CMET
Center for Microbial Ecology and Technology

CAPTURE
Centre for Advanced Process Technology for Urban REsource recovery

FACULTY OF BIOSCIENCE ENGINEERING

# High resolution assessment of water production and reuse driven by on-site electricity production

## A Simulink modelling approach available as standalone application

Seppe Ongena 21/10/24

De Watergroep

Image credit: WRF

# Contents (click for link)



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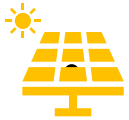
# What is it for?

High temporal resolution (15 min) simulation of household

- Diurnal water usage patterns
- Water balance: incoming precipitation, storage tanks, usage, and infiltration
- Simplified treatment simulation: removal efficiency, energy use, design flow, recovery

→ Adding commercial technologies based on “specsheet”



Renewable energy (PV) simulation for pumping + treatment

- Energy use: prioritized between demanding treatments
- Grid electricity: back-up
- Battery can be used
- Built-in simple PV and cloud models if data is unavailable

Rapid simulation: 30±10s for 10 years @ 15 min resolution

(depends on hardware platform)

# What is it for?

High flexibility:

- Direct use of city water → from centralized to extremely decentralized
- Scalable from single household to district level (e.g. weighted rain correction factor for roads vs. roofs, increased pump energy for greater distances,…)

High modifiability: easily choose streams to reuse and for which applications

Standalone app (.exe) with user interface

- Built-in key performance indicators (KPI) for scenario analysis
- Scheme automatically adapts to user input
- Simulation results displayed in graphs
- Results, settings, and graphs savable to file

# What is it ***not*** for?

Complex modeling of wastewater treatment

- e.g. distinction between recalcitrant and degradable organics not *currently* possible
- Degradation is implemented in model code, but not released in app

Design tool for dimensioning volumes/treatments/photovoltaics

- Not straightforward *currently*
- Main focus = scenario comparison
- Possible through trial-and-error
- Future “design mode” potential

Smart control of rainwater tank refilling/emptying (e.g. RainPlus project)

- Full refill when empty
- Implementation of more dynamic control possible in future

OPEX/CAPEX estimation

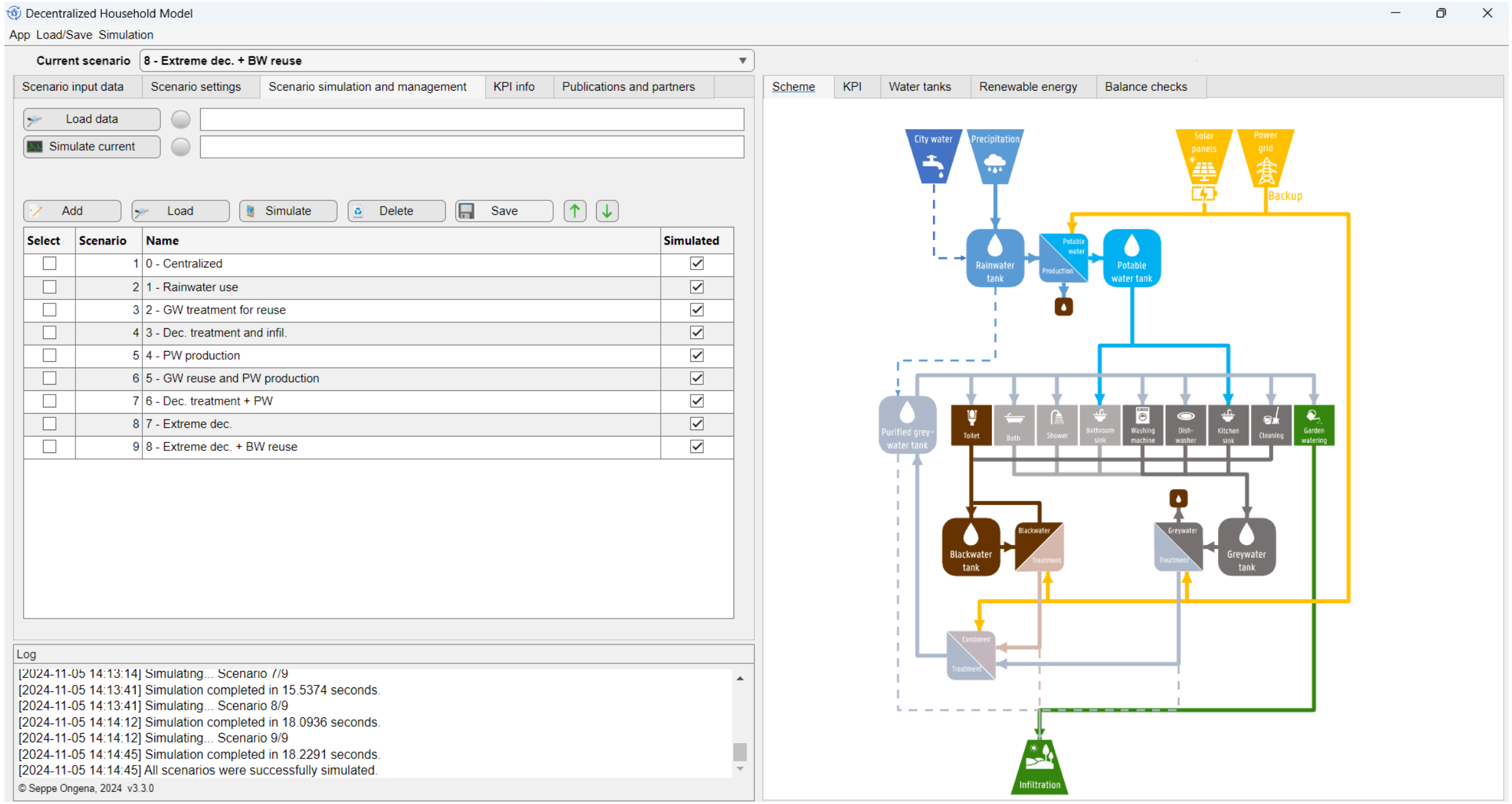
# Decentralized closed loop – C++ model

- 90% of model code written in C++, MATLAB for data pre-processsing, output visualization, app,…

- Leveraging class/object-based programming, e.g., rainwater tank is an object of the `tank` class

- Main code loop based on on/off control system with hysteresis (e.g. treatment flows between tanks) which reacts to perturbations (precipitation and water use), followed by water and pollutant balances to verify model correctness

# App layout


Decentralized Household Model
App Load/Save Simulation
Current scenario
8 - Extreme dec. + BW reuse
Scenario input data
Scenario settings
Scenario simulation and management
KPI info
Publications and partners
Load data
Simulate current
Add
Load
Simulate
Delete
Save
Select
Scenario
Name
Simulated
1 0 - Centralized
2 1 - Rainwater use
3 2 - GW treatment for reuse
4 3 - Dec. treatment and infil.
5 4 - PW production
6 5 - GW reuse and PW production
7 6 - Dec. treatment + PW
8 7 - Extreme dec.
9 8 - Extreme dec. + BW reuse
Log
[2024-11-05 14:13:14] Simulating... Scenario 7/9
[2024-11-05 14:13:41] Simulation completed in 15.5374 seconds.
[2024-11-05 14:13:41] Simulating... Scenario 8/9
[2024-11-05 14:14:12] Simulation completed in 18.0936 seconds.
[2024-11-05 14:14:12] Simulating... Scenario 9/9
[2024-11-05 14:14:45] Simulation completed in 18.2291 seconds.
[2024-11-05 14:14:45] All scenarios were successfully simulated.
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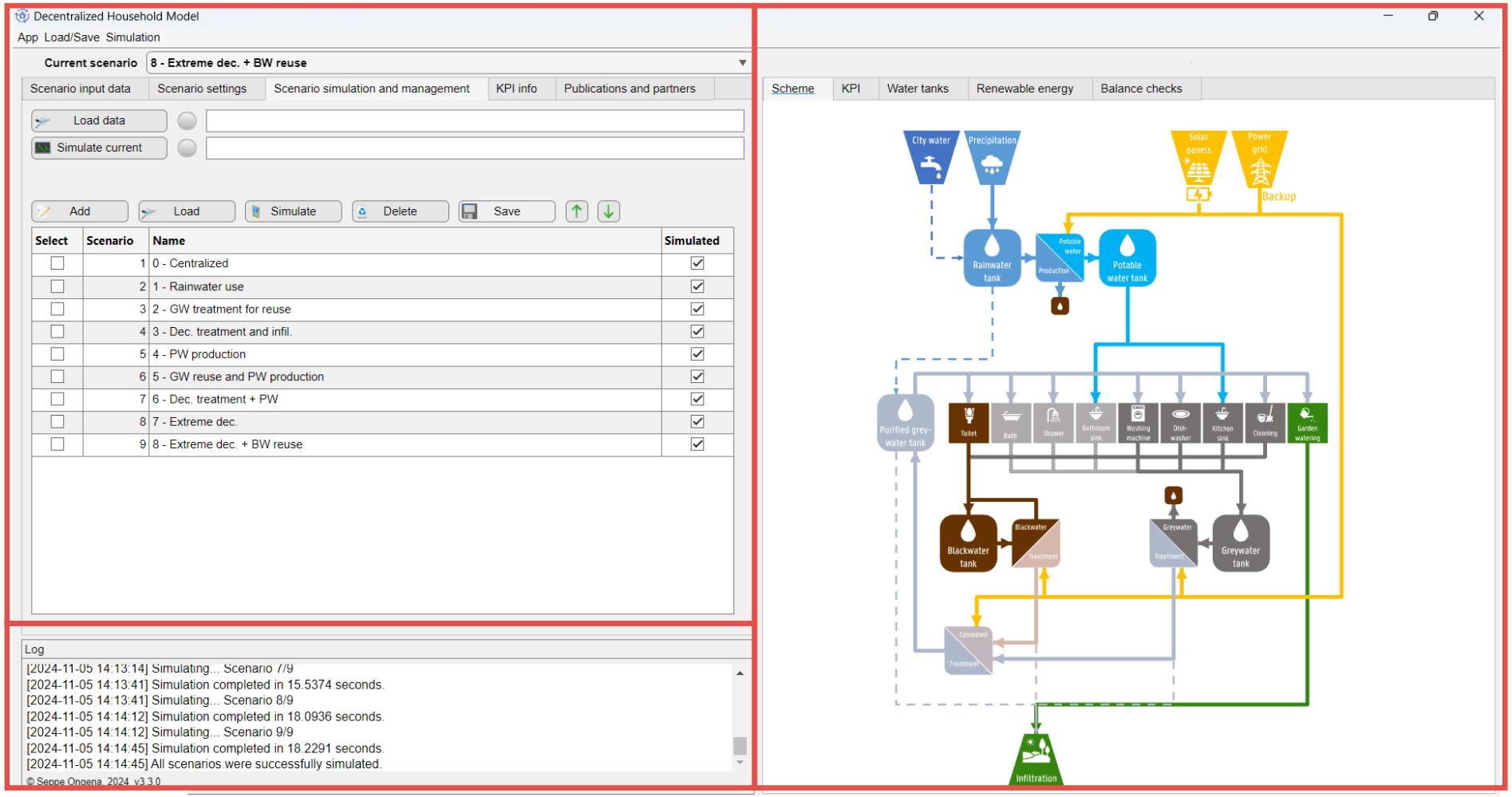
Scheme
KPI
Water tanks
Renewable energy
Balance checks
City water
Precipitation
Solar panels
Power grid
Backup
Rainwater tank
Potable water
Production
Potable water tank
Purified grey-water tank
Toilet
Bath
Shower
Bathroom sink
Washing machine
Dish-washer
Kitchen sink
Cleaning
Garden watering
Blackwater
Treatment
Blackwater tank
Greywater
Treatment
Greywater tank
Combined
Treatment
Infiltration

# Main Interface

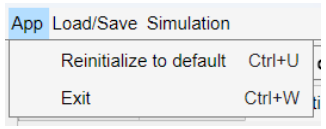
## 1.0 User input side (changing settings, scenario's,…)

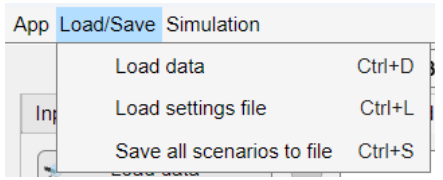
## 2.0 Graph side (display results, current scheme,…)

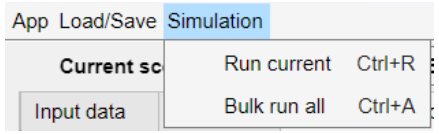



## Log (simulation progress, errors, info,…)

# 1.0 User input side




Main menus (quickly select actions, shortcut keys possible)

Tab selector

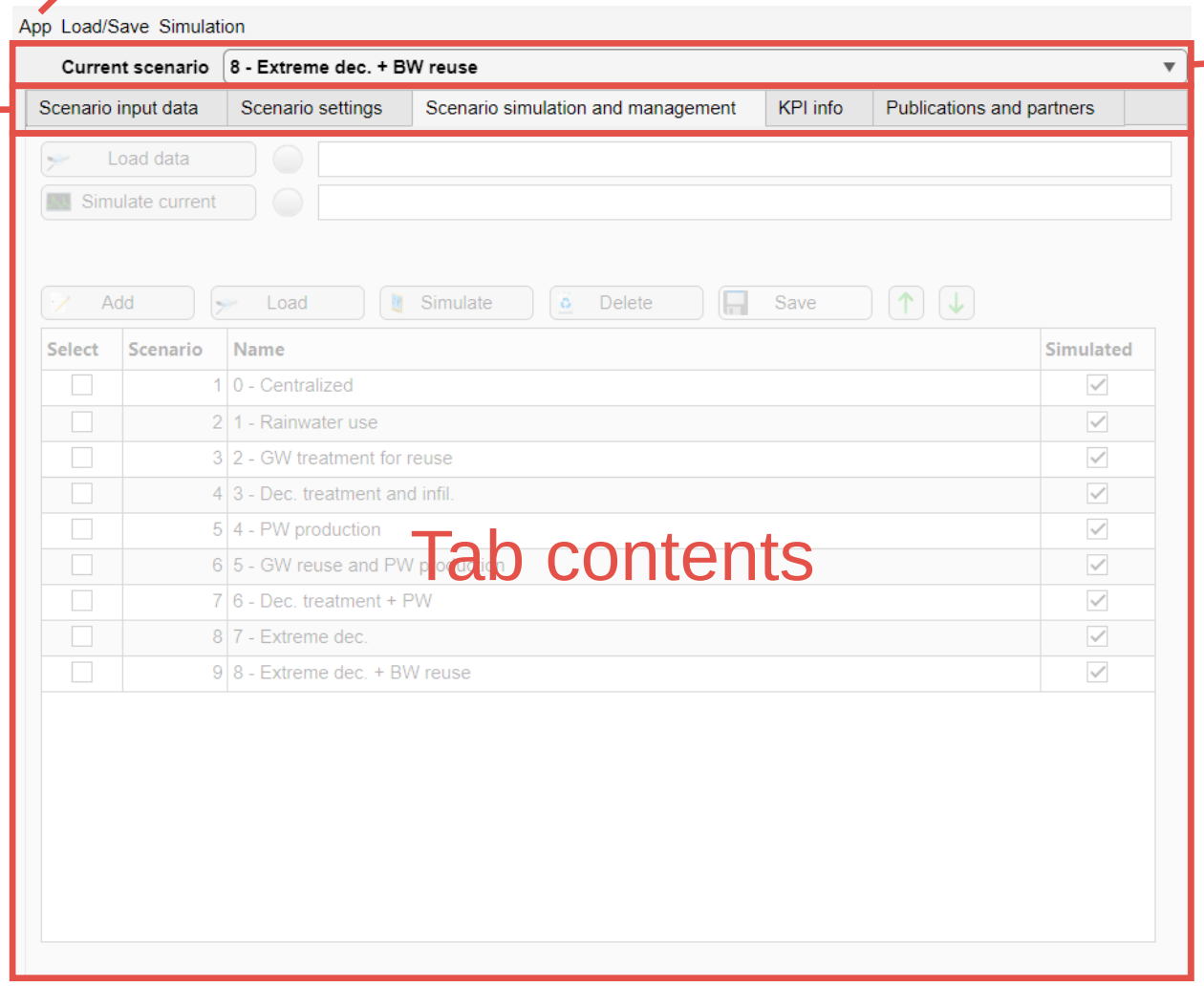
1.1 Scenario input data

1.2 Scenario settings

1.3 Scenario simulation and management

1.4 KPI info

1.5 Publications and partners



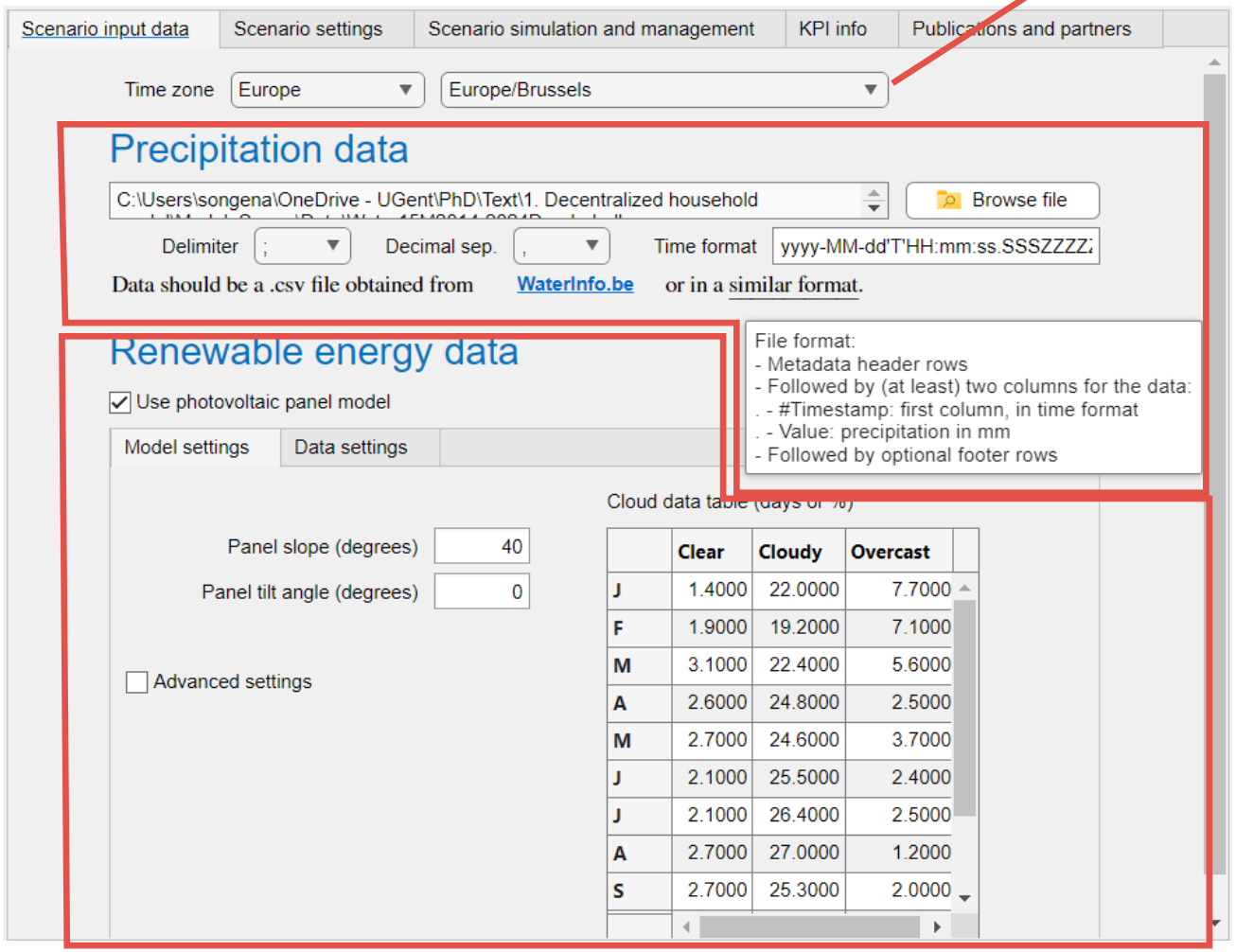

Tab contents

Scenario selector

select scenario for editing, copying settings to new scenario, displaying plots,…

