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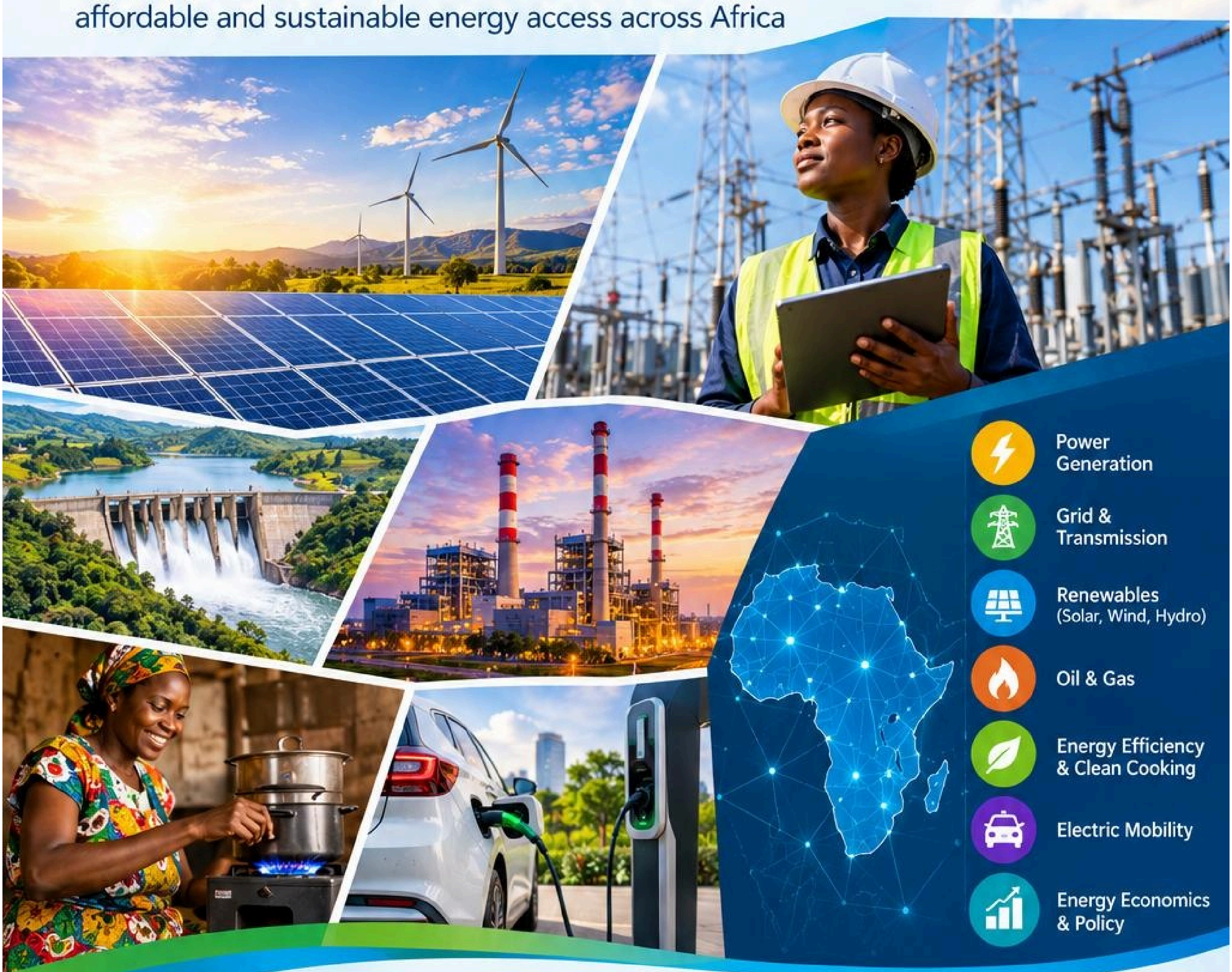

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EGY 501

Energy Sector Modelling

Course Technical Manual

A power system solved on a real national network, and eight things the estate reports that this course had to correct

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COURSE	EGY 501 — Energy Sector Modelling
SCHOOL	05 Sector Planning — Energy
DOCUMENT	Course Technical Manual
ESTATE	EDIS Energy Planning System (EDISEnergySystemModel v0.3.0, power system solved in PyPSA)
SPECIFICATION	EDIS Energy Planning System Technical Manual, EDIS, 2026
SPECIFICATION SIZE	24 parts, 97 numbered sections, 70 equations
ESTATE SIZE	29 Julia modules, 2,853 lines
CASE	the Uganda case built from AEGID: 24 buses, 30 corridors, 474 MW peak
CASE, REBUILT	the Uganda 2023 case built from ERA, UETCL, UEGCL and UBOS primary returns: 17 buses, 24 corridors, 2,033 MW, 917 MW peak, 25 periods
EVIDENCE	Uganda LSMS-ISA National Panel Survey 2019/20 (UNPS); EDIS Africa Energy GIS and Energy Intelligence Database (AEGID)
SPATIAL	67,650 settlement clusters; 78 transmission circuits
MACRO LINK	CDCGE PowerLink, executed end to end
HOURS	55
VERSION	1.1
BUILT	2026-08-27; revised 2026-09-04
EXTRACT DIGEST	8f0c4329171c6b35

DATA AND SOURCING STATEMENT

> This manual teaches an energy-sector model estate and the judgement required to use it. Every number in it was produced by running that estate on its own Uganda case, or by estimating on real household microdata, a real continental register and real geography. Every number carries its denominator and the name of the file it came from.
>
> It is not a user guide. A user guide tells you which function to call. This manual also tells you when the answer that function returns is wrong, because eight times in this build it was — and each of those eight is set out with the arithmetic that establishes it, so you can check the correction rather than take it on trust.

1

Right-click the field above and choose Update Field to build the table of contents.

Preface — what this manual is, and what it is not

This is a manual for an implemented system. Every chapter that follows describes something that exists at `D:/EDIP/models/EnergyModelling`: 29 Julia modules, 2,853 lines, a bridge to a production power-system optimiser, a versioned contract to a computable general equilibrium model, and a documented set of things it cannot yet do.

Three things this manual does that a specification does not

It runs the model. A specification says what an equation means. This manual reports what the equation returned when it was solved on the estate's Uganda case, at a stated carbon price, with 24 buses and 30 corridors. The dispatch solved to optimality; the objective, the emissions and the unserved energy in these pages are what came back.

It re-derives what the model reports. Every headline number the estate produces is recomputed here from the inputs, independently of the function that produced it. That is not distrust; it is the only way to find out whether a number means what its name says. Eight times it did not.

It states what cannot be known. The gaps register in Chapter 22 carries 24 entries. Sixteen were read out of the estate's own honest documentation. Eight were found by running it. A course that only reported the first sixteen would be teaching the estate's self-image rather than the estate.

What you will be able to do

- Load a national energy case, run the diagnostics, and say which of its columns are observed, which are estimated and which are imputed — before solving anything.
- Solve an economic dispatch, read the duals, and check the price against the value of lost load before quoting it.
- Build a generation expansion plan over a rolling horizon and say what the renewable target actually bought.
- Build a least-cost electrification plan, and recognise a corner solution when the optimiser hands you one.
- Design a cost-reflective tariff with a lifeline block, and name who pays for the lifeline.
- Push the generation mix through the CDCGE contract, verify that the carriers survived the crossing, and repair the contract when they do not.
- Carry a carbon price through the macro model onto real households and report the poverty effect with the survey's own poverty line — and say why the tariff channel is the wrong place to look.

> **THE RULE THIS MANUAL IS BUILT ON**
>
> A number you have not re-derived is a number you are quoting, not a number you know. This manual re-derives every headline figure the estate produces. Where the re-derivation agrees, the agreement is stated and so is its reason — twice this build found agreement that came from one source being counted twice, which is not corroboration. Where it disagrees, the disagreement is the lesson.

How to read a number in this manual

Every quantitative claim here comes from one of five places, and the sentence that carries it says which:

Source	What it is	How it is written

Source	What it is	How it is written
The estate	A function in EDISEnergySystemModel, run on the Uganda case	named with the function, e.g. run_economic_dispatch()
The re-derivation	The same quantity computed here from the input tables	named as a re-derivation, with the arithmetic shown
The survey	Uganda LSMS-ISA National Panel Survey 2019/20 (UNPS), survey-weighted	carries its unweighted n and its denominator
The register	EDIS Africa Energy GIS and Energy Intelligence Database (AEGID) and D:/EDIP/SDInfrastracture	carries the dataset, the vintage and the licence
A declared assumption	A parameter this course chose because no file contains it	stated as an assumption, with the value and the reason

Table 1. The five kinds of number in this manual, and how each is marked.

Reproducing everything in this manual

The build is five scripts, run in order. Each writes files the next one reads, so a change anywhere propagates without anyone retyping a figure.

The build, end to end

```
# 1. read the specification and the estate
python energy_extract.py            -> energy_tables.json

# 2. run the estate on its own Uganda case
julia --pkgimages=no --project=<model> energy_run.jl
julia --pkgimages=no --project=<model> energy_run2.jl
julia --pkgimages=no --project=<model> energy_probe.jl

# 3. push the result through CDCGE's own reader
julia --pkgimages=no --project=<cdcge> energy_cdcge.jl

# 4. the survey, the registers and the geography
python energy_analysis.py           -> energy_estimates.json
python energy_link.py               -> energy_link.json

# 5. figures, then the course folder
python energy_figures.py
python build_egy501.py
```

The cover carries the extract digest `8f0c4329171c6b35`. If the specification or the estate changes, the digest changes, and every number in this manual is rebuilt rather than edited.

Part I — The system, the estate and what it can be asked

Four chapters on what an energy-planning system is for, how this one is built, what its specification actually specifies, and what its own status register says it does not do. Nothing here is solved yet. The point of these chapters is that most bad energy analysis is a question asked of a layer that cannot answer it.

1. What an energy-planning system is for

1.1 Four questions, four different models

A ministry of energy asks four questions, and they are not the same question at four horizons. They are four different problems, and each one has a model that can answer it and three that cannot.

Question	Horizon	What decides it	The model
Can we serve the load tomorrow?	hours	which units are running and what the network can carry	economic dispatch, unit commitment
What do we build, and when?	years	capital cost against avoided operating cost and unserved energy	generation and network expansion
Who gets a connection, and how?	years	distance to the network against the cost of an alternative	least-cost electrification planning
What does any of it do to the economy?	decades	the price of electricity in every sector's cost structure	a computable general equilibrium model

Table 2. The four questions. A number produced for one of them is usually wrong for the other three.

The estate this course teaches answers the first three itself and hands the fourth to CDCGE across a documented contract. Chapter 19 shows that contract working — and shows the two places where it silently did not.

1.2 The question this course keeps returning to

Uganda's modelled system has 772 MW of generating plant and a peak demand of 474 MW. On any capacity test it is comfortably adequate. Solve it for a year and 69.4 GWh of demand goes unserved.

The estate's own documentation explains this as an artefact of how the network was clustered. It is not. Chapter 11 sets out the arithmetic, which closes to 0.0 MWh: the system is short of energy, not of capacity, and the shortage is written into a single column of a single input file. That distinction — between a capacity problem and an energy problem, and between a modelling artefact and a national deficit — is the difference between a plan that builds peaking plant and a plan that builds storage, imports or firm generation.

WHY THIS MATTERS MORE THAN IT LOOKS

A capacity-adequacy framing leads a ministry to procure megawatts. An energy-adequacy framing leads it to procure megawatt-hours. In a hydro-dominated system in a drying climate, those are different procurements with different counterparties, different contract structures and different fiscal exposure. Getting the diagnosis wrong is not an academic error.

