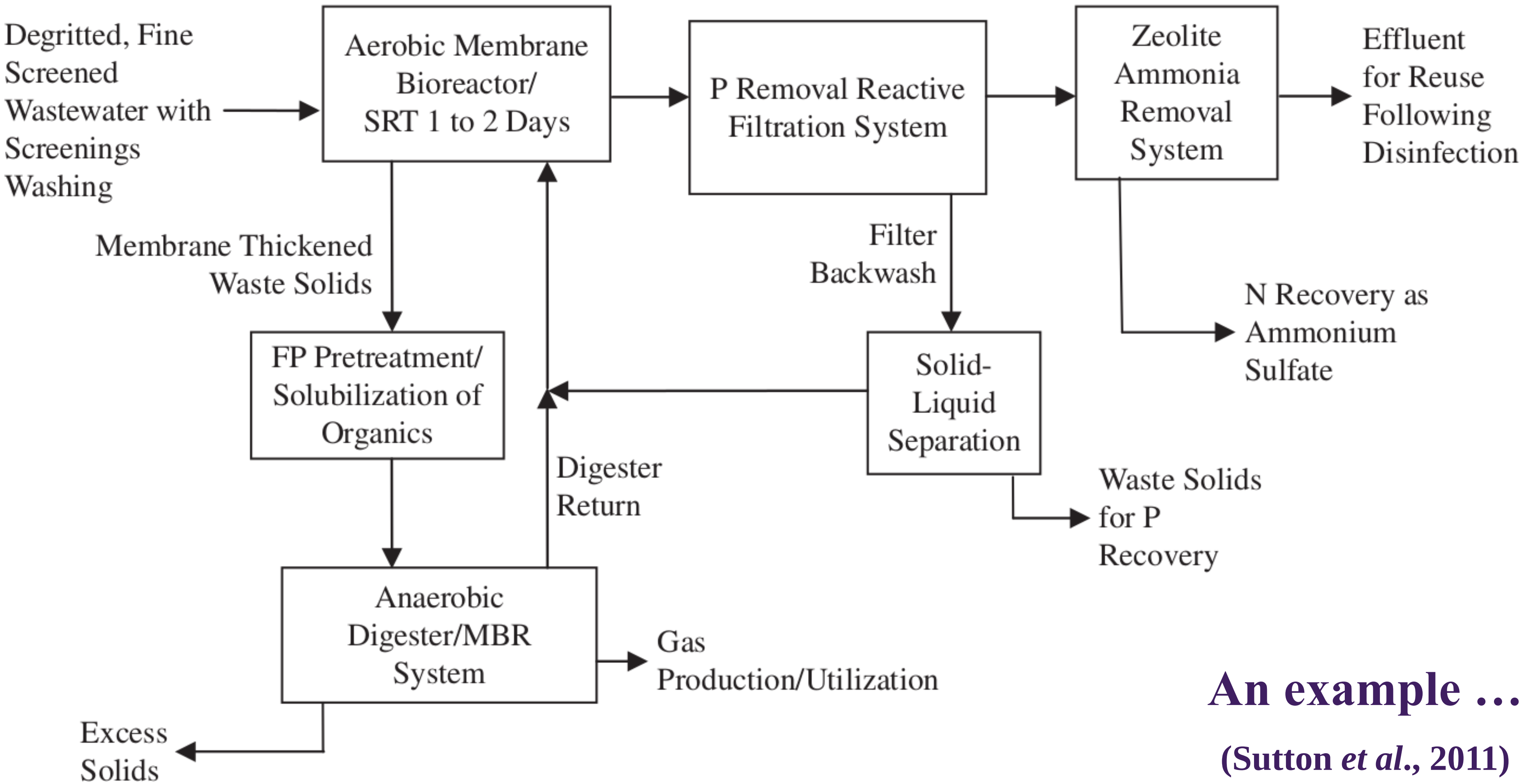
An integrated WWT concept



An example …

(Sutton *et al.*, 2011)

Wastewater treatment plant (WWTP) synthesis

- A range of promising treatment & recovery technologies
- A number of possible interconnections
- Trade-offs - economic viability vs. environmental objectives

Calls for a systems approach

What is Life Cycle Assessment (LCA)?

Phase 1 -LCA goal & scope

- Functional unit
- System boundary
- Impact categories
- Allocation approach

Phase 2- LCI analysis

- LCA data (energy and resource flow)

