

Facilitating the Planning of integrated Water, Energy, Food, and Environment Systems through Open-source Software

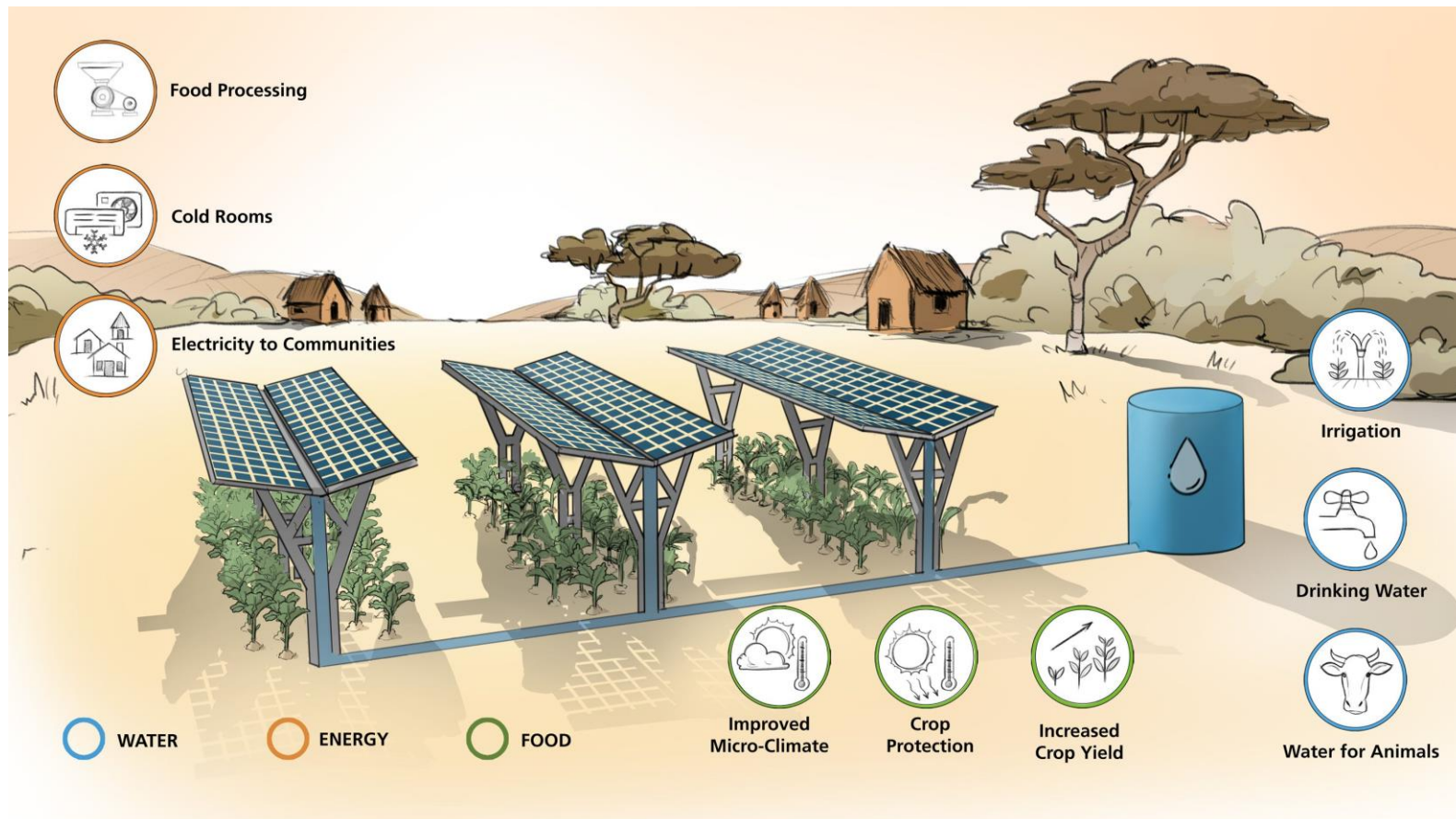
Doctoral Project – Julian Fleischmann

24.05.2023

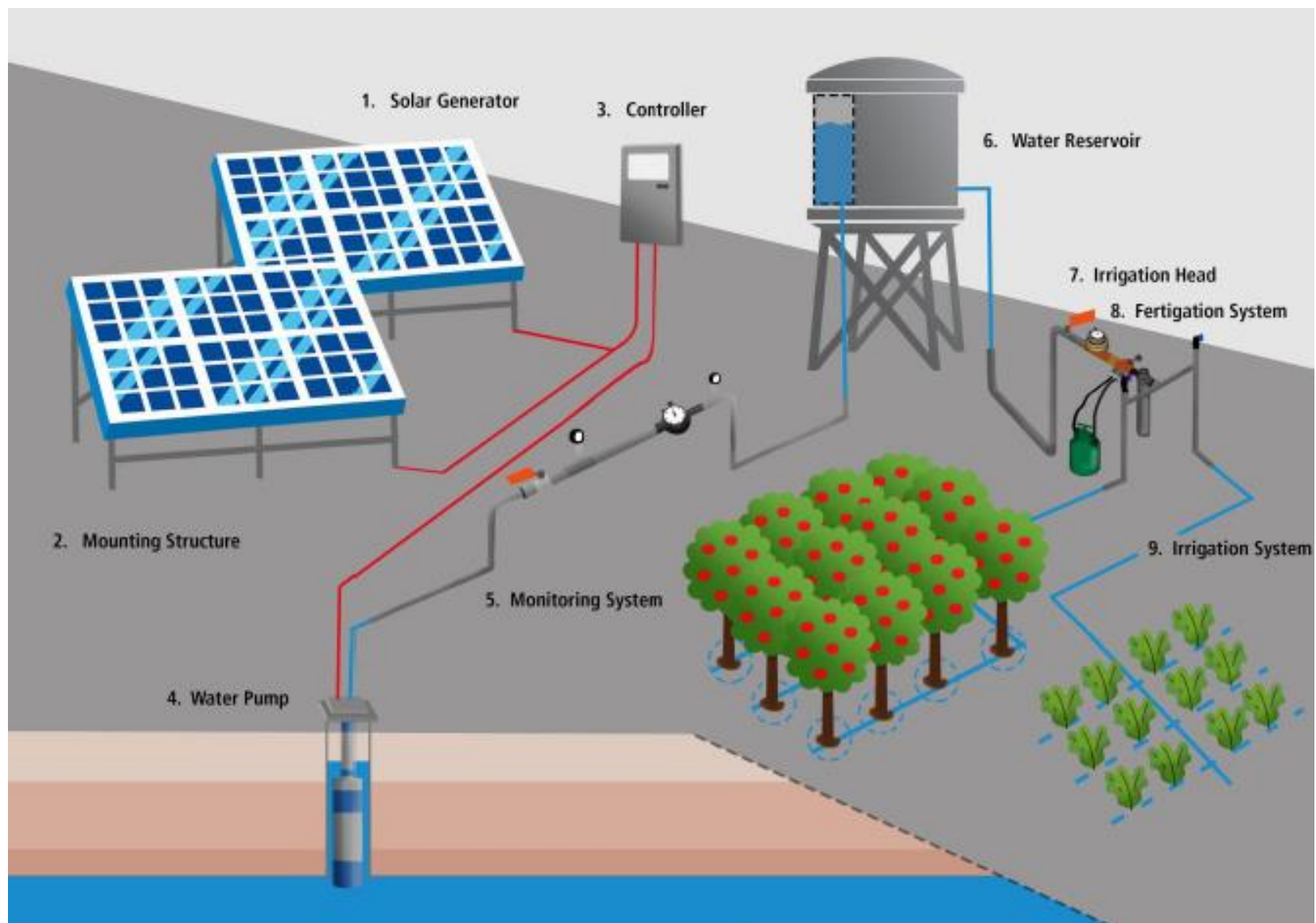
Examples for integrated water, energy, food, and environment systems