1.3 What the estate is

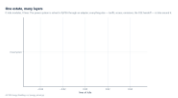


Figure 1. The estate by layer: where each kind of energy number is produced, and how much code stands behind it. — EDIS Energy Modelling estate, module line counts

29 Julia modules, 2,853 lines. The power system itself is not solved in Julia: the estate builds a network object and hands it to PyPSA, which builds the linear programme through linopy and solves it with

HiGHS. Everything around that — demand projection, access planning, tariff design, emissions accounting, the CGE contract — is Julia.

That division matters for a reason that recurs throughout this manual. The optimiser is a well-tested general-purpose tool and it does what it is asked. Almost every defect this course found sits in the layer around it: in how a table was written, in how a result was read back, in what a column was named. The optimiser was right every time.

1.4 The layers, and which questions each can answer

Layer	What it owns	What it cannot answer
Data and schema	the input tables, their provenance and their diagnostics	whether a value is true — only whether it is present and well-formed
Power system (PyPSA)	dispatch, commitment, expansion, network flows	anything electrical: there is no voltage law here, only a transport model
Planning layer	access, cooking, storage, hydro, climate cases	anything about a specific site: it plans and visualises, it does not site
Accounting layer	tariffs, utility finance, emissions, fuels	behaviour: nothing here responds to a price
Integration layer	the CGE and MTEF contracts	the macro model itself — it only marshals the payload

Table 3. Five layers. The third column is the one that gets forgotten.

THE COMMONEST CATEGORY ERROR IN ENERGY PLANNING

The bridge represents corridors as paired directed links with losses. It is a transport model. Kirchhoff's voltage law is not imposed and the schema carries no reactance. A flow that comes out of this model is an economic flow — the cheapest way to move energy subject to capacity and losses — and not the flow that physics would produce on the same network. Quoting one as the other is how a plan ends up specifying a line that will not load.

2. The estate, module by module

The estate is 29 modules over 2,853 lines, with 5 bridge scripts to the Python side and 43 equation identifiers appearing as comments in the source. Those identifiers are the spine of this manual: an equation numbered `E-DSP-01` in the specification appears as `E-DSP-01` in the Julia that implements it, and this manual quotes both.

2.1 The equation identifiers, and why they are the spine

Family	Identifiers	What it covers
E-ACC	E-ACC-01, E-ACC-02	access and clean cooking
E-BAL	E-BAL-01, E-BAL-02	—
E-BOE	E-BOE-01	—
E-CAP	E-CAP-00, E-CAP-01, E-CAP-02	—
E-CLI	E-CLI-01, E-CLI-02	—
E-DEM	E-DEM-01, E-DEM-02, E-DEM-03	demand projection
E-DIST	E-DIST-01, E-DIST-02	—
E-DSP	E-DSP-01, E-DSP-03	dispatch and commitment
E-EMI	E-EMI-01	emissions accounting
E-EQU	E-EQU-01, E-EQU-02, E-EQU-03	household burden and incidence
E-EXP	E-EXP-01, E-EXP-02	generation and network expansion
E-FIN	E-FIN-01, E-FIN-02, E-FIN-03, E-FIN-04	revenue requirement, tariffs, subsidy
E-FUE	E-FUE-01, E-FUE-02, E-FUE-03	fuel balance and energy security
E-GIS	E-GIS-01, E-GIS-02	—
E-INV	E-INV-01, E-INV-02	—
E-MAC	E-MAC-01, E-MAC-02, E-MAC-03	the macro and CGE contract
E-MTEF	E-MTEF-01, E-MTEF-02, E-MTEF-03	—
E-OPS	E-OPS-01	—
E-UCSN	E-UCSN-01, E-UCSN-02	—

Table 4. The equation families. Every numbered equation in this manual carries one of these identifiers, and so does the line of Julia that implements it.

2.2 How to read the source alongside this manual

Each domain chapter names the module it describes. Open the two side by side. The specification tells you what the equation should be; the source tells you what it is; this manual tells you what it returned. When those three disagree, the third one is the fact.

Specification, implementation, result, re-derivation

```
# the pattern every domain chapter follows

specification   EDIS Energy Planning System Technical Manual
                Part VIII, section 8.2, equation E-DSP-01

implementation  src/PowerSystem/PyPSABridge.jl
                run_economic_dispatch -> run_power_model
                bridge/run_pypsa_case.py builds the LP
```

```
result          derived_egy501/uga_dispatch.csv
                objective, emissions_t, unserved_mwh

re-derivation   energy_link.py adequacy()
                the same quantity from the input tables
```

2.3 The bridge to PyPSA

The estate does not write a linear programme. It writes CSV files into a working directory, calls a Python script that builds a PyPSA network from them, and reads the results back out of the same directory. That is a clean design and it is also where two of this course's eight findings live: the results the Julia side reads back are not identical to what the optimiser produced.

- Load shedding is an explicit generator per bus, priced at the value of lost load. The Julia side never sees those generators: the writer filters them out of the dispatch table, so the results tell you how much was shed but not where.
- The marginal price is divided by the snapshot weighting on its way out. PyPSA's marginal price is already per megawatt-hour, so every price in the results file is out by the weight. Chapter 11 shows both.

A BRIDGE IS A PLACE WHERE UNITS GO TO DIE

Both sides of this bridge are correct on their own terms. The defects are in the crossing: a filter that hides where the shedding happened, a division that changes what a price means, a column name that one side writes and the other does not read. When you inherit a system built of two correct halves, the seam is the first place to look and the last place anyone tests.

3. The specification as a map

The specification runs to 24 parts and 97 numbered sections, with 70 equations and 17 tables. This course is organised around it, but not one chapter per part: the parts are of very unequal weight, and several of them describe the same modelling decision from different angles.

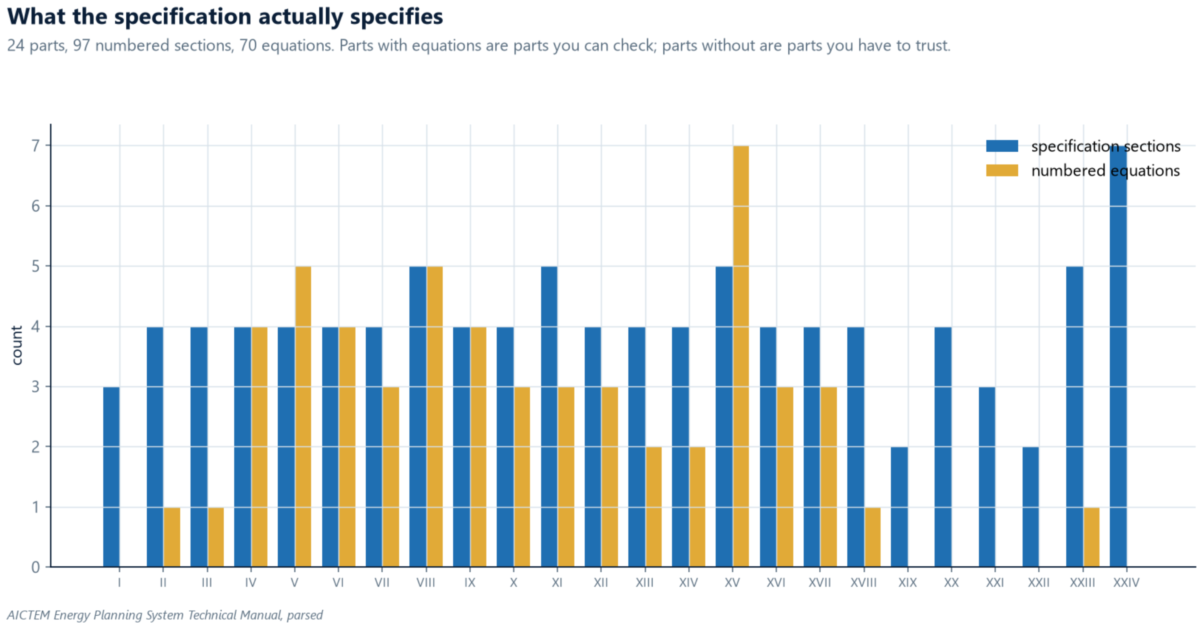


Figure 2. The technical manual as a map: how many specification sections and equations sit behind each part. — EDIS Energy Planning System Technical Manual

3.1 The fourteen domains, and the parts each covers

Domain	Title	Specification parts	Sessions
A	Architecture, principles and the estate	I, XX, XXI, XXII	5
B	Data, GIS and provenance	II	6
C	The power-system core and the adapter	III	7
D	Demand: households, services, peak and shape	IV	8
E	Productive and transport load	V, VI	9
F	Renewable resource and project planning	VII	10
G	Dispatch and generation expansion	VIII	11
H	Transmission and network development	IX	12
I	Storage, flexibility and hydrogen	X	13
J	Hydropower, water and climate	XI	14
K	Access and decentralised systems	XII	15
L	Trade, reliability and resilience	XIII, XIV	16
M	Tariffs, utility finance, fiscal risk and portfolio	XV, XVI, XVII	17
N	CDCGE integration, scenarios and validation	XVIII, XIX, XXIII, XXIV	18

Table 5. The fourteen teaching domains against the specification's parts.

3.2 Which parts carry equations, and which do not

A part with numbered equations is a part you can check. A part without them is a part you have to take on trust — not because it is wrong, but because there is nothing in it a reader can re-derive. This distinction runs through the whole manual: where a chapter has equations, it shows them and solves them; where it does not, it says so.

18 of the 24 parts carry at least one numbered equation. The rest are architecture, governance, workflow and reporting — necessary, and not checkable in the same way.

3.3 What each domain owns, and what it must not be asked

Domain A — Architecture, principles and the estate

What the system is for, which layer owns which question, and how the software is divided between the planning engine and the accounting around it.

The trap. The power system is not solved in the same language as everything else. Confusing 'the model' with 'the optimiser' is how a question gets asked of a layer that cannot answer it.

Depends on. Every other family: it decides where a number comes from.

Domain B — Data, GIS and provenance

The warehouse, the spatial and temporal hierarchies, and the provenance rule that every value is observed, estimated, imputed or projected.

The trap. A national case is mostly estimated. The provenance table says which columns are observed and which are assumptions, and a result that rests on an estimated column is a result about the assumption.

Depends on. Everything downstream. A model is only as good as the column it read.

Domain C — The power-system core and the adapter

How the estate delegates the network to an established open-source power-system framework and keeps its own accounting around it.

The trap. The adapter is a contract. What the bridge does not implement does not happen, however standard it is in the upstream tool.

Depends on. Dispatch, expansion, networks, storage, climate re-dispatch.

Domain D — Demand: households, services, peak and shape

Where the load comes from: population and electrification for households, floorspace and intensity for services, and the shape that turns energy into a peak.

The trap. Energy and peak are different quantities with different drivers. A demand forecast without a load shape cannot size anything.

Depends on. Dispatch, expansion, network adequacy, the tariff base.

Domain E — Productive and transport load

Industry, mining, agriculture and transport electrification, and the connection question each one raises.

The trap. A large industrial or mining load is a location decision as much as a demand forecast. Whether the site is connectable at acceptable cost is part of the answer, not a footnote.

Depends on. Sector coupling, network reinforcement, the industrial tariff.

Domain F — Renewable resource and project planning

Technical potential, candidate generation, project scoring and what each technology needs before it can be represented.

