MovingIMPACT

CLOVER Workshop Introduction—Mini-grid simulation and appraisal







Dr Benedict Winchester

November 10th, 2026

Imperial College London

UK Research and Innovation

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Prerequisites:

1. Python 3.12 or later downloaded and installed on your machine
2. CLOVER v5.12; renewables.ninja API token
3. [Recommended] VSCode or a similar programming IDE (Development Env.)

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Intended Learning Outcomes (ILOs):

After today, you should be better able to

1. Understand and describe the operation of the CLOVER modelling framework
2. Run and launch simulations in CLOVER and understand their outputs
3. Through the tasks, explain links between supply, demand and system reliability.

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Tasks:

1. Simulate a mini-grid system using CLOVER
2. Explore the impact of supply and demand in CLOVER on reliability, cost, *etc.*

Outline

A. General overview (15 mins)
   a. Background:
      i. What CLOVER can do
   b. Model structure
   c. How to use CLOVER
   d. Quick-start demonstration
B. Guided tasks (30 mins)
   1. Energy supply (today: 30 mins)
      Q&A
   2. Energy demand (self-guided: 30 mins)
      Q&A
C. General Q&A (15 mins)
   a. Troubleshooting
   b. Code structure: What/how to edit

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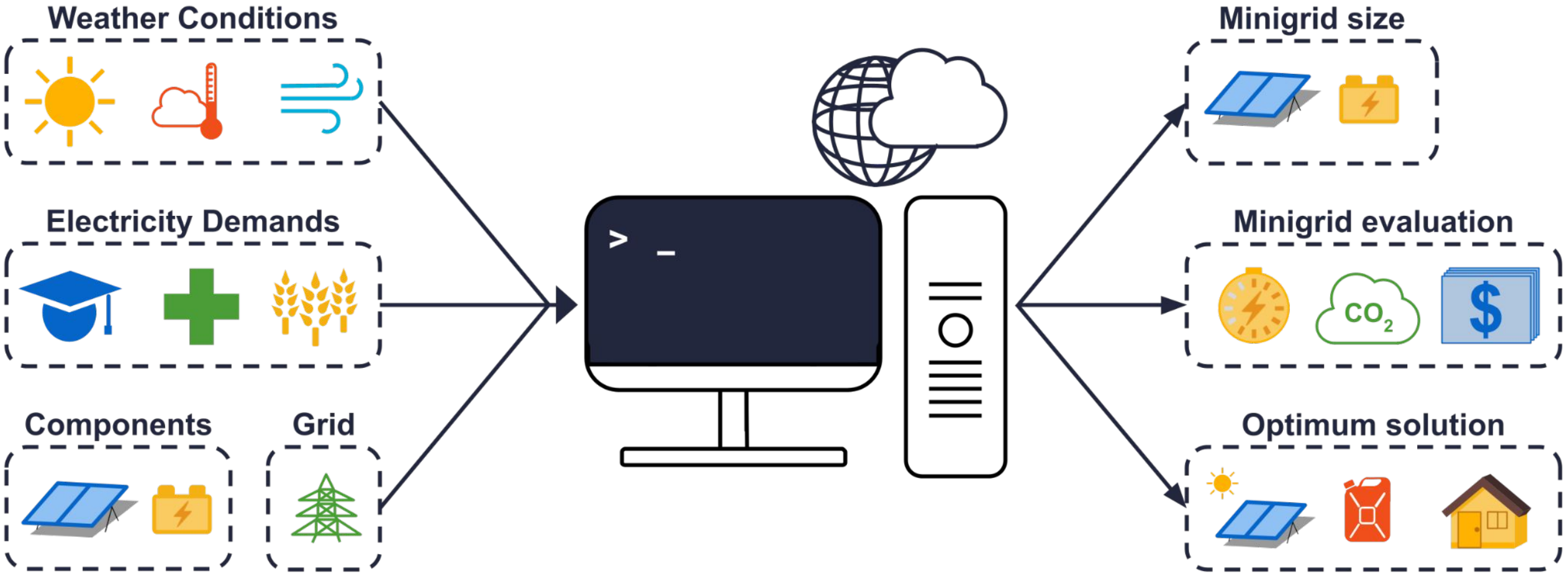
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MovingIMPACT — CLOVER Workshop 1: Simulation and Appraisal

Timeline	Type	Focus	Who	Documentation
2015–18	PhD research	Different PV techs for GHG mitigation in India Minigrids and GHG mitigation in India	Phil Sandwell	Journal paper
2016–17	Research (GCRF)	Minigrids in Nepal and Rwanda	Phil Sandwell & Scot Wheeler	Grantham briefing paper
2017	MSc in SEF	Minigrids and SHSs in Peru	Louise Alter	MSc thesis
2017	PhD research	OPV for minigrids in India	Ajay Gambhir	PhD chapter
2018	MSc in SEF	Minigrids for households and health centres in India	Muriel Hauser & Hamish Beath	MSc thesis
2018	MSc in SEF	Energy for enterprises in Rwanda	Noah Ochima & Hamish Beath	MSc thesis
2018–23	PhD research	Power modelling in minigrids	Hamish Beath	PhD thesis
2020–25	PhD research	Mini-grid systems for mitigating asset stranding Minigrids powering desalination	Ben Winchester	PhD thesis
2022	MSc in SEF	Rural health-centre cooling loads in Uganda	Ilaria delFrate	MSc thesis
2022	MSc in SEF	Rooftop solar mini-grid systems in Lebanon	Paul Harfouche	MSc thesis
2023	MSc in SEF	Modelling e-bike swap stations in Nairobi	Harry Griffiths	MSc thesis
2023	MSc in SEF	Modelling agrivoltaic installations in Zimbabwe	Naa Oaikey	MSc thesis Paper in preparation
2024	Research paper	Pathways for universal access under various reliability and carbon-tax scenarios	Hamish Beath *et al.*	Nat. Comms paper
2024	MSc in SEF	Potential of agrivoltaic minigrids in Tanzania	Ade Jimoh	MSc thesis Preprint
2025	Research paper	Impact of asset stranding in mini-grid systems	Phil Sandwell & Ben Winchester *et al.*	Preprint

CLOVER


Weather Conditions
Electricity Demands
Components
Grid
Minigrid size
Minigrid evaluation
CO_2
$
Optimum solution

CLOVER

CLOVER

Repository for the CLOVER-energy Github organisation

- Home
- About
- Run guide
- Publications

View the Project on GitHub
https://github.com/CLOVER-energy/CLOVER

CLOVER modelling framework for community-scale energy systems

CLOVER (Continuous Lifetime Optimisation of Variable Electricity Resources) is a an open-source Python based modelling framework enabling the simulation and optimisation of community-scale energy systems, typically minigrids, to support energy access in developing countries [1]. It is a framework under constant development, with new features being added, and has been applied to many different scenarios and case studies (see the publications page for more information).