- Cross-sectoral integrated photovoltaics: for example floating photovoltaics and agrivoltaics Resource recovery from organic waste and wastewater
- Integrated microgrids for water-energy-food services
- Renewable-energy-powered water treatment
- Renewable-energy-powered irrigation
- Constructed wetlands
- Agroforestry
- Aqua- and Hydroponics

Agrivoltaics



Solar-powered Irrigation System

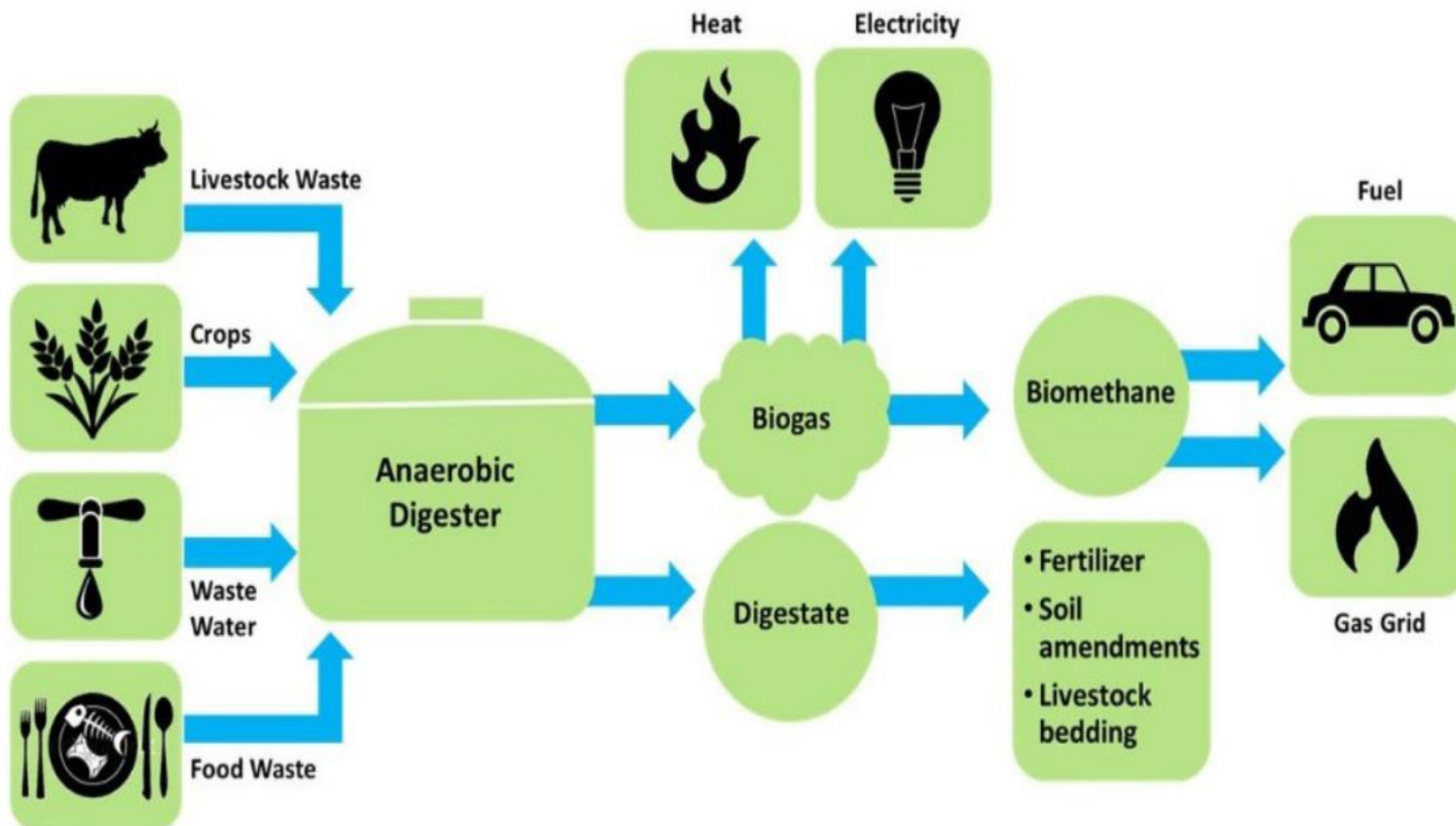


Water Treatment powered by Renewable Energy

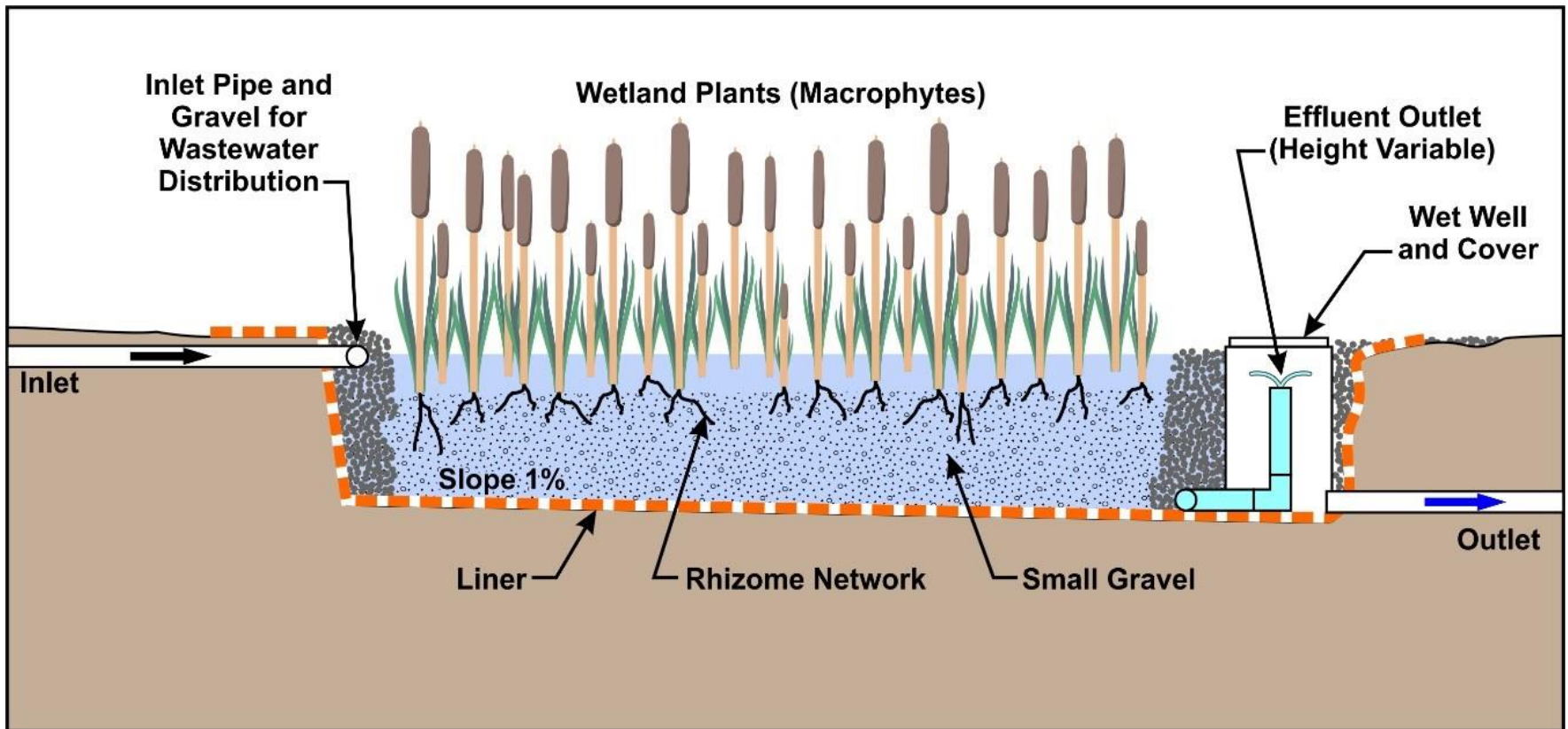


solar desalination plant, PV-RO, Mascara, Doha, UAE, (own photograph)