The trap. Technical potential is not a pipeline. The step from a resource map to a bankable candidate is where most of the work is, and it is not in the resource map.

Depends on. The candidate set the expansion model chooses from.

Domain G — Dispatch and generation expansion

The least-cost objective, the nodal balance, generator limits, ramping and the multi-period investment identity.

The trap. The objective is least cost under the constraints you wrote. Every policy — a renewable target, a reserve margin, an emissions cap — is a constraint someone chose, and the plan is a statement about the constraint set.

Depends on. The capital programme, the emissions path, the CGE handover.

Domain H — Transmission and network development

The linear power-flow representation, corridor expansion, candidate corridors and adequacy metrics.

The trap. A transport model with losses is not power flow. Kirchhoff's voltage law is not imposed in this bridge, so a corridor result is an economic flow, not an electrical one.

Depends on. Reinforcement plans, connection studies, adequacy.

Domain I — Storage, flexibility and hydrogen

The storage state equation, the technologies it covers, green hydrogen conversion and how flexibility is valued.

The trap. Storage value is entirely a function of the price spread the dispatch produces, and that spread is a function of the time resolution. Coarse slices understate the value of flexibility.

Depends on. Expansion, reliability, the renewable integration case.

Domain J — Hydropower, water and climate

The reservoir balance, climate-conditioned inflow, renewable climate sensitivity, climate-driven demand and asset resilience.

The trap. In a hydro-dominated system the climate case is not a sensitivity, it is the scenario. A drought year changes the merit order, not just the cost.

Depends on. Reliability, the fuel bill, the emissions path, fiscal risk.

Domain K — Access and decentralised systems

Settlement-level technology choice between grid, mini-grid and standalone systems, the grid-extension cost, and access metrics.

The trap. The cheapest technology per settlement is not the cheapest programme. A budget constraint changes the answer, and so does whether the household can pay the connection fee.

Depends on. The capital programme, the subsidy bill, the poverty analysis.

Domain L — Trade, reliability and resilience

Regional pools and interconnector economics; reliability cost, adequacy, contingency analysis and the stress-test library.

The trap. Value of lost load is a price the analyst sets. It determines how much reliability the model buys, and it is almost never measured.

Depends on. Reserve margins, the interconnector case, the resilience programme.

Domain M — Tariffs, utility finance, fiscal risk and portfolio

The revenue requirement, utility cash flow, losses, tariff design and affordability; fiscal exposure, power-purchase agreements and public investment; and the portfolio programme that chooses among them.

The trap. A tariff that recovers the revenue requirement and a tariff a household can pay are two different objects. The gap between them is the subsidy, and somebody is paying it whether or not it is on a budget line.

Depends on. The MTEF, the subsidy bill, the poverty analysis, the CGE handover.

Domain N — CDCGE integration, scenarios and validation

The two-way mapping to the economy-wide model, the convergence loop, the double-counting rule, the scenario catalogue and the calibration and validation protocol.

The trap. The coupling is iterative and it can be run without converging. A single pass is a handover, not an equilibrium, and the double-counting rule is what stops the same effect being reported twice.

Depends on. The macro model, the fiscal framework, the published scenario set.

4. What the estate says it does not do — and what it does not say

The estate ships a status register and a remaining-gaps document. Both are unusually honest and both are incomplete. This chapter reads the first and then explains why this course went looking for the second.

4.1 The status register

Grade	Meaning	Components
A	complete and tested	21
B	implemented, not fully validated	1
D	not implemented	3
E	blocked by an external dependency	1

Table 6. The estate's own grading of 26 components.

Read the grade before quoting a result. A grade B component produces numbers; it has not been checked that they are the right numbers. Several of this course's findings sit in grade A and grade B components alike, which is the point: a grade is a statement about testing effort, not about correctness.

4.2 The tests

The estate carries 107 tests across 21 files. That is a serious test suite for a model of this size. None of the eight defects this course found is caught by it, and the reason is instructive: the tests check that each function does what its own specification says. Every one of the eight defects is a disagreement between two components, each of which is behaving correctly.

WHAT A UNIT TEST CANNOT SEE

export_generation_for_cge writes a carrier column exactly as specified. PowerLink reads a carrier column exactly as specified. Each has tests and each passes. The generation is dropped in between, because nothing owns the sentence 'the carrier the writer emits must be one the reader knows'. Contract tests, not unit tests, are what catch this — and they are the tests almost nobody writes.

4.3 The gaps register, in outline

Chapter 22 sets out all 24 entries in full. In outline:

EN-01 to EN-16	Read out of the estate's own documentation	Limits the authors knew about and wrote down: no power flow, myopic expansion, independent reservoirs, no price response, no learning curves, licence restrictions on a tenth of the spatial catalogue.
EN-17 to EN-24	Found by running the estate	Defects that only appear when the system is executed and its output re-derived: a silently dropped 81 % of generation, a corrupted headline indicator, a broken column contract, a price out by a factor of 730, a misdiagnosed energy deficit, a tautological finance test, a duplicated data column, and a survey question that cannot

	support the indicator built on it.

Table 7. Two kinds of gap. The second kind is why a course has to run the model rather than read about it.

4.4 How the gaps are used in this manual

Every domain chapter names the gaps that bear on it before it presents a result, not after. Where a gap makes a result unusable for a particular purpose, the chapter says which purpose. Where a gap has a one-line fix, the fix is given and the students apply it in the laboratories.

THE STANDARD THIS COURSE HOLDS ITSELF TO

Eight defects were found in a production estate built by competent people and documented with unusual candour. That is not an argument against the estate; it is the normal yield of actually running a system and checking its arithmetic. The question to ask of any model you are handed is not whether it has defects of this kind. It is whether anyone has looked.

Part II — Data, geography and the power-system core

Three chapters on where the numbers come from before anything is solved: the input schema and its provenance, the continental register and the national spatial layers, and the adapter that turns a set of tables into a linear programme. Most of what goes wrong in an energy plan goes wrong here, quietly, and is only visible in the answer.

5. The input schema, and what each column is worth

The estate loads a country case from a directory of CSV files. The Uganda case has 14 of them. This chapter reads them the way a planner has to: not as data, but as a set of claims of very different strength.

5.1 The tables

Table	Rows	What it carries	Required?
access_sites	40	unelectrified demand sites with households	for access
availability	36	capacity factor by unit and period	yes
buses	24	network nodes with coordinates and a region	yes
candidates	3	what may be built, with annualised capex	for expansion
cooking	3	clean-cooking technology options	optional
customers	3	customer classes for tariff design	optional
fuels	2	fuel accounts: production, imports, price, tax	optional
hazards	1	assets, hazards, hardening cost, avoided loss	optional
households	3	household groups for equity analysis	optional
hydro	6	reservoir units: capacity, inflow, reservoir bounds	optional
lines	30	corridors with capacity, loss factor and length	yes
projects	3	policy-portfolio projects	optional
storage	1	batteries: power, energy, efficiencies	optional
technologies	5	generating units, cost, emission factor, carrier	yes

Table 8. The Uganda case, table by table. Every 'optional' in the last column is a model that silently does not run when the file is absent.

OPTIONAL DOES NOT MEAN UNIMPORTANT

hydro.csv is optional. It also carries 666.5 of Uganda's 772.5 MW. A case that omits it still loads, still solves, and gives a completely different country. Three of this course's eight findings trace back to hydro living in an optional table with a different column set from the required one.

5.2 Provenance: six words that decide how a number may be used

The estate's schema documentation asks every value to be labelled with one of six provenance classes. This is the single most valuable convention in the whole system and it is the one most often skipped.

Class	Means	What you may do with it
observed	measured and recorded by someone	quote it, with its source and vintage
estimated	inferred from data by a stated method	quote it with its interval; never as a fact
imputed	filled in where data are missing	quote it only with the imputation rule stated
calibrated	chosen so the model reproduces something known	never quote it as evidence for the thing it was calibrated to
projected	a forward path under stated drivers	quote the drivers with it, always
scenario	a choice, not a finding	quote it as a choice

Table 9. The provenance classes. The third column is the whole point of the convention.

The Uganda case's provenance note labels 6 column groups as observed, 8 column groups as estimated. That is a partial labelling of a case with several hundred cells, and the chapter treats the unlabelled remainder as unknown provenance rather than as observed.

THE CALIBRATION TRAP

A calibrated value cannot be evidence for the thing it was calibrated to. If the demand table was built so that annual energy matches a published figure, then the model reproducing that figure is arithmetic, not validation. Chapter 21 shows two checks in this build that look like validation and are identities.

5.3 The diagnostics the estate runs, and what they miss

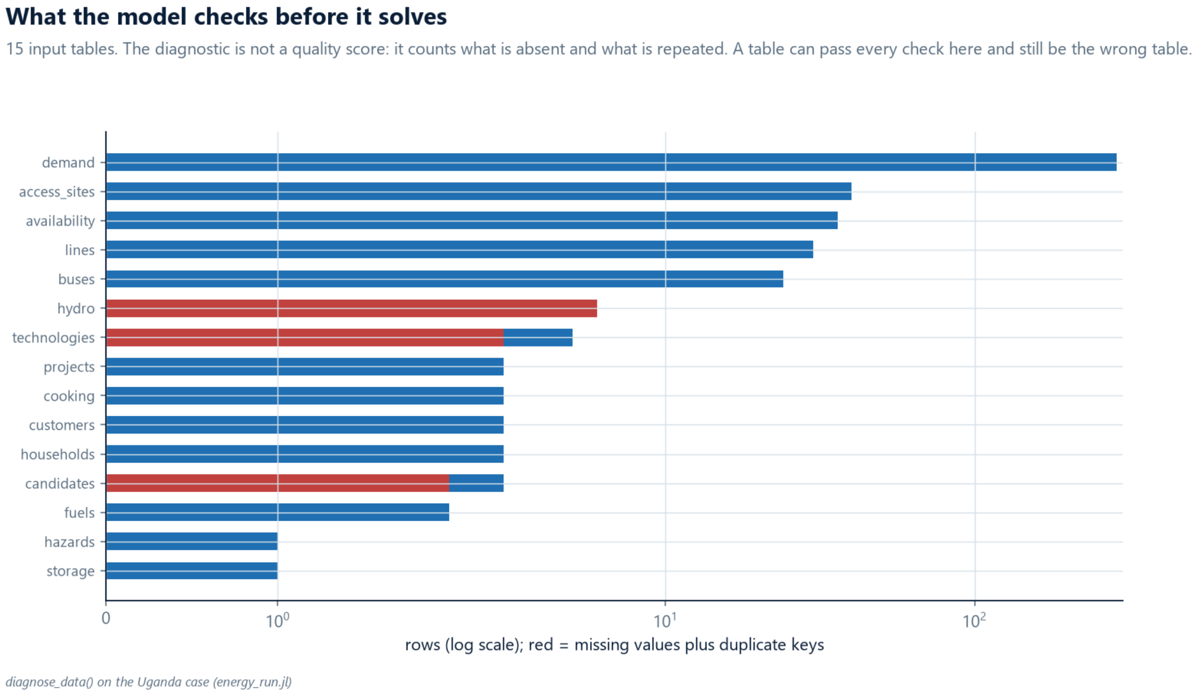


Figure 3. The estate's own data diagnostics on the Uganda case, table by table. — diagnose_data() output

`diagnose_data()` counts rows, missing values and duplicate keys per table. It is a useful first pass and it is not a quality check. It cannot tell you that a column is a copy of another column, that a capacity factor of 0.50 was assumed rather than measured, or that a plant is in the wrong table.