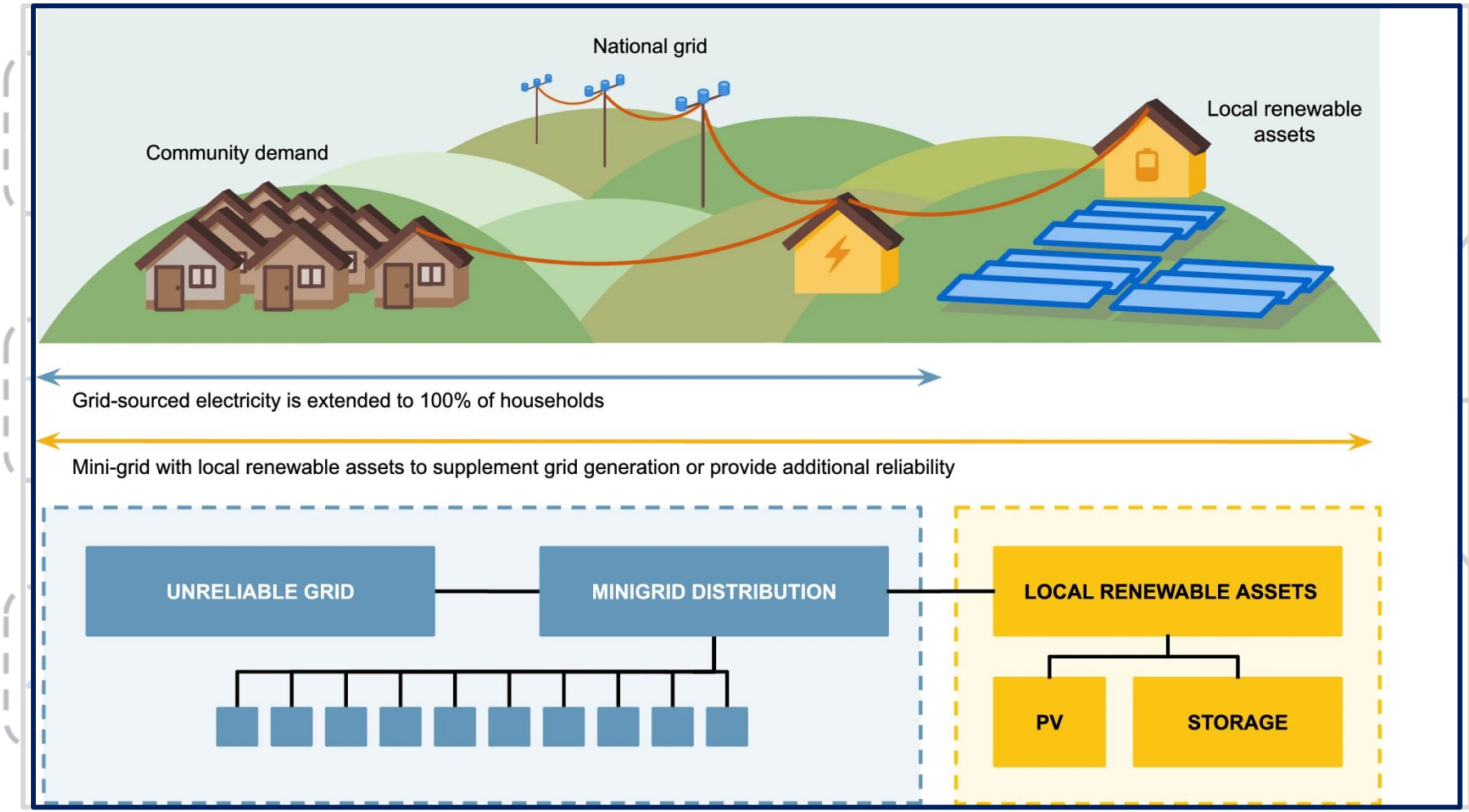
The model operates with an hourly resolution and is designed to be able to simulate or optimise community-scale energy systems over a multi-year timeframe. The model is modular, with solar electrcity, solar thermal, PVT, grid, diesel, and load modules. As an open-srouce repository, the development of new functionality is encouraged. For a list of open issues and feature requests see the Github issues page.



Minigrid size

clover-energy.org

CLOVER



Minigrid size

Nat. Commun. **16** 8061 (2025)

CLOVER

CLOVER is…

- an energy system model
- that offers techno-economic analysis,
- that can estimate GHG emissions and waste products,
- and which is open-source and fully editable.

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CLOVER is/does not…

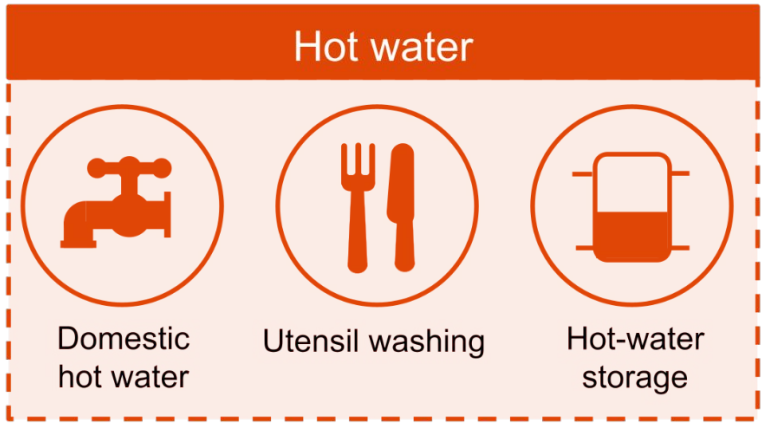
- a power system model,
- offer financial modelling,
- cannot estimate other environmental parameters,
- might not be able to do *exactly* what you want out of the box depending on the types of questions that you want to ask…