Biogas System: Converting Waste to Energy & Fertilizer



Constructed Wetlands



Agroforestry

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Factor	Process	(a) Forest ecosystem	(b) Agroforestry ecosystem	(c) Agricultural ecosystem
Canopy	Shading effect	Natural condition or little disturbance	Appropriate design and management of trees and crops	Intensive human disturbance and mechanical activity
	Carbon fixation			
	Intercept rainfall			
	Evapotranspiration			
	Raindrop energy			
	Splash erosion			
Trunk	Stemflow volume			
	Localized surface runoff and vertical percolation			
Ground	Intercept rainfall and protect soil			
	Runoff velocity and water erosion			
	Soil properties and soil biota			
Soil-root system	Root activity			
	Stabilize soil structure			
	Nutrients leaching			
	Soil organic matter			
	Soil physical and chemical property			
	Soil organism and enzyme activity			
	Safety-net effect			
	Groundwater contamination			
Services		Little runoff, erosion, and nutrient losses from the system	Little runoff, erosion, and nutrient losses from the system	Severe runoff, erosion, and nutrient losses from the system

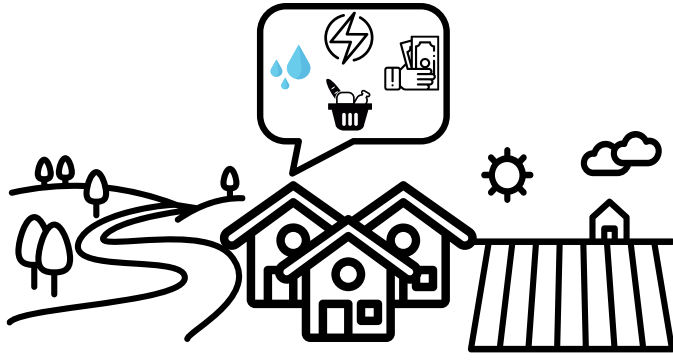
Gap and Objective

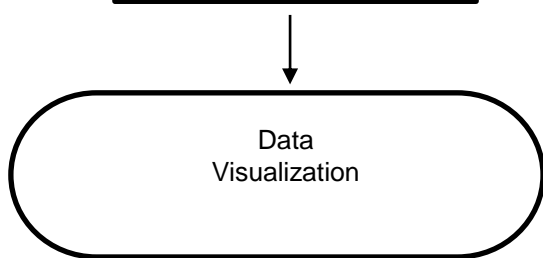
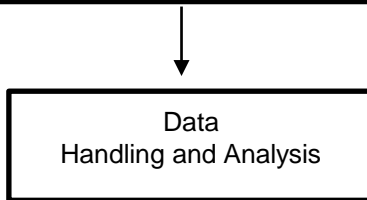
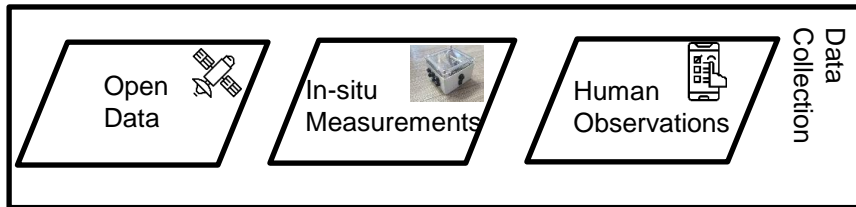
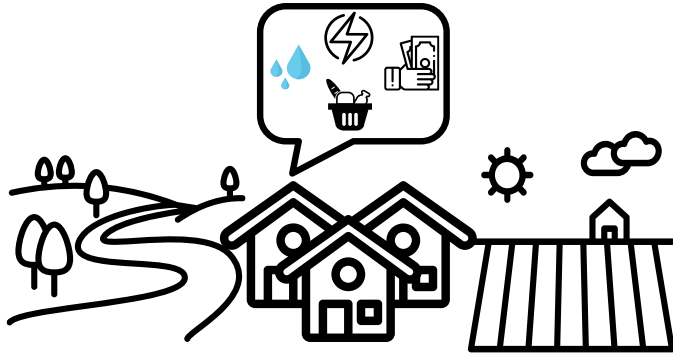
Gap:

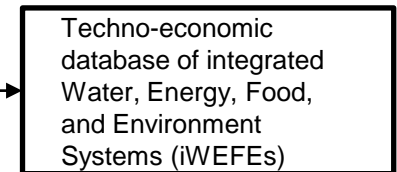
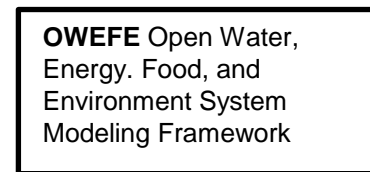
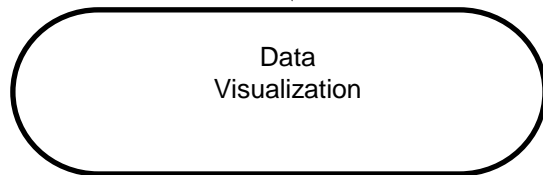
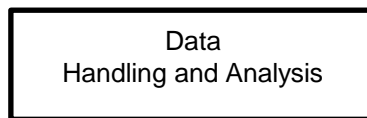
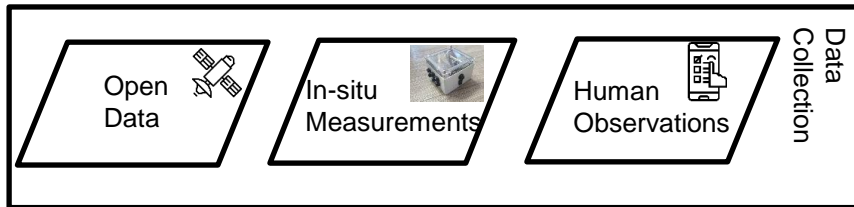
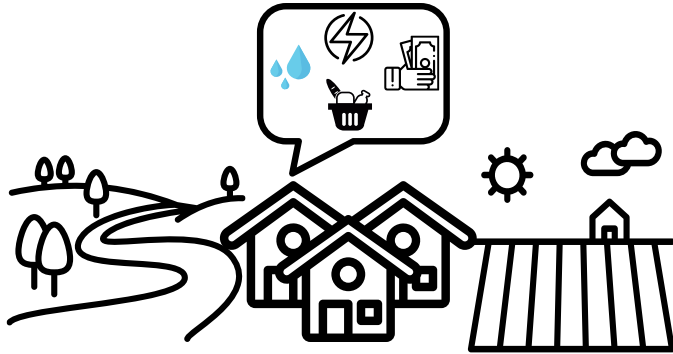
- Few cross-sectoral model and design approaches
- Low cross-sectoral data availability, especially in global south
- Low support for site-tailored technology selection and sizing