Phase 3- Impact assessment

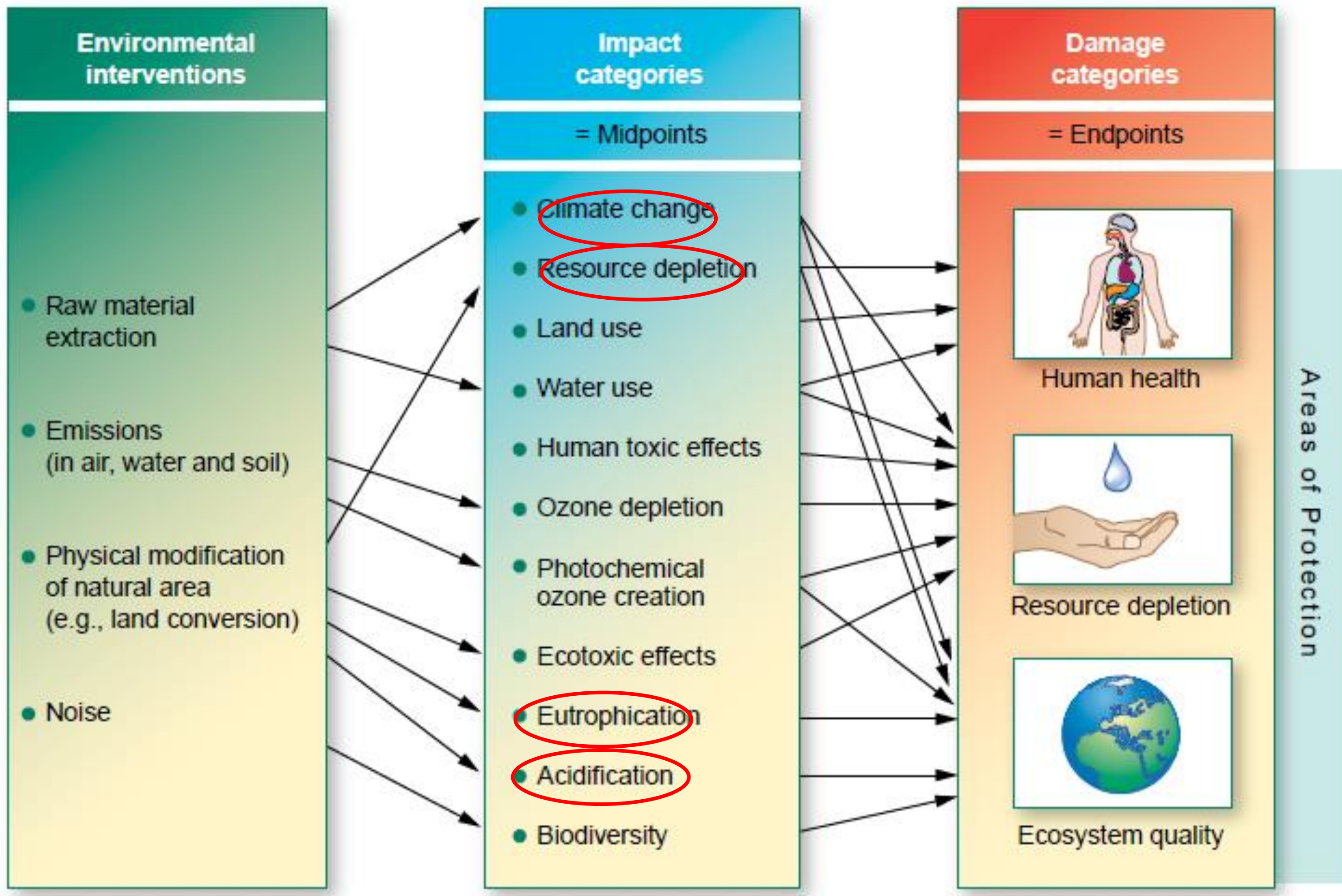
- Classification
- Characterisation
- Normalisation, aggregation, weighting – optional

Phase 4 - LCA interpretation

- 'Hotspot' analysis
- *LCA comparison*
- Data quality analysis
- Other concerns (time horizon etc.)

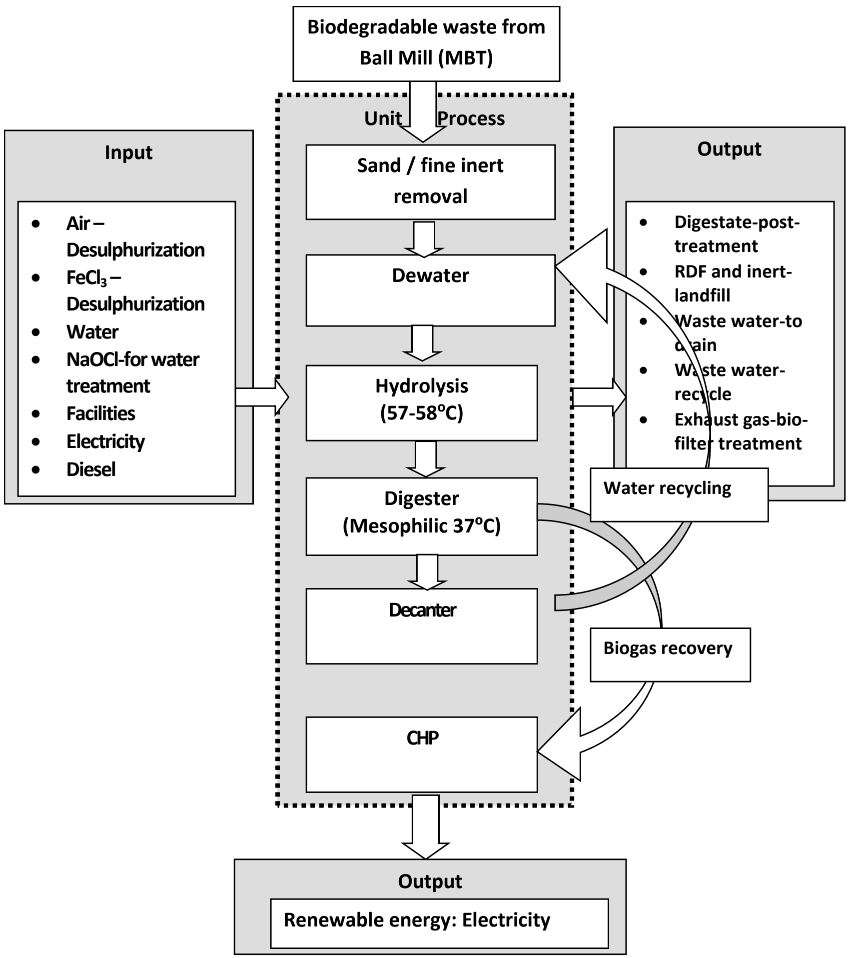
(ISO, 2006)

