Data-Driven Discovery in Wastewater Resource Recovery Facilities (3D-WRRF)

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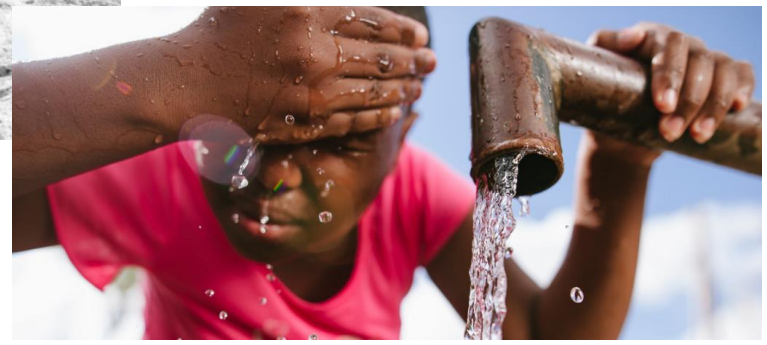
Wastewater treatment service is a long-term, global-scale challenge

By **2050** - Nearly **70% of the world population is urban** and the **pressure** on and **unwanted effects** of expanding wastewater systems will increase.

By **2015 -** Over **80% of wastewater** resulting from global human activities is discharged into rivers or sea **without any pollution removal**.



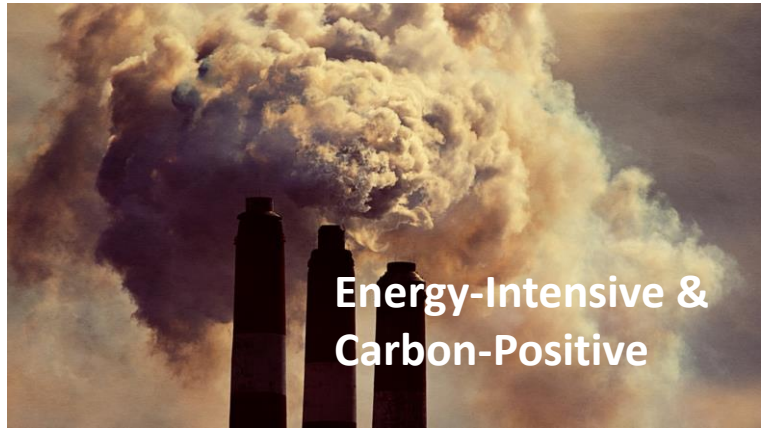
UNITED NATIONS MILLENIUM DEVELOPMENT GOALS

SUSTAINABLE DEVELOPMENT GOALS

Developing wastewater resource recover facilities (WRRF) is a solution in point

Current wastewater industry:

- **Consumes** over **57 Terawatt hour** of electricity every year, nearly 3% of the total U.S. electrical energy generation (= **5.4 million household** annual use)
- **Emits 0.75 Gigatonnes of CO_2-eq**, 1.5% of greenhouse gas emissions (=**260 million tonnes of coal burn**)



Emerging WRF:

- The **chemical energy** embedded in wastewater is **4–10 times** that needed for clean-up
- The **nutrient elements (N & P), chemicals, and water itself** are value-added products when recovered

Evolving to WRRF is still challenging…

- Different stakeholders refer to **different sources of information** and have **different points of views**, it is difficult to identify best solutions to these challenges.

  ➢ **Data collection (from different dimensions and scales)**

- Wastewater service systems often **function in isolation**, relying on technocentric approaches and failing to address non-engineering factors.

  ➢ **Data integration (with multiple data-source layers)**

- WRRF are **complex integrated systems** intended to deliver broader benefits yet the existing paradigms have not been designed with **multiple purposes** in mind.