Three checks this course adds to intake, all one-liners, all of which caught something in this build:

Three intake checks worth more than they cost

```
# 1. duplicate columns — a column that promises more than it has
for a, b in combinations(df.columns, 2):
    if df[a].equals(df[b]):
        warn(f'{a} is byte-identical to {b}')

# 2. degenerate columns — no variation, or one value dominating
if df[c].nunique() <= 1 or df[c].value_counts(normalize=True).iloc[0] > 0.95:
    warn(f'{c} carries almost no information')

# 3. suspiciously round ratios — a written-in assumption
r = df.inflow_mwh / df.capacity_mw
if r.round(2).nunique() == 1:
    warn(f'every row has the same ratio {r.iloc[0]:.2f} — assumed, not measured')
```

The third of these is how the energy deficit in Chapter 11 was found. Every row of `hydro.csv` has an inflow exactly half its capacity: 0.50 for all six plants. A capacity factor identical to two decimal places across six unrelated rivers is not a measurement. It is an assumption someone wrote into a file, and it determines whether the country has an energy deficit.

5.4 Reading the Uganda case as a set of claims

5.4. technologies.csv

5 rows, 17 columns: `technology`, `bus`, `existing_mw`, `variable_cost`, `emission_factor`, `carrier`, `fuel`, `ramp_rate`, `min_stable`, `startup_cost`, `min_up`, `min_down`….

Five units, 106 MW, and no hydro. `renewable` is a flag on this table and nowhere else, which is why the estate's own renewable-share indicator reports 6.6 % for a system that is 87.8 % renewable (EN-18).

5.4. hydro.csv

6 rows, 11 columns: `plant`, `bus`, `capacity_mw`, `inflow_mwh`, `reservoir_max_mwh`, `reservoir_initial_mwh`, `min_release_mwh`, `capacity_credit`, `lat`, `lon`, `commissioning_year`.

Six units, 666.5 MW — six sevenths of the country. This table has no `carrier` column and no `renewable` column, which is the root of EN-17 and EN-18, and its `inflow_mwh` column is the root of EN-21.

5.4. candidates.csv

3 rows, 13 columns: `candidate`, `bus`, `technology`, `carrier`, `max_mw`, `annualized_capex_per_mw`, `variable_cost`, `emission_factor`, `fixed_om_per_mw`, `available_from`, `renewable`, `capacity_credit`….

Three candidates: solar, hydro and gas. Every expansion result in this course is a choice among these three, and no result can name a technology that is not on this list. The annualised capex here is also the only capital-cost information anywhere in the case, which is why Chapter 16 has to invert the annuity to get an asset base.

5.4. customers.csv

3 rows, 7 columns: `class`, `energy_mwh`, `customers`, `cost_to_serve`, `lifeline_mwh`, `collection_rate`, `current_tariff`.

5.4. households.csv

3 rows, 8 columns: `group`, `households`, `income`, `electricity_spend`, `cooking_spend`, `connected`, `urban`, `female_headed`.

Three stylised groups standing for 6.8 million households. Urban connection is 1.0 by construction — there is no urban unconnected group — which is why the estate's access_equity() reports a 91-point rural-urban gap against the survey's 54. Chapter 20 redoes this on 3,062 real households.

5.5 What to do when the case is not yours

- Read the provenance note before the data. If there is none, write one as you read, and record what you could not classify.
- Run the three intake checks above. They cost a minute and they found three of this course's eight findings.

- Total every physical quantity against an independent register. Uganda's 772.5 MW matches the WRI database exactly — and Chapter 21 explains why that agreement is not corroboration.
- Find the optional tables that are absent. Ask what model silently did not run.

6. Geography: the continental register and the national layers

This estate is unusual in shipping its own continental data infrastructure. The register catalogues energy datasets for 55 African countries, tracks which have been acquired, and records the licence on each. This chapter reads it as a planning constraint, because that is what it is.

6.1 The register

Quantity	Value
Catalogued datasets	618
Country-dataset pairs tracked	940
Countries	55
Held on disk	618 files, 1.3 GB
Share of tracked pairs held	31.3 %
Datasets that may not be redistributed	54
Datasets with a share-alike condition	472

Table 10. The register, in seven numbers.

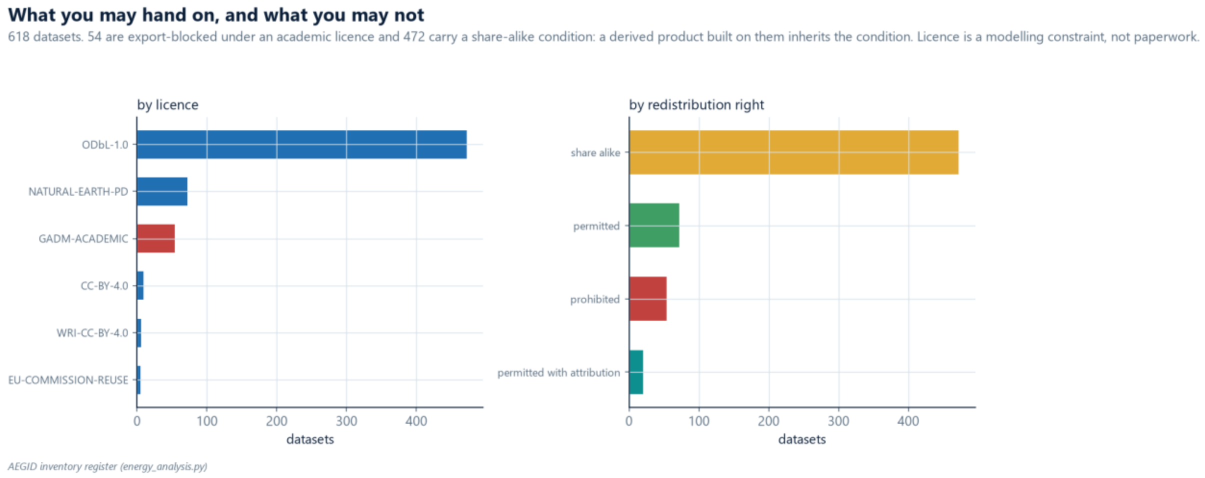


Figure 4. Licence and redistribution status of the 618 datasets in the continental register. — AEGID inventory register

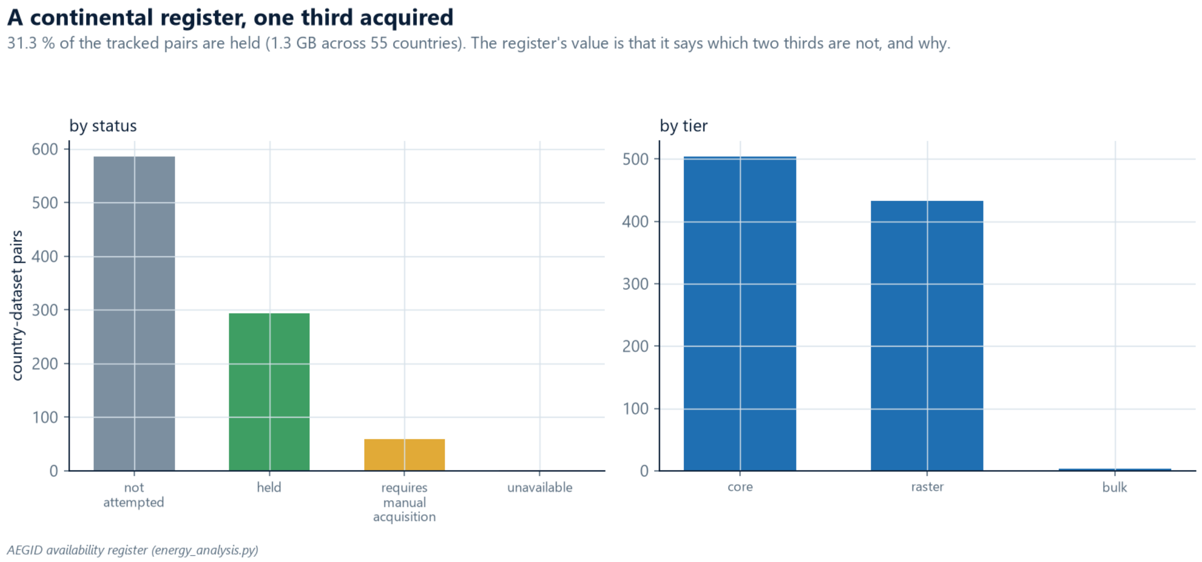


Figure 5. Acquisition status of the 940 country-dataset pairs the register tracks. — AEGID availability register

6.2 Licence as a modelling constraint

Fifty-four datasets in the register carry an academic licence that forbids redistribution, and 472 carry a share-alike condition under ODbL. These are not administrative details. They determine what a ministry may publish.

THE SHARE-ALIKE TRAP IN A NATIONAL PLAN

A derived product built on an ODbL layer inherits the share-alike condition. If a national electrification plan is built on gridfinder or on OpenStreetMap-derived geometry, the plan's own spatial layers may have to be published under the same licence. That is often acceptable and occasionally not — and it is a question to settle before the analysis, not after the cabinet paper.

The practical rule this course teaches: build the map from the permissive layers, and use the restricted ones only for checking. Every map in this manual names its layer and its licence, and the ones that cannot be redistributed appear as aggregates rather than as geometry.

6.3 The national layers

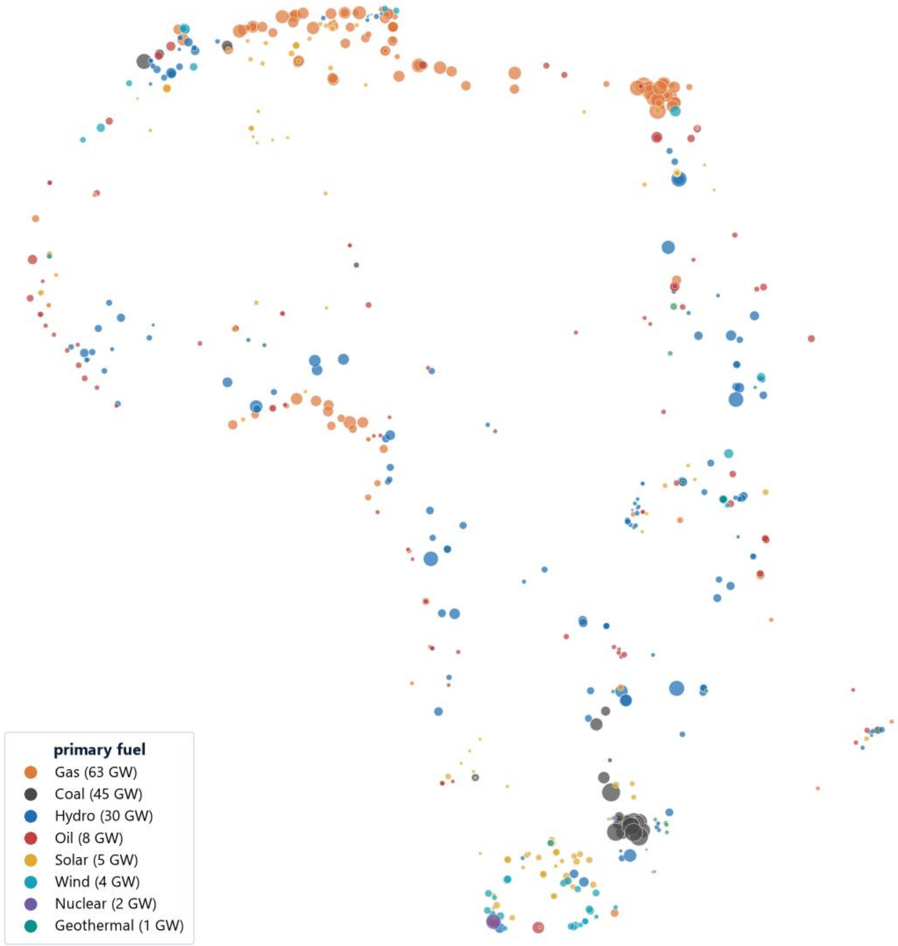
Uganda has an unusually good spatial record and this course uses six layers of it.