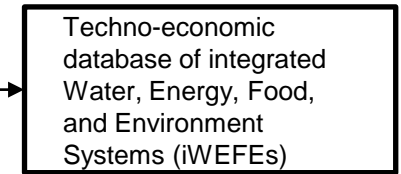
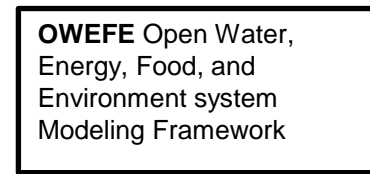
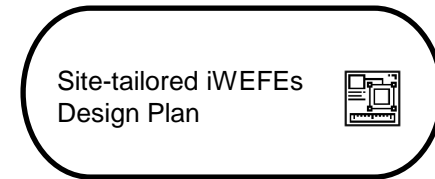
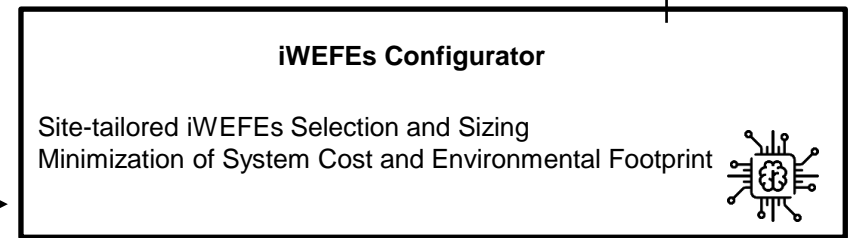
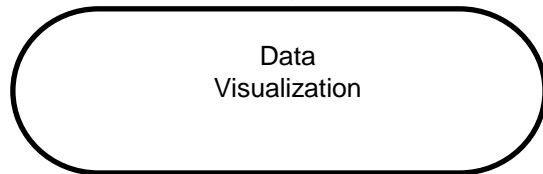
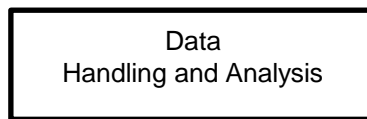
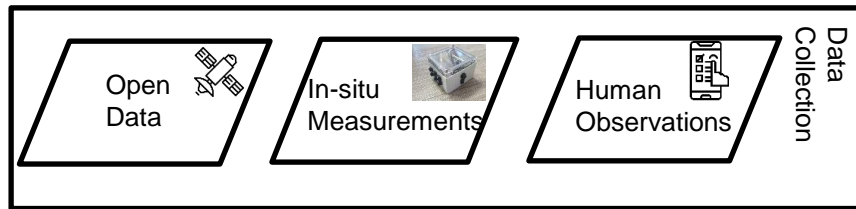
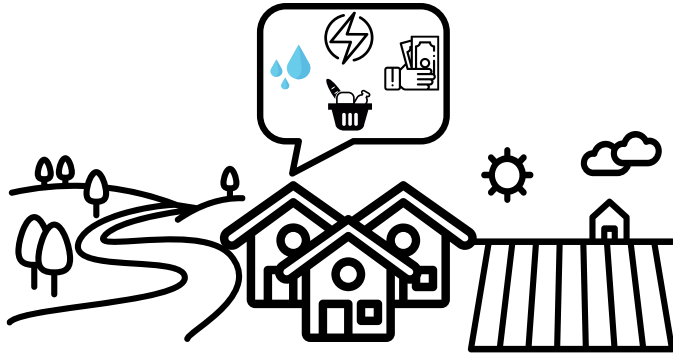
Objective:

Facilitating the planning of iWEFES to tap cross-sectoral WEF synergies & to meet basic human WEF demands while sustaining the environment and the climate