  ➢ **Data visualization and interpretation (to drive decisions)**

Data-driven discovery in WRRF

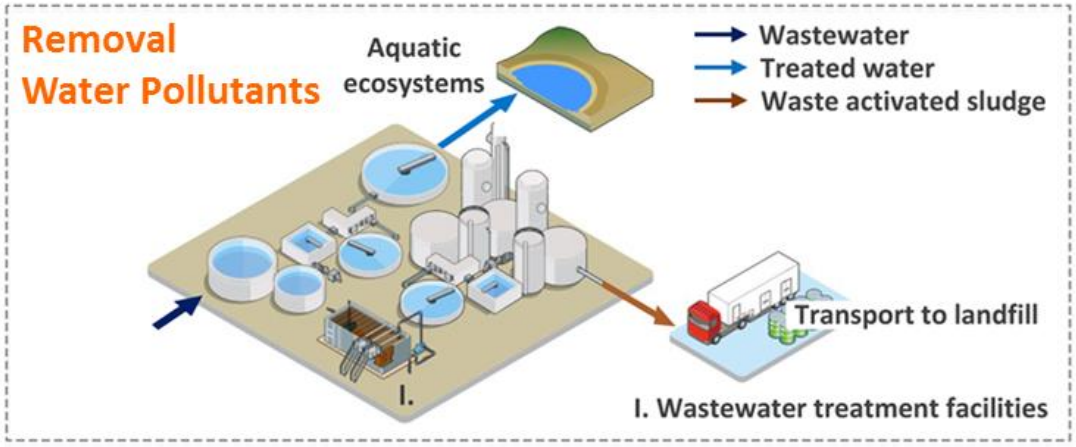
Can we

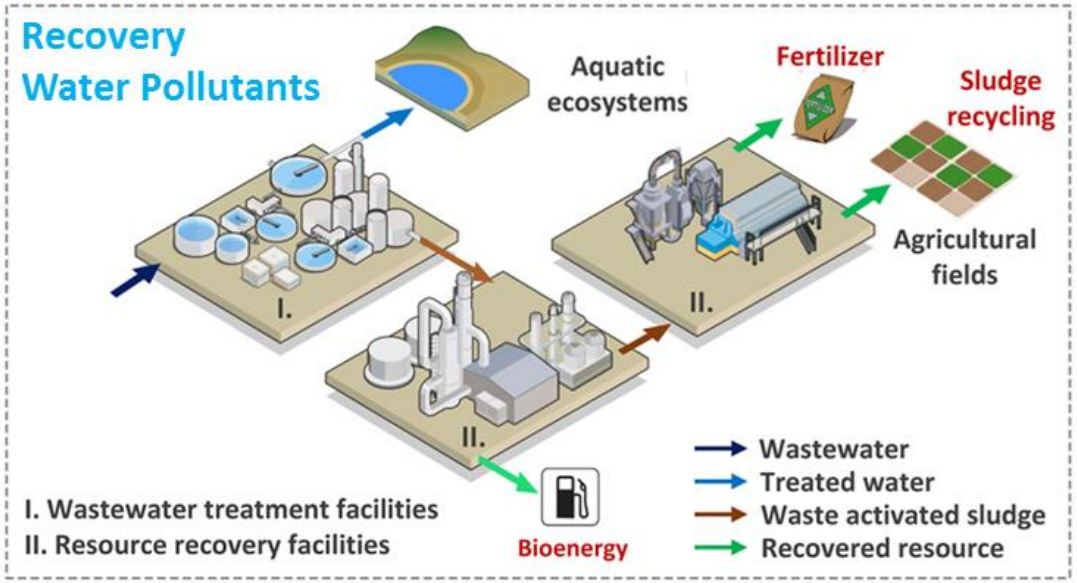
- Project the potential benefits of novel enterprises in wastewater industry prior to any substantial change? (policy traction)

- Design, explore and assess innovative new systems in an integrated, more comprehensive manner? (technological transformation)

3D-WRRF Case 1: How best to ensure environmental sustainability

Pollutant Clean-up vs. Resource Recovery

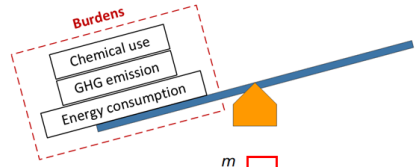




① Assessment scheme

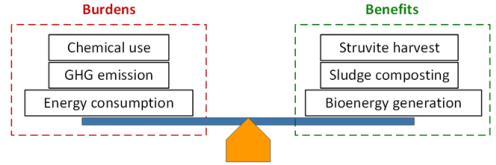
② Quantitative models

Removal water pollutants ('Waste')



$$NEB(a) = -\sum_{j}^{m} w_j \times NF_j(a)$$

Reuse water pollutants ('Resource')