# 1.1 Scenario input data

Timezone for data reading



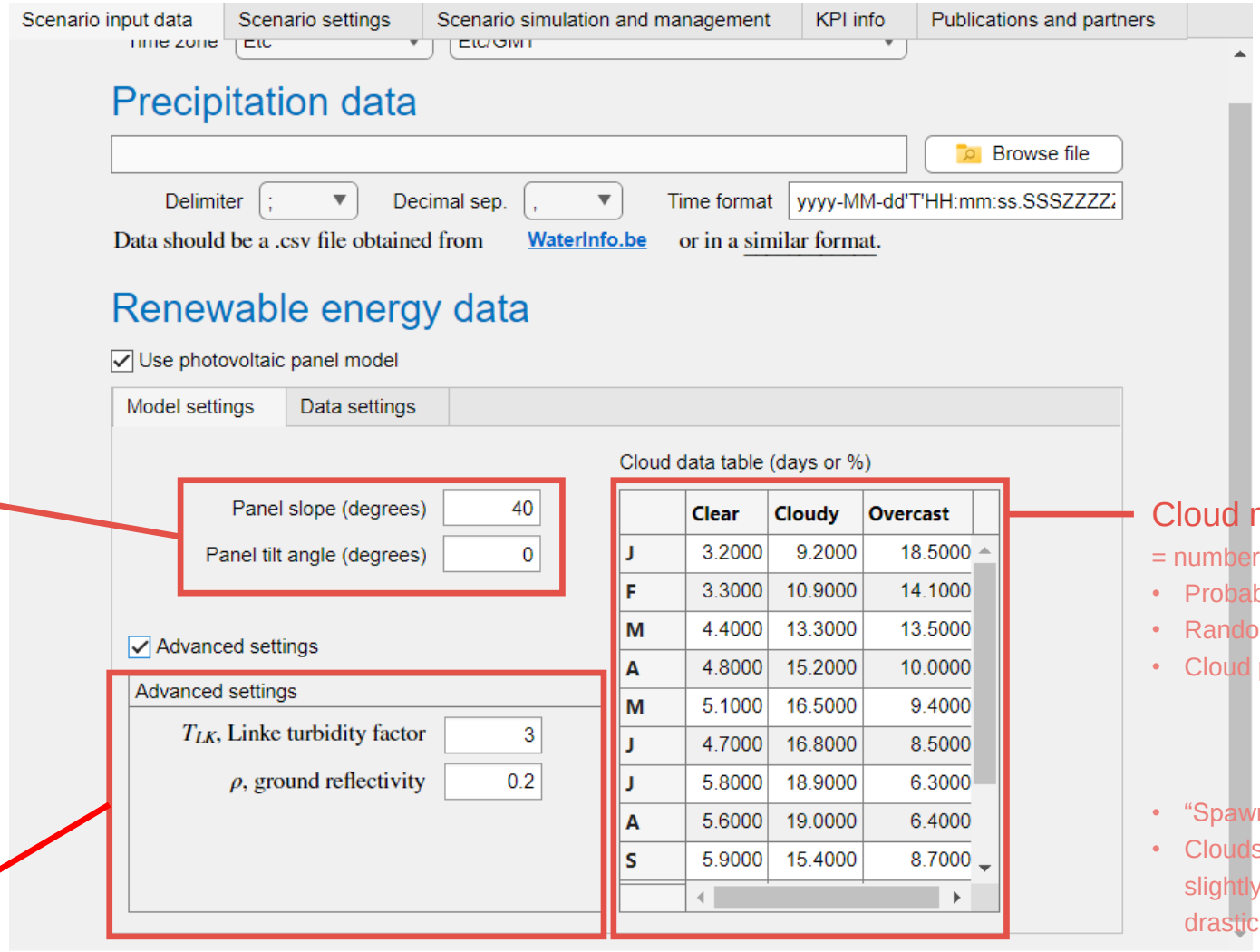

## Precipitation file selection

including browse button, file options, required format tooltip

## Renewable energy data

option between PV model (1.1.1) and datafile (1.1.2)

# 1.1.1 Scenario input data: PV model




## Solar panel orientation

(Solar panel technological settings in House characteristics (1.2.1))

## Cloud model parameters

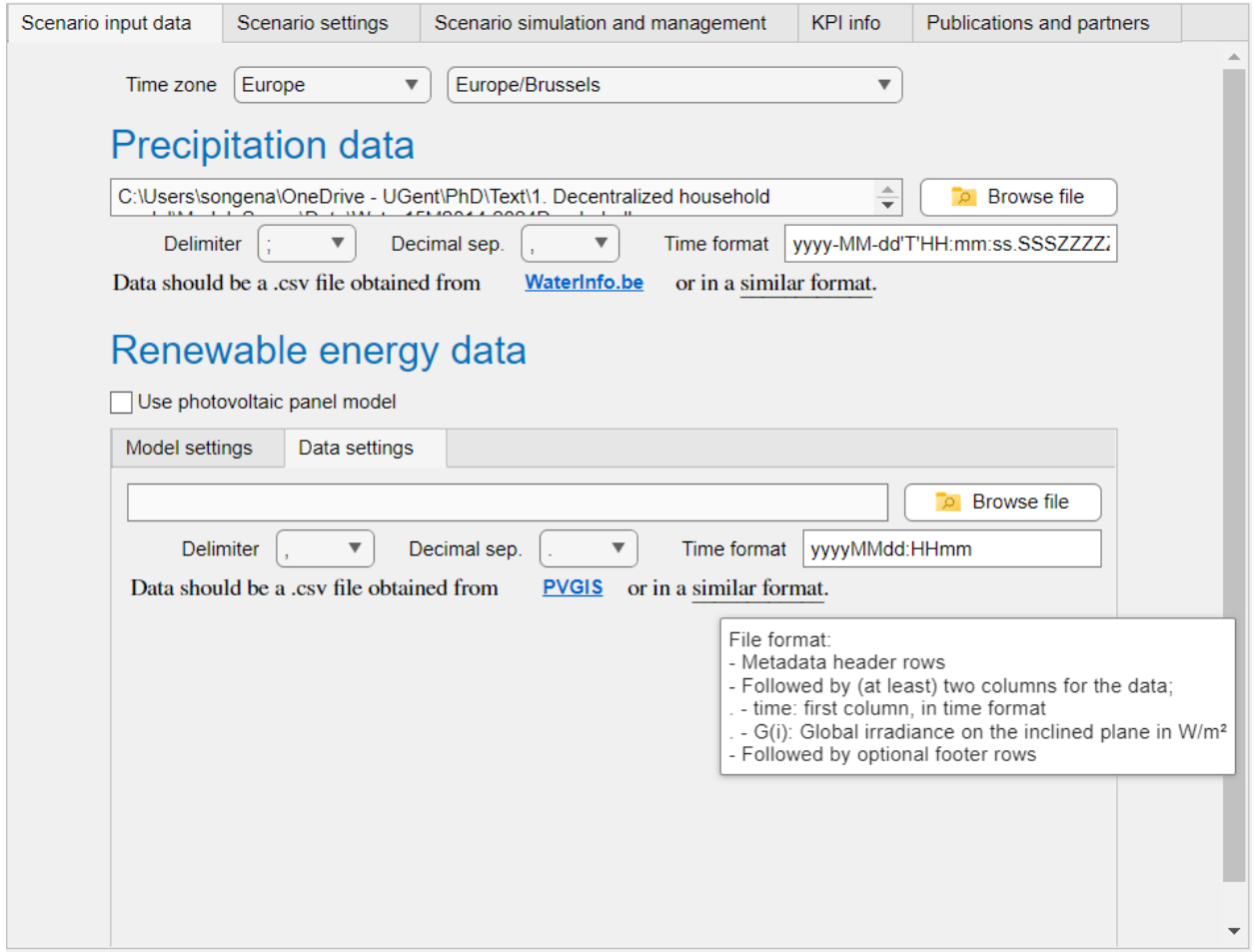
= number or % of clear, cloudy, and overcast days

- Probabilistic model
- Random number to determine type of day
- Cloud probability:
  - 0-20% on a clear day
  - 20-80% on a cloudy day
  - 80-100% on overcast day
- “Spawn” in cloud: value 0 or 1
- Clouds eliminate beam insolation, slightly increase diffuse insolation, drastically reduce reflections

## (Advanced) Atmospheric model parameters

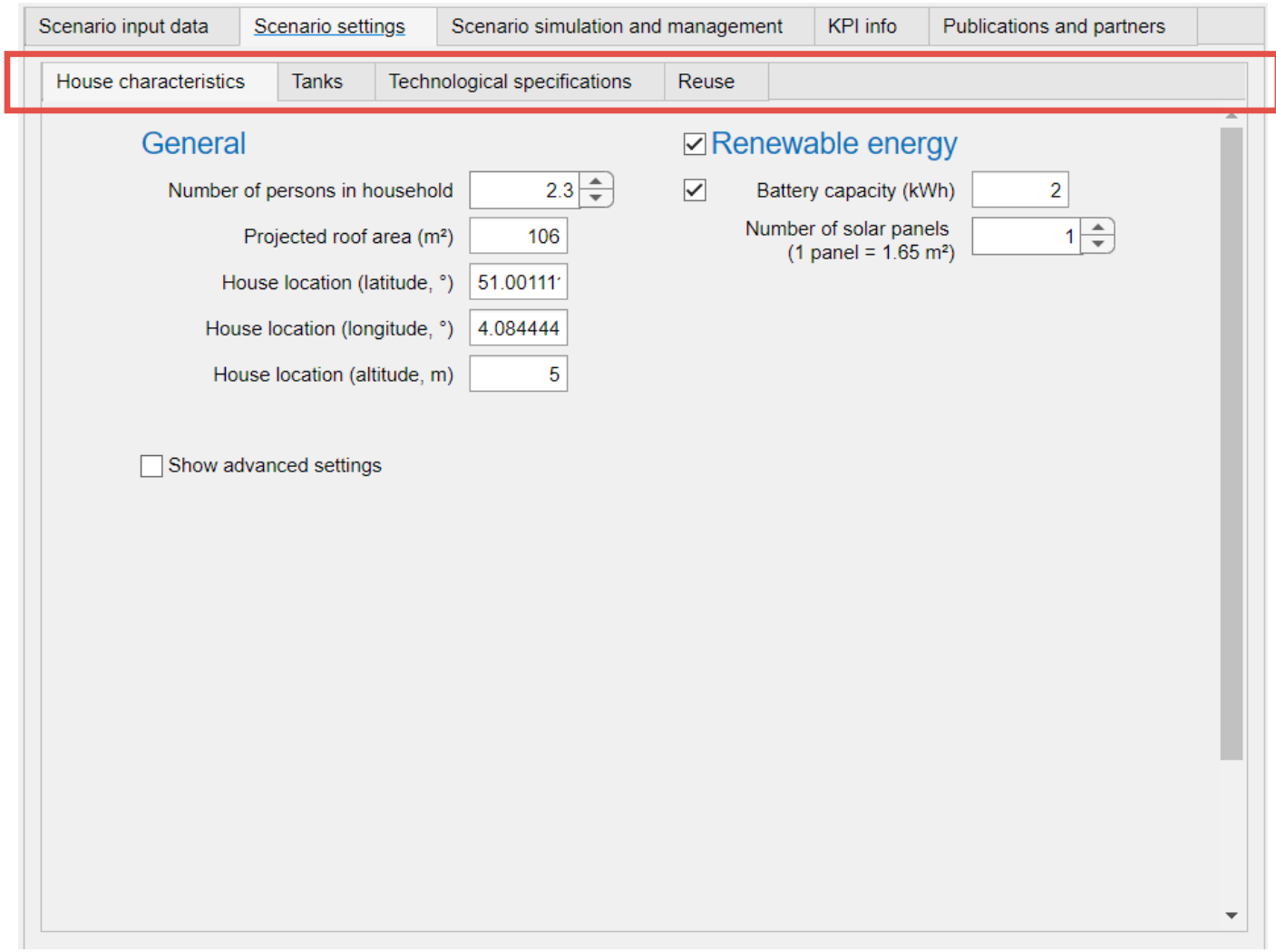
- For calculation of total panel irradiation
  = beam, diffuse and reflected irradiance
- Based on trigonometric model

# 1.1.2 Scenario input data: renewable energy




Similar to precipitation data

# 1.2 Scenario settings




Subtab selection

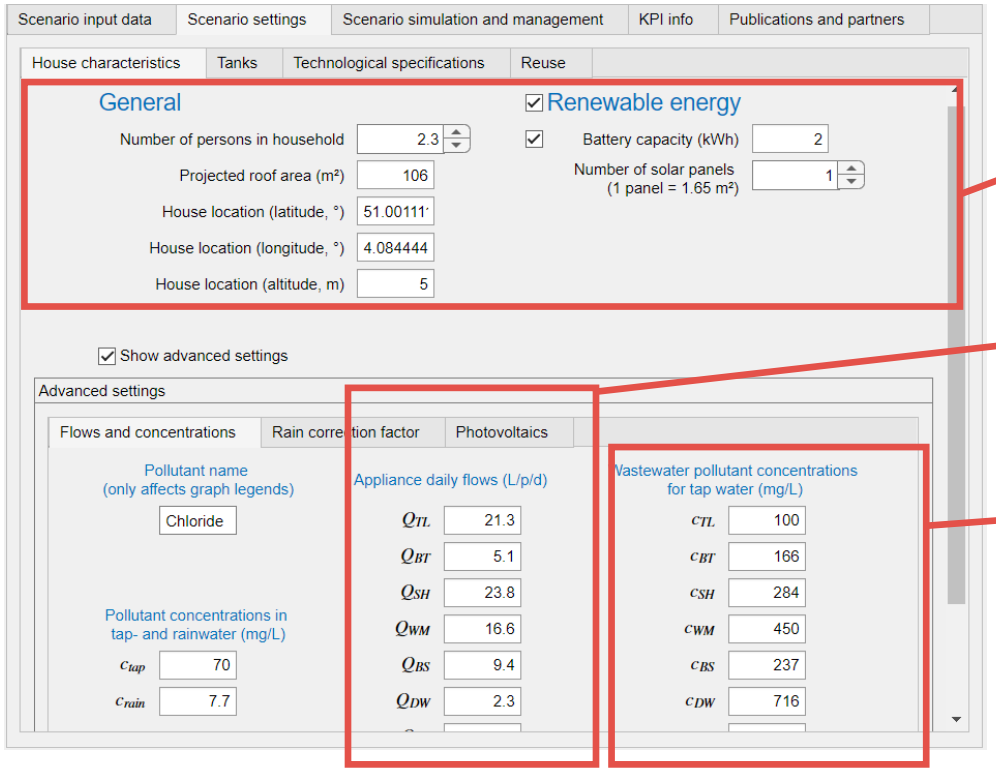
1.2.1 House characteristics

1.2.2 Tanks

1.2.3 Technological specifications

1.2.4 Reuse

# 1.2.1 Scenario settings: house characteristics




General settings and renewable energy settings

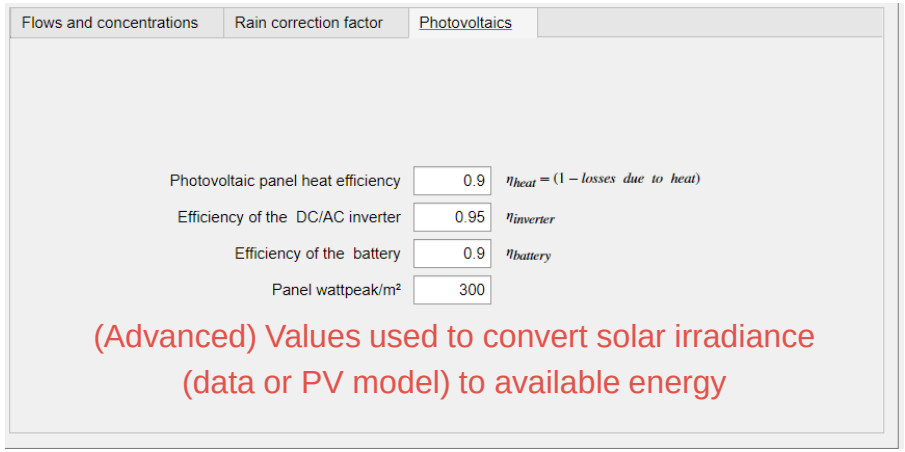
(i.a. checkbox whether to use renewable energy and whether to use a battery)