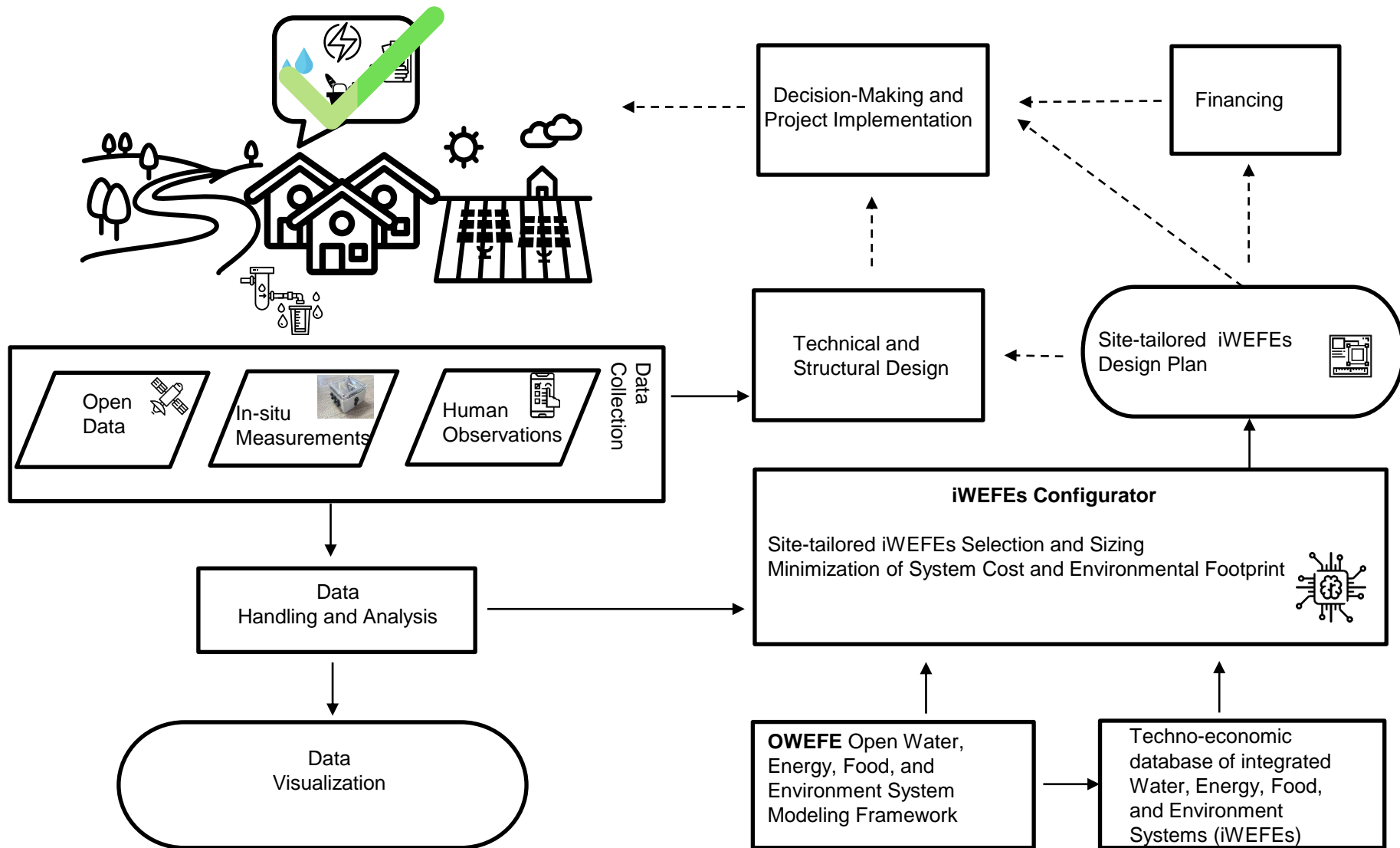








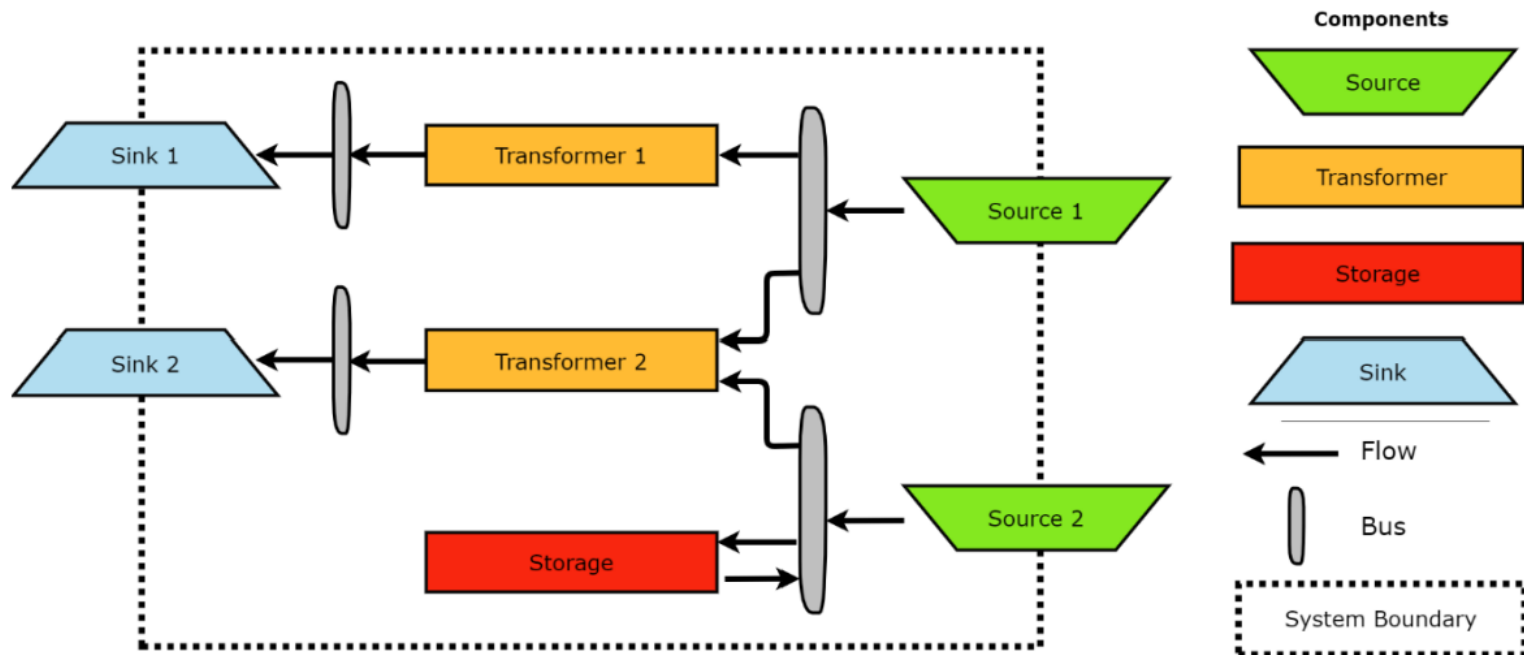
WEFE Site Analyst



Three main pillars of the doctoral project

1. Conceptualization of an Open Water, Energy, Food, and Environment System Modelling Framework based on oemof – **OWEFE**
2. Automatized WEFEE data collection and analysis – **WEFEE Site Analyst**
3. Development of a software-based configurator for site-tailored iWEFEs - **iWEFEs Configurator**

OWEFE – Open Modeling Framework for integrated water, energy, food, and environment systems



Find the project on GitHub

<https://github.com/rl-institut/OWEFE>

See the Publication

<https://iopscience.iop.org/article/10.1088/2634-4505/acbcee>

OWEFE is based on oemof

<https://github.com/oemof/oemof-solph>

Case Studies OWEFE Paper:

**Wastewater biogas production for a municipality in Lebanon &
Agrivoltaics in Germany**

Objective: Simulate iWEFEs for both cases and compare electricity and biomass production with conventional feasibility studies/measured values

Time step: hour

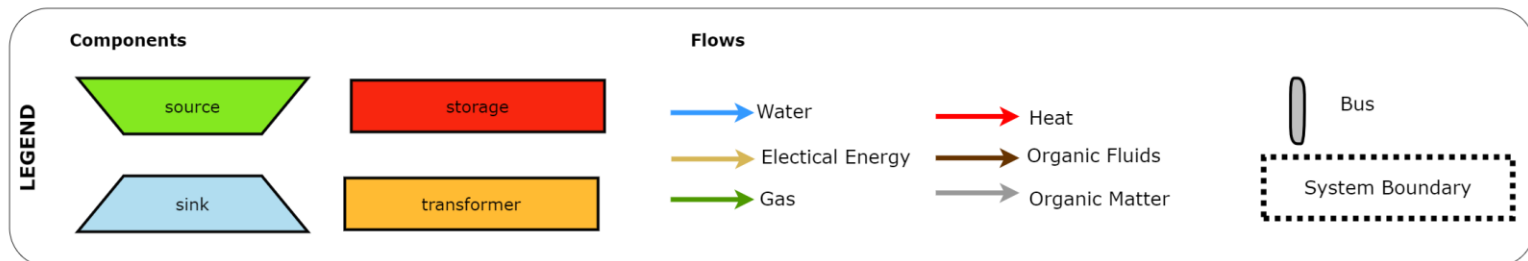
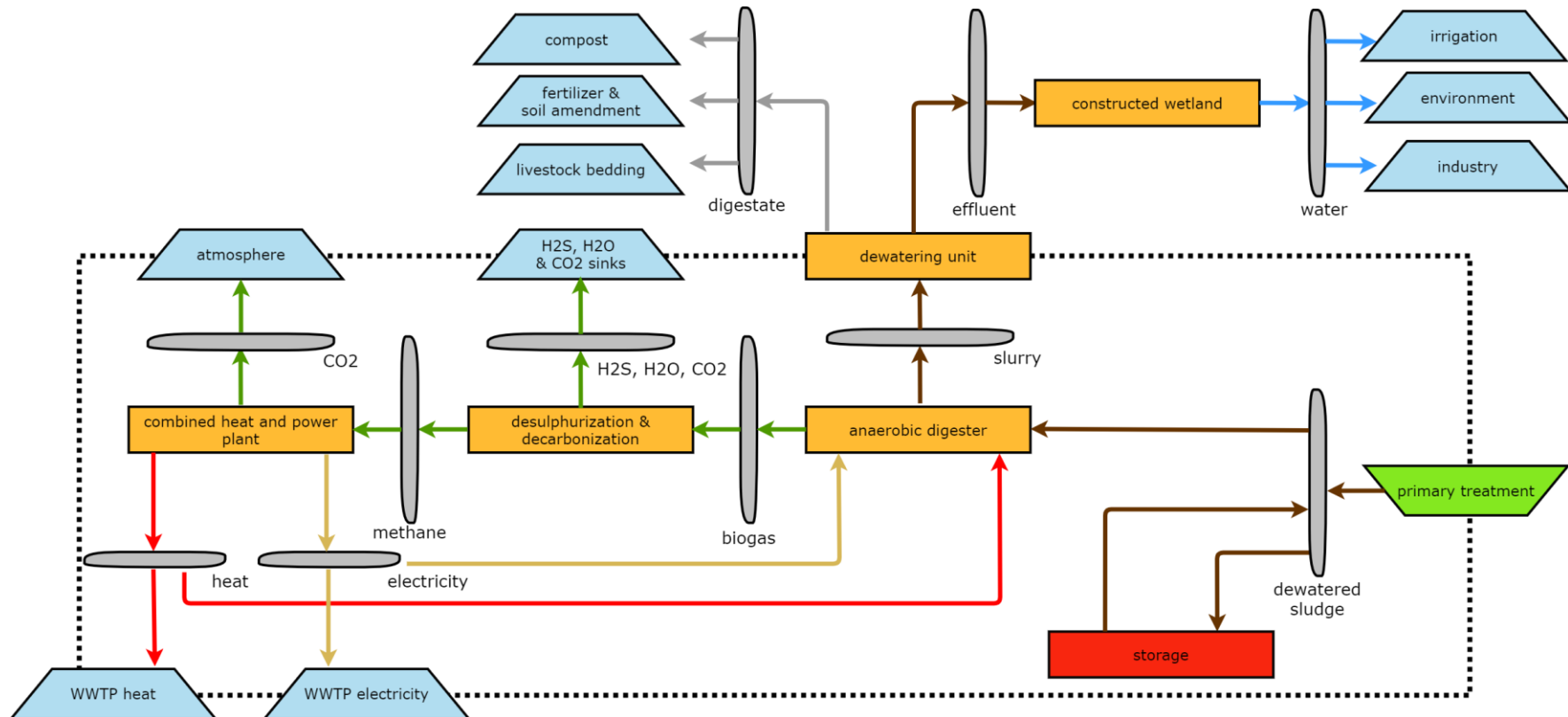
Temporal coverage: one year