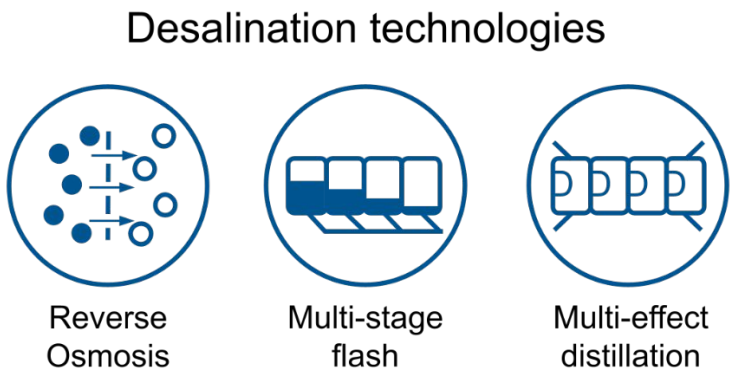
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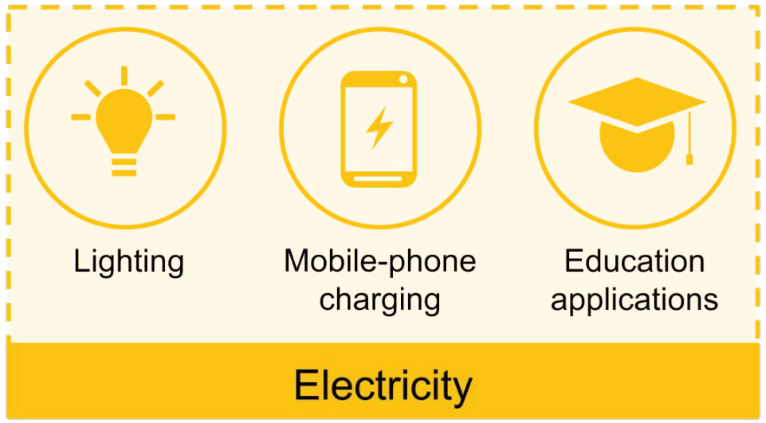
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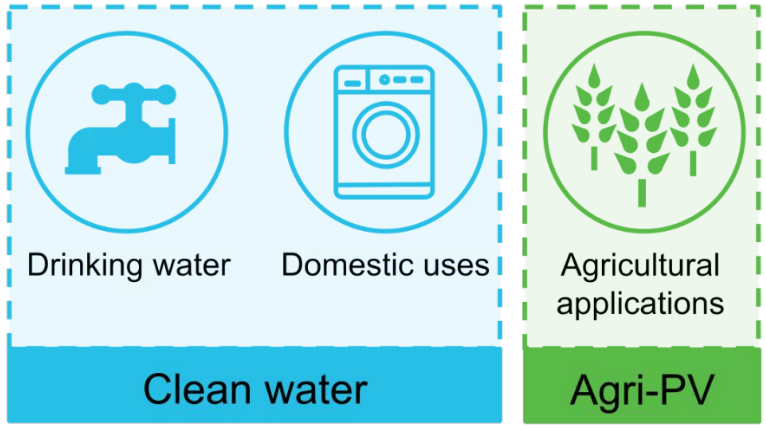
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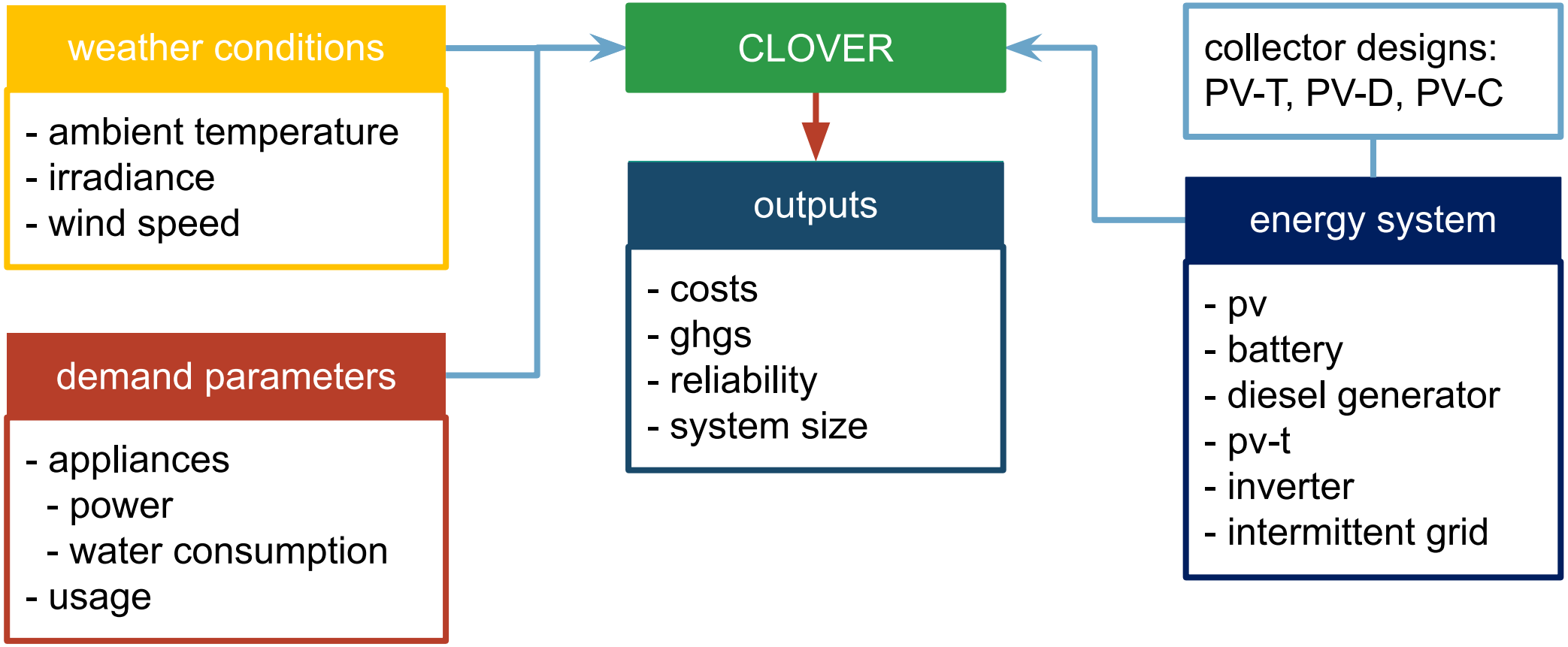