(Advanced) Total daily flows

(used to calculate diurnal flow values based on literature patterns)

(Advanced) Pollutant concentrations for tap water

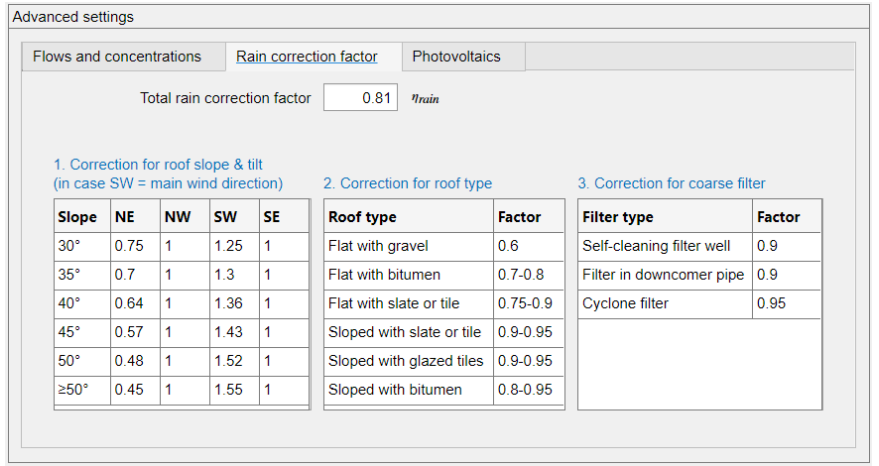
(the model will subtract the tap water concentration from these values and add the background concentration from the used source water streams)




(Advanced) Values used to convert solar irradiance (data or PV model) to available energy

(Advanced) Rain correction factor tables

(for main wind/rain direction, evaporation, filter efficiencies,…)

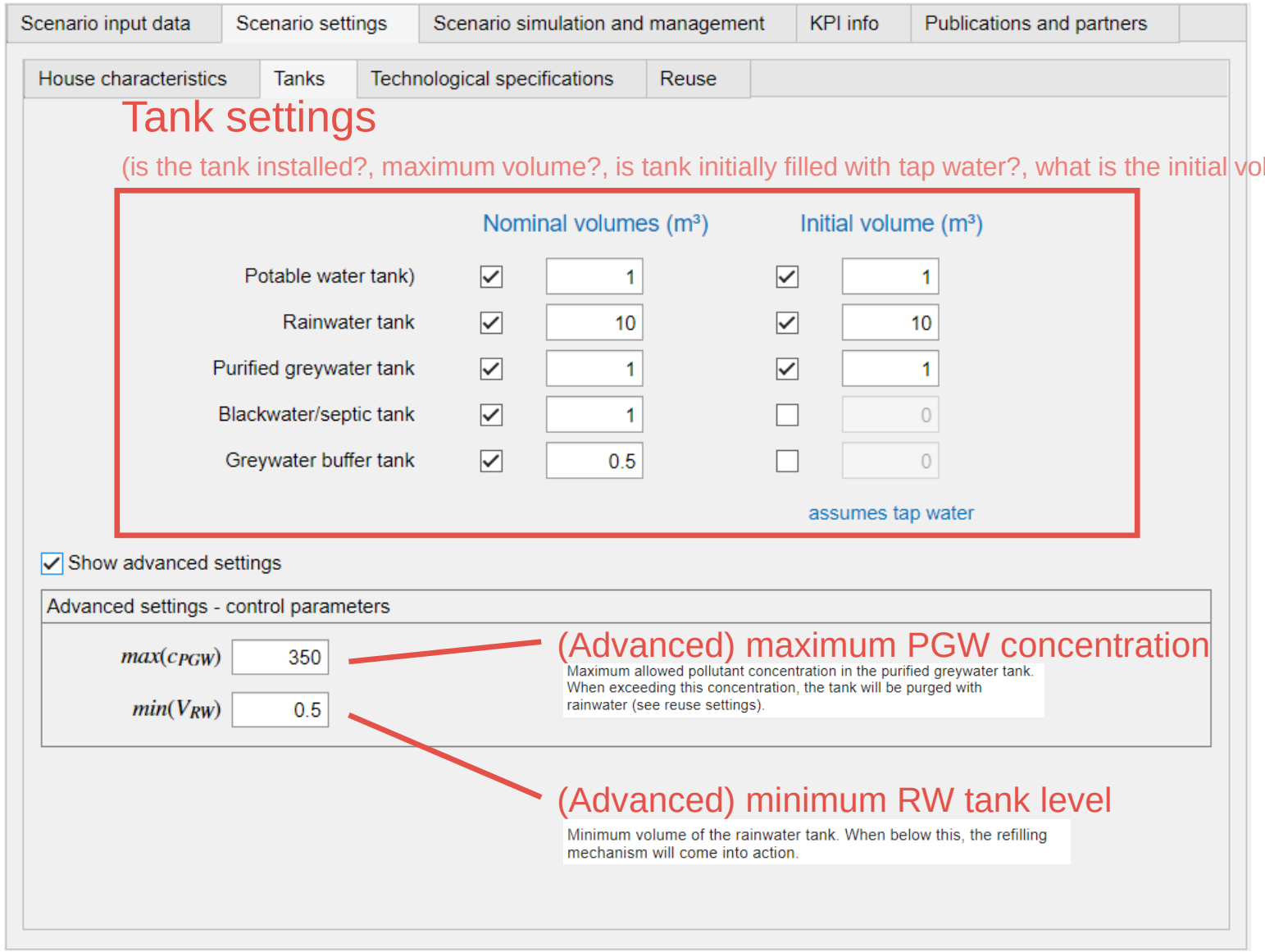



| Slope | NE | NW | SW | SE |
|---|---|---|---|---|
| 30° | 0.75 | 1 | 1.25 | 1 |
| 35° | 0.7 | 1 | 1.3 | 1 |
| 40° | 0.64 | 1 | 1.36 | 1 |
| 45° | 0.57 | 1 | 1.43 | 1 |
| 50° | 0.48 | 1 | 1.52 | 1 |
| ≥50° | 0.45 | 1 | 1.55 | 1 |

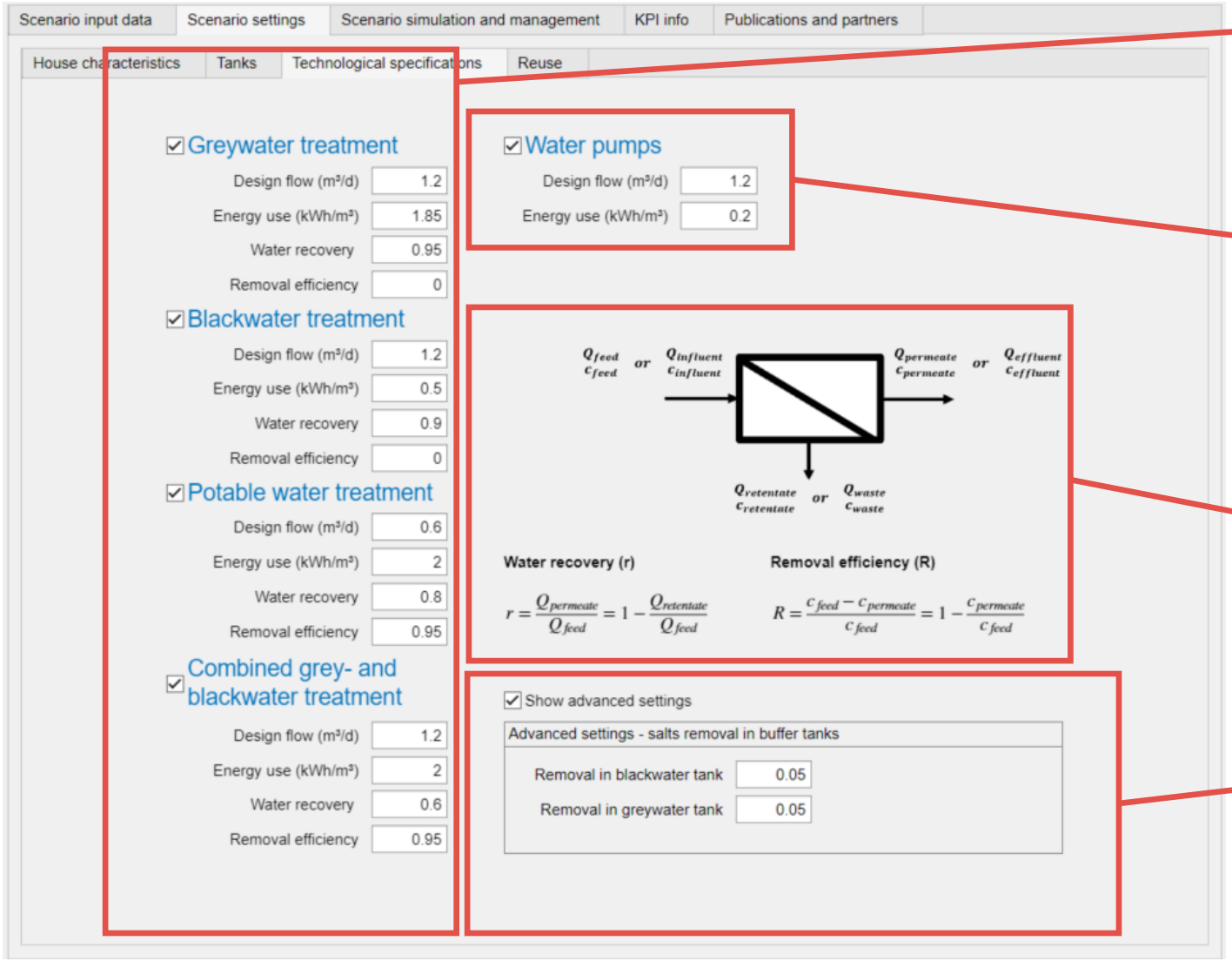
| Roof type | Factor |
|---|---|
| Flat with gravel | 0.6 |
| Flat with bitumen | 0.7-0.8 |
| Flat with slate or tile | 0.75-0.9 |
| Sloped with slate or tile | 0.9-0.95 |
| Sloped with glazed tiles | 0.9-0.95 |
| Sloped with bitumen | 0.8-0.95 |

| Filter type | Factor |
|---|---|
| Self-cleaning filter well | 0.9 |
| Filter in downcomer pipe | 0.9 |
| Cyclone filter | 0.95 |

# 1.2.2 Scenario settings: tanks



# 1.2.3 Scenario settings: technological specifications




## Technology selection

(select whether a technology is present and fill its primary specifications)

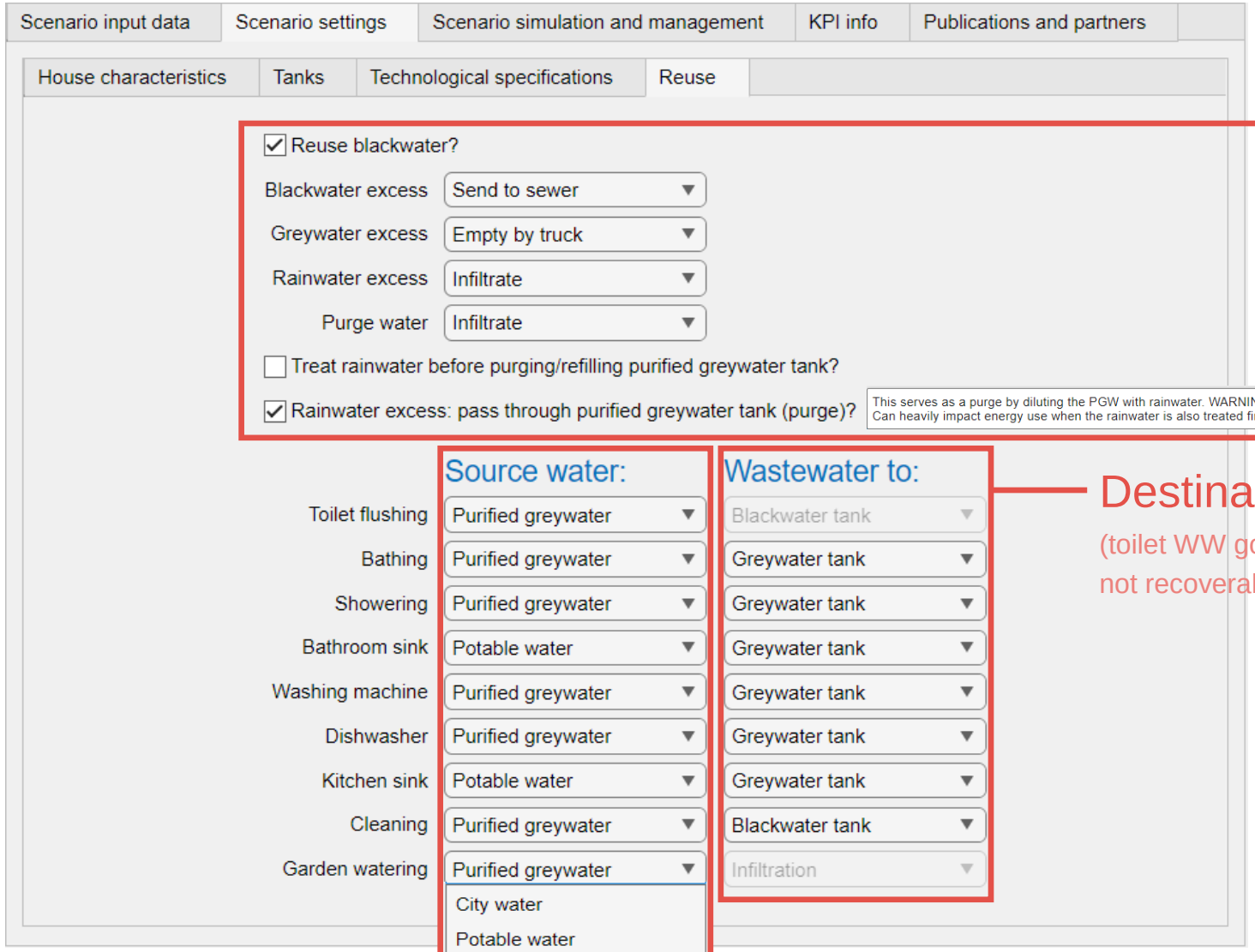
## Water pumps

(whether to consider pump energy for i.a. rainwater pumping to applications or when a treatment is not installed)

Theoretical explanation and visualisation of the primary specifications recovery and removal

(Advanced) Salts removal due to sedimentation

# 1.2.4 Scenario settings: reuse



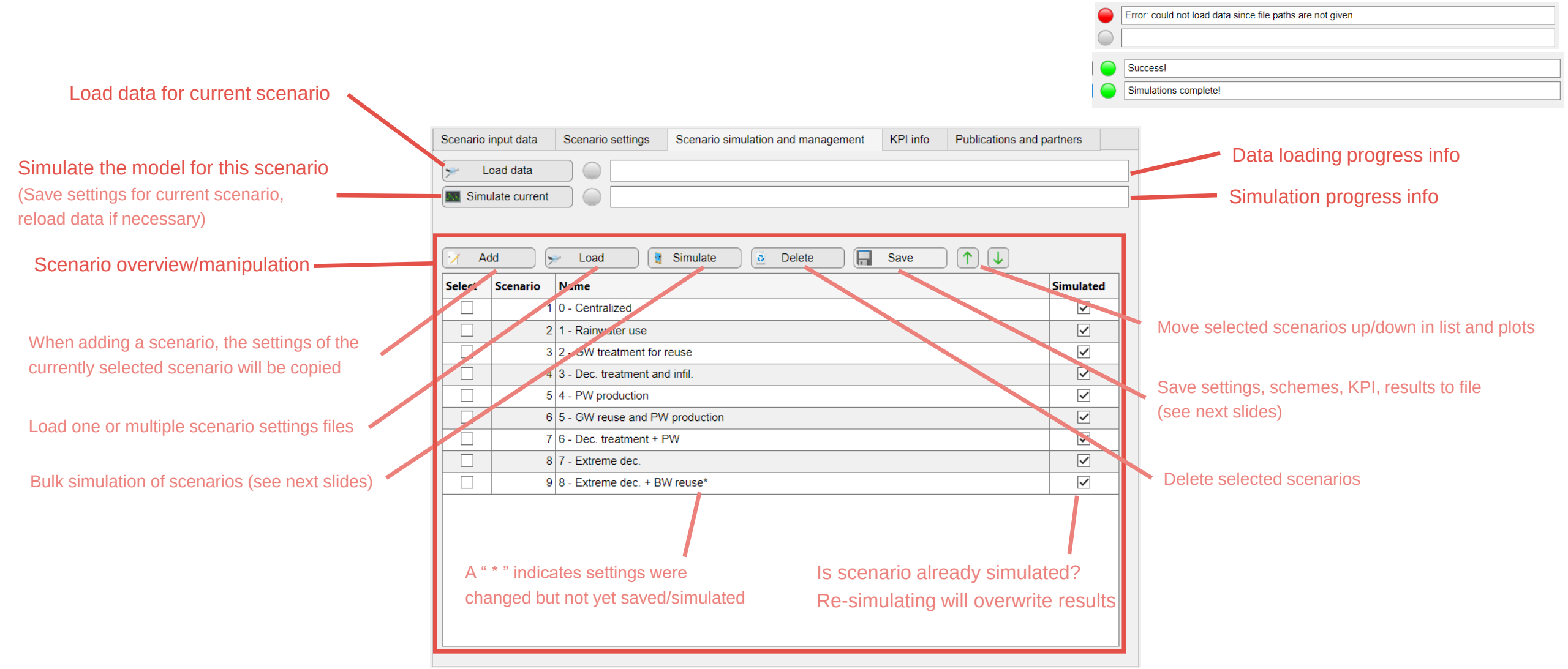

General reuse settings

Destination tank of wastewater after use

(toilet WW goes to blackwater tank per definition, gardening water is not recoverable)