Case Study 1:

WEFE interaction matrix for wastewater biogas systems

	Water	Energy	Food	Environment
Water	/	Wastewater is a source of renewable energy production	Dewatering slurry digestate which can be used as fertilizer, soil amendment, or livestock bedding, treated water can be used for irrigation	Reduction of environmental pollution reclamation of treated water to the environment, constructed wetlands as wildlife habitat
Energy	Energy for water pumping, treatment, and distribution of sludge	Thermal energy can be used for heating the digester, biogas power plant produce energy flexibly	Biogas or electricity can be used as fuel for agricultural machinery	Biogas to methane conversion releases hydrogen sulfide, combustion of methane emits CO_2 to the atmosphere
Food	Food and agricultural wastes are carried by water	Food waste is a source of biogas/renewable energy production	Food remnants can be used for keeping the soil fertile/	Food and agricultural wastes pollute the environment
Environment	Precipitation affects wastewater quantity	Temperature affects the heat demand of the digester	Climate affects wastewater sludge density	/

Case Study 1: Flowchart wastewater biogas production



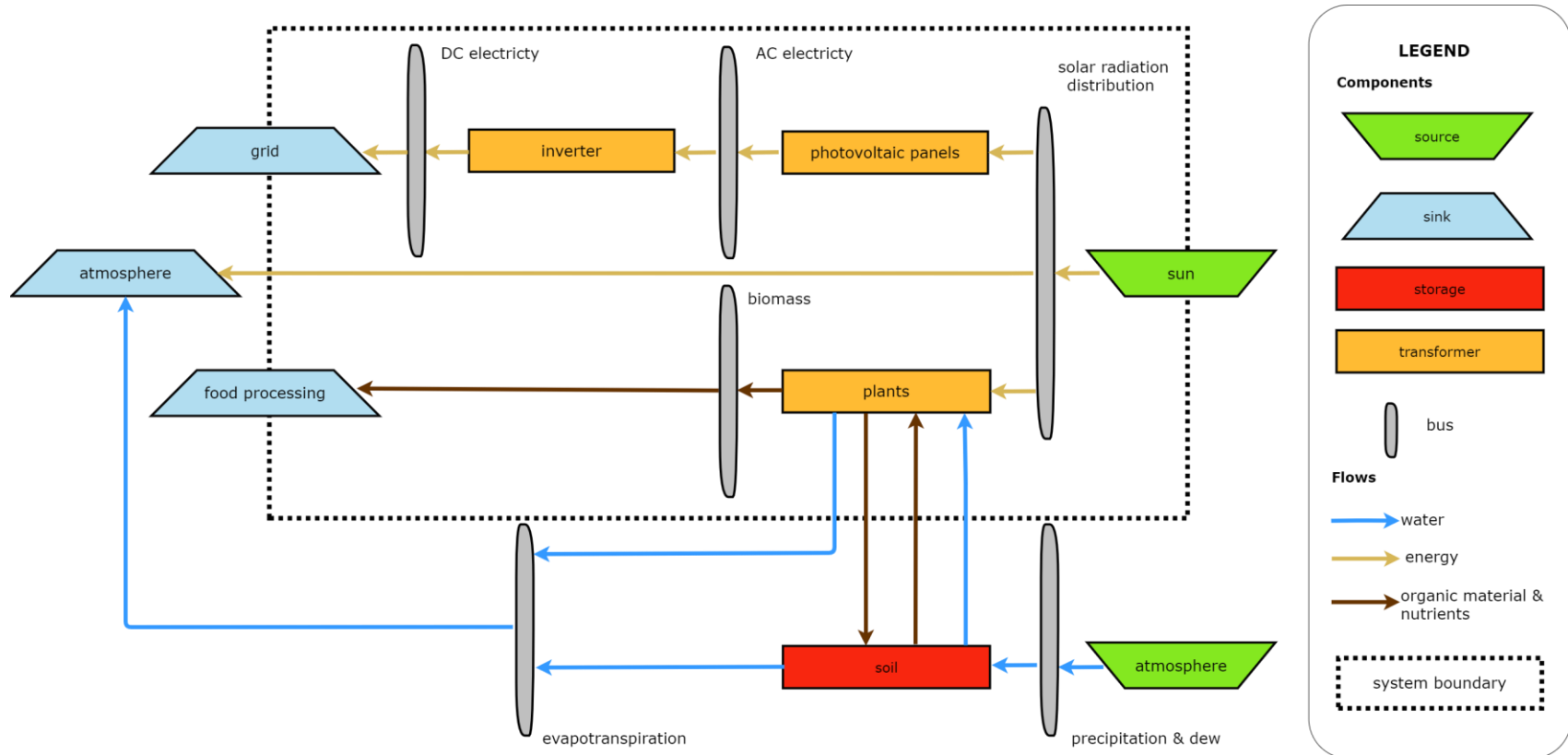
Case Study 1: Biogas reactor design and simulation results: OWEFE and Izmerly et al (2021), annual sums (2020)

Parameters	OWEFE	Izmerly et al. (2021)
Biogas reactor type	CSTR	CSTR
Total active volume of digester [m ³]	50.65	51.39
Design flow rate [m ³ /d]	1.69	1.71
Organic loading rate [kgVS/m ³]	3.56	3.56
Minimum sludge storage requirement [m ³]	82.13	-
Methane Production [m ³ /a]	22393	22719
Electrical Energy Production [MWh/a]	58.73	59.39
Electricity Demand Digester [MWh/a]	17.75	18.13
Net Electricity Production [MWh/a]	40.98	41.27
Heat Production [MWh/a]	123.14	-
Net Heat Production [MWh/a]	100.79	-
Heat Demand Digester [MWh/a]	22.35	19.86
Electrical Energy Demand WWTP [MWh/a]	412	412
Electrical Energy Recovery Potential [%]	9.95	10.02