Layer	Features	What it is	Vintage
WRI Global Power Plant Database	11 in Uganda, 615 in Africa	plants with capacity, fuel and coordinates	v1.3
UETCL transmission network	78	circuits with voltage, status and structure type	2017
UETCL substations	56	substation points	2017
gridfinder predicted grid	3,216	lines inferred from night-lights and OSM	v1.1.1
GADM administrative boundaries	58 regions, 166 districts	administrative polygons	4.1
DRE settlement clusters	67,650	settlements with population, buildings, wealth, distance to the network	current

Table 11. The six spatial layers this course uses, and what each one is.

Africa's generating fleet, as recorded

615 plants, 159 GW. Four countries hold two thirds of it. Uganda's 772 MW is one dot near the equator — the scale a national plan works at.



WRI Global Power Plant Database v1.3 via AEGID

Figure 6. Every power plant the WRI register records in Africa, by capacity and primary fuel. — WRI Global Power Plant Database v1.3

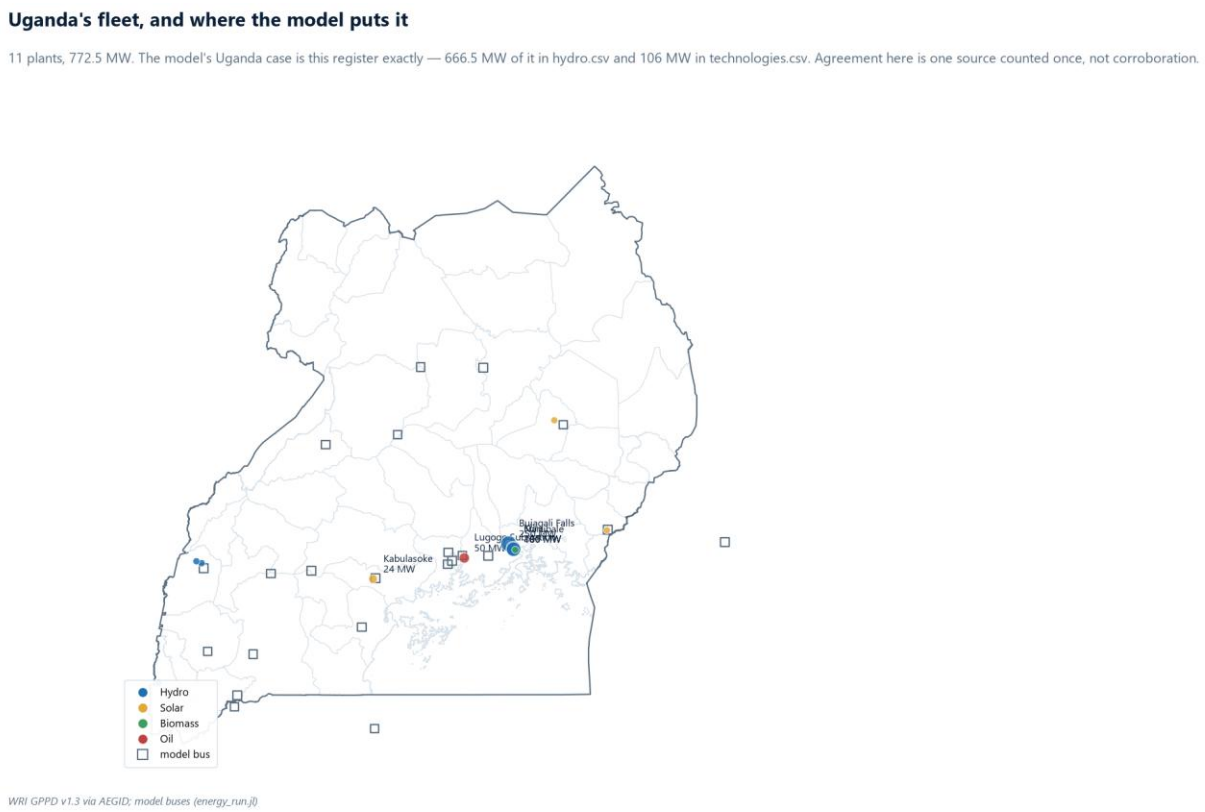


Figure 7. Uganda's generating fleet and the model's buses, on the same map. — WRI GPPD v1.3; model buses

6.4 Status is not existence

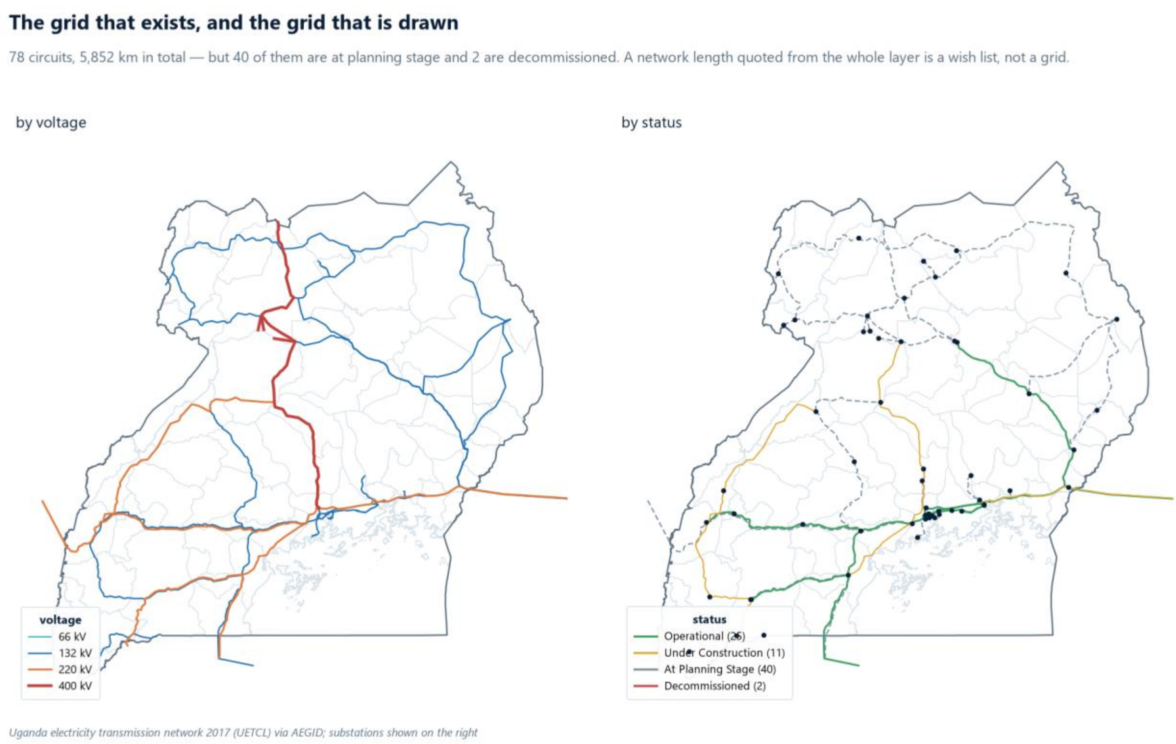


Figure 8. The Ugandan transmission network by voltage and by status: operational, under construction, planned. — Uganda electricity transmission network 2017

The transmission layer has 78 circuits and 5,852 km. Read without the status column that is the national grid. Read with it:

Status	Circuits
At Planning Stage	40
Operational	25
Under Construction	11
Decommissioned	2

Table 12. The same layer, by status. More than half of it has not been built.

Forty of the seventy-eight circuits are at planning stage and two are decommissioned. A network length quoted from the whole layer is a wish list. This is the commonest error in infrastructure mapping and it always flatters the country.

6.5 A predicted network is not a surveyed one

Figure 9. The surveyed transmission network against gridfinder's satellite-inferred grid. — UETCL 2017; gridfinder v1.1.1

gridfinder infers lines from night-time lights and OpenStreetMap and finds 14,323 km in Uganda — 2.4 times the surveyed transmission layer. It is not a better transmission map. It is a different thing, mostly distribution, produced by a global model with a published accuracy that varies by country. Using it as a transmission layer overstates the transmissible network everywhere.

6.6 The settlement layer, and the column that lied

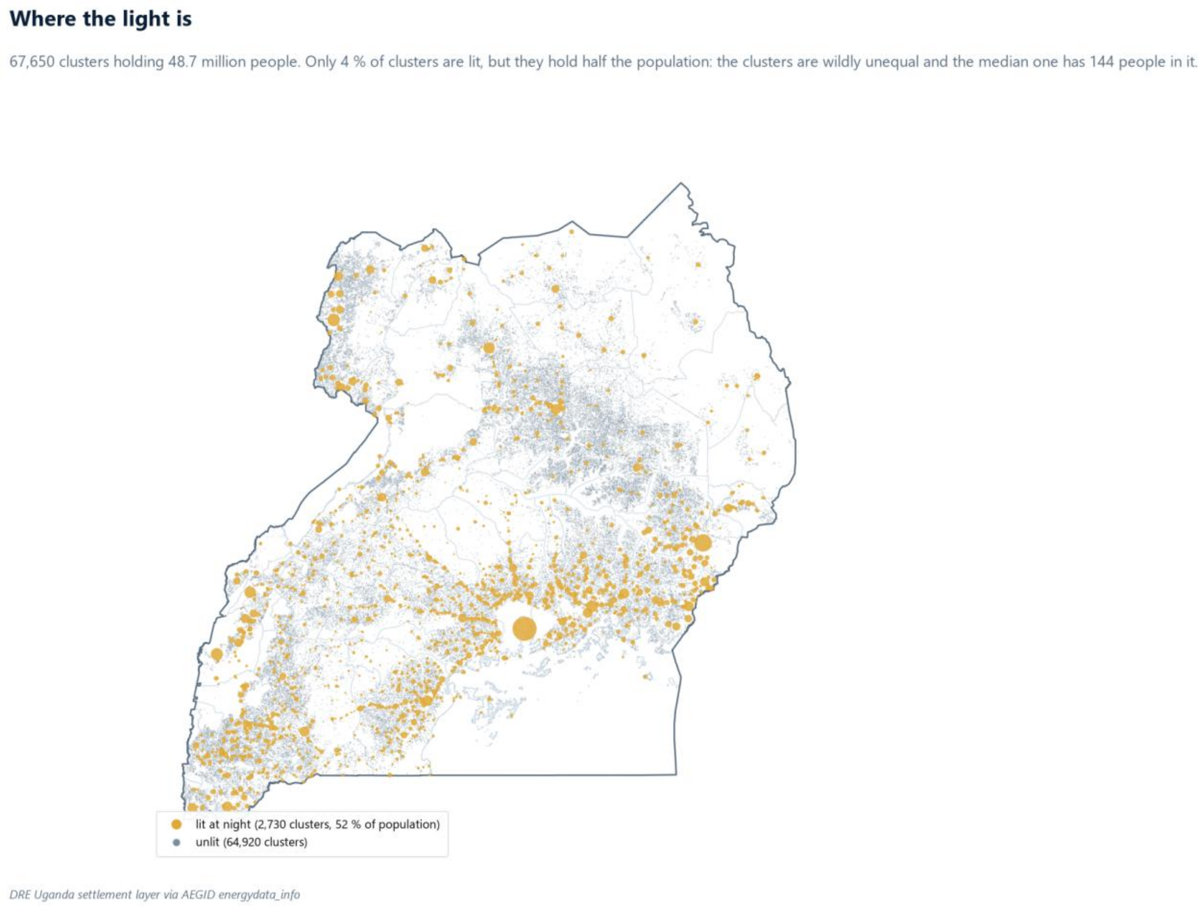


Figure 10. All 67,650 Ugandan settlement clusters, lit and unlit. — DRE Uganda settlement layer

67,650 settlement clusters holding 48.7 million people and 13.7 million buildings, each with a wealth index, a distance to the network, a solar-resource value and flags for health and education facilities. This is the richest layer in the course and it carries the access chapter.