Selection of water source per application

# 1.3 Scenario simulation and management



# Bulk simulation

App Load/Save Simulation

**Current scenario** 6 - Dec. treatment + PW

Scenario input data | Scenario settings | Scenario simulation and management | KPI info | Publications and partners

Load data

Simulate current

Add | Load | Simulate | Delete | Save

Simulate the selected scenarios

| Select | Scenario | Name | Simulated |
|---|---|---|---|
| ☐ | 1 | 0 - Centralized | ☑ |
| ☐ | 2 | 1 - Rainwater use | ☑ |
| ☐ | 3 | 2 - GW treatment for reuse | ☑ |
| ☐ | 4 | 3 - Dec. treatment and infil. | ☑ |
| ☐ | 5 | 4 - PW production | ☑ |
| ☐ | 6 | 5 - GW reuse and PW production | ☑ |
| ☑ | 7 | 6 - Dec. treatment + PW | ☑ |
| ☑ | 8 | 7 - Extreme dec. | ☑ |
| ☑ | 9 | 8 - Extreme dec. + BW reuse | ☑ |

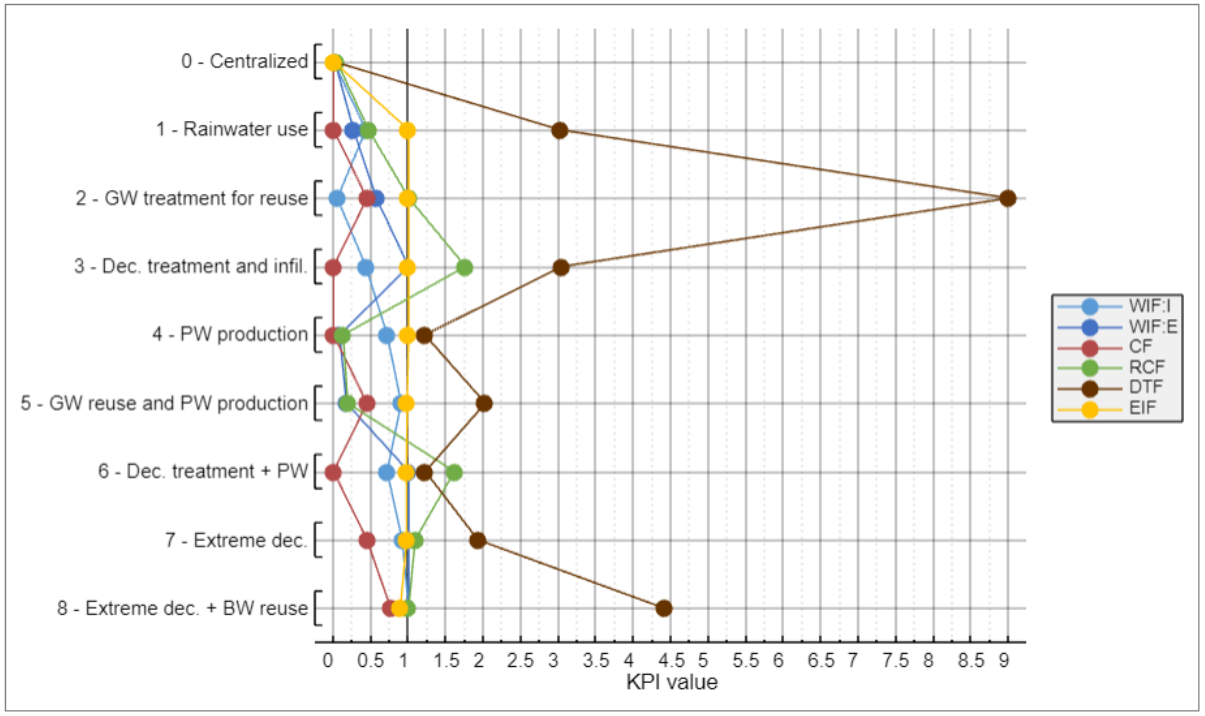
Log

```
[2024-11-05 14:45:54] Simulating... Scenario 1/3
[2024-11-05 14:46:16] Simulation completed in 11.5429 seconds.
[2024-11-05 14:46:16] Simulating... Scenario 2/3
[2024-11-05 14:46:38] Simulation completed in 11.3351 seconds.
[2024-11-05 14:46:38] Simulating... Scenario 3/3
[2024-11-05 14:46:59] Simulation completed in 11.0887 seconds.
[2024-11-05 14:46:59] All scenarios were successfully simulated.
```



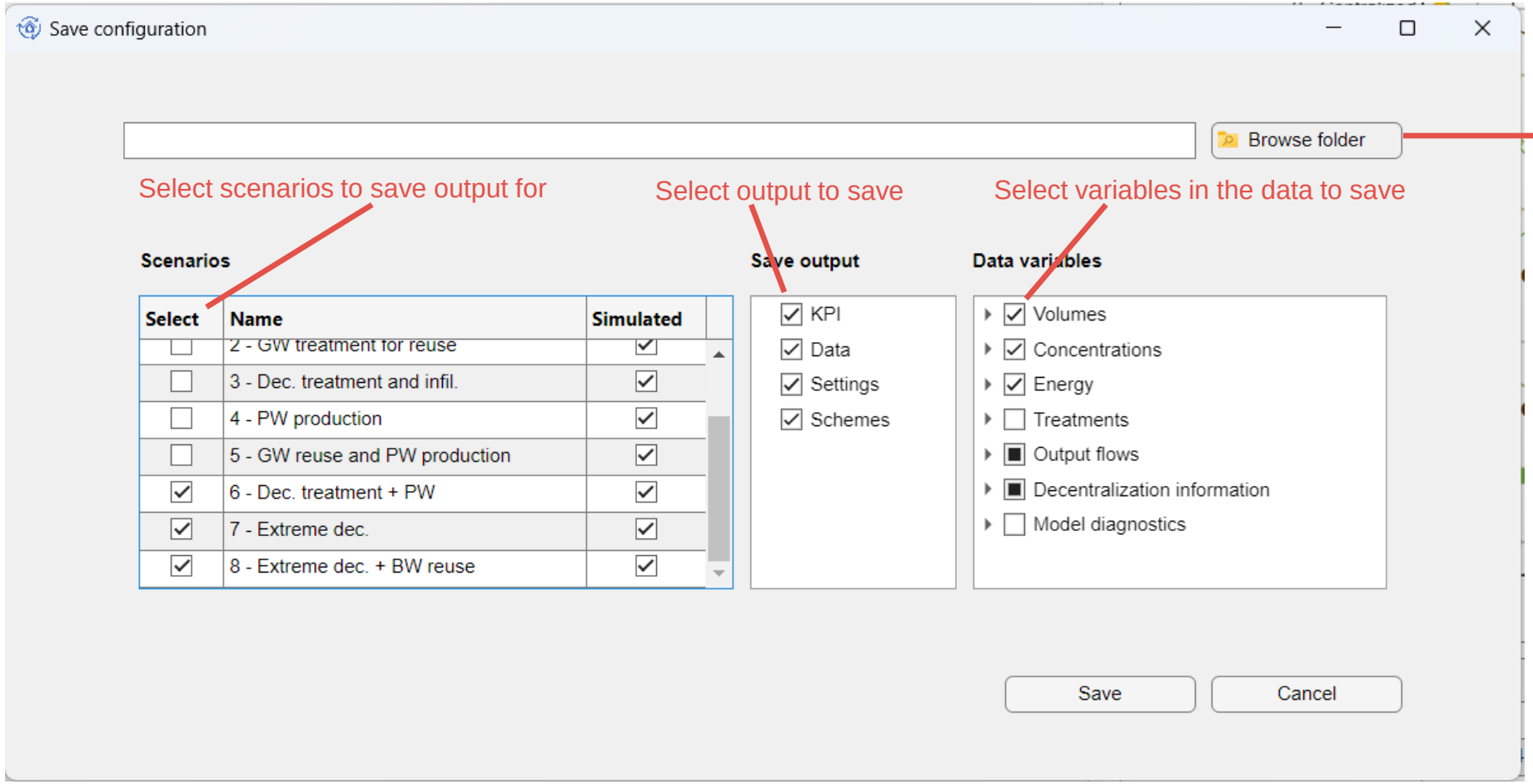
Scheme | KPI | Water tanks | Renewable energy | Balance checks

Configure




| Scenario | WIF:I | WIF:E | CF | RCF | DTF | EIF |
|---|---|---|---|---|---|---|
| 0 - Centralized | 0 | 0.0181 | 0 | 0.0424 | 0 | 0 |
| 1 - Rainwater use | 0.4306 | 0.2655 | 0 | 0.4671 | 3.0189 | 1.0000 |
| 2 - GW treatment for reuse | 0.0489 | 0.5705 | 0.4447 | 1.0033 | 9.0060 | 1.0000 |
| 3 - Dec. treatment and infil. | 0.4306 | 1.0000 | 0 | 1.7588 | 3.0467 | 1.0000 |
| 4 - PW production | 0.7139 | 0.0797 | 0 | 0.1284 | 1.2158 | 1.0000 |
| 5 - GW reuse and PW production | 0.9011 | 0.1719 | 0.4447 | 0.1881 | 2.0230 | 0.9809 |
| 6 - Dec. treatment + PW | 0.7139 | 1.0000 | 0 | 1.6101 | 1.2234 | 0.9709 |
| 7 - Extreme dec. | 0.9140 | 1.0000 | 0.4447 | 1.0875 | 1.9247 | 0.9735 |

# Saving files: save dialog screen

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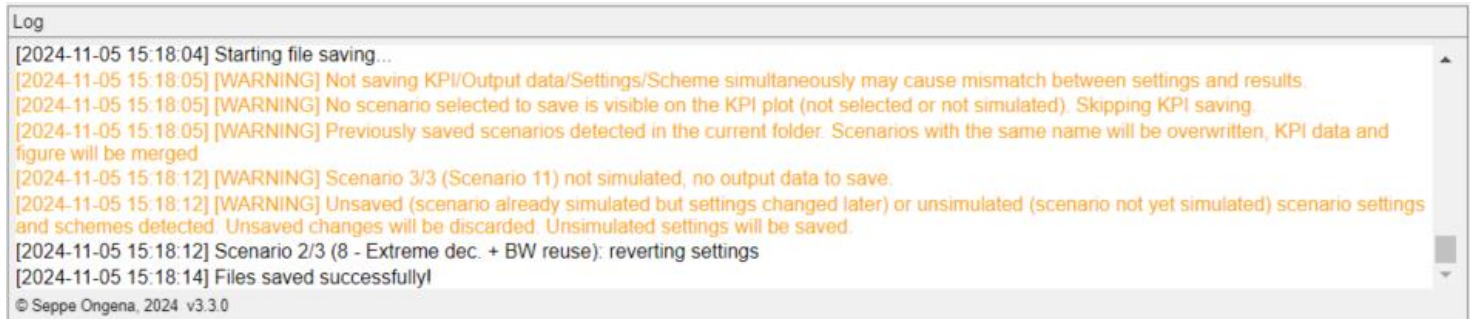
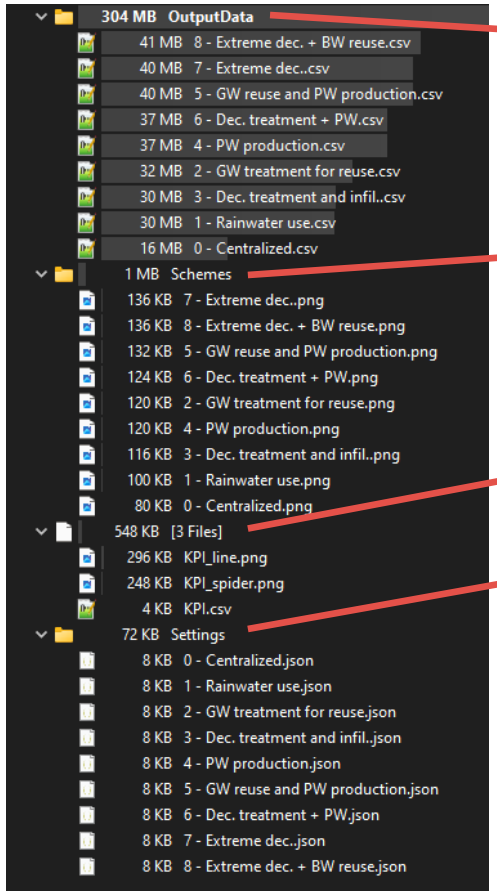
# Saving files: output




All possible warnings triggered



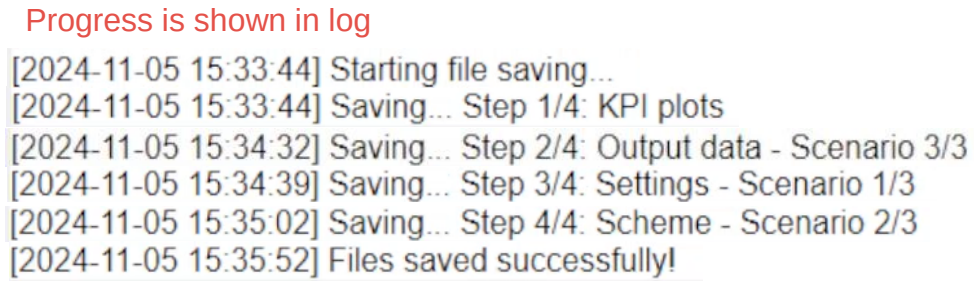

Datafiles: per scenario as .csv files, each variable = column

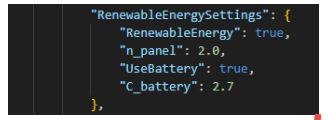
.png of schemes per scenario

KPI spider and line plot (.png) and KPI table (.csv)

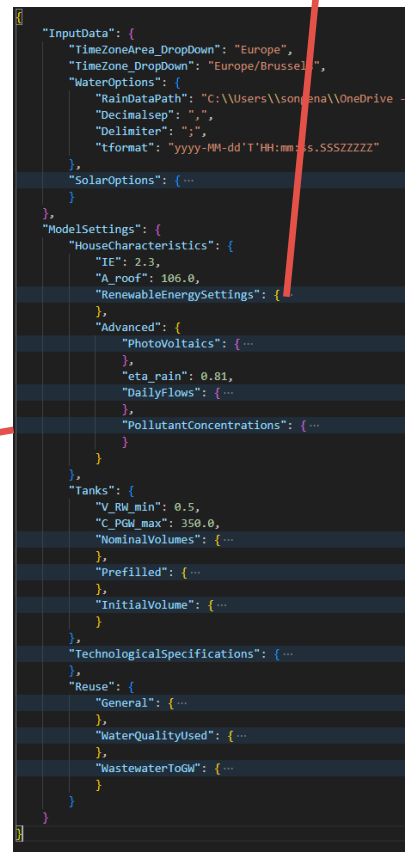
Scenario settings as “human readable” .json files

Progress is shown in log




(full view - example)




(collapsed view)

# 1.4 KPI info

Decentralized Household Model

App Load/Save Simulation Debug

**Current scenario** 8 - Extreme dec. + BW reuse

Scenario input data | Scenario settings | Scenario simulation and management | KPI info | Publications and partners

**Water independence factor on import (WIF:I)**

$$WIF_I = \frac{RW\ use\ (m^3)}{Total\ water\ use\ (m^3)} = \frac{RW\ use}{RW\ use + CW\ use}$$

When the rainwater tank does not need refilling and no city water is directly used (CW use = 0), the WIF:I is 100%. When either is present, the WIF:I will decrease.

**Water independence factor on export (WIF:E)**

$$WIF_E = \frac{Infiltration\ (m^3)}{Total\ water\ disposal\ (m^3)} = \frac{Infiltration}{Infiltration + Sewer +}$$

If all excess water is infiltrated, the WIF:E is 100%.
If any water is sent to the sewer or a tank is emptied by truck, the WIF:E will decrease.

**Circularity factor (CF)**

$$CF = \frac{Water\ reused\ (m^3)}{Wastewater\ produced\ (m^3)}$$

The circularity factor is the ratio of water reused (from the PGW tank) to the total amount of wastewater produced. If all wastewater is reused, the CF will be 100%.

**Recharge factor (RCF)**

$$RCF = \frac{Water\ infiltrated\ (m^3)}{Precipitation\ (m^3)}$$

The recharge factor represents the closure of the local water cycle. If all harvested precipitation will eventually be infiltrated, and no water is either imported or exported (WIF:I = WIF:E = 100%), the RCF will be 100%. In all other cases, RCF>100% (net water import) or <100% (net water export).