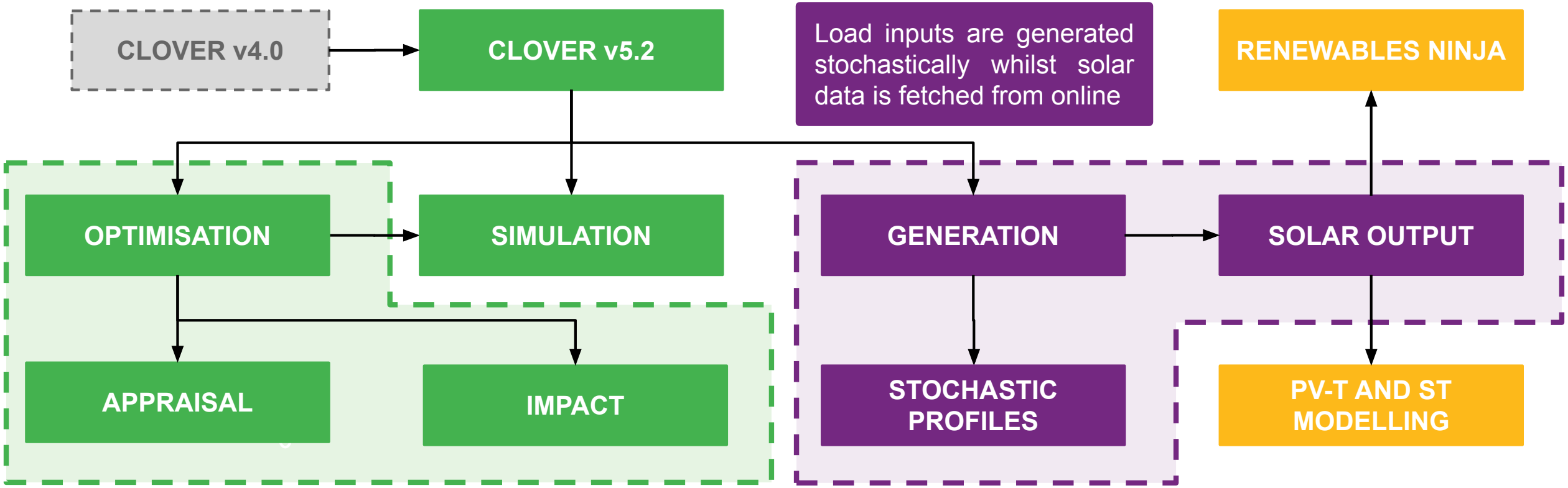
JOSS

Github

CLOVER


weather conditions
- ambient temperature
- irradiance
- wind speed
demand parameters
- appliances
- power
- water consumption
- usage
CLOVER
outputs
- costs
- ghgs
- reliability
- system size
collector designs:
PV-T, PV-D, PV-C
energy system
- pv
- battery
- diesel generator
- pv-t
- inverter
- intermittent grid

CLOVER


CLOVER v4.0
CLOVER v5.2
Load inputs are generated stochastically whilst solar data is fetched from online
RENEWABLES NINJA
OPTIMISATION
SIMULATION
GENERATION
SOLAR OUTPUT
APPRAISAL
IMPACT
STOCHASTIC PROFILES
PV-T AND ST MODELLING