Environmental assessment - midpoint vs. endpoint



(UNEP/SETAC Life Cycle Initiative 2011)

An example – *How to apply LCA to WWTP*

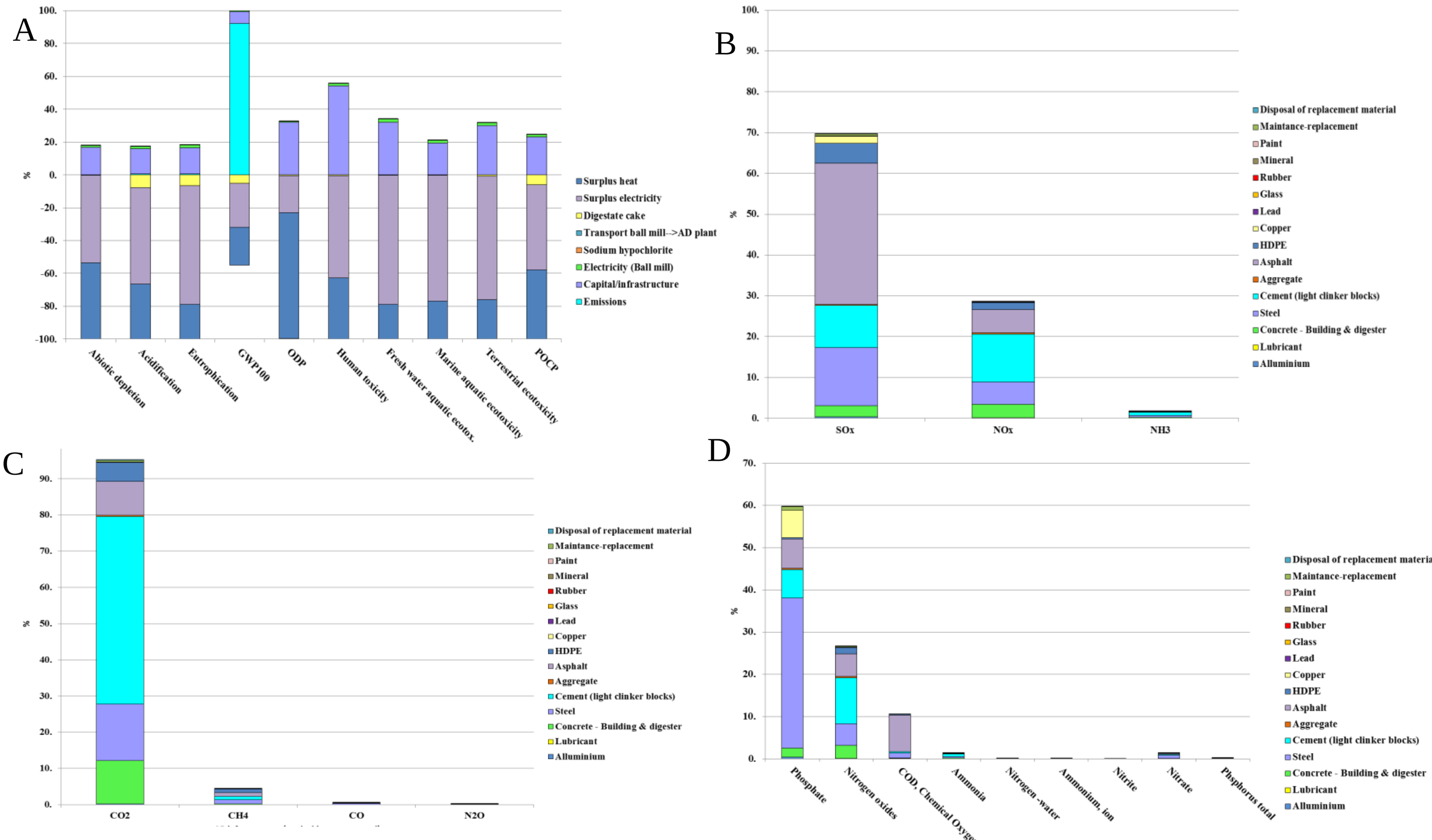


A wet (dry solid less than 15%), continuous-feeding multiple-stage digestion system operated at mesophilic temperature

Parameters	Inventory(statistical results not presented)	Data sources
OLR of OFMSW	2.393g COD/L/day	• A UK commercial AD plant three month operational data; experimental results • Waste and Resources Assessment Tool for the Environment (WRATE) model
TSS	50.56±3.74 g /L	
VSS	25.01±3.02g/L	
Electricity for operation	1704.70 kwh/day equivalent to 15.7% of the generated electricity	
Thermal energy for operation	3.37 MJ /kg bio-waste treated	
Makeup water	150 m^3/day Equivalent to 3.34E-3 kg//kg bio-waste treated	
Internally recycled water	150 m^3/day	
NaOCl	5.02 E-5 kg//kg bio-waste treated	
Infrastructure	Concrete, steel, cement, HDPE,	
Life span	20 years	
Exported surplus electricity	3.01 MJ /kg bio-waste treated	
Exported heat	5.5 MJ /kg bio-waste treated	
CO_2 emissions	1.63 kg//kg bio-waste treated	
NO_x emissions	3.15 E-5 kg//kg bio-waste treated	
Digestate cake	1.12 E-1 kg//kg bio-waste treated	

(Guo *et al.*, 2012)

An example - *LCA 'hotspots' in WWT system*



A: Characterized LCIA profiles for AD treatment of bio-waste; B:Acidifying gas profiles for AD infrastructure;
C: GHG profiles for AD infrastructure; D:Precursors of eutrophication caused by AD infrastructure .
(unit: per kg biowaste treated; method: CML 2 baseline 2000)