**Drought tolerance factor (DTF)**

$$DTF = \frac{Volume\ RW\ tank\ (m^3)}{\frac{Peak\ monthly\ RW\ use\ (m^3/month)}{10yrs\ drought\ duration\ (month)}}$$

The numerator represents how long a full rainwater tank can supply peak usage (usually summers if rainwater is used for gardening). This is divided by the longest 10 years drought perios (0.95 months, Flanders). A DTF of >100% indicates a full rainwater tank could bridge this drought period.

**Energy independence factor (EIF)**

$$EIF = \frac{Renewables\ use\ (kWh)}{Total\ energy\ use\ (kWh)}$$

The EIF indicates the self-sufficiency of the system in terms of energy use. It will be 100% for no grid energy use, i.e., the renewable energy supply is always sufficient (esp. in the winter months) either trough production or storage capacity. If the grid backup is used, the EIF will decrease

Log

```
and schemes detected. Unsaved changes will be discarded. Unsimulated settings will be saved.
[2024-11-05 15:27:18] Scenario 3/3 (8 - Extreme dec. + BW reuse): reverting settings
[2024-11-05 15:28:41] Files saved successfully!
[2024-11-05 15:33:44] Starting file saving...
[2024-11-05 15:33:44] [WARNING] Previously saved scenarios detected in the current folder. Scenarios with the same name will be overwritten, KPI data and figure will be merged
[2024-11-05 15:34:37] [WARNING] Unsaved (scenario already simulated but settings changed later) or unsimulated (scenario not yet simulated) scenario settings and schemes detected. Unsaved changes will be discarded. Unsimulated settings will be saved.
[2024-11-05 15:34:37] Scenario 3/3 (8 - Extreme dec. + BW reuse): reverting settings
[2024-11-05 15:35:52] Files saved successfully!
```

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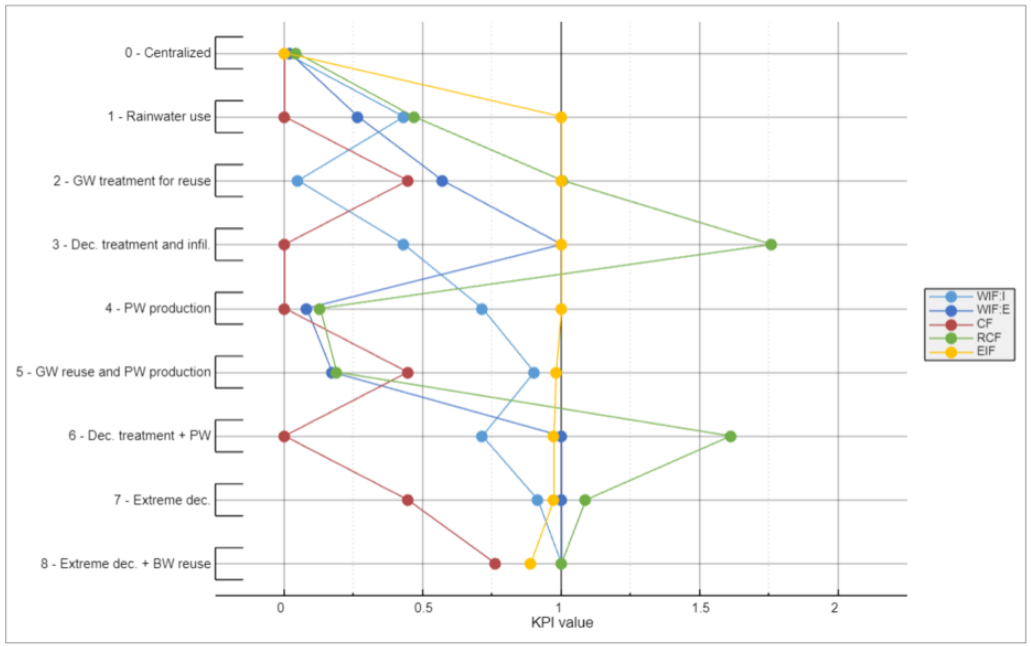
Scheme | KPI | Water tanks | Renewable energy | Balance checks

Configure




| Scenario | WIF:I | WIF:E | CF | RCF | DTF | EIF |
|---|---|---|---|---|---|---|
| 0 - Centralized | 0 | 0.0181 | 0 | 0.0424 | 0 | 0 |
| 1 - Rainwater use | 0.4306 | 0.2655 | 0 | 0.4671 | 3.0266 | 1.0000 |
| 2 - GW treatment for reuse | 0.0488 | 0.5705 | 0.4447 | 1.0034 | 9.0060 | 1.0000 |
| 3 - Dec. treatment and infil. | 0.4306 | 1.0000 | 0 | 1.7588 | 3.0579 | 1.0000 |
| 4 - PW production | 0.7139 | 0.0798 | 0 | 0.1285 | 1.2215 | 1.0000 |
| 5 - GW reuse and PW production | 0.9011 | 0.1719 | 0.4447 | 0.1881 | 2.0169 | 0.9801 |
| 6 - Dec. treatment + PW | 0.7139 | 1.0000 | 0 | 1.6103 | 1.2164 | 0.9723 |
| 7 - Extreme dec. | 0.9140 | 1.0000 | 0.4447 | 1.0874 | 1.9816 | 0.9723 |
| 8 - Extreme dec. + BW reuse | 1.0000 | 1.0000 | 0.7622 | 0.9992 | 4.4033 | 0.8878 |

Best used in conjunction with KPI graph tab

(gives calculation method for each KPI and a brief explanation)

# 1.5 Publications and partners

Scenario input data | Scenario settings | Scenario simulation and management | KPI info | Publications and partners

**For more information:**

Van de Walle et. al (2022). In silico assessment of household level closed water cycles: Towards extreme decentralization. Environmental Science and Technology, 10, 100148

Ongena et. al (s.d.). An in silico, high resolution assessment of water production and reuse at house level driven by on site electricity production. Unpublished.

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List of publications with more in-depth information on model and used default values