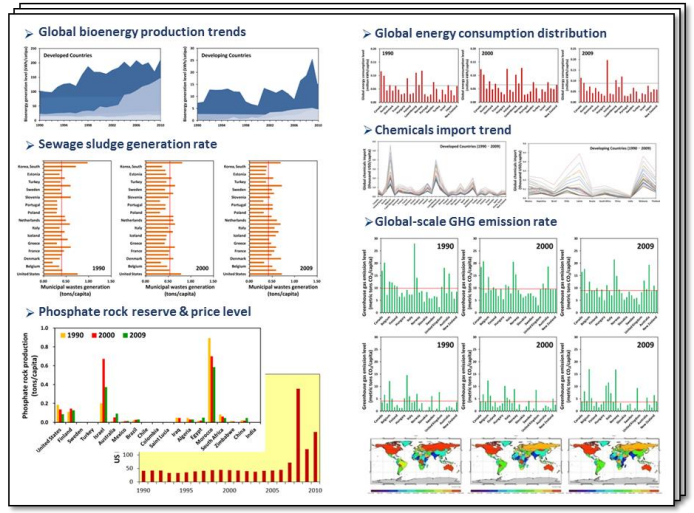
$$NEB(a) = \sum_{i}^{n} w_i \times PF_i(a) - \sum_{j}^{m} w_j \times NF_j(a)$$

③ Data Mining/ ④ Weighting

Net Environmental Benefit (NEB)

i.e., the total gains from integration of resource capture and improved wastewater treatment practices minus the adverse environmental effects of those actions

③ Big-Data Analysis — $\omega = \omega(t)$?

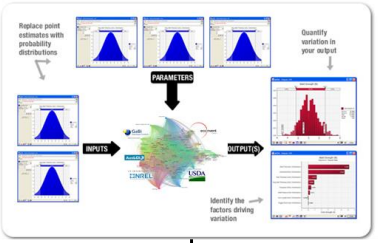


$$\phi(B)(1-B)^2 X_t = \theta(B) Z_t, \quad \{Z_t\} \sim WN(0, \sigma^2)$$

④ Weighting Element

$$\sum_{i}^{n} w_i + \sum_{j}^{m} w_j = 1 \qquad w_{ij}^{(absolute)} = \frac{D_{ij}^{(target)}}{D_{ij}^{(baseline)}}$$