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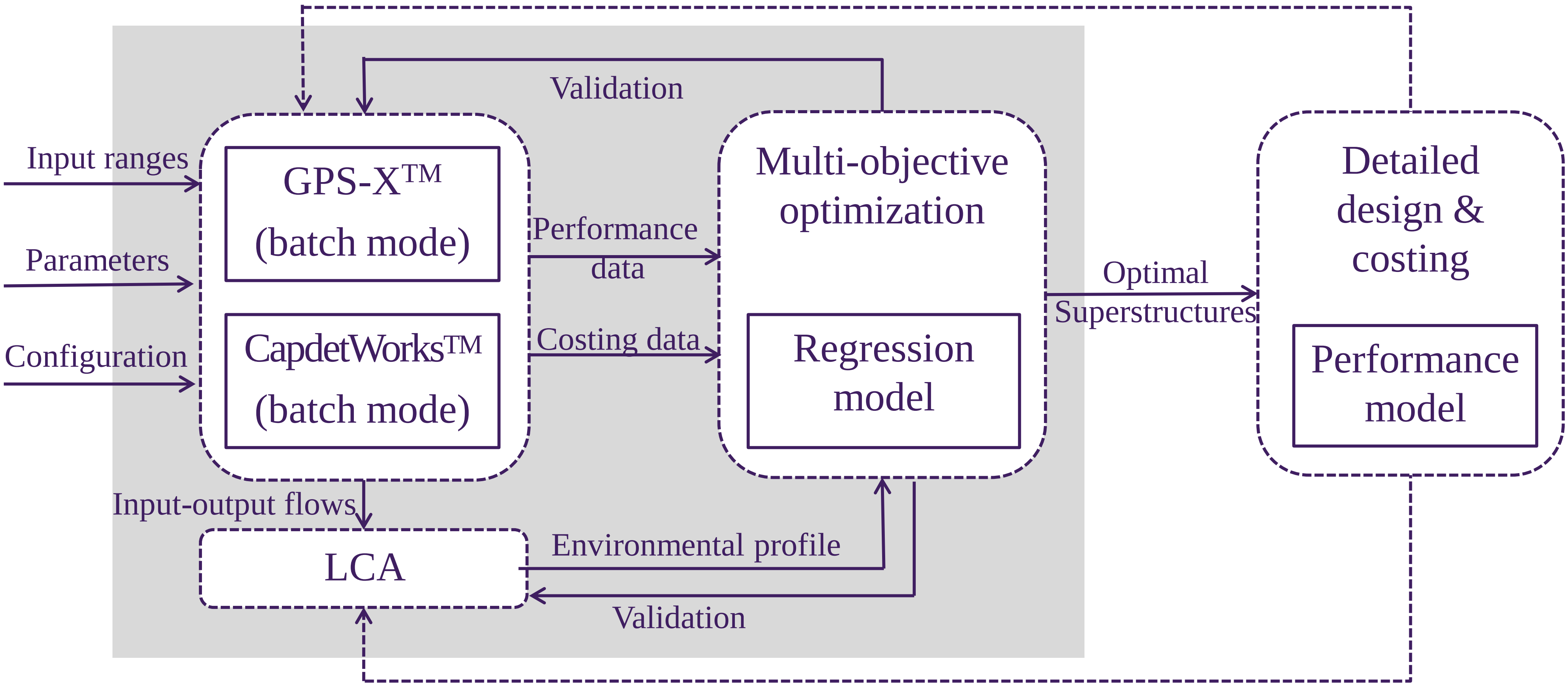
Integration of LCA into WWTP Synthesis



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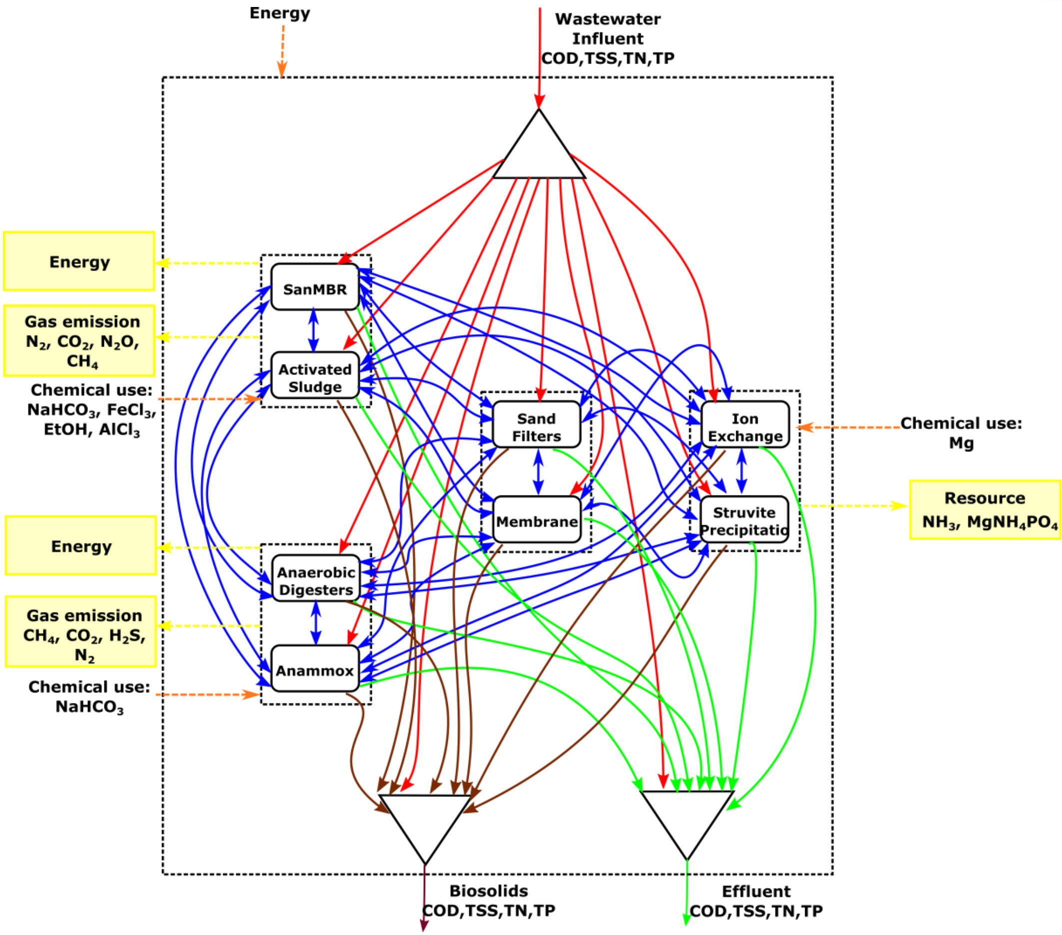
Superstructure modelling and optimization