EN-23 — NUM_CONNECTIONS IS NUM_BUILDINGS

The layer has a column called `num_connections`. It is byte-identical to `num_buildings` in all 67,650 rows — 100.0 % agreement, not approximate agreement. Read as electricity connections it makes Uganda universally electrified. The check that catches it is one line and it belongs on every column whose name promises more than the codebook delivers.

With that column set aside, the layer supports a nightlight flag instead. 4.0 % of clusters are lit, and they hold 52.0 % of the population. Those two numbers are not in tension: the clusters are wildly unequal. The median cluster holds 144 people and the largest holds 7,613,045.

A NIGHTLIGHT IS NOT A CONNECTION

A lit pixel means someone in that cluster has light at night. It does not mean a household has a meter, and it does not distinguish a grid connection from a diesel generator or a solar lantern. This course uses it as a proxy and says so every time. Chapter 21 sets it beside three other access rates for the same country in the same decade.

6.7 Distance to the network

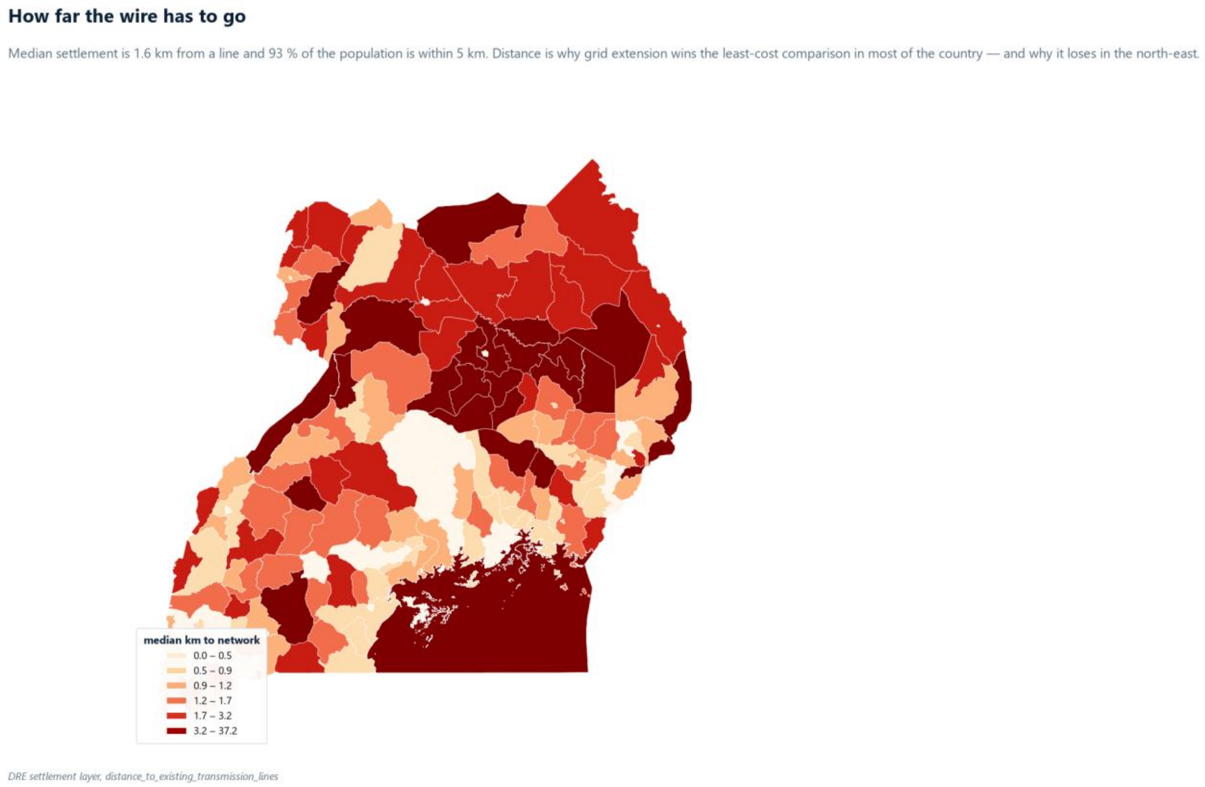


Figure 11. Median distance from settlement to the existing network, by district. — DRE settlement layer on GADM 4.1

The distance column is what makes least-cost electrification planning possible at all. In Uganda the distribution is strikingly short-tailed:

Population within	Share
1 km of a line	75.2 %
5 km	93.0 %
10 km	97.3 %
25 km	99.9 %

Table 13. Distance from settlement to the existing network, population-weighted.

This single distribution explains why the electrification plan in Chapter 15 chooses grid extension at every site. It is also why the plan is less interesting than it looks: when 93 % of the population is within 5 km of a wire, the least-cost comparison is not close anywhere, and the optimiser is not really choosing.

6.8 Wealth, darkness and distance

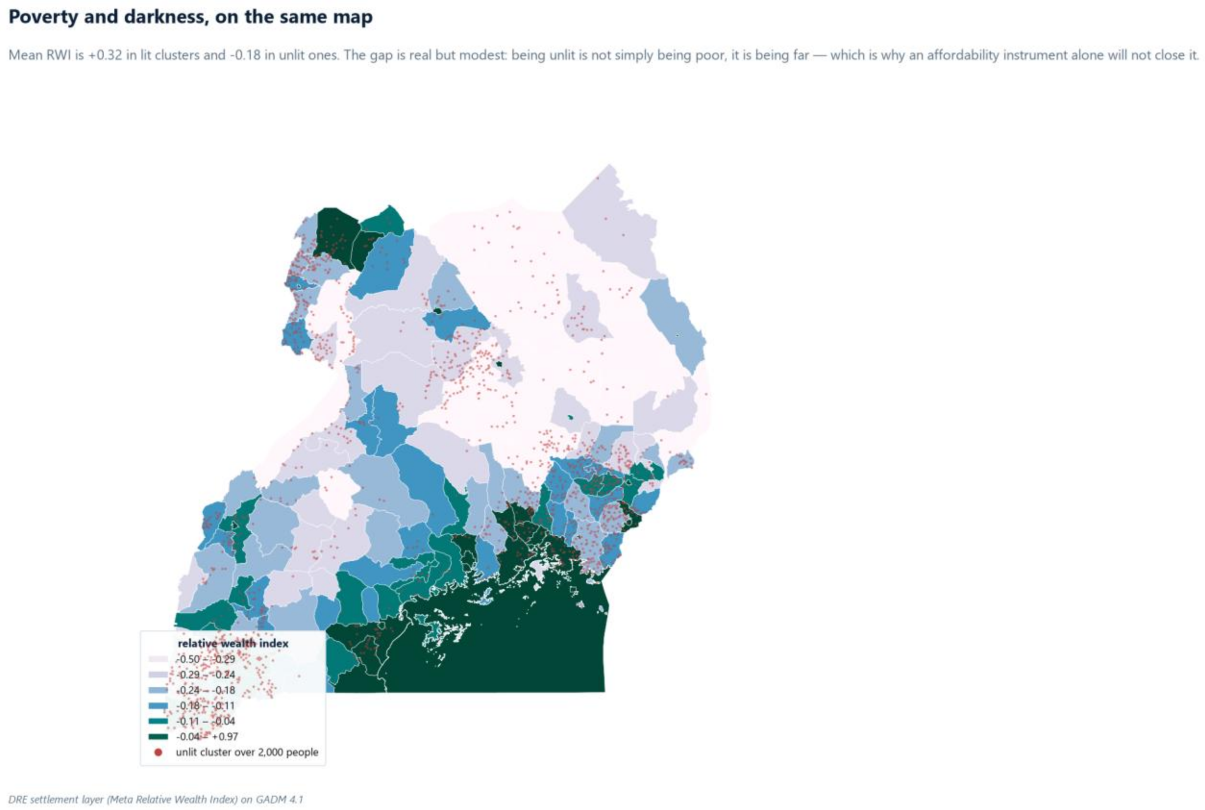


Figure 12. Relative wealth index by district, with the unlit population on top. — DRE settlement layer (Meta RWI)

The relative wealth index in lit clusters is 0.32 against -0.18 in unlit ones. The gap is real and it is modest. Being unlit in Uganda is not primarily being poor; it is being far, and in a few districts it is being both. That distinction decides the instrument: an affordability subsidy reaches the second group and does nothing for the first.

7. The power-system core and the adapter

This chapter is about the seam. The estate builds tables; PyPSA builds and solves a linear programme; the estate reads the results back. Everything in the middle is a translation, and translations lose things.

7.1 What the adapter builds

For each mode the adapter constructs a PyPSA network:

Model element	Built from	Note
Bus	buses.csv	one per row, with its region
Load	demand.csv	per bus and period, with snapshot weightings
Generator	technologies.csv	marginal cost = variable cost + carbon price x emission factor
Generator (p_max_pu)	availability.csv	the capacity-factor profile, by unit or by carrier
StorageUnit (battery)	storage.csv	cyclic state of charge
StorageUnit (hydro)	hydro.csv	inflow as a time series, cyclic SOC, no pumping
Link pair	lines.csv	two directed links per corridor, efficiency = 1 - loss_factor
Generator (unserved)	every bus	p_nom 1e6 at the value of lost load — the shedding term

Table 14. The translation from tables to a PyPSA network.

7.2 The objective, written out

E-DSP-01

$$\min \; \sum_{t} w_t \Big[\sum_{g} c_g \, p_{g,t} + \sum_{b} V \, u_{b,t} \Big] \text{s.t.}\quad \sum_{g \in b} p_{g,t} + \sum_{\ell \to b} \eta_\ell f_{\ell,t} - \sum_{\ell \leftarrow b} f_{\ell,t} + u_{b,t} \;=\; d_{b,t} 0 \le p_{g,t} \le \bar{p}_g \, a_{g,t}, \qquad 0 \le f_{\ell,t} \le \bar{f}_\ell, \qquad u_{b,t} \ge 0 \tag{1}$$

Read the terms. w_t is the snapshot weighting — the number of hours the representative period stands for. V is the value of lost load, 10,000 per MWh in this case. $u_{b,t}$ is unserved energy, and it is a variable like any other: the optimiser will shed load whenever serving it costs more than V. η_ℓ is the corridor efficiency, one minus the loss factor. There is no voltage angle anywhere in this formulation, which is the whole content of EN-03.

THE WEIGHTING IS WHERE THE UNITS GO WRONG

w_t appears in the objective, so the dual of the balance constraint comes back scaled by it. PyPSA divides it out for you and hands you a price per MWh. The adapter then divides by w_t again on the way to the results file. That is EN-20, it is a factor of 730 in this case, and it reaches the CGE.