List of contributing partners

# 2.0 Graph side

## Tab selector

2.1 Scheme

2.2 KPI

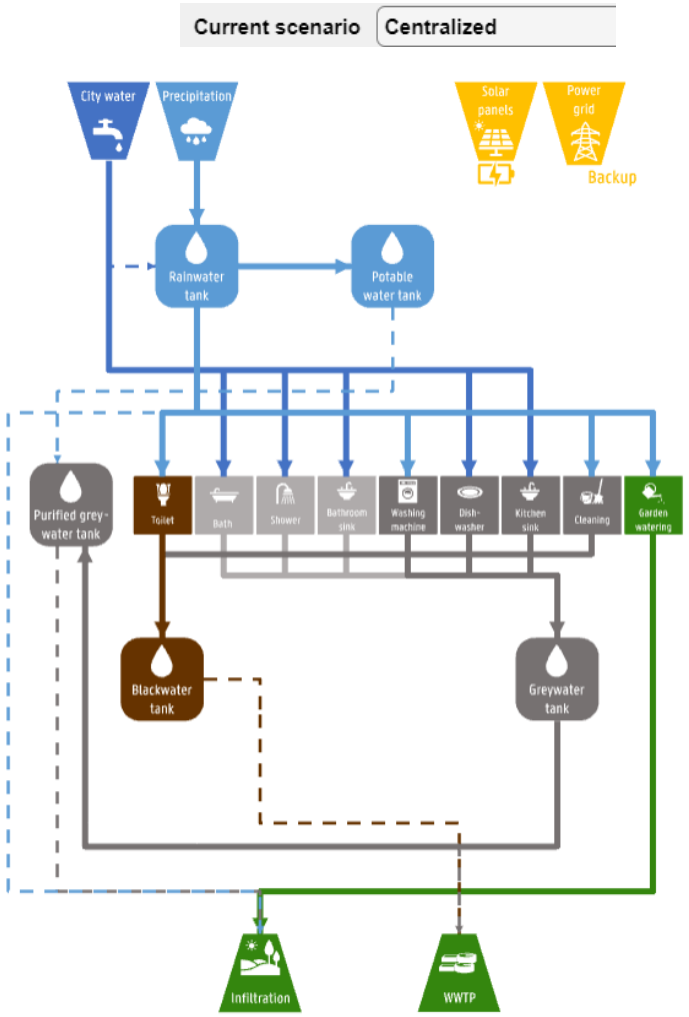
2.3 Water tanks

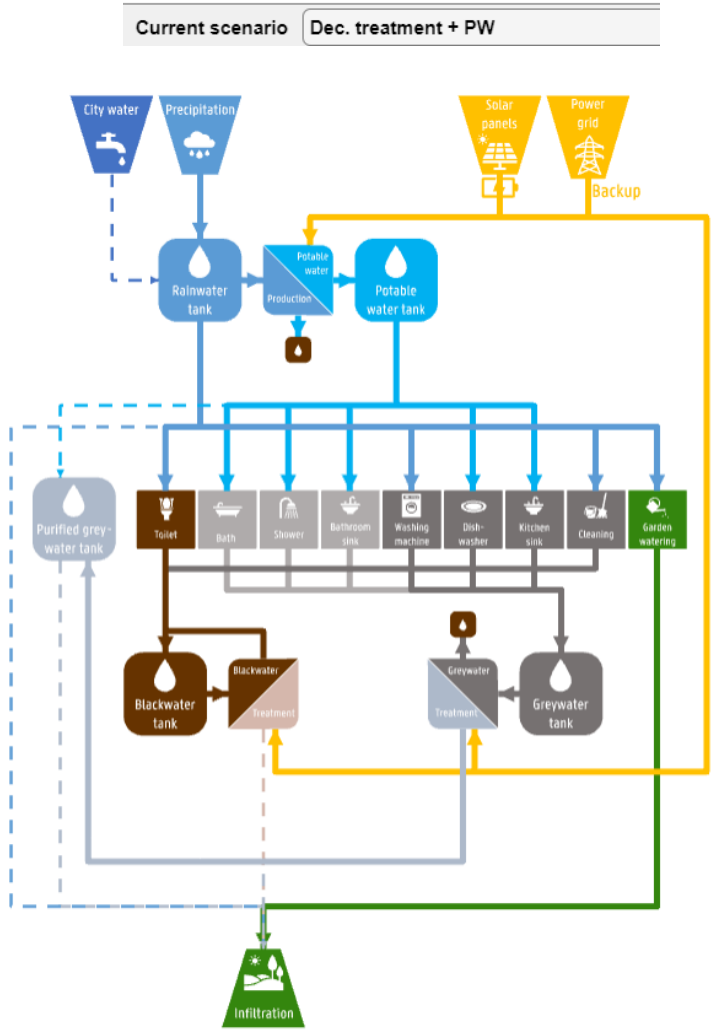
2.4 Renewable energy

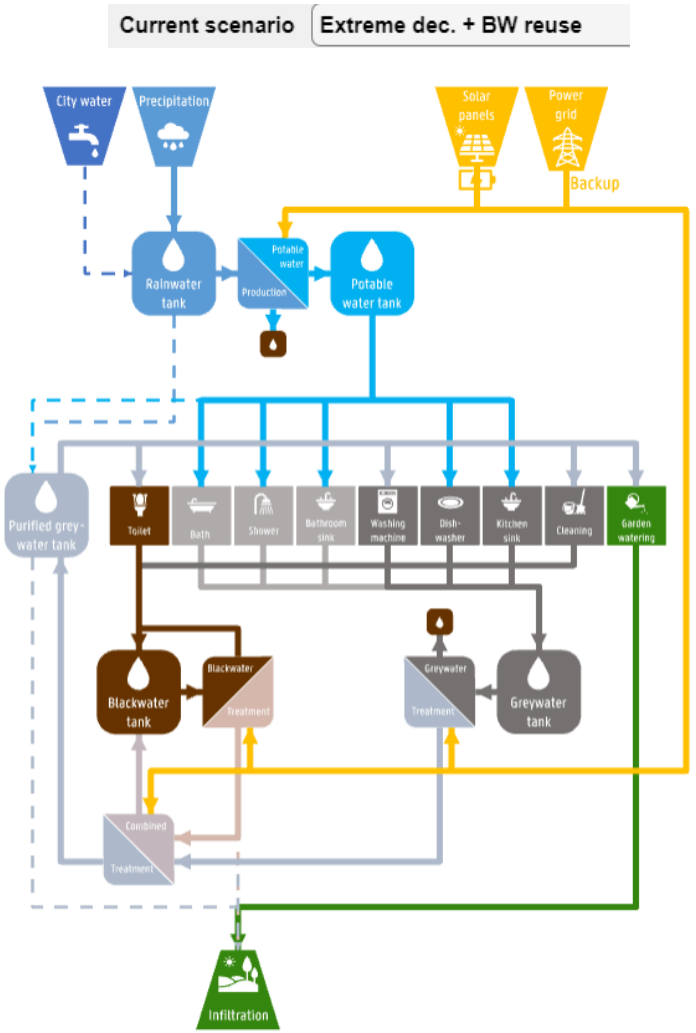
2.5 Balance checks

# 2.1 Graphs: scheme

## Scheme updates based on selected settings

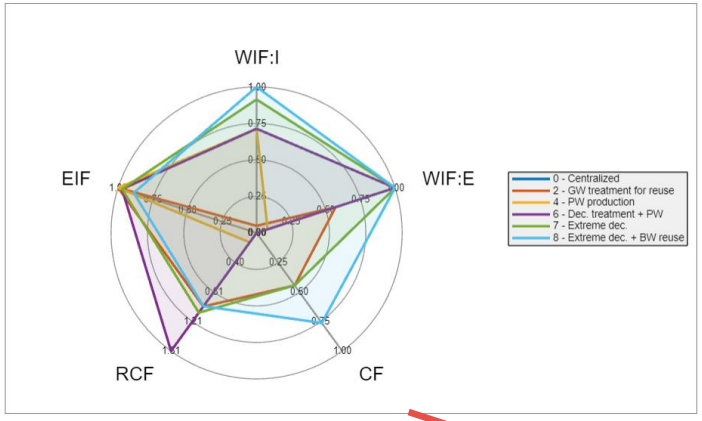


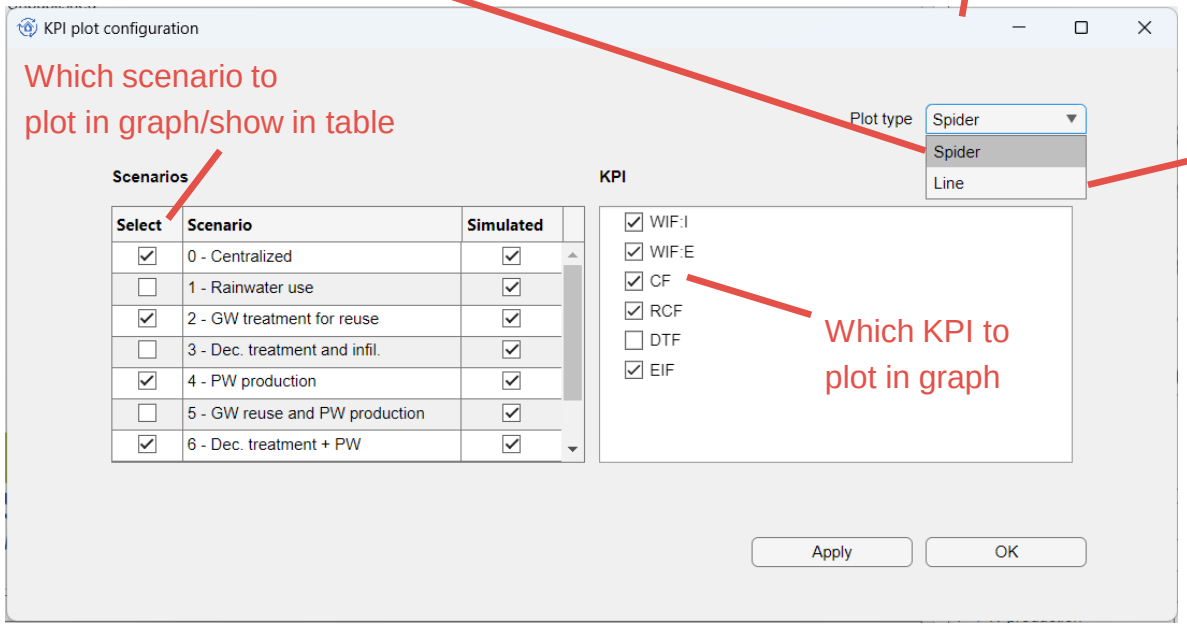



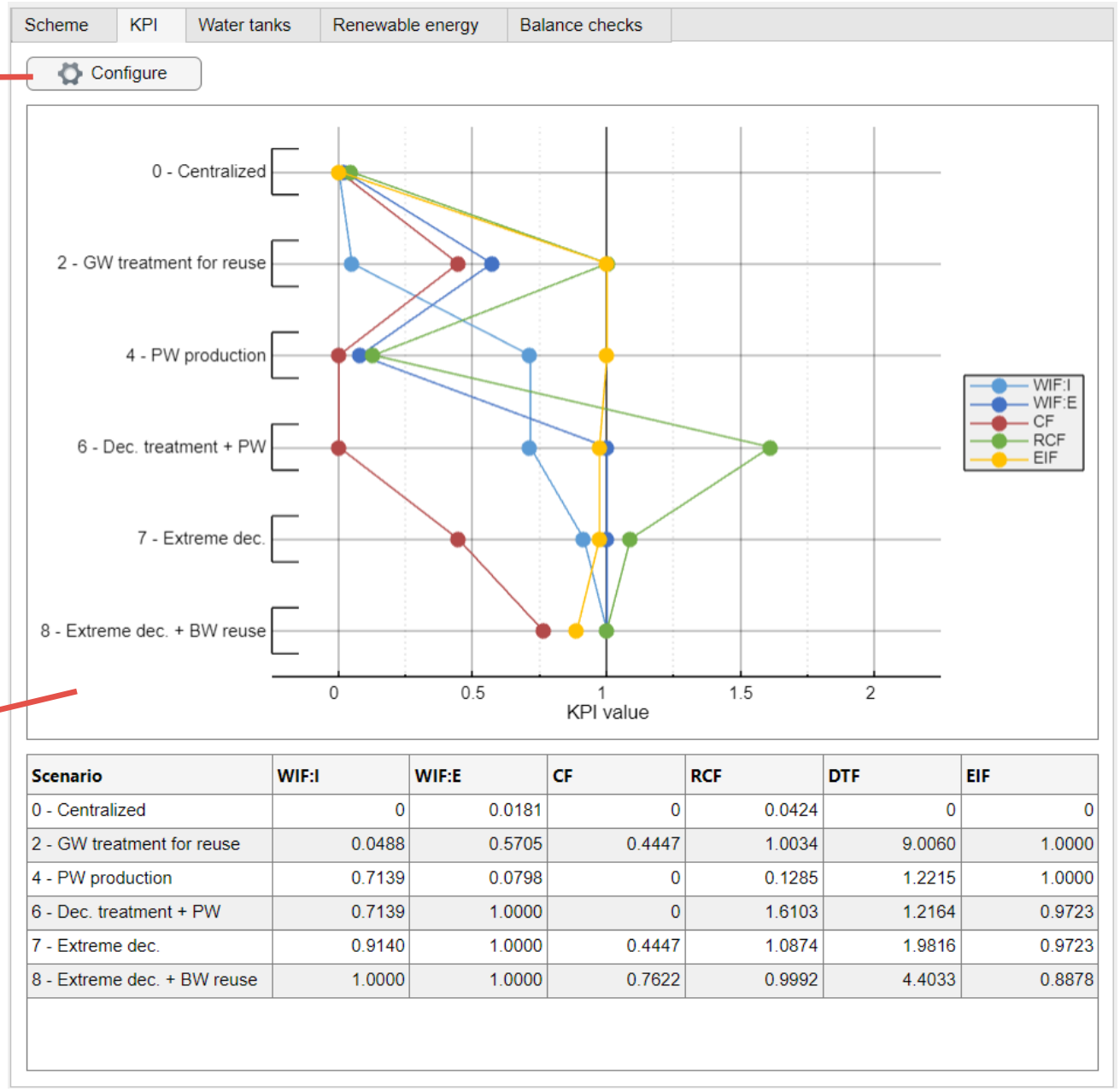
# 2.2 Graphs: KPI

Plot (line or spider), table



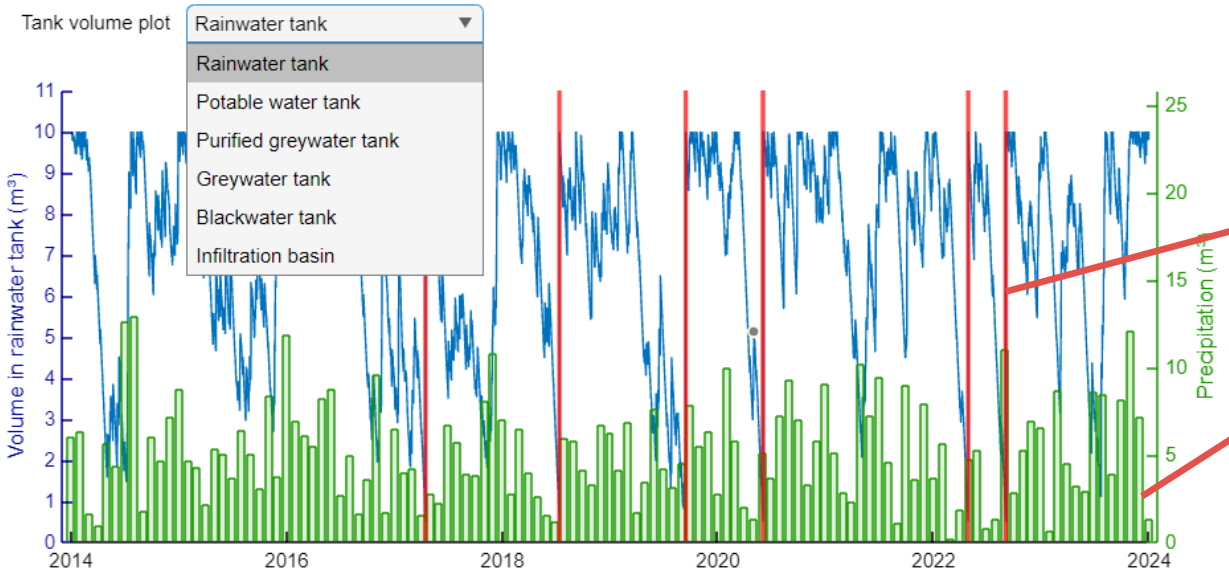

Configuration dialog




| Scenario | WIF:I | WIF:E | CF | RCF | DTF | EIF |
|---|---|---|---|---|---|---|
| 0 - Centralized | 0 | 0.0181 | 0 | 0.0424 | 0 | 0 |
| 2 - GW treatment for reuse | 0.0488 | 0.5705 | 0.4447 | 1.0034 | 9.0060 | 1.0000 |
| 4 - PW production | 0.7139 | 0.0798 | 0 | 0.1285 | 1.2215 | 1.0000 |
| 6 - Dec. treatment + PW | 0.7139 | 1.0000 | 0 | 1.6103 | 1.2164 | 0.9723 |
| 7 - Extreme dec. | 0.9140 | 1.0000 | 0.4447 | 1.0874 | 1.9816 | 0.9723 |
| 8 - Extreme dec. + BW reuse | 1.0000 | 1.0000 | 0.7622 | 0.9992 | 4.4033 | 0.8878 |

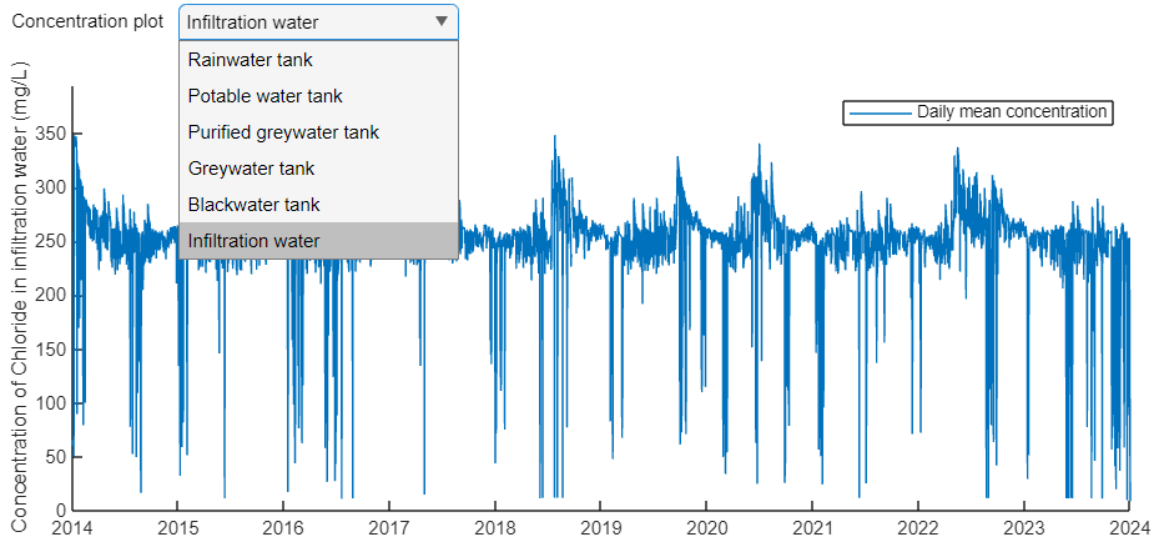
# 2.3 Graphs: Water tanks




Plotting tank volumes over time

Rainwater tank refill

Total monthly precipitation

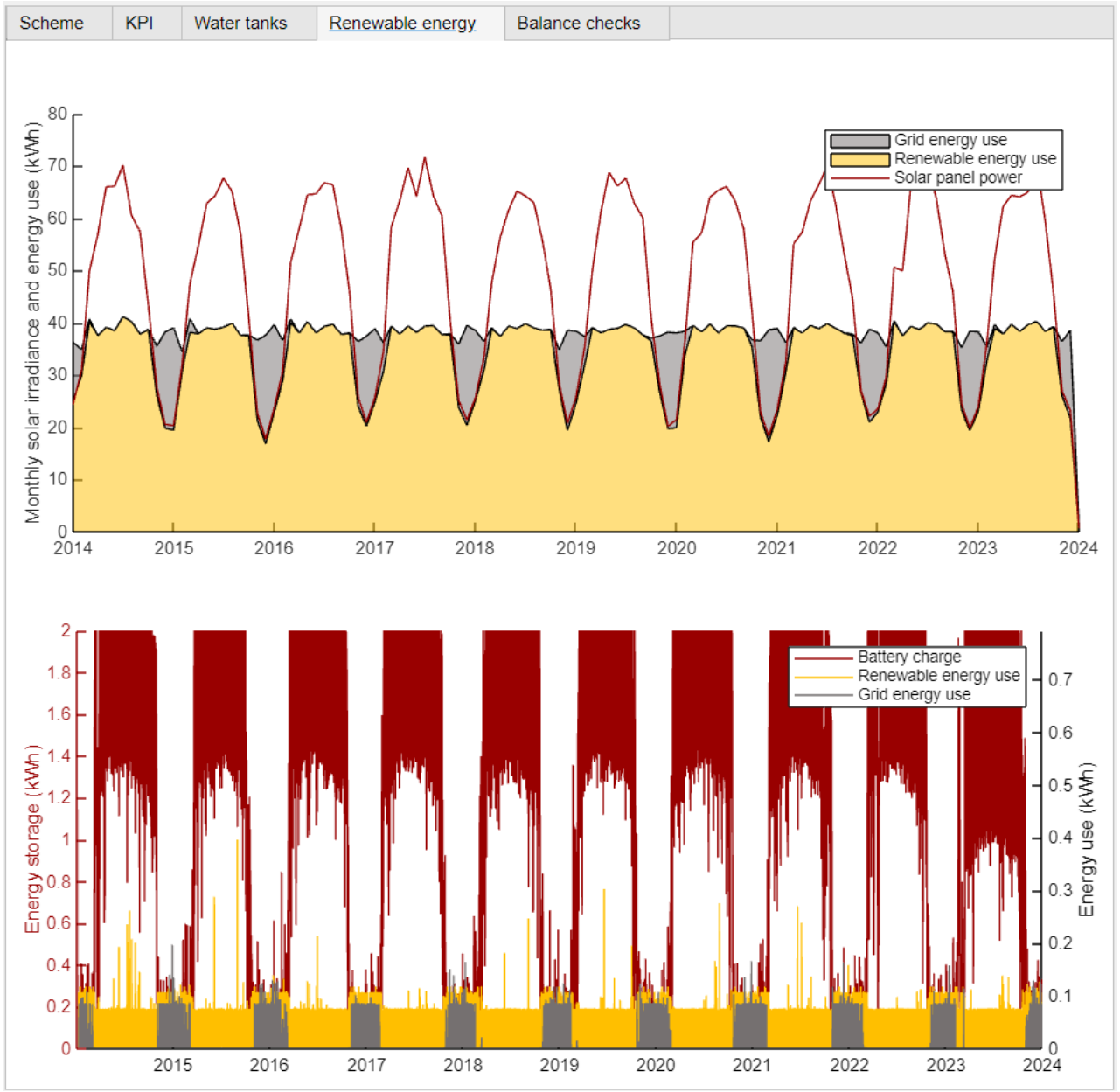



Plotting tank concentrations over time

# 2.4 Graphs: renewable energy

Total monthly solar irradiance (line), and stacked area renewables and grid use

Battery charge and energy use over time



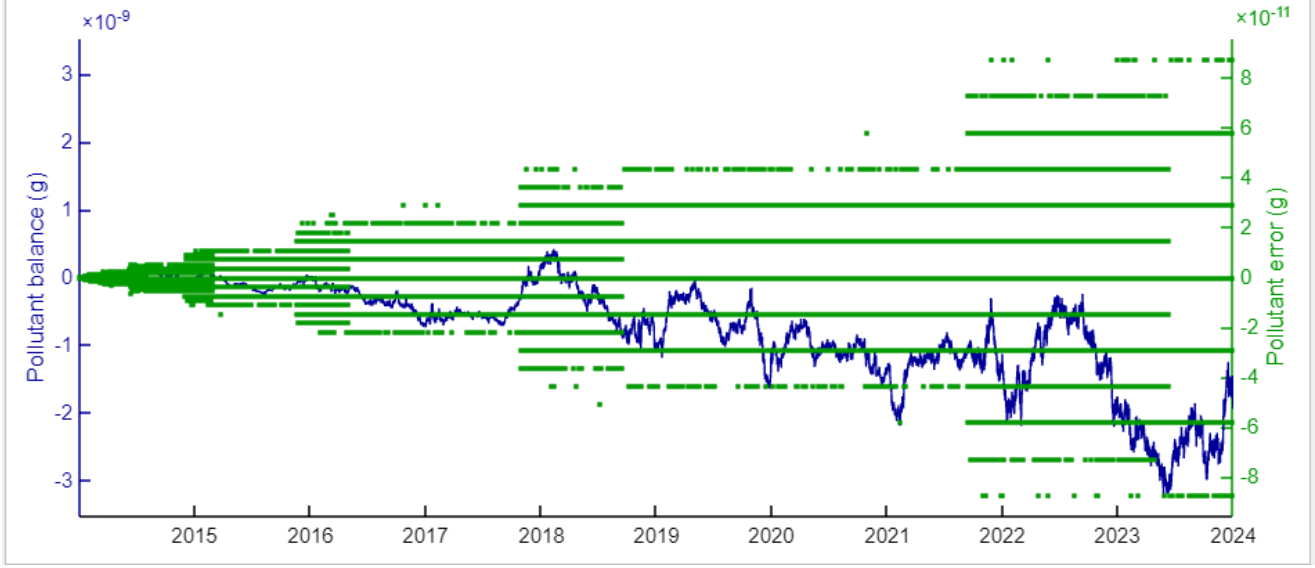
# 2.5 Graphs balance checks

## Balance checks for model correctness

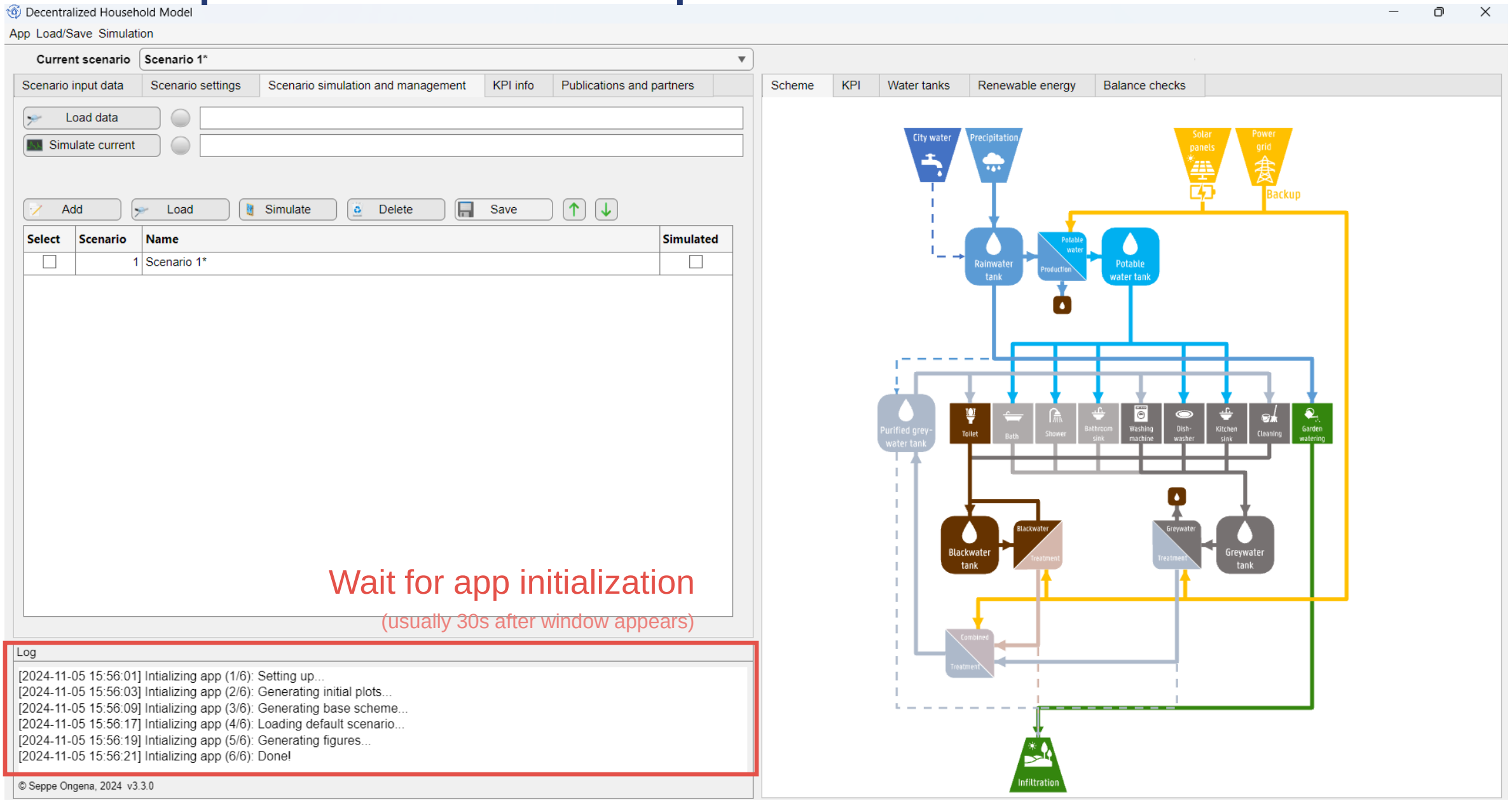
(see explanation)

Scheme | KPI | Water tanks | Renewable energy | Balance checks

Balances should appear random (random walk) and be of small magnitude (e.g. < 1 mL and < 1 mg). Errors should be heteroskedastic around 0.