Case Study 2: WEFE interaction matrix for agrivoltaics systems

	Water	Energy	Food	Environment
Water	/	<i>Rainwater harvesting can be implemented on panel surfaces</i>	Increased retention of water improves crop water content and plant available water for higher food yield	<i>Improved water availability may support flora and fauna</i>
Energy	Electrical energy from panels can be used to pump, treat, and distribute water for irrigation and household use	Bifacial panels increase energy outputs (in the current case study)	Shading of photovoltaic panels reduces heat stress and sunburns of plants, electricity for food processing	<i>Deployment of photovoltaic panels reduces CO2 emission from electricity production</i>
Food	The introduction of plants changes the local water cycle	<i>Plant-induced transpiratory cooling increases the efficiency of solar panels, reduced soiling through plants covering the soil</i>	/	<i>Land coverage through an agrivoltaics system reduces soil erosion, increased land productivity lowers pressure on ecosystems</i>
Environment	The micro-environment of the agrivoltaics system increase soil and plant water retention time	<i>Soiling lowers the efficiency of solar panels</i>	Environmental site conditions determine optimal crop selection	/

Case Study 2: Flowchart Agrivoltaics



Plant Model in OWEFE

$$F_{\text{biomass}} = F_{\text{ghi}} * \text{RUE} * e_{\text{shading}} * e_{t_{\text{air}_{\text{APV}}}} * e_{\text{heat}} * e_{\text{water}}$$

F_{biomass} : The biomass production [g/h*m²]

F_{GHI} : global horizontal radiation [MJ/h]

e_{shading} : shading [%]

$e_{t_{\text{air}_{\text{APV}}}}$: effect air temperature below the photovoltaic panels [%]

e_{water} : effect of soil water availability [%]

e_{heat} : effect of heat stress [%]

RUE: Radiation use efficiency of the specific crop type [g/(MJ·m²)]:

Case Study 2: Simulation results for Agrivoltaics OWEFE Model

Parameters	OWEFE	Reference Values at Case Study Hegelbach
Shading factor, $e_{shading}$ [%]	70.0	69.1
Optical bifacial gain. $e_{bifacial}$ [%]	12.6	13.5
Electrical energy production [MWh/a]	241.09	249.86
Yield (wheat harvest) [g/(a*m ²)]	439.34	474.78

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iWEFEs Configurator Concept

Open software for the configuration of integrated water, energy, food, and environment systems (iWEFEs) following a two-step approach:

1. Selection of suitable solution(s) using iWEFEs application range matrix
2. Site-tailored sizing of iWEFEs using multi-objective optimization (Cost, Environmental Impact (CO₂-Emission, Water Footprint)

iWEFEs configurator: Characteristics wishlist

- Open-source code and open-access application
- **Two- step design approach:**
 - 1) Automatized selection of suitable iWEFEs combinations
 - 2) System Sizing
- **Multi-objective optimization:** Minimization of Cost, CO₂-Emission, and Water Footprint
- Model of complex WEFE components, processes, and interactions like plant growth, and the microclimatic effects within agrivoltaics systems
- **Easy GUI**, app shall be usable without need for software development and technical background
- Desktop and mobile-phone **app**

Challenges

Configurator Software Concept & Development

- automatized selection of suitable iWEFEs combinations
- support of multi-objective optimization
- non-linear relations or smart ways of linearization
- GUI & App Development
- Support of AI-based algorithms
- machine learning

Thank you for your feedback!!

-> <https://forum.openmod.org/t/challenges-for-development-of-configurator-based-on-integrated-water-energy-food-and-environment-systems-based-on-oemof/3573>

Case Studies Colombia

Case Studies

Case Study 1: Arusi, Chocó

Case Study 2: Hotel Aiwa, la
Guajira

Case Study 3: La Raya, la
Guajira

Case Studies for the
development of integrated
water, energy, food, and
environment systems