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Help Command

```
python -u -m src.clover --help
```

```
usage: python -m src.clover [-h] [--location LOCATION] [--refetch]
                            [--regenerate]
                            [--electric-load-profile ELECTRIC_LOAD_PROFILE]
                            [--output OUTPUT]
                            [--pv-system-size PV_SYSTEM_SIZE]
                            [--scenario SCENARIO]
                            [--storage-size STORAGE_SIZE]
                            [--num-clean-water-tanks NUM_CLEAN_WATER_TANKS]
                            [--clean-water-pvt-system-size CLEAN_WATER_PVT_SYSTE
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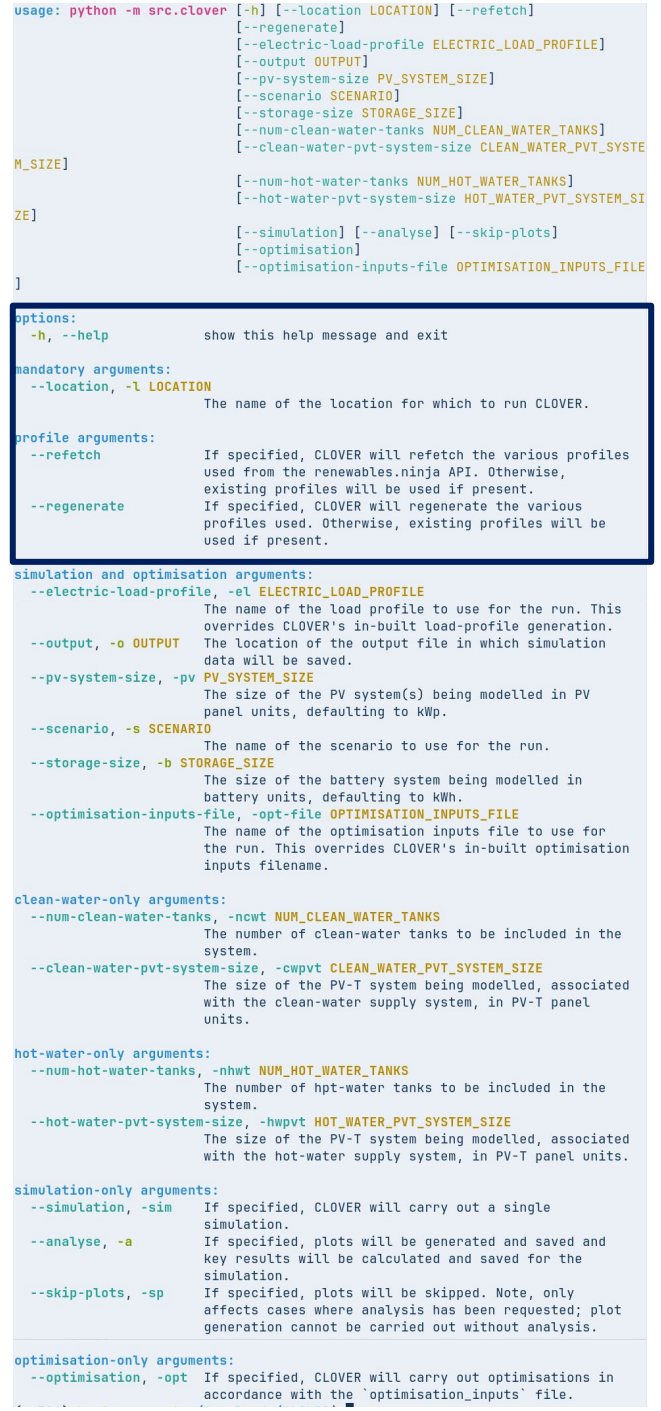
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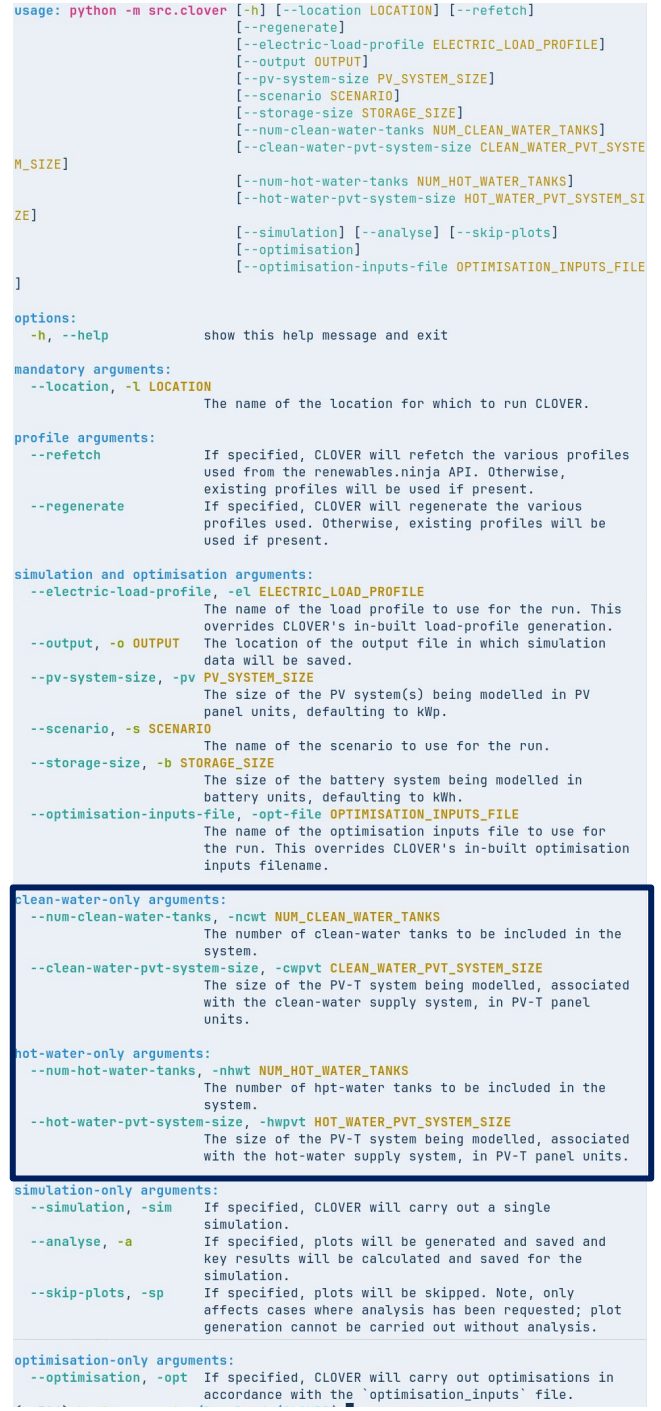
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]

options:
  -h, --help            show this help message and exit

mandatory arguments:
  --location, -l LOCATION
                        The name of the location for which to run CLOVER.

profile arguments:
  --refetch             If specified, CLOVER will refetch the various profiles
                        used from the renewables.ninja API. Otherwise,
                        existing profiles will be used if present.
  --regenerate          If specified, CLOVER will regenerate the various
                        profiles used. Otherwise, existing profiles will be
                        used if present.

simulation and optimisation arguments:
  --electric-load-profile, -el ELECTRIC_LOAD_PROFILE
                        The name of the load profile to use for the run. This
                        overrides CLOVER's in-built load-profile generation.
  --output, -o OUTPUT   The location of the output file in which simulation
                        data will be saved.
  --pv-system-size, -pv PV_SYSTEM_SIZE
                        The size of the PV system(s) being modelled in PV
                        panel units, defaulting to kWp.
  --scenario, -s SCENARIO
                        The name of the scenario to use for the run.
  --storage-size, -b STORAGE_SIZE
                        The size of the battery system being modelled in
                        battery units, defaulting to kWh.
  --optimisation-inputs-file, -opt-file OPTIMISATION_INPUTS_FILE
                        The name of the optimisation inputs file to use for
                        the run. This overrides CLOVER's in-built optimisation
                        inputs filename.

clean-water-only arguments:
  --num-clean-water-tanks, -ncwt NUM_CLEAN_WATER_TANKS
                        The number of clean-water tanks to be included in the
                        system.
  --clean-water-pvt-system-size, -cwpvt CLEAN_WATER_PVT_SYSTEM_SIZE
                        The size of the PV-T system being modelled, associated
                        with the clean-water supply system, in PV-T panel
                        units.

hot-water-only arguments:
  --num-hot-water-tanks, -nhwt NUM_HOT_WATER_TANKS
                        The number of hpt-water tanks to be included in the
                        system.
  --hot-water-pvt-system-size, -hwpvt HOT_WATER_PVT_SYSTEM_SIZE
                        The size of the PV-T system being modelled, associated
                        with the hot-water supply system, in PV-T panel units.

simulation-only arguments:
  --simulation, -sim    If specified, CLOVER will carry out a single
                        simulation.
  --analyse, -a         If specified, plots will be generated and saved and
                        key results will be calculated and saved for the
                        simulation.
  --skip-plots, -sp     If specified, plots will be skipped. Note, only
                        affects cases where analysis has been requested; plot
                        generation cannot be carried out without analysis.

optimisation-only arguments:
  --optimisation, -opt  If specified, CLOVER will carry out optimisations in
                        accordance with the `optimisation_inputs` file.
```

Help Command

```
python -u -m src.clover --help
```

```
simulation-only arguments:
  --simulation, -sim    If specified, CLOVER will carry out a single
                        simulation.
  --analyse, -a         If specified, plots will be generated and saved and
                        key results will be calculated and saved for the
                        simulation.
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                        affects cases where analysis has been requested; plot
                        generation cannot be carried out without analysis.

optimisation-only arguments:
  --optimisation, -opt  If specified, CLOVER will carry out optimisations in
                        accordance with the `optimisation_inputs` file.
```

```
usage: python -m src.clover [-h] [--location LOCATION] [--refetch]
                            [--regenerate]
                            [--electric-load-profile ELECTRIC_LOAD_PROFILE]
                            [--output OUTPUT]
                            [--pv-system-size PV_SYSTEM_SIZE]
                            [--scenario SCENARIO]
                            [--storage-size STORAGE_SIZE]
                            [--num-clean-water-tanks NUM_CLEAN_WATER_TANKS]
                            [--clean-water-pvt-system-size CLEAN_WATER_PVT_SYSTE
M_SIZE]
                            [--num-hot-water-tanks NUM_HOT_WATER_TANKS]
                            [--hot-water-pvt-system-size HOT_WATER_PVT_SYSTEM_SI
ZE]
                            [--simulation] [--analyse] [--skip-plots]
                            [--optimisation]
                            [--optimisation-inputs-file OPTIMISATION_INPUTS_FILE
]

options:
  -h, --help            show this help message and exit

mandatory arguments:
  --location, -l LOCATION
                        The name of the location for which to run CLOVER.

profile arguments:
  --refetch             If specified, CLOVER will refetch the various profiles
                        used from the renewables.ninja API. Otherwise,
                        existing profiles will be used if present.
  --regenerate          If specified, CLOVER will regenerate the various
                        profiles used. Otherwise, existing profiles will be
                        used if present.

simulation and optimisation arguments:
  --electric-load-profile, -el ELECTRIC_LOAD_PROFILE
                        The name of the load profile to use for the run. This
                        overrides CLOVER's in-built load-profile generation.
  --output, -o OUTPUT   The location of the output file in which simulation
                        data will be saved.
  --pv-system-size, -pv PV_SYSTEM_SIZE
                        The size of the PV system(s) being modelled in PV
                        panel units, defaulting to kWp.
  --scenario, -s SCENARIO
                        The name of the scenario to use for the run.
  --storage-size, -b STORAGE_SIZE
                        The size of the battery system being modelled in
                        battery units, defaulting to kWh.
  --optimisation-inputs-file, -opt-file OPTIMISATION_INPUTS_FILE
                        The name of the optimisation inputs file to use for
                        the run. This overrides CLOVER's in-built optimisation
                        inputs filename.

clean-water-only arguments:
  --num-clean-water-tanks, -ncwt NUM_CLEAN_WATER_TANKS
                        The number of clean-water tanks to be included in the
                        system.
  --clean-water-pvt-system-size, -cwpvt CLEAN_WATER_PVT_SYSTEM_SIZE
                        The size of the PV-T system being modelled, associated
                        with the clean-water supply system, in PV-T panel
                        units.

hot-water-only arguments:
  --num-hot-water-tanks, -nhwt NUM_HOT_WATER_TANKS
                        The number of hpt-water tanks to be included in the
                        system.
  --hot-water-pvt-system-size, -hwpvt HOT_WATER_PVT_SYSTEM_SIZE
                        The size of the PV-T system being modelled, associated
                        with the hot-water supply system, in PV-T panel units.

simulation-only arguments:
  --simulation, -sim    If specified, CLOVER will carry out a single
                        simulation.
  --analyse, -a         If specified, plots will be generated and saved and
                        key results will be calculated and saved for the
                        simulation.
  --skip-plots, -sp     If specified, plots will be skipped. Note, only
                        affects cases where analysis has been requested; plot
                        generation cannot be carried out without analysis.

optimisation-only arguments:
  --optimisation, -opt  If specified, CLOVER will carry out optimisations in
                        accordance with the `optimisation_inputs` file.
```