⑤ Monte-Carlo Simulation

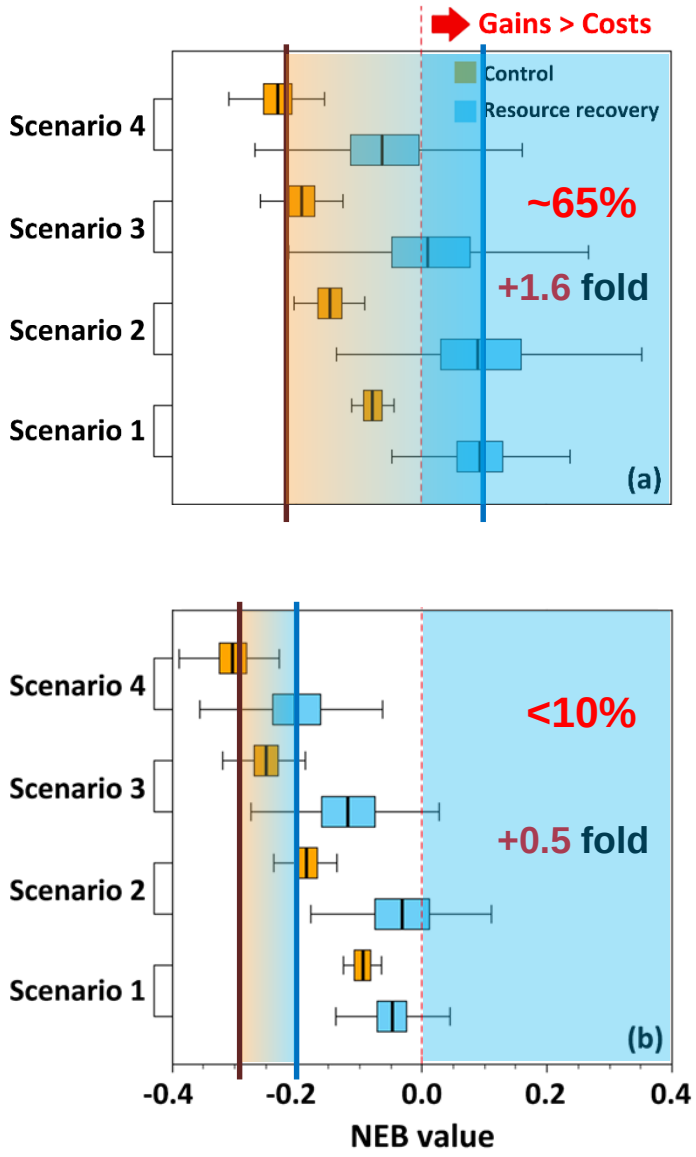


⑥ Quantitative Environmental Sustainability Assessment

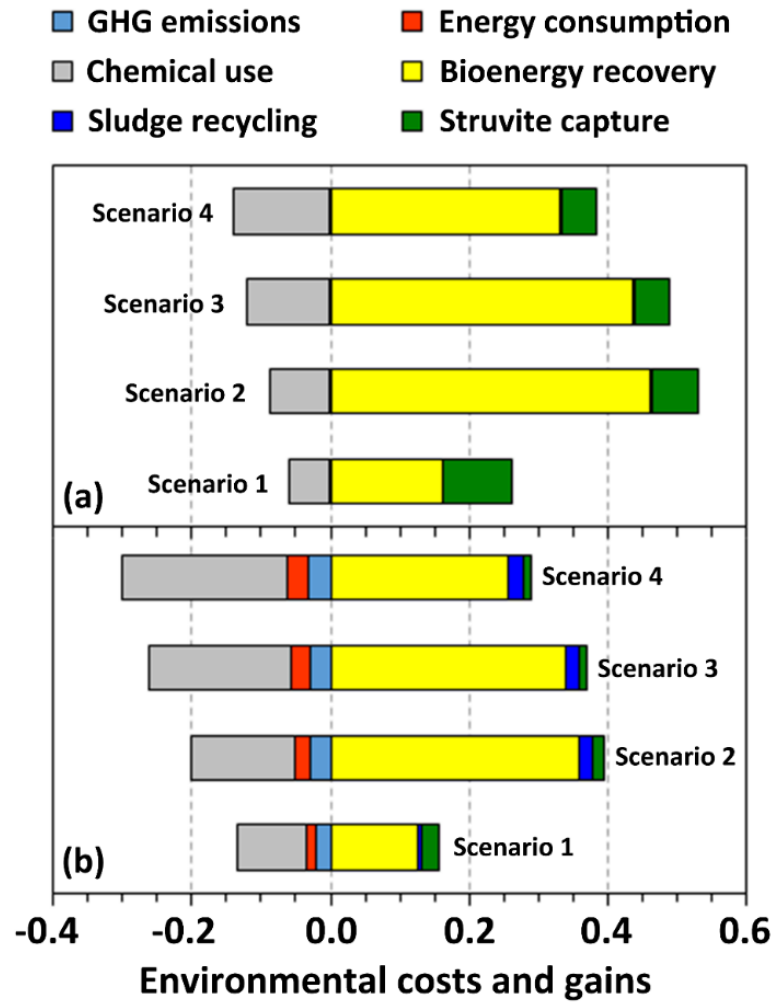
3D-WRRF Case 1: How best to ensure environmental sustainability