Case Study Chocó - Arusi



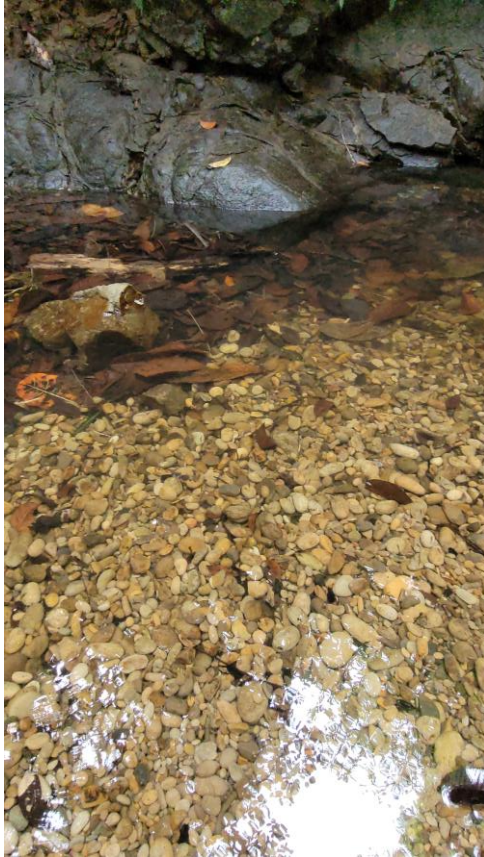
Case Study Arusi - Electricity



Case Study Arusi - Electricity



Case Study Arusi - Water



Case Study Arusi - Water



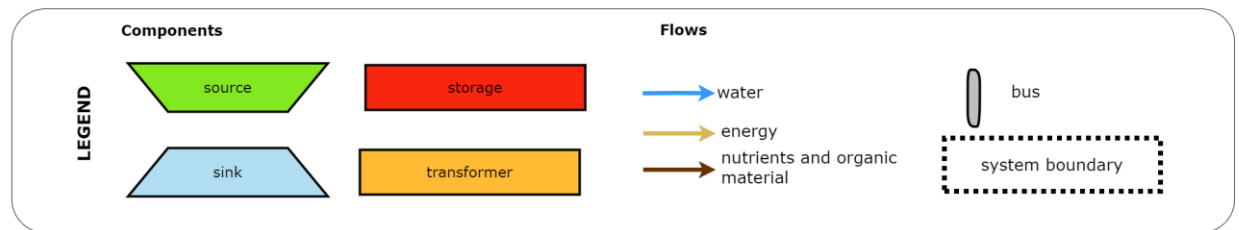
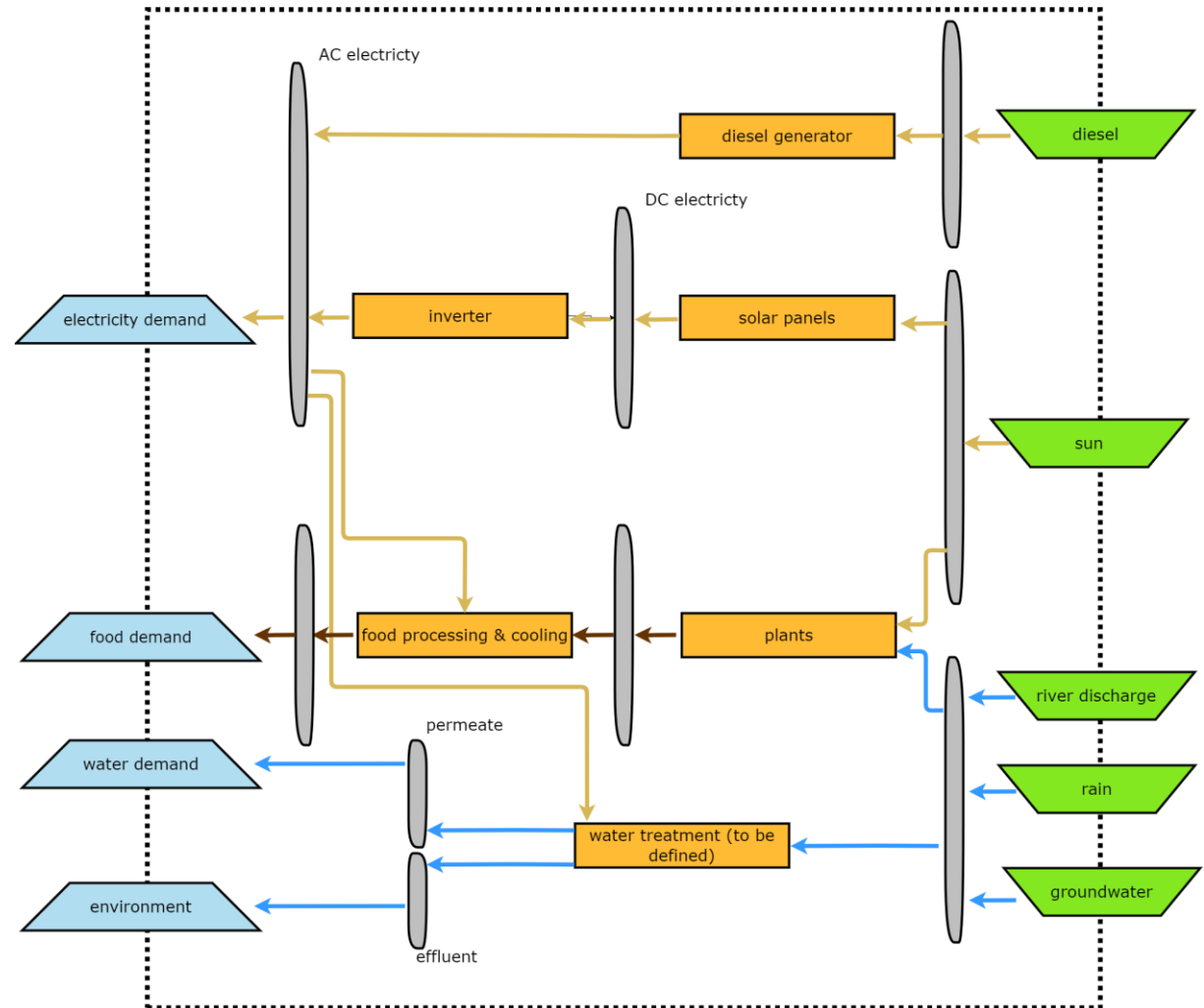
Case Study Arusi



Case Study Arusi – Environmental Pollution



Potential Topology of iWEFE system in la Guajira, Chocó, Colombia



Case Study la Guajira – Comunidad la Raya



Case Study la Guajira – Water



Case Study la Guajira – Water



Case Study la Guajira - Water



Case Study la Guajira – Water



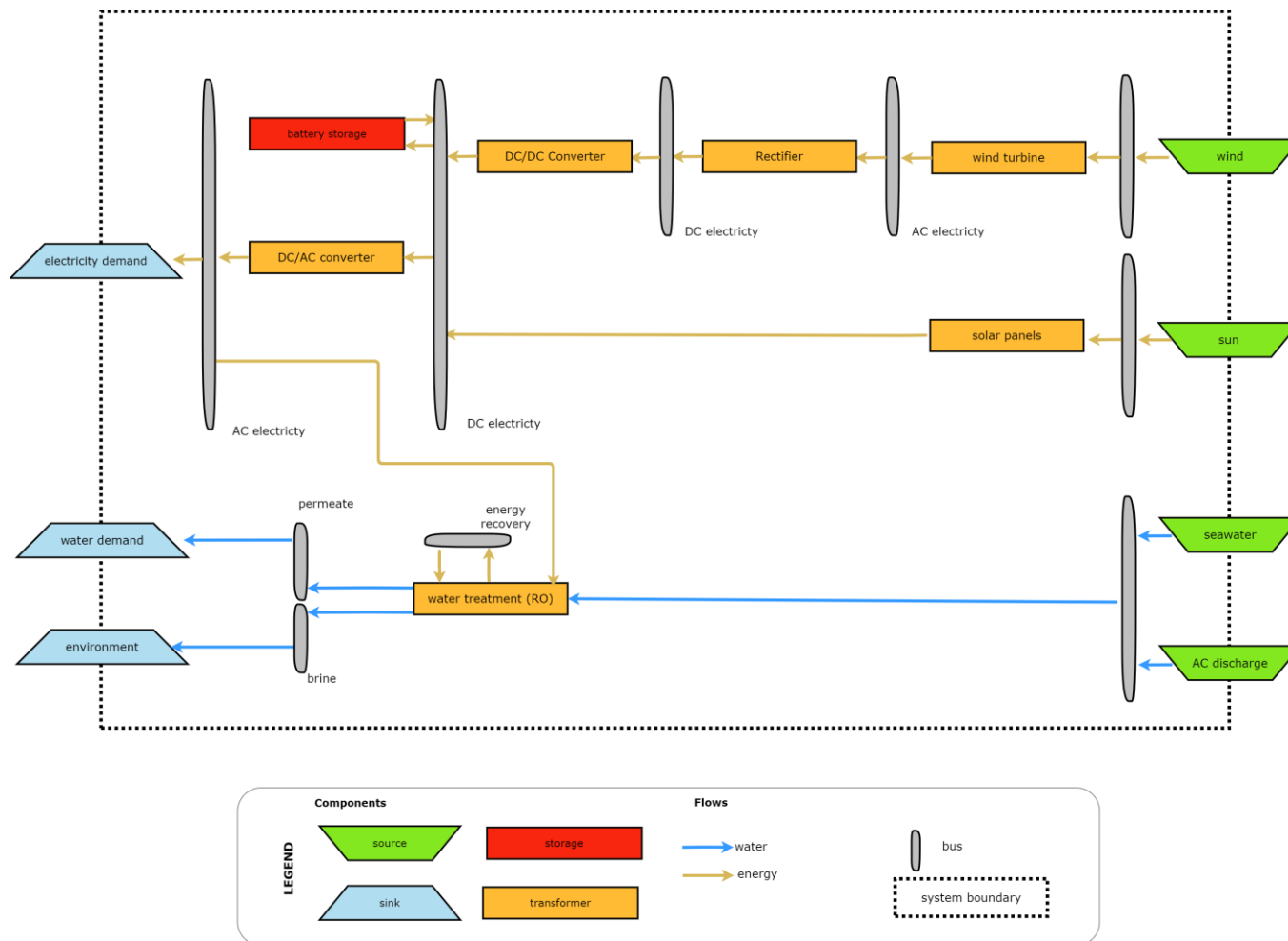
Case Study la Guajira – Comunidad la Raya - Environment



Case Study la Guajira – Hotel Aiwa, Maiapo



Potential topology of iWEFE system in Hotel Aiwa, la Guajira, Colombia



Thank you for your attention!

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OWEFE: <https://github.com/rl-institut/OWEFE>,
<https://doi.org/10.1088/2634-4505/acbcee>

WEFESiteAnalyst:
<https://github.com/JulianBarinton/WEFESiteAnalyst>



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