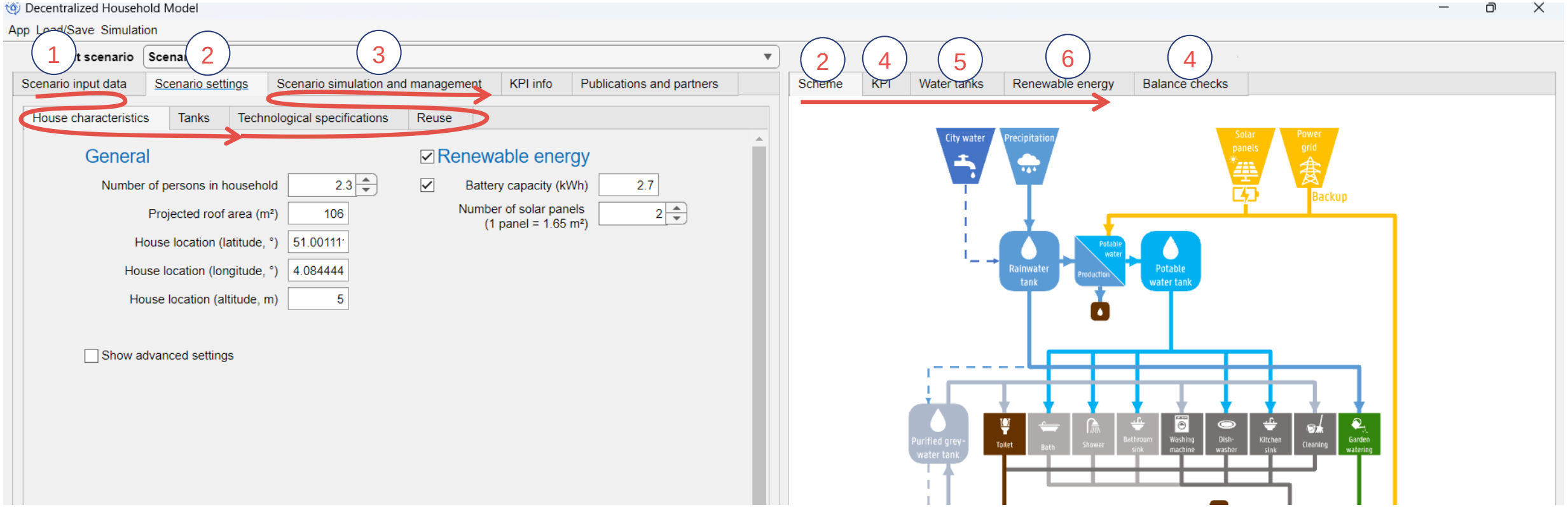



# Example workflow: step 0 – Initialization



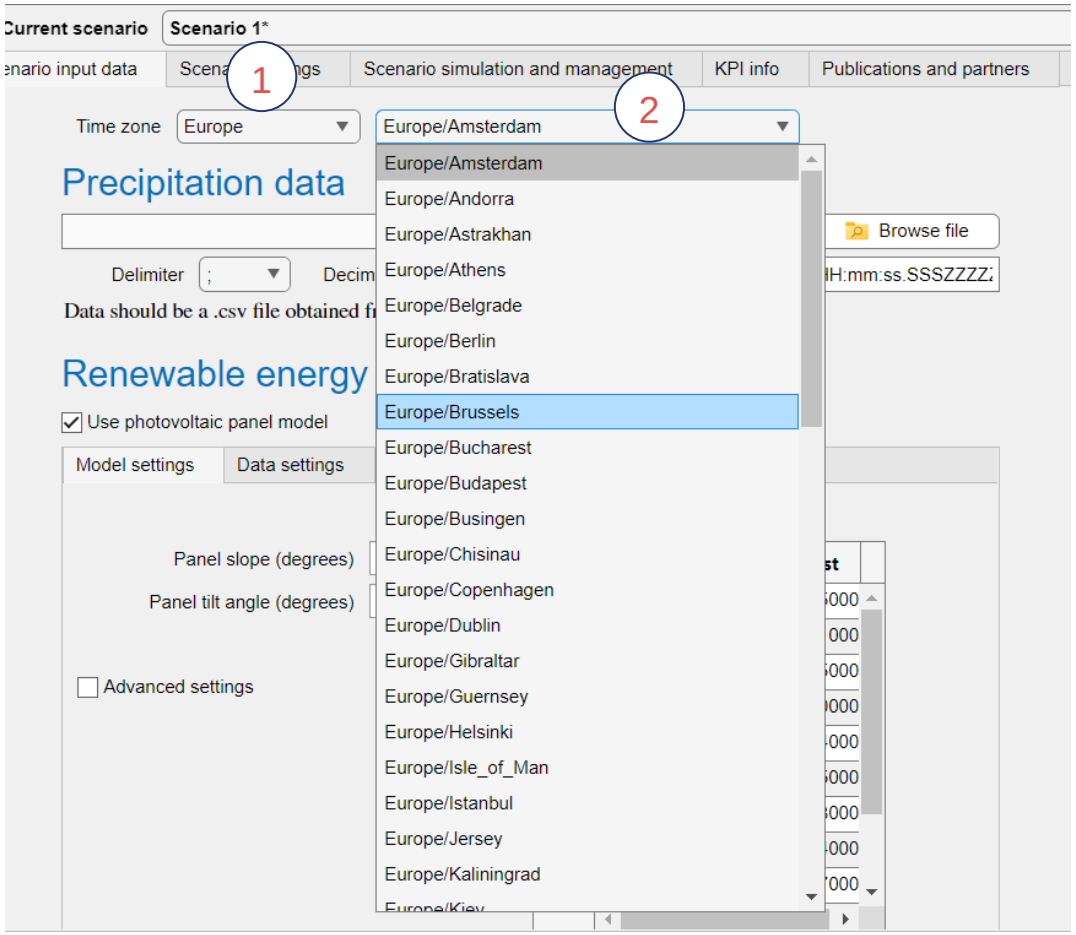
# Example workflow: overview

Within a scenario, go through tabs from left to right, changing settings where needed (see next slides)

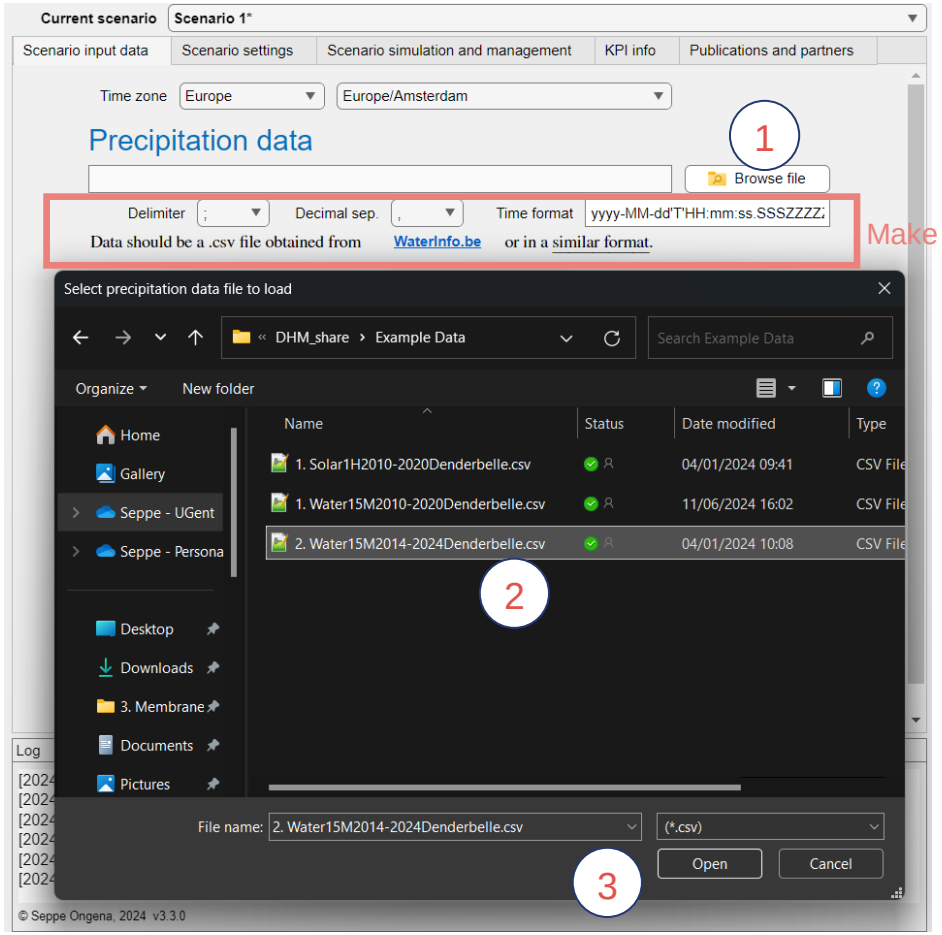


# Example workflow: step 1 – Input data

## Select time zone area and time zone




## Select precipitation file from example data

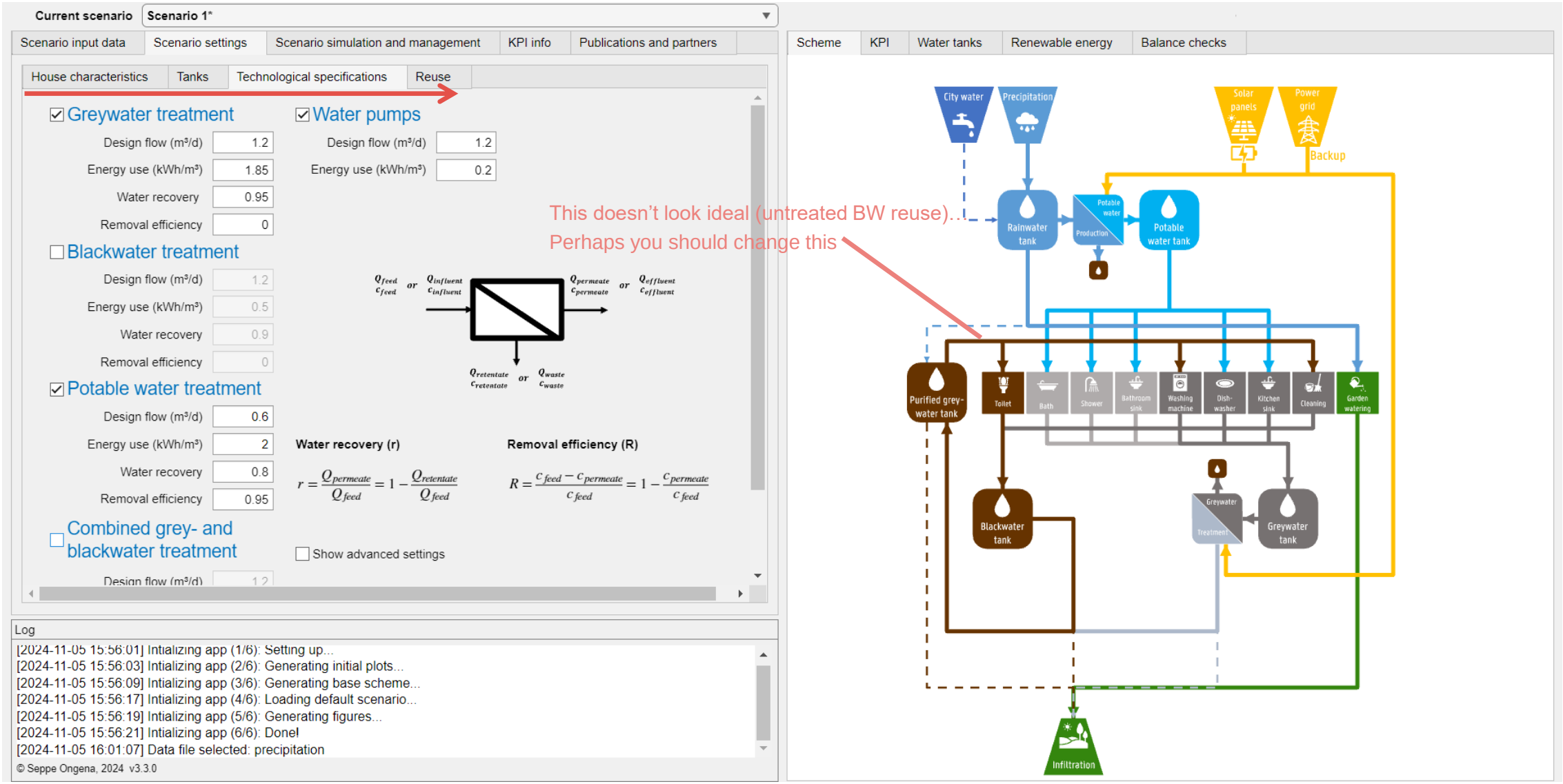



Make sure the formats are correct

Solar data can be loaded or left to the photovoltaic panel model to generate. **If using photovoltaic data, the temporal coverage should be equal or greater than the precipitation data!**

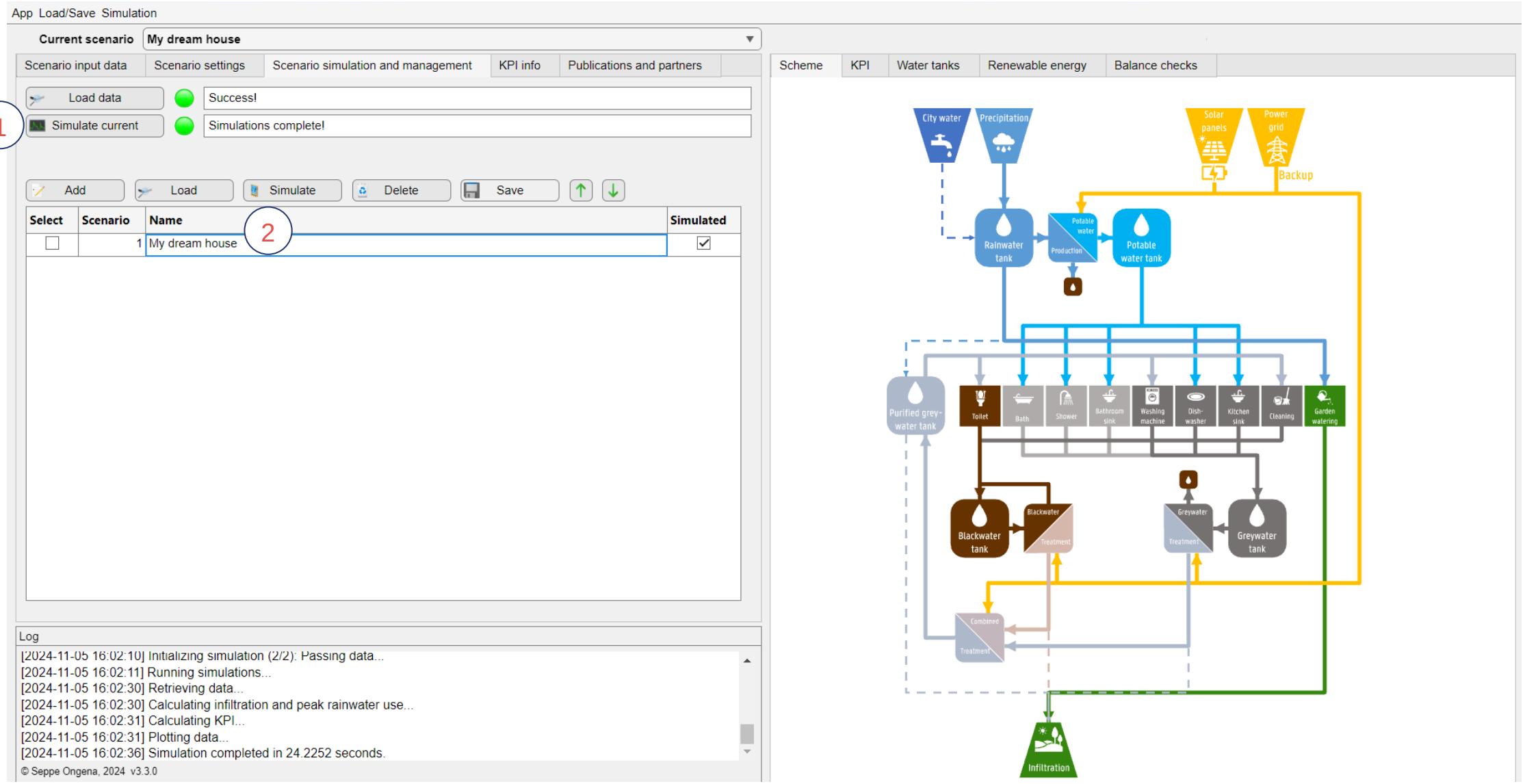
# Example workflow: step 2 – Settings

Go over each tab and change settings where wanted (open the scheme tab for visual feedback)