7.3 The shedding term, and why you cannot see it

Load shedding is modelled as a generator at every bus with unlimited capacity and a marginal cost of V. That is the standard construction and it is correct. What is not correct is what happens next: the results writer filters those generators out of the dispatch table before saving it.

Where the shedding goes

```
# bridge/run_pypsa_case.py
for g in n.generators.index:
    if n.generators.at[g, 'carrier'] == UNSERVED_CARRIER:
        continue                      # <- the shedding vanishes
    for s in n.snapshots:
        rows.append((s, g, n.generators.at[g, 'bus'],
                     float(gp.at[s, g] * w[s])))
```

Listing 1. The dispatch table tells you how much was shed in total and never where. Recovering the location took a re-run with the working directory kept.

The consequence is practical. A planner reading the results sees an unserved-energy total and no way to act on it. This course recovers the location in Chapter 11 by re-running with the working directory preserved and reading the raw output, and the answer turns out to matter a great deal.

7.4 Modes

Mode	What changes	Entry point
dispatch	linear, all generators continuous	run_economic_dispatch
unit_commitment	committable thermal units, binaries, MILP	run_unit_commitment
network	links extendable up to candidate_max_mw	run_network_expansion
expansion	rolling horizon over cfg.years, myopic	run_generation_expansion

Table 15. The four modes of the power core.

Expansion is myopic: each planning year is solved with that year's demand and the prior builds promoted to existing capacity. It does not anticipate. A myopic plan will build a cheap asset in 2032 that a perfect-foresight plan would have skipped in favour of a better 2040 asset, and the difference is not small in systems with lumpy hydro. That is EN-05, and Chapter 12 quantifies it on this case.

7.5 Reading a solve

Every solve returns a named tuple. The fields worth checking, in the order to check them:

Field	Check	Why
status	is it optimal?	an infeasible or suboptimal solve returns numbers
unserved_mwh	is it zero?	if not, the answer is about scarcity, not about cost
lole_hours	is it 8,760?	a system short in every hour is structurally short
curtailment_mwh	is it zero?	curtailment and unserved energy together mean a network problem
cost.generation vs objective	how far apart?	the gap is the lost-load penalty, and it can dominate
prices	against the value of lost load	if the mean is near V, shedding is setting the price

Table 16. Six checks before quoting anything from a solve. In this build, checks two, three, five and six all fired.

On the Uganda case at a carbon price of 25, those six checks return: status optimal; unserved 69.4 GWh; LOLE 8,760 hours — every hour of the year; curtailment 0 MWh; objective $788.9 m against a generation cost of $86.9 m, so the lost-load penalty is 88 % of the objective; and a mean price of 12.37 per MWh as reported, which is 730 times too small.

FOUR OF SIX CHECKS FAILING IS NOT A BROKEN MODEL

The solve is correct. The case it was given describes a country that cannot meet its own demand, and the results say so in four different ways. The failure was in reading them: the estate's own documentation explains the unserved energy as an artefact, and the headline indicator table reports a price that makes the system look cheap. Chapter 11 does the arithmetic.

Part III — Demand, load and resource

Three chapters on the right-hand side of the balance constraint and on what can supply it. Demand is the input planners spend least time on and the one that moves every result the most; the resource tables decide what the optimiser is even allowed to choose.

8. Demand: households, services, peak and shape

Every result in this course rests on a demand table with 0 rows. This chapter asks what those rows are, what they can support, and what they cannot.

8.1 Twelve periods stand for a year

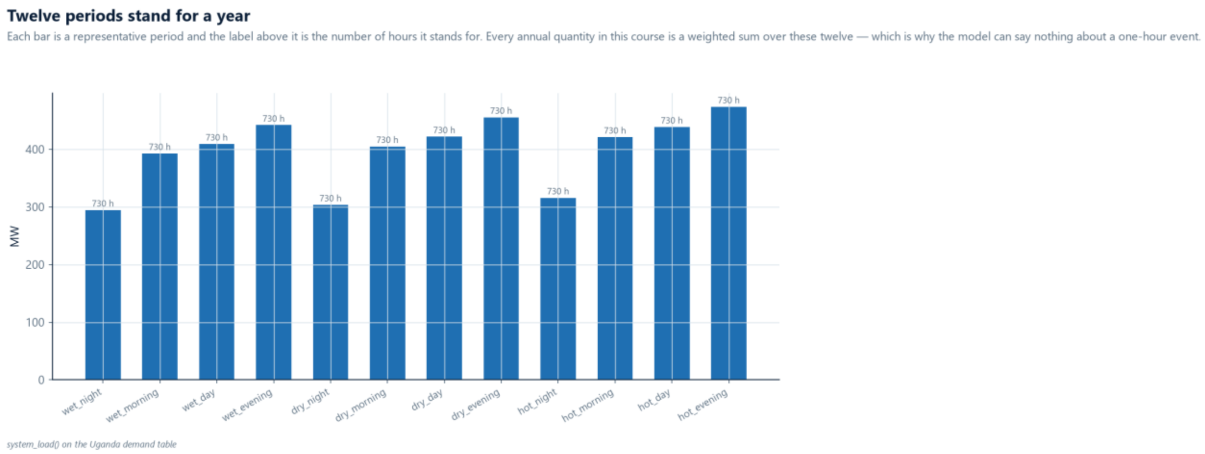


Figure 13. System load across the representative periods. — system_load() on demand.csv

The Uganda case carries twelve representative periods — wet, dry and hot seasons crossed with night, morning, day and evening — each weighted at 730 hours. Twelve times 730 is 8,760, so the weights are exact and every annual quantity in this course is a weighted sum over these twelve.

WHAT TWELVE PERIODS CAN AND CANNOT TELL YOU

They can tell you annual energy, seasonal balance and the approximate shape of the load. They cannot tell you anything about a one-hour event: a morning ramp, a cloud passing over a solar farm, a unit tripping. Reserve adequacy, ramping constraints and frequency response are all questions this resolution cannot answer, and the estate does not claim they are. Chapter 11's LOLE of 8,760 hours means 'in every representative period', not 'in every hour of a real year'.

8.2 The load-duration curve

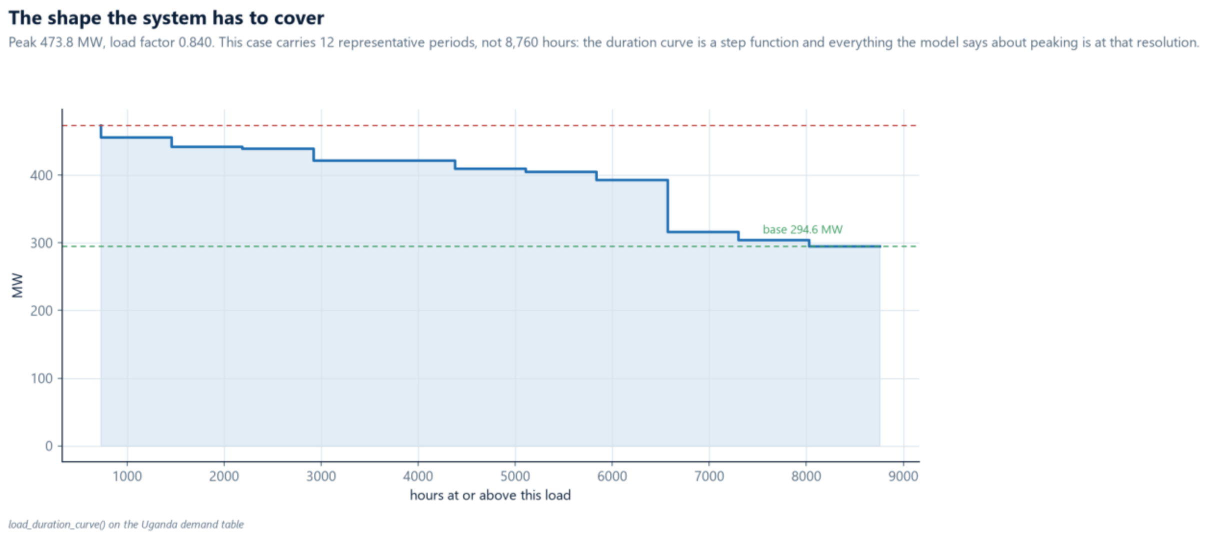


Figure 14. The load-duration curve of the Uganda case. — load_duration_curve() on demand.csv

At this resolution the duration curve is a twelve-step staircase. Peak demand is 473.8 MW and the load factor is 0.840. A load factor of 0.84 is high — it is what a system dominated by a few industrial and urban loads looks like, and it is also partly an artefact of aggregating real hours into twelve buckets, which flattens the peak.

E-DEM-01

$$E_{\text{annual}} = \sum_{t} w_t \sum_b d_{b,t}, \qquad P_{\text{peak}} = \max_t \sum_b d_{b,t}$$
$$\text{LF} = \frac{E_{\text{annual}}}{8760 \, P_{\text{peak}}} \quad (2)$$

Annual energy is 3.49 TWh against a peak of 473.8 MW. Hold on to both. Chapter 11 turns on the fact that the system has plenty of megawatts for the peak and not enough megawatt-hours for the year — a distinction that a capacity-margin calculation cannot see.

8.3 Demand by bus and by sector

8.4 Projecting demand

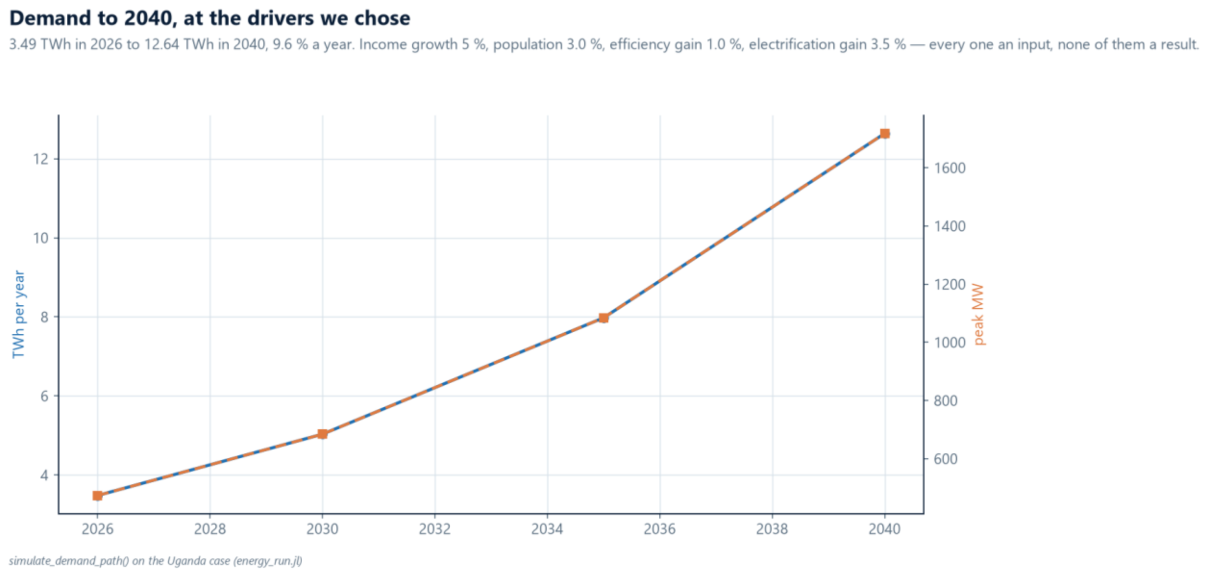


Figure 15. Demand to 2040 under the projection the estate's own driver function produces. — simulate_demand_path()

`simulate_demand_path()` scales the base-year table forward under four declared drivers. It is not a demand model in the econometric sense: there is no price term, no income elasticity estimated on anything, and no saturation.