Making a new location

```
python -u -m src.clover.scripts.new_location
<new_location_name>
```

Making a new location

```
python -u -m src.clover.scripts.new_location
<new_location_name>
```

```
(py314) ben@cormorant:~/Downloads/CLOVER$ python -u -m src.clover.scripts.new_lo
cation test_26_10_26
<frozen runpy>:130: RuntimeWarning: 'src.clover.scripts.new_location' found in s
ys.modules after import of package 'src.clover.scripts', but prior to execution
of 'src.clover.scripts.new_location'; this may result in unpredictable behaviour
(py314) ben@cormorant:~/Downloads/CLOVER$
```

Making a new location

```
python -u -m src.clover.scripts.new_location
<new_location_name>
```

```
(py314) ben@cormorant:~/Downloads/CLOVER$ python -u -m src.clover.scripts.new_lo
cation test_26_10_26
<frozen runpy>:130: RuntimeWarning: 'src.clover.scripts.new_location' found in s
ys.modules after import of package 'src.clover.scripts', but prior to execution
of 'src.clover.scripts.new_location'; this may result in unpredictable behaviour
(py314) ben@cormorant:~/Downloads/CLOVER$ ls locations/
Bahraich/      test/          test_26_10_26/
(py314) ben@cormorant:~/Downloads/CLOVER$
```

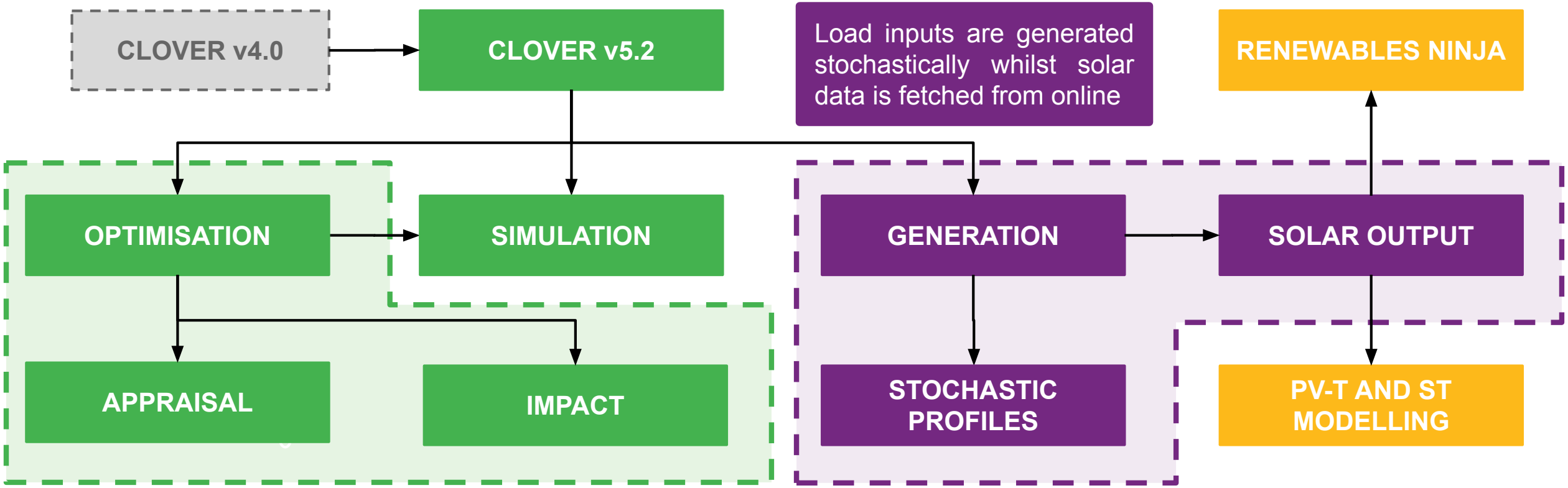
Making a new location

```
python -u -m src.clover.scripts.new_location
<new_location_name>
```