Superstructure



Synthesis problem

Given:

- A set of waste water streams
- A set of water sinks and specification
- A set of treatment & separation units

Determine optimal systems

- Units & interconnections
- Flows and composition

Multi-objective optimization

- Maximize net present value (NPV)
- Minimize environmental impacts for each performance indicator kpi (EI_{kpi})

$$NPV = \sum_{yr=1}^{lifetime} \frac{SALES - OPEX}{(1 + RATE_{discount})^{yr}} - CAPEX$$

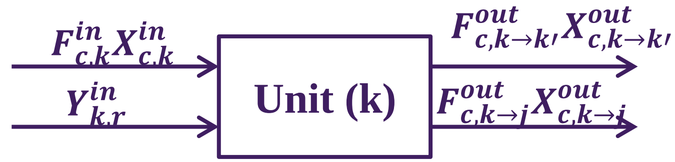
$$EI_{kpi} = \sum_{k} \alpha_k \left(\sum_{c} EIf_{c,kpi} X^{out}_{k \to j,c} F^{out}_{k \to j,c} + \sum_{r} EIf_{r,kpi} Y^{in}_{k,r} \right)$$

(Puchongkawarin *et al.*, 2015)

Superstructure modelling and optimization – unit models

Material balance –

$$F^{in}_{c,k}X^{in}_{c,k}(1-\rho_{k,c}) = \sum_{k'} F^{out}_{c,k\to k'}X^{out}_{c,k\to k'} + \sum_{j} F^{out}_{c,k\to j}X^{out}_{c,k\to j}$$



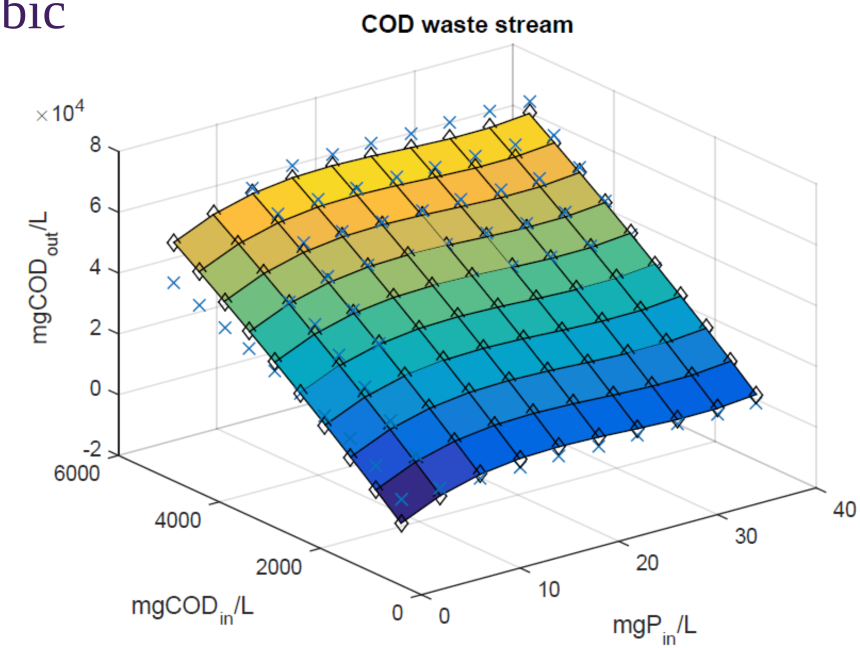
c=compounds
r=resources (energy, infrastructure)
$\rho_{k,c}$ *= removal efficiency for c in unit k*

Treatment / separation units

- State-of-the-art wastewater models e.g. ADM1, ASM1-3 or Mantis1-3
- To derive regression models(linear, quadratic, cubic)

cubic

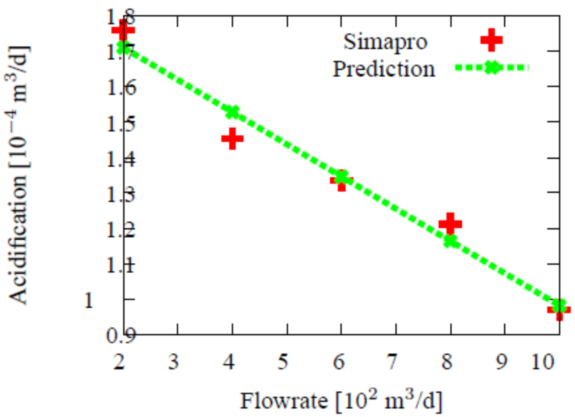
$$X^{out}_{k,c} = f\left(X^{in}_{COD}, X^{in}_{N}, X^{in}_{P}\right)$$