Developed countries

Developing countries



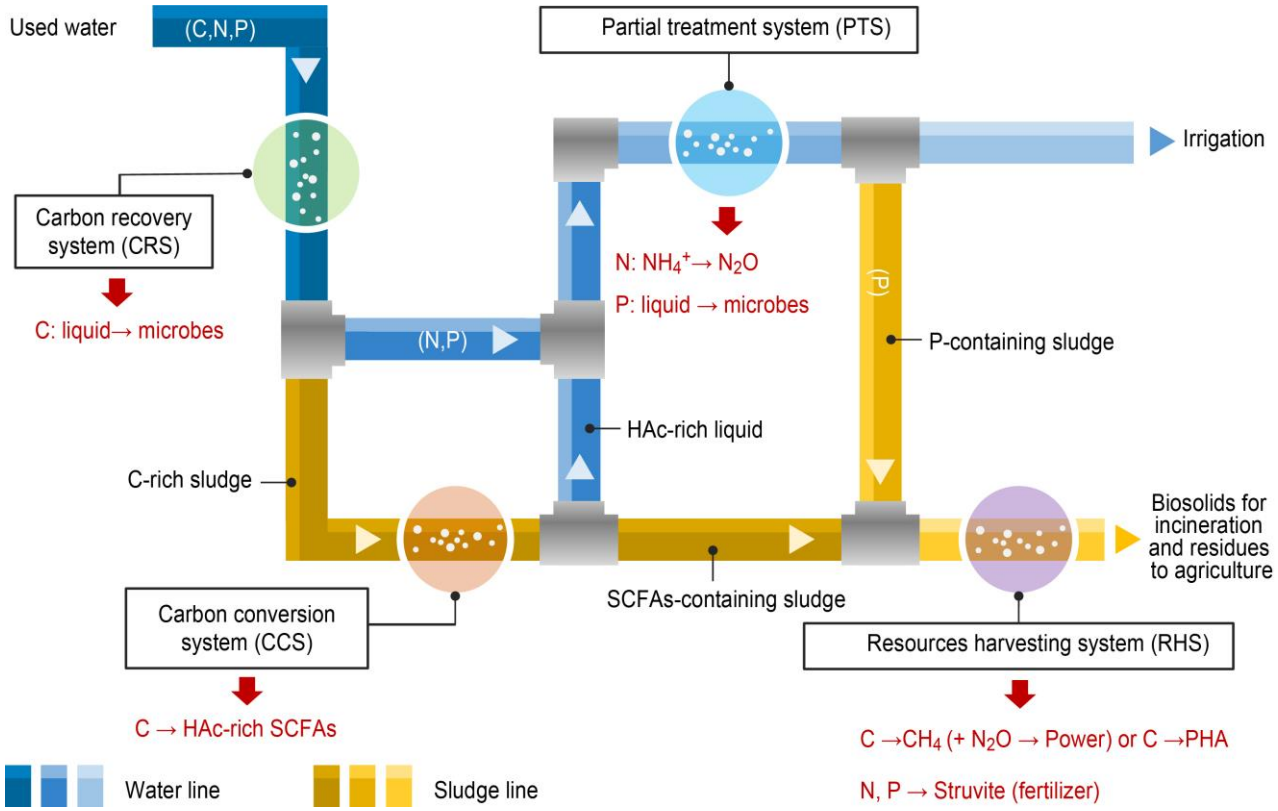
2020 forecasting



Wang et al, *PNAS*, 2015, 112(5), 1630-1635.

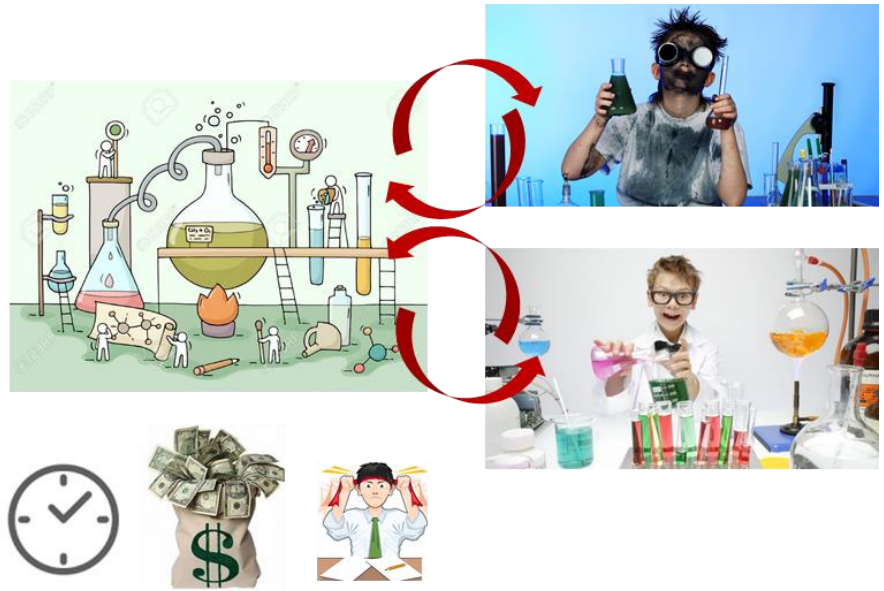
3D-WRRF Case 2: Enable fast design and full exploration of innovative new systems

From idea to reality? How to formulate?