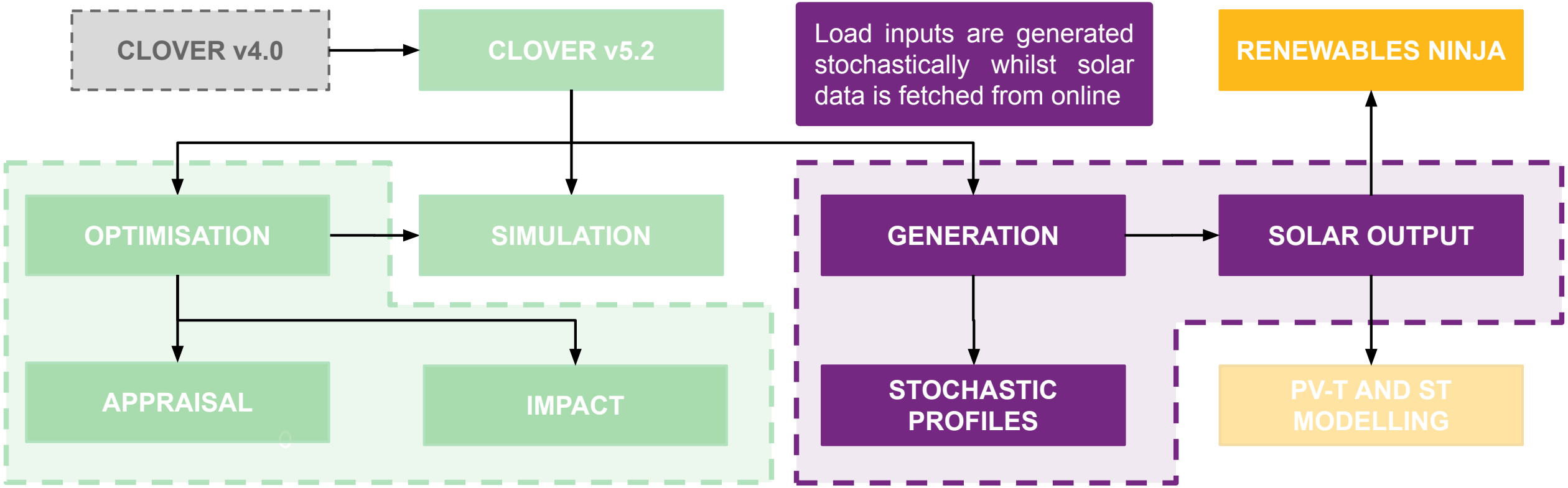
```
(py314) ben@cormorant:~/Downloads/CLOVER$ python -u -m src.clover.scripts.new_lo
cation test_26_10_26
<frozen runpy>:130: RuntimeWarning: 'src.clover.scripts.new_location' found in s
ys.modules after import of package 'src.clover.scripts', but prior to execution
of 'src.clover.scripts.new_location'; this may result in unpredictable behaviour
(py314) ben@cormorant:~/Downloads/CLOVER$ ls locations/
Bahraich/      test/          test_26_10_26/
(py314) ben@cormorant:~/Downloads/CLOVER$ tree locations/test_26_10_26/
locations/test_26_10_26/
├── auto_generated
│   ├── grid
│   ├── load
│   │   ├── clean_water
│   │   │   └── device_load
│   │   ├── device_ownership
```

Profile generation (first time only)

CLOVER


CLOVER v4.0
CLOVER v5.2
Load inputs are generated stochastically whilst solar data is fetched from online
RENEWABLES NINJA
OPTIMISATION
SIMULATION
GENERATION
SOLAR OUTPUT
APPRAISAL
IMPACT
STOCHASTIC PROFILES
PV-T AND ST MODELLING

CLOVER


CLOVER v4.0
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Load inputs are generated stochastically whilst solar data is fetched from online
RENEWABLES NINJA
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PV-T AND ST MODELLING

Profile generation (first time only)

```
python -u -m src.clover --location <new_location_name>
```

Profile generation (first time only)

```
python -u -m src.clover --location <new_location_name>
```

```
<frozen runpy>:130: RuntimeWarning: 'src.clover.__main__' found in sys.modules a
fter import of package 'src.clover', but prior to execution of 'src.clover.__mai
n__'; this may result in unpredictable behaviour


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      Continuous Lifetime Optimisation of Variable Electricity Resources
                        Copyright Phil Sandwell, 2018
                                Version 5.1.2

                        For more information, contact
                    Phil Sandwell (philip.sandwell@gmail.com),
                     Hamish Beath (hamishbeath@outlook.com),
                or Ben Winchester (benedict.winchester@gmail.com)


Neither `simulation` or `optimisation` specified, running profile generation onl
y for test_26_10_26
Verifying location information ..............................    [   DONE   ]
Parsing input files ........................................    [   DONE   ]
Generating necessary profiles
electric load profiles: 100%|                | 12/12 [00:00<00:00, 40.84device/s]
total load profile: 100%|                    | 12/12 [00:00<00:00, 1597.98device/s]
grid profiles: 100%|                         | 5/5 [00:00<00:00, 72.52grid/s]
```

Just run CLOVER

```
$ python -m src.clover --location <location_name> \
  --simulation --pv-system-size <pv_system_size> \
  --storage-size <storage_size>
  --other commands...
```

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Questions?



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Outline

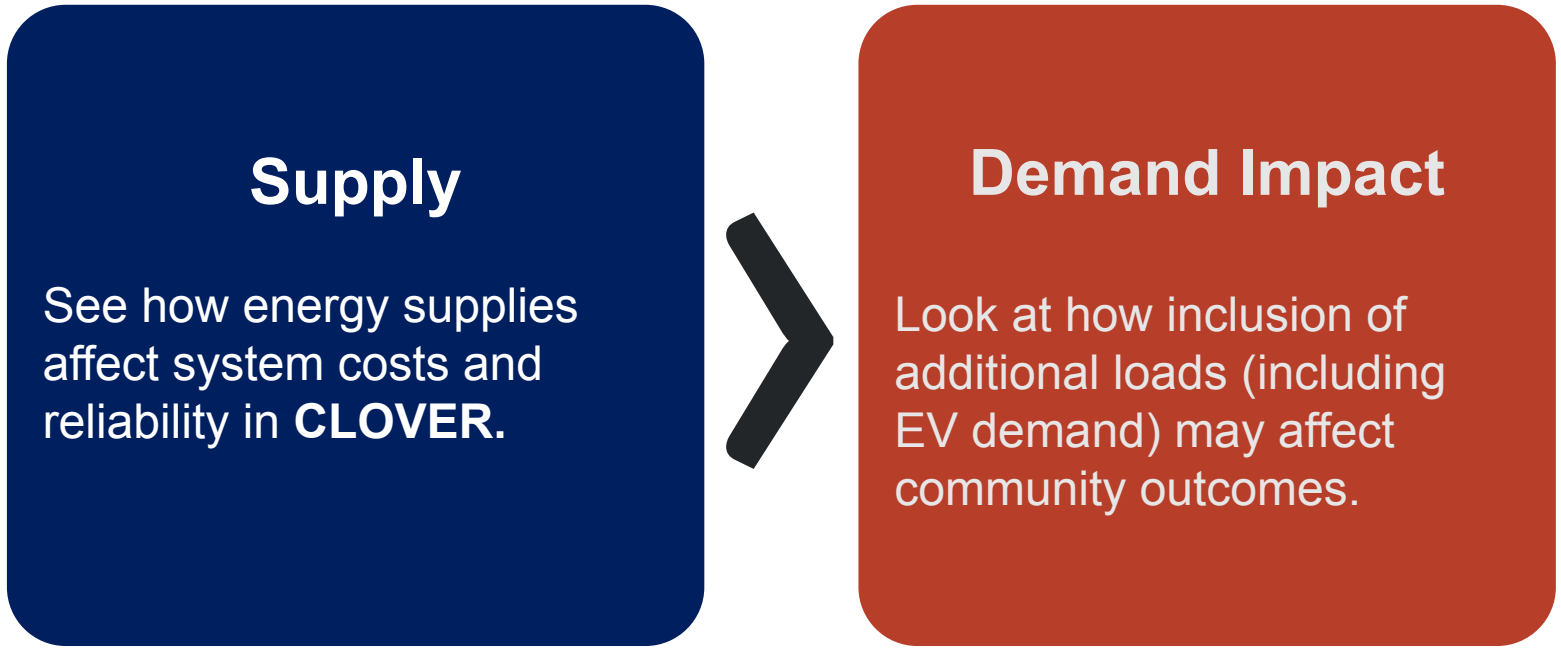
A. General overview
   a. Background:
      i. What CLOVER can do
   b. Model structure
   c. How to use CLOVER
   d. Quick-start demonstration