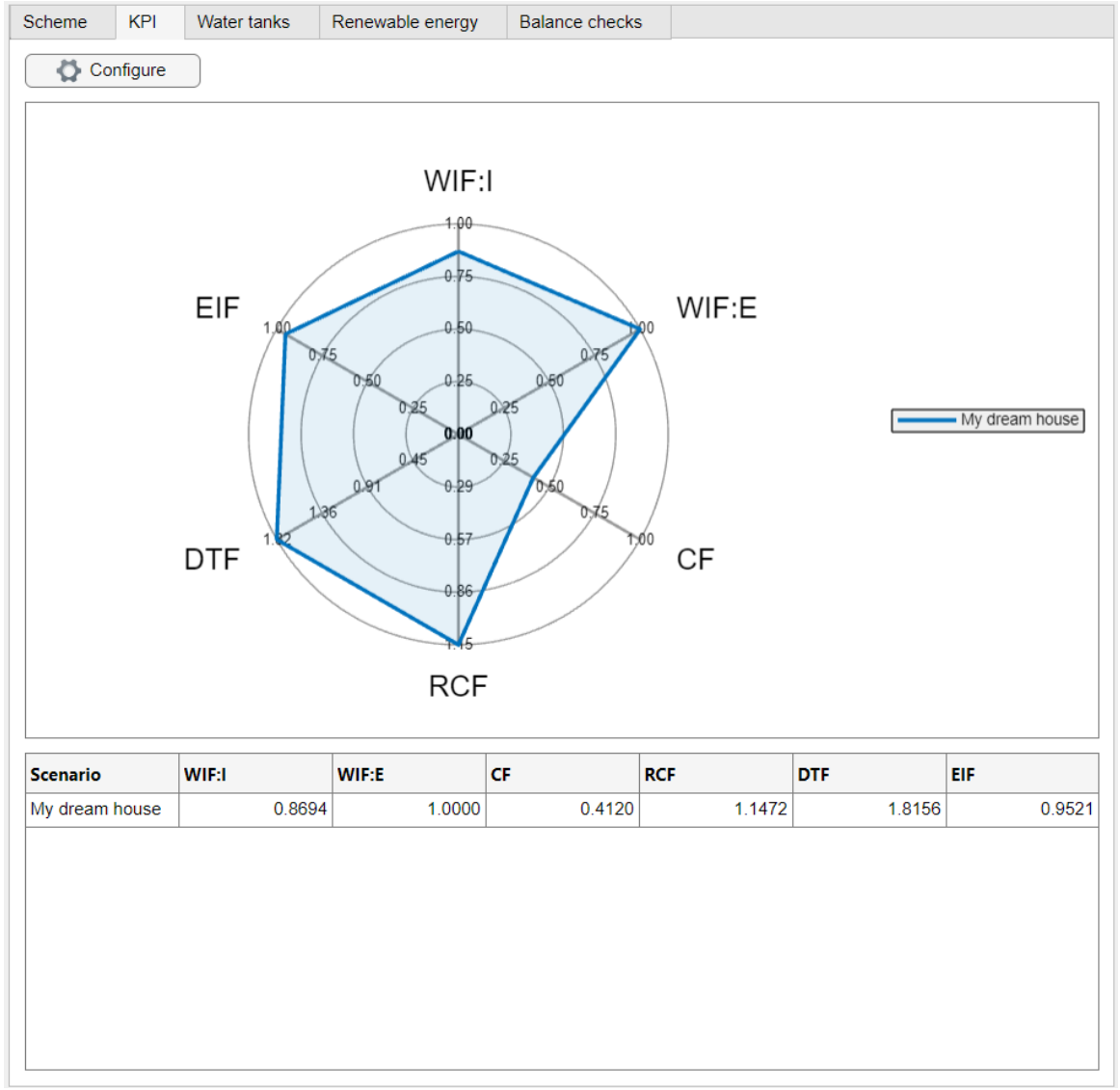
# Example workflow: step 3 – Simulate

Press the “simulate current” button and change the scenario name by double clicking it in the table



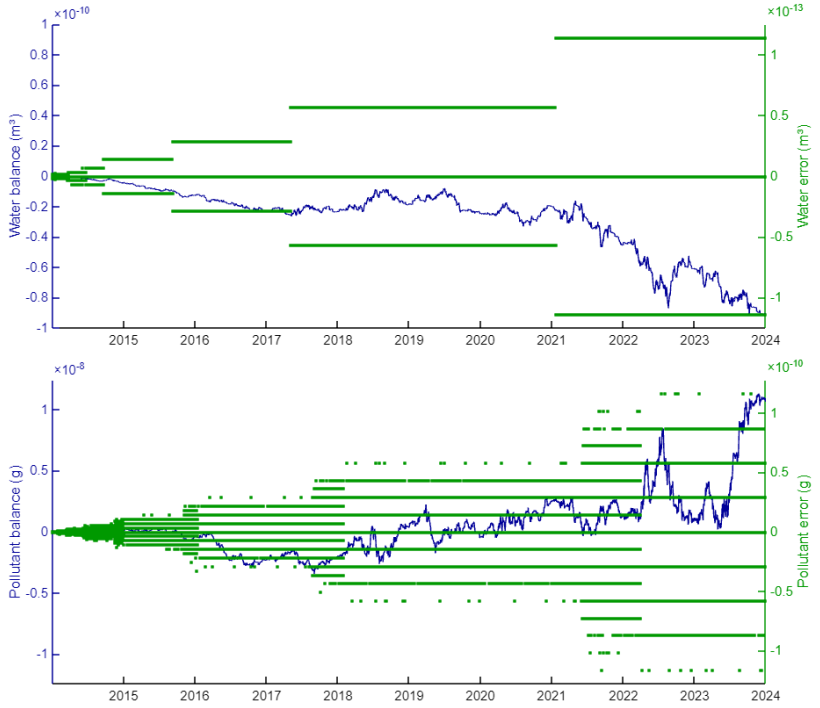
# Example workflow: step 4 – Evaluate KPI

Evaluate the KPI graph (right side of app) and table. Are these results what you expected?



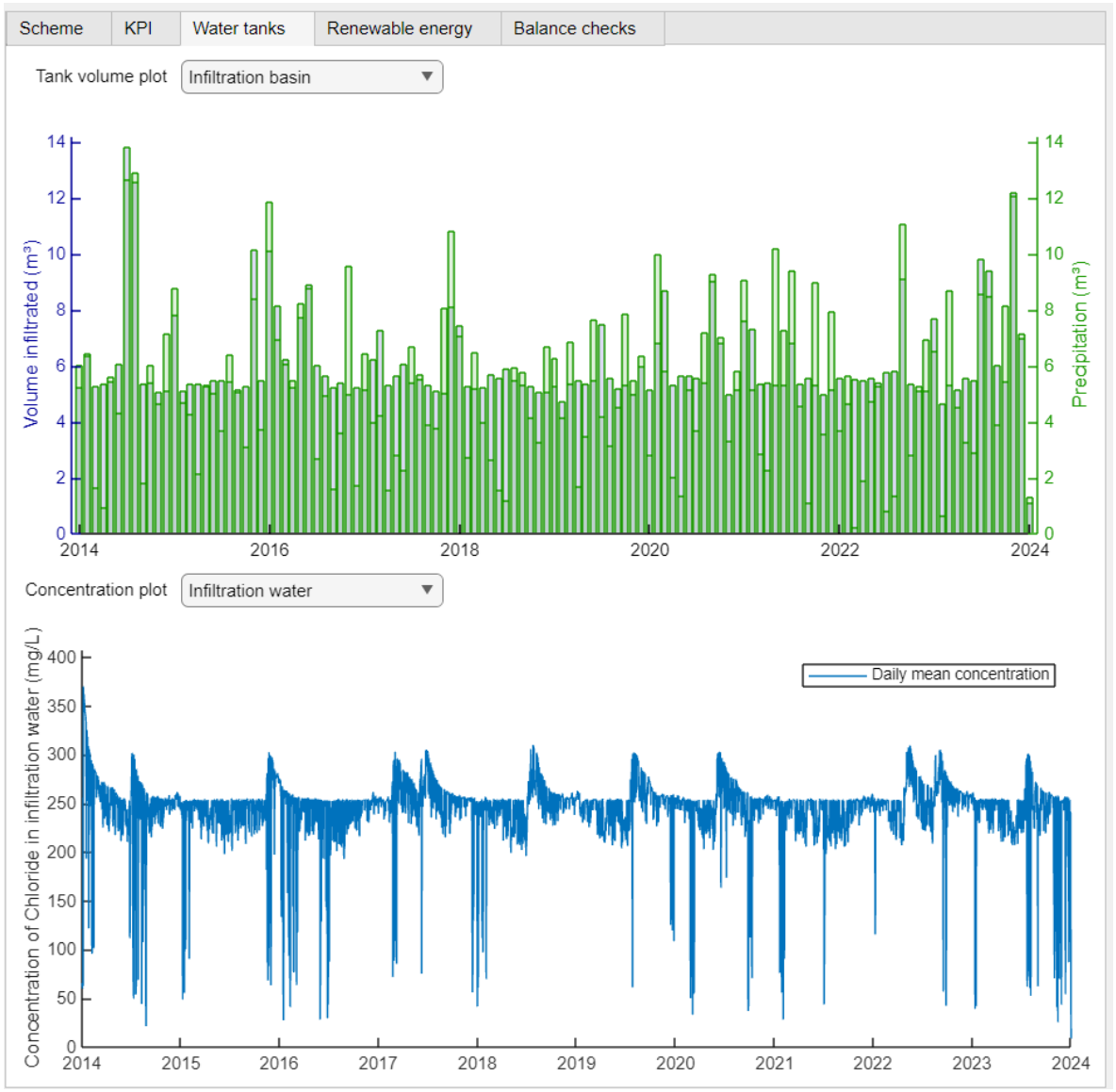

| Scenario | WIF:I | WIF:E | CF | RCF | DTF | EIF |
|---|---|---|---|---|---|---|
| My dream house | 0.8694 | 1.0000 | 0.4120 | 1.1472 | 1.8156 | 0.9521 |

If the results seem weird to you, you can always check the balance to see if I forgot to account for something in the model.



# Example workflow: step 5 – Delve into water tanks

Take a closer look at the levels and concentrations of each tank – and the infiltration basin

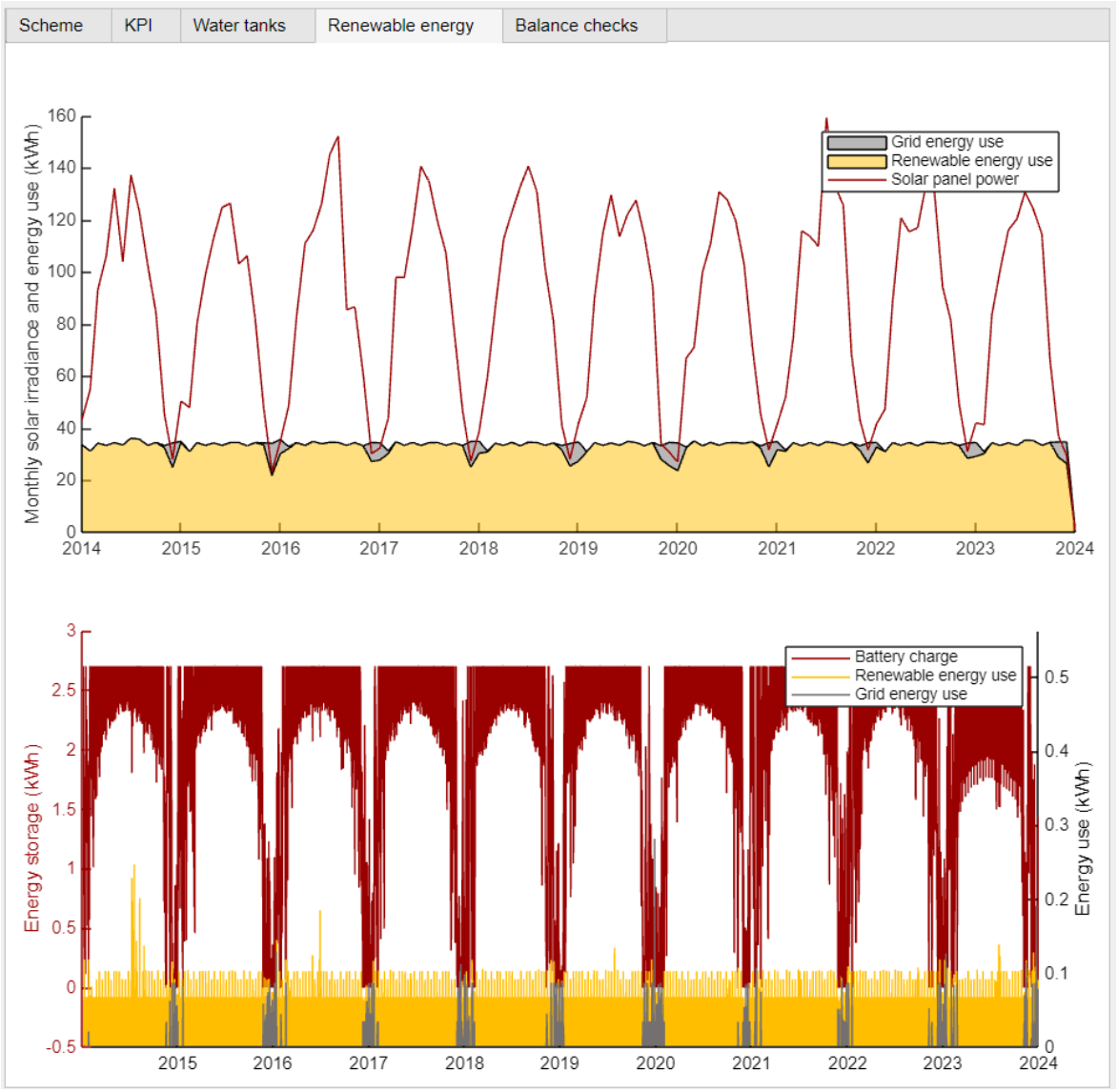



Admire the buffering effect of a decentralized household

Local regulations may apply here!

# Example workflow: step 6 – Feeling energetic

## Examine the energy usage

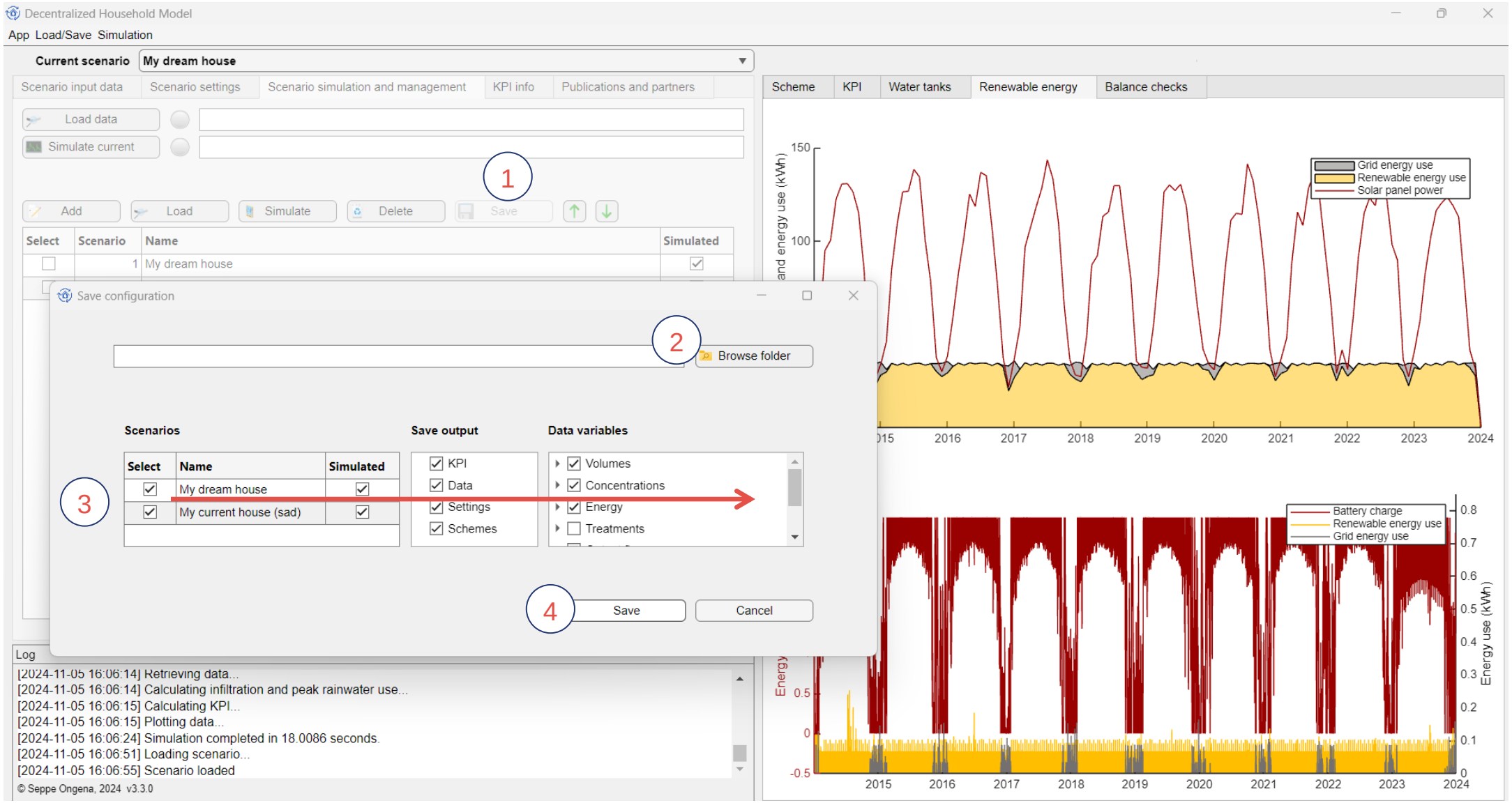



Grid energy used in winter. Notice the intersection of solar panel power and total energy requirement (use) and the disparity between renewable energy use and available solar power.

Battery is discharged most in winter, plenty full in summer.

# Example workflow: step 7 – Save results

Press save, choose folder, select scenarios to save, which outputs, and which variables to save



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CAPTURE
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for Urban REsource recovery


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