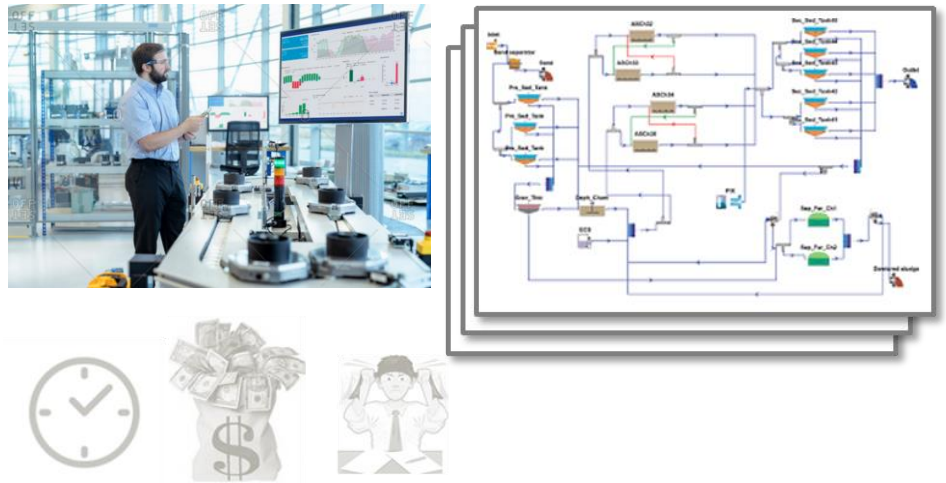


"REPURE (reuse pollutants from used-water as resources)"

Traditional: repeated trails

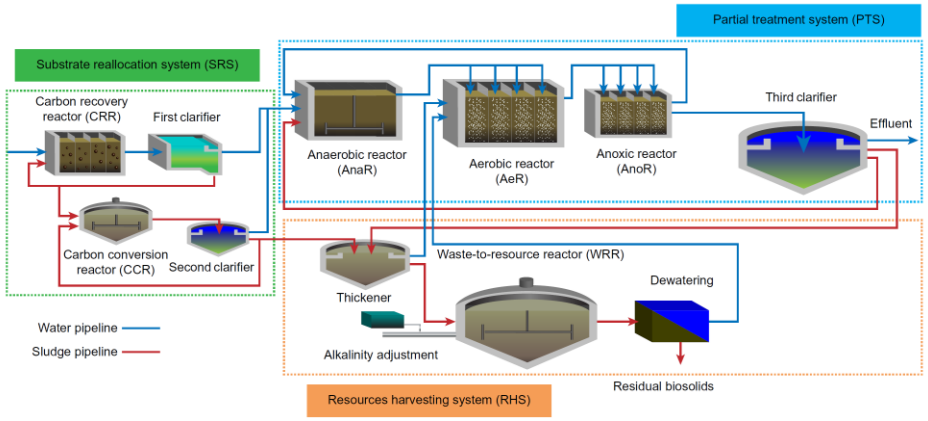


Alternate: data-driven simulations



3D-WRRF Case 2: Enable fast design and full exploration of innovative new systems

Tailored REPURE process configuration



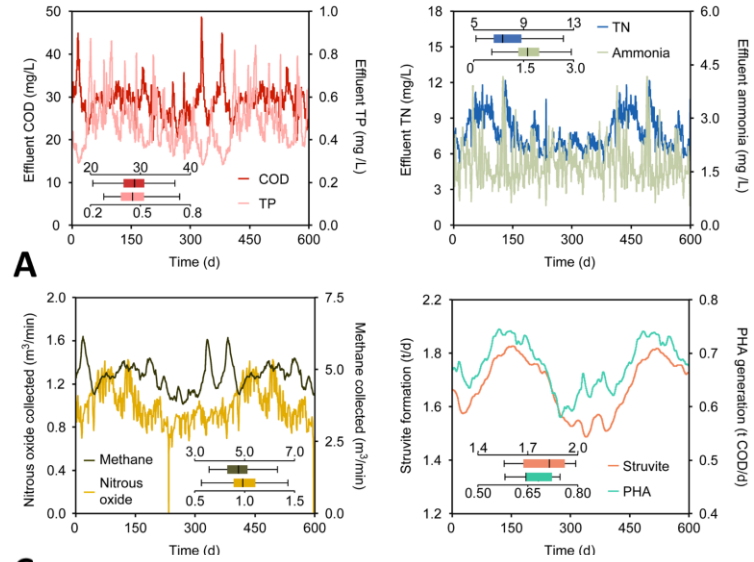
Multiple layers of data flows:

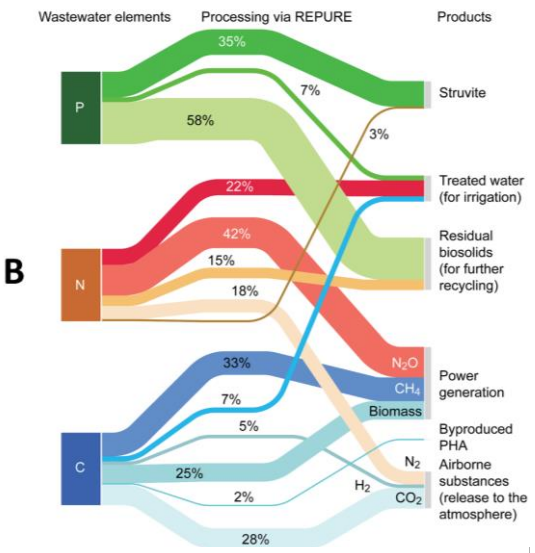
A. Long-term performance

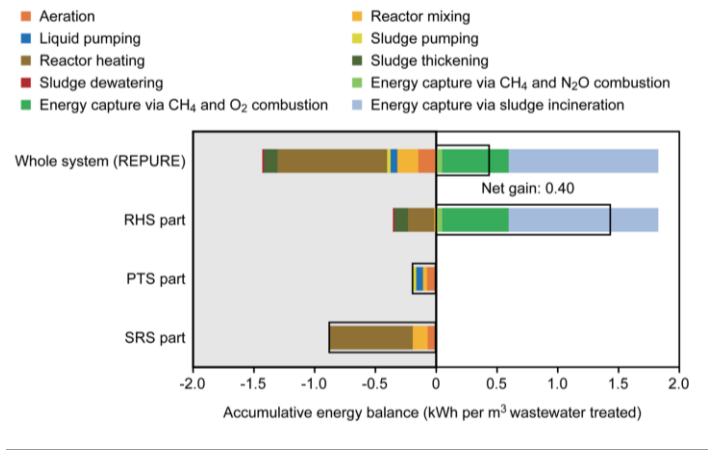
B. Intersystemic flows of substances

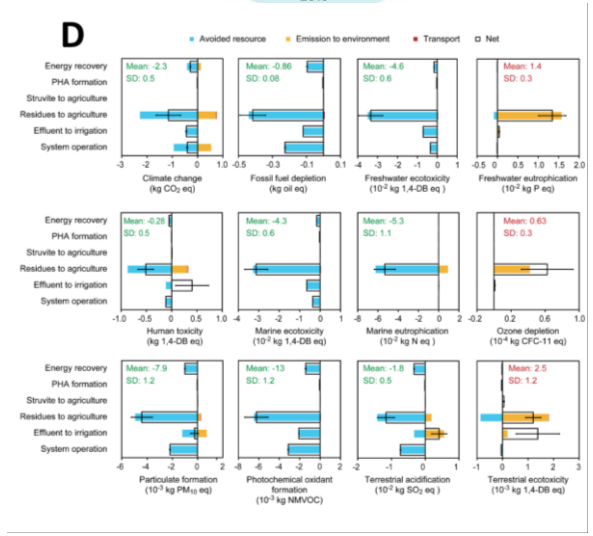
C. Energy balance and distribution

D. Life cycle environmental effects









Wang et al, *Science Advances*, 2018, 4, eaaq0210.

Take home message

- Data-driven approaches provide a promising foundation for dealing with emerging challenges and supporting fundamental changes in wastewater treatment and resource recovery facilities.

- Data-driven wastewater infrastructure allows us to design and use innovative new methods, to enhance the overall performance of the existing water technologies, and to extend functionality of today's systems.

- More research is needed to understand further the potentials and challenges.

Acknowledgement

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Thank you!

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