B. Guided tasks
   1. Energy supply
   Q&A
   2. Energy demand
   Q&A

C. General Q&A
   a. Troubleshooting
   b. Code structure: What/how to edit

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CLOVER



1. **Usability:** How easy were the model(s) to use?
2. **Findings:** Were there any interesting things your table found?
3. **Connecting:** How does, or, could this connect with your work? What requests or challenges would increase the value of tools like these?

#1 Supply: How supplies affect costs and reliability

Goals:

1. To use CLOVER to simulate a mini-grid energy system;
2. To investigate the impact of electricity supply the cost of electricity and system reliability in CLOVER.

Tasks:

1. Simulate a mini-grid system using CLOVER
2. Adjust the availability of electricity sources and the system's prioritisation strategy to assess the impact.

1. **Usability:** How easy were the model(s) to use?
2. **Findings:** Were there any interesting things you found?
3. **Connecting:** How does or could this connect with your work/study?

#1 Supply: How supplies affect costs and reliability

1. **Run a CLOVER Simulation [10 minutes]**
   a. Load the location `<location_name>` that you created earlier which, by default, represents:
      - A 100 household mini-grid community located in North India (in Uttar Pradesh).
      - The community has households' domestic loads, commercial and public loads.
   b. Run a simulation in CLOVER:
      - Use the `--simulate` flag along with `-pv 25` and `-b 25` to simulate with 25 kW_p of solar PV modules and 25 kWh of battery storage.
      - If you didn't run profile generation before, this will also generate stochastic outputs and download profiles from renewables.ninja for the solar insolation.
      - Use the `--analyse` flag to make sure that analysis of the system takes place.
   c. Explore CLOVER's outputs:
      - Two generated files: `info_file.json` and `simulation_output_1.csv`
      - Find the:
        - **LCUE:** The levelised cost of **used** electricity;
        - **Blackouts:** The number of hours for which not all of the demand was met;
        - **Unmet energy fraction:** The fraction of demand which went unmet;
        - And any other outputs that you find are interesting.

#1 Supply: How supplies affect costs and reliability

2. Explore how electricity supply affects the system [20 minutes]

a. Record baseline costs and reliability (if you haven't already done so).
To see the impact of changing supplies in a quantitative measure, first, note down the **LCUE** and **blackouts** from the Summary table for the baseline case (where all electricity supplies are available).

b. Turn off diesel backup generation:
- Diesel generation (along with other sources) are in `scenario_inputs.yaml`
- Switch the diesel to be `disabled` rather than `unmet`.
- Run the same CLOVER simulation (same sizes) as you did in step 1.

c. Take a look at the outputs:
- Has the LCUE changed? What about the blackouts?
- How do the reliability graphs look? These graphs are in `simulation_1_plots`.

d. Explore other supply options.
The scenario inputs file lets you configure the availability of PV modules, battery storage, and a connection to the national-grid network.
- Which of these has the greatest impact on reliability? LCUE?
- If you have time, try adjusting the prioritisation strategy. This variable determines how CLOVER sources electricity when multiple supply options are available.

#2 Human Impact: How uneven supplies and loads affect communities

Goals:

1. To use CLOVER to generate a series of load outputs;
2. To consider how the inclusion and removal of certain loads may affect communities.

Tasks:

1. Simulate a mini-grid system using CLOVER
2. Investigate the impact of loads on community outcomes

1. **Usability:** How easy were the model(s) to use?
2. **Findings:** Were there any interesting things you found?
3. **Connecting:** How does or could this connect with your work/study?

Padlet

#2 Human Impact: How uneven supplies and loads affect communities

1. Run a CLOVER Simulation [10 minutes]

a. Load the location you set up before.

b. Run a simulation in CLOVER following the same steps as for task 1:
- Use the `--simulate` flag along with `-pv 25` and `-b 25` to simulate with 25 kW_p of solar PV modules and 25 kWh of battery storage.
- If you're trying task #2 with a new location in your own time, you'll need to make sure that your renewables.ninja profile API token is configured correctly.
- Use the `--analyse` flag to make sure that analysis of the system takes place.

c. Explore CLOVER's outputs:
- Two generated files: `info_file.json` and `simulation_output_1.csv`
- In the `infl_file.json`, find the:
  - **LCUE:** The levelised cost of **used** electricity;
  - **Blackouts:** The number of hours for which not all of the demand was met;
  - **Unmet energy fraction:** The fraction of demand which went unmet;
  - And any other outputs that you find are interesting.
- A series of plots which show the availability and reliability of the electricity supplied by the minigrid system: take a look at the availability profiles for various electricity sources.

Padlet

#2 Human Impact: How uneven supplies and loads affect communities

2. Explore the impact of loads on community outcomes [20 minutes]

a. Record baseline costs, emissions and reliability.
To see the impact of changing supplies in a quantitative measure, first, note down the **LCUE, Unmet Energy Fraction,** and **Emissions intensity** from the Summary table for the baseline case (where all electricity supplies are available).

b. Adjust the devices and loads on the system:
These are edited in two places:
- In `scenario_inputs.yaml`, you can turn off groups of demand (domestic, *etc.*),
- In `devices.yaml`, you can toggle individual device availability.
All of the devices will likely have been enabled, so let's disable a device or category.
- Try disabling `public` loads in the scenario file and turning off `phone` in devices.

c. Explore CLOVER's outputs:
- Has the LCUE changed? What about the unmet energy?
- Has the emissions intensity (a measure of CO_2/kWh) changed?
- How do the reliability graphs look?

d. Try adding and removing other loads from the system to see how the reliability and costs & emissions change.

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Thank you!







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