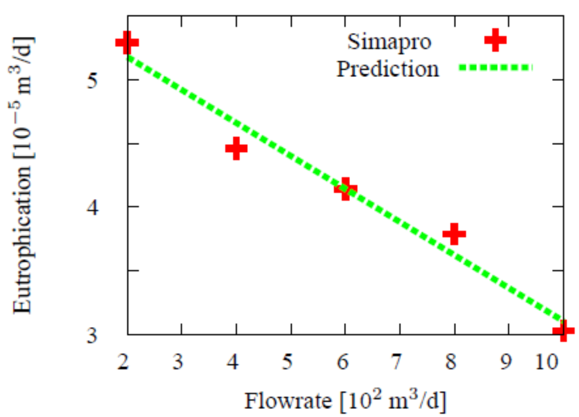


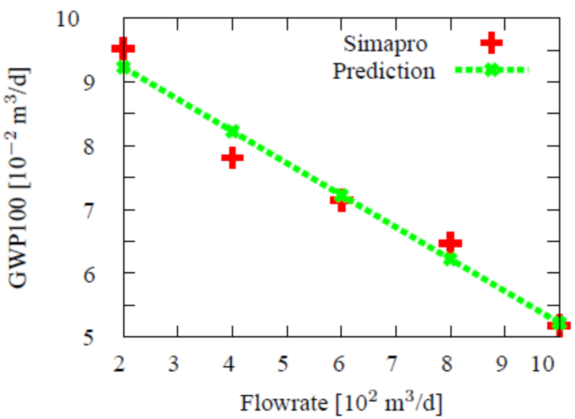
Costing - CAPEX, OPEX

- To derive regression models

LCIA profiles - operational & capital environmental impacts







Impact categories	UK electricity production mix	Grid electricity medium voltage	Grid electricity high voltage
Acidification (kg SO_2 eq/kwh)	2.12E-03	2.18E-03	2.14E-03
Eutrophication (kg PO_4^{3-} Eq/kwh)	7.34E-04	7.64E-04	7.43E-04
GWP100 (kg CO_2 eq/kwh)	4.70E-01	4.87E-01	4.77E-01

(Source: Digest of UK energy statistics , 2014)

Emissions	Factor
GWP100 (kg CO_2 eq/kg)	
CO_2	1
CH_4	25
N_2O	298
Acidification (kg SO_2 eq/kg)	
NH_3	1.6
SO_2	1.2
SO_x	1.2
NO_2	0.5
NO_x	0.5
Eutrophication (kg PO_4^{3-} Eq/kg)	
NH_3	0.35
NH_4^+	0.33
NO_3^-	0.1
NO_2^-	0.1
Total N	0.42
PO_4^{3-}	1
Total P	3.6
COD	0.022

(Method: CML 2 baseline 2000)

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Case study

Case study : Definition

Municipal Wastewater effluent

Total COD	Soluble COD	TSS	VSS	VFA
569 mg/L	129 mg/L	259 mg/L	231 mg/L	10 mg/L
Total N	**Ammonia**	**Total P**	**Phosphate**	**Alkalinity**
51.6 mg/L	38 mg/L	7.6 mg/L	4.1 mg/L	253 mg$CaCO_3$/L

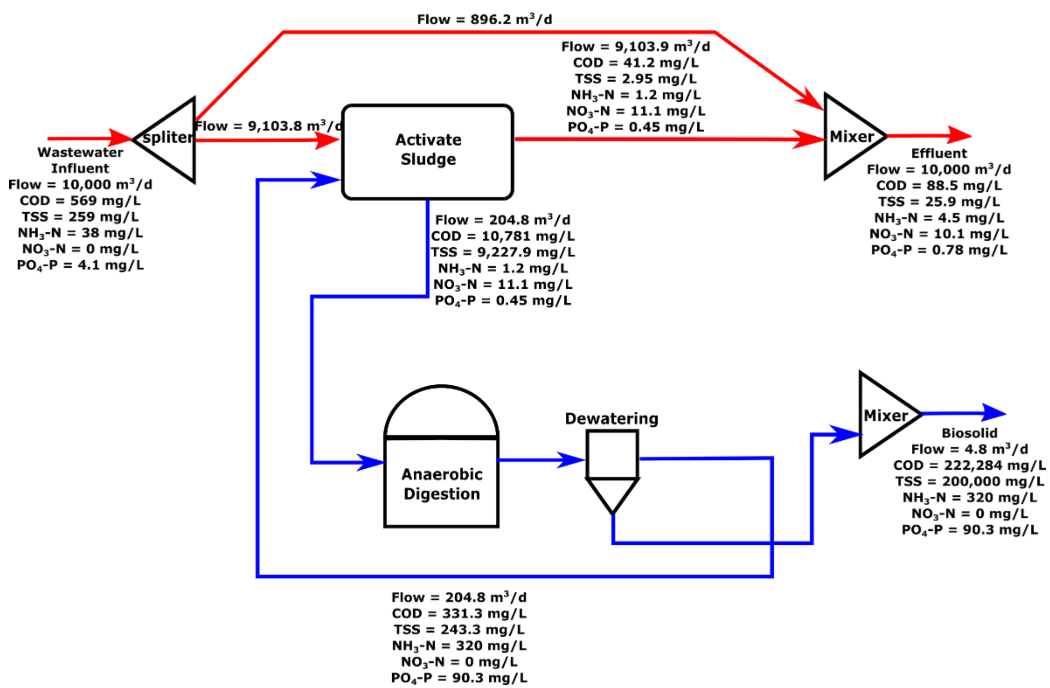
Maximum discharge regulations (EU Directive 91/271/ECC on Urban Wastewater Treatment)

	Max. Concentration	Min. abatement
Total COD	< 143 mg/L	TCOD > 75 %
TSS	< 25.9 mg/L	TSS > 90 %
Ammonia	< 7.6 mg/L	TN > 80 %
Nitrate	< 10.3 mg/L	
Phosphates	< 0.82 mg/L	TP > 80 %

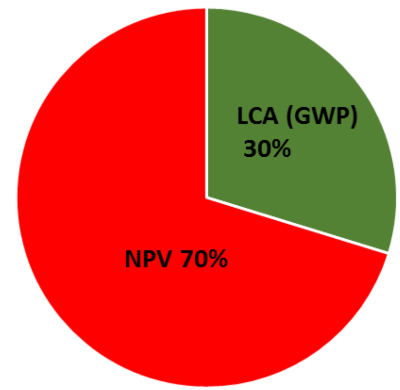
Objective: Maximize NPV– LCA (GWP) over 20 years

Case study – superstructure optimization results

Case 1 – Optimal superstructure



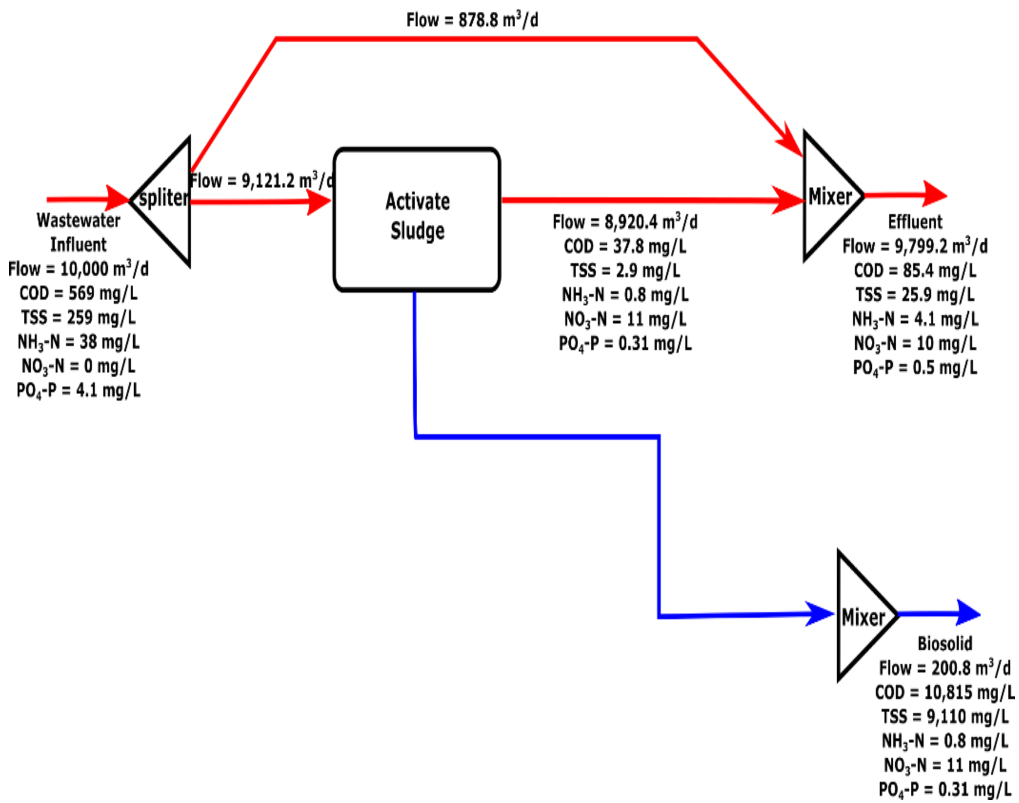
Objective function : -13 M£



- Bottleneck – abatement of TSS
- GWP objectives mostly driven by operation of activated sludge (~80% N_2O/CO_2)
- Beneficial effects by anaerobic digestion (both NPV and GWP due to energy recovery)

Case study – superstructure optimization results

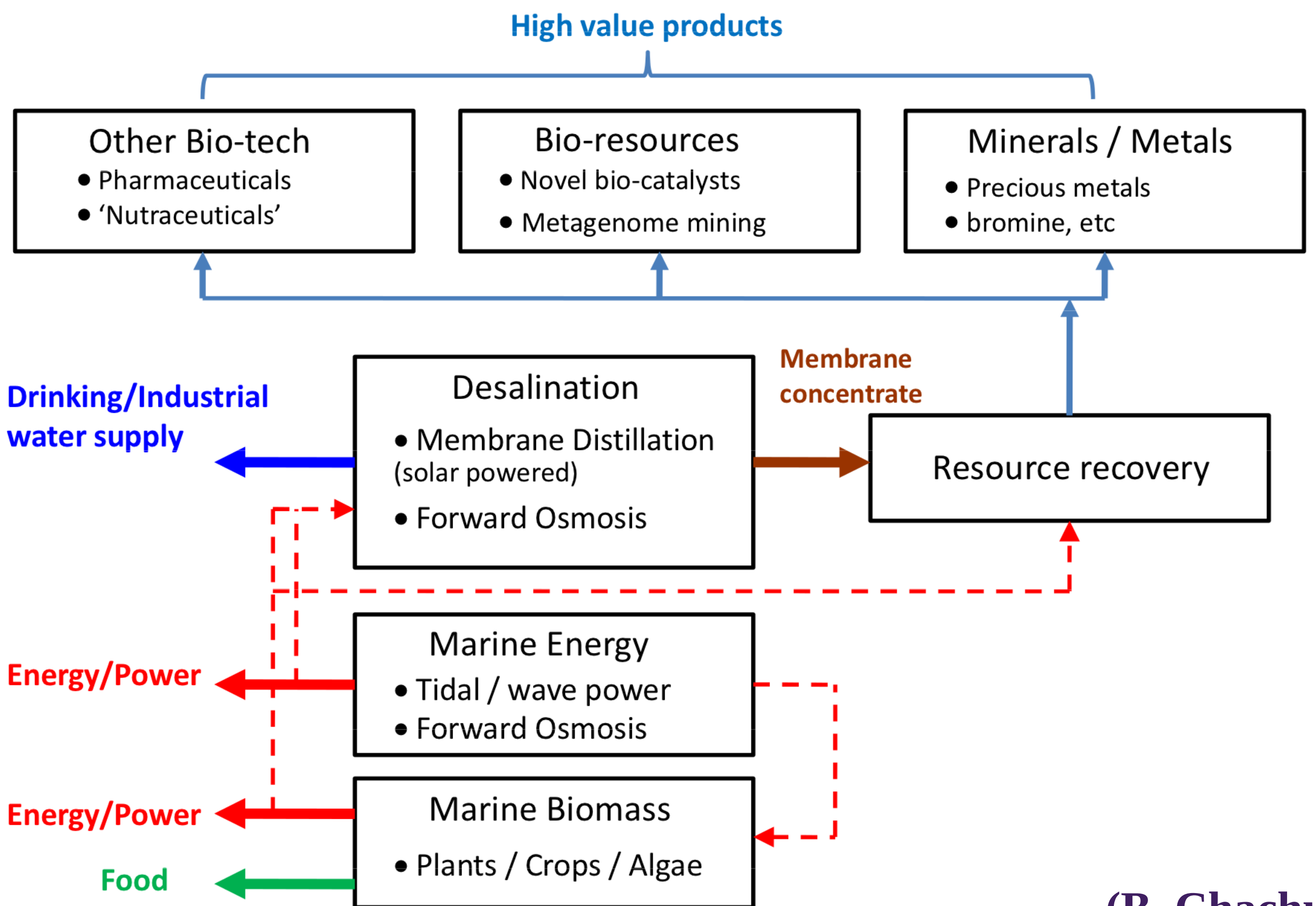
Case 2 – No anaerobic digestion (energy recovery)



Objective function : -61 M£

- Case 2 – No contribution from anaerobic digestion and low objective function is driven by higher landfill cost
- Minimal abatement in TSS appears to be bottle neck

Integrated marine resource recovery

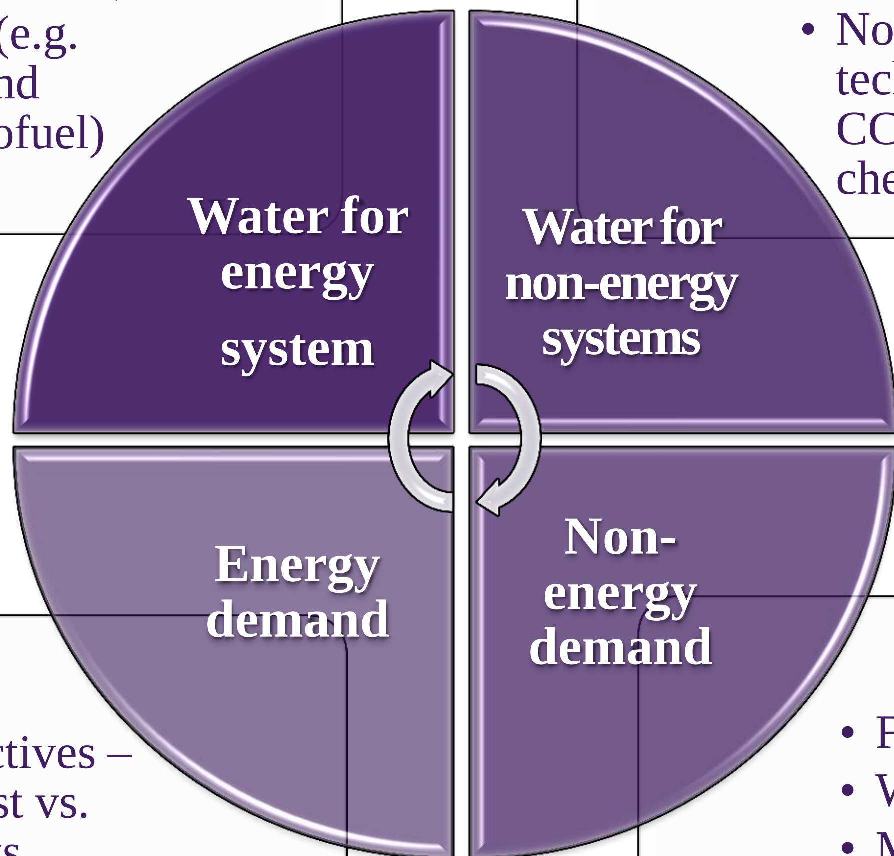


(B. Chachuat, 2012)

Potential collaboration

- Renewable energy (e.g. solar)
- Bioenergy (e.g. electrical and thermal, biofuel)

- Spatially explicit resource map;
- Non-energy technologies (e.g. CCS, high-value chemicals)



- Multi-objectives – e.g. min cost vs. GHG targets
- Multi-period

- Food security
- Water security
- Multi-period

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Thanks for your attention!