E-DEM-02

$$d_{b,t}(y) = d_{b,t}(y_0) \cdot (1+g_{\text{inc}})^{\alpha (y-y_0)} \cdot (1+g_{\text{pop}})^{(y-y_0)} \cdot (1-g_{\text{eff}})^{(y-y_0)} \cdot (1+g_{\text{elec}})^{(y-y_0)} \quad (3)$$

Driver	Value used	Status

Driver	Value used	Status
Income growth	5.0 % a year	declared assumption
Population growth	3.0 % a year	declared assumption
Efficiency gain	1.0 % a year	declared assumption
Electrification gain	3.5 % a year	declared assumption

Table 17. Every driver in the projection is an input. None is a result, and none was estimated here.

The path runs from 3.49 TWh in 2026 to 12.64 TWh in 2040. That is the arithmetic consequence of the four numbers in the table above and nothing else. A projection is a way of making assumptions legible, not a forecast.

EN-11 — DEMAND DOES NOT RESPOND TO PRICE

There is no price term anywhere in the demand path and no elasticity inside the dispatch. Every tariff result in Chapter 16 and every carbon-price result in Chapter 11 therefore assumes that consumption is unchanged by the price. For a first-order welfare calculation that is a stated approximation with a known sign: it overstates the welfare loss and understates the demand reduction. For a demand forecast under a large tariff change it is simply wrong.

8.5 What the survey says about demand that the case does not

The case has three household groups. The survey has 3,062 real households, and it disagrees with the case in ways that matter for demand:

Quantity	The case	The survey
Household connection rate	21.7 %	25.9 %
Urban connection rate	100.0 %	62.6 %
Rural connection rate	8.8 %	8.9 %

Table 18. The stylised household table against 3,062 real households. The urban figure in the case is 100 % because the table has no urban unconnected group.

A case whose urban connection rate is 100 % by construction cannot be used to study urban access, and any equity result computed on it inherits that. Chapter 20 redoes the whole distributional analysis on the survey instead.

9. Productive and transport load

The specification devotes two parts to load that is not residential: productive uses in agriculture and industry, and electrified transport. This chapter sets out what the estate implements and, more usefully, what the Uganda case actually contains.

9.1 What productive load is for

Productive load is the argument for electrification that is not about lighting. A mill, a pump, a cold chain: these are loads that generate income, which changes both the willingness to pay and the economic case for the connection. In a least-cost electrification model they matter twice — once as demand, and once as the benefit that justifies the capital.

9.2 What the case contains

`access_sites.csv` has 40 rows and carries `site`, `region`, `lat`, `lon`, `households`, `grid_distance_km`, `demand_tier`, `benefit_per_household`, `grid_cost`, `minigrid_cost`, `shs_cost`. Demand at each site is expressed in households. There is no productive-load column, no anchor customer, and no income effect.

> **THE GAP BETWEEN THE SPECIFICATION AND THE CASE**
> The specification describes productive-use modelling in detail. The Uganda case carries households and nothing else. That is not a defect in the estate — it is a data gap — but it means every access result in this course is a cost-minimisation over households, with no benefit side at all. A plan built this way will rank a large village above a small one with a maize mill, every time.

9.3 What the settlement layer could supply

The DRE settlement layer carries what the case does not: agricultural area and value, crop types, health and education facilities, road access and a wealth index, for all 67,650 clusters. Joining it to the access sites would give a productive-load proxy for every site in the country.

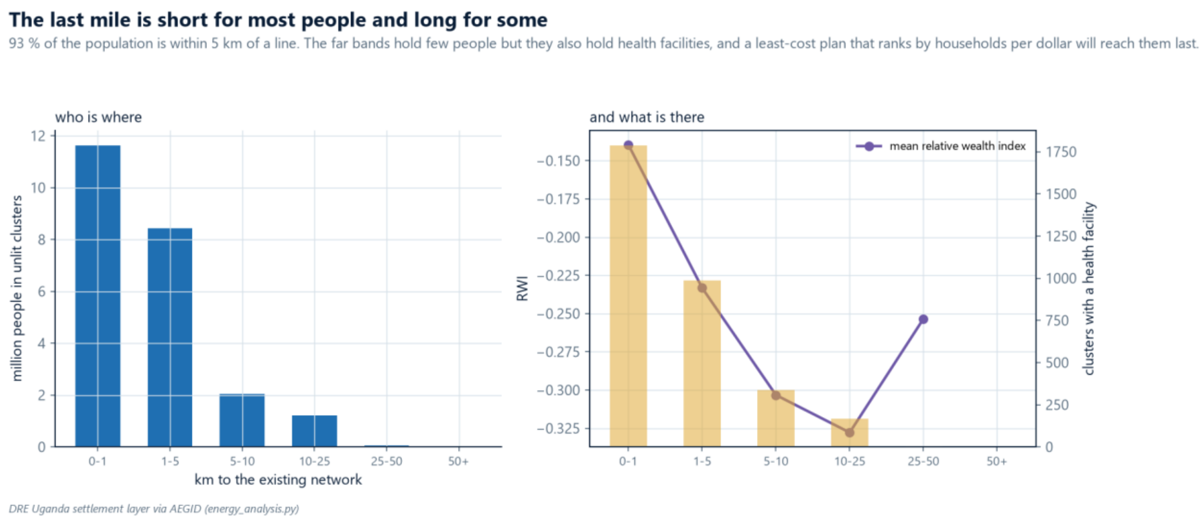


Figure 16. The unlit population by distance to the network, and what sits in each band. — DRE settlement layer

Distance band	Clusters	Population	With a health facility	With a school

Distance band	Clusters	Population	With a health facility	With a school
0-1 km	23,444	11,626,831	1,787	8,477
1-5 km	28,756	8,433,130	988	7,239
5-10 km	7,930	2,033,997	337	1,705
10-25 km	4,673	1,207,730	168	884
25-50 km	117	50,621	5	23
50+ km	0	0	0	0

Table 19. Unlit clusters by distance to the network, with the social infrastructure in each band.

This is the table a productive-use analysis would start from, and it is why the far bands matter more than their population suggests. A least-cost plan ranked on households per dollar reaches them last; a plan that counts a health facility as a load worth serving reaches them differently.

9.4 Transport load

Electrified transport appears in the specification and does not appear in the Uganda case at all: there is no transport sector in the demand table and no charging load anywhere. This course teaches the modelling question and does not present a result, because there is no result to present.

The modelling question is worth stating anyway, because it is the one a ministry will ask within the decade. Charging load is not a new sector of demand; it is a new degree of freedom in the shape of existing demand. Whether it helps or hurts a hydro-dominated system depends entirely on when it is allowed to happen — and at twelve representative periods, this model cannot answer that.

10. Renewable resource and project planning

The resource tables decide what the optimiser may choose. This chapter reads them and shows how much of the answer is settled before any optimisation happens.

10.1 Availability profiles

`availability.csv` has 36 rows: a capacity factor for each unit in each period. It enters the model as `p_max_pu`, the maximum output as a fraction of nameplate.

E-RES-01

$$p_{g,t} \;\le\; \bar{p}_g \cdot a_{g,t} \tag{4}$$

For solar in this case the mean availability is 0.3396, and that single number determines every solar result in the course. It is a declared capacity factor, not a measured one, and it does not vary by site: the three Ugandan solar plants share a profile.

10.2 The candidate list is the answer's boundary

Candidate	Carrier	Max MW	Annualised capex/MW	Variable cost	From
SolarNew	solar	600	78000	0	2026
HydroNew	hydro	400	150000	3	2028
GasNew	gas	300	120000	70	2028

Table 20. Every technology the expansion model may build. There are three.

NO RESULT CAN NAME A TECHNOLOGY THAT IS NOT ON THIS LIST

The expansion model in Chapter 12 chooses solar. It could not have chosen wind, geothermal, nuclear, imports or storage, because none of them is a candidate. A plan that reports 'the least-cost technology is solar' when the alternatives were hydro and gas has reported the contents of a three-row file.

10.3 Levelised cost, and what it hides

E-CAP-01

$$\text{LCOE}_g = \frac{K_g \cdot \text{CRF}(r, n) + \text{FOM}_g}{8760 \cdot \text{CF}_g} + \text{VOM}_g$$

$$\text{CRF}(r,n) = \frac{r(1+r)^n}{(1+r)^n - 1} \tag{5}$$

The capital recovery factor at 8 % over 25 years is 0.09368. The candidates table gives annualised capex directly, so the estate never needs the overnight cost — which is why Chapter 16 has to invert this formula to get an asset base at all.

Figure 17. The productivity lever the LCOE path hands the CGE. — PowerLink.power_prod_from_lcoe()

The left panel is levelised cost by carrier and year, computed from the candidate cost structure at the capacity factor each carrier actually achieves. Only solar falls, because only solar carries a learning rate — 3.0 % a year, a declared assumption of this build and not a model result.

LCOE IS NOT A RANKING

Levelised cost divides an annual cost by an annual output. It says nothing about when the output arrives, and in a system with a binding energy constraint and a seasonal hydro profile, when is most of the question. The expansion model does not rank by LCOE; it solves. The LCOE path exists here because CDCGE wants it as a productivity shock, and that is the only thing it is used for.

10.4 Siting

The estate plans and visualises; it does not site. There is no suitability surface, no exclusion mask, no slope or land-use constraint, and no interconnection queue. A candidate has a bus and a maximum size, and that is the whole of its geography. This is EN-13 and it is a hard limit on what an expansion result can be used for.

The settlement layer carries a solar-resource value for every cluster — mean 1,615 — which is exactly the input a siting analysis would need. Joining it is a natural extension and it is not implemented here.

10.5 What a resource chapter should make you check

- Is the capacity factor measured or declared? If every unit of a carrier shares one number, it is declared.
- Does the candidate list contain the technology you expect the answer to be? If not, the answer cannot be it.
- Is there a maximum annual build rate? Without one, an expansion model will build a decade of capacity in a year.
- Does the resource vary seasonally in the same direction as demand, or against it? In a hydro system this is the single most important fact and it is in the availability table.

Part IV — Dispatch, networks, storage and water

Four chapters on the operating problem and the physical system it runs on. Chapter 11 is the longest in this manual and the one everything else depends on: it takes a single reported number — two per cent of demand unserved — and follows it until the arithmetic closes.

11. Dispatch, and the number that did not add up

This chapter solves the Uganda case, reads the result, finds that the explanation on offer does not survive contact with the topology, and re-derives the answer from the input tables. The re-derivation closes to 0.0 MWh. It is the single most important thing in the course, and not because of the finding: because of the method.

11.1 The solve

`run_economic_dispatch(d, ScenarioConfig(carbon_price=25.0))` on the Uganda case: 24 buses, 30 corridors, 5 thermal and solar units, 6 reservoir hydro plants, twelve representative periods. Status optimal.

Quantity	Value
Objective	$788.9 m
of which generation cost	$86.9 m
of which lost-load penalty	$702.0 m
Generation	3.59 TWh
Demand	3.49 TWh
Unserved energy	69.4 GWh
Unserved share of demand	2.0 %
Emissions	333.8 kt
Loss of load expectation	8,760 hours — every hour

Table 21. The dispatch result. Two of these numbers should stop you: 88 % of the objective is a penalty for energy not delivered, and the system is short in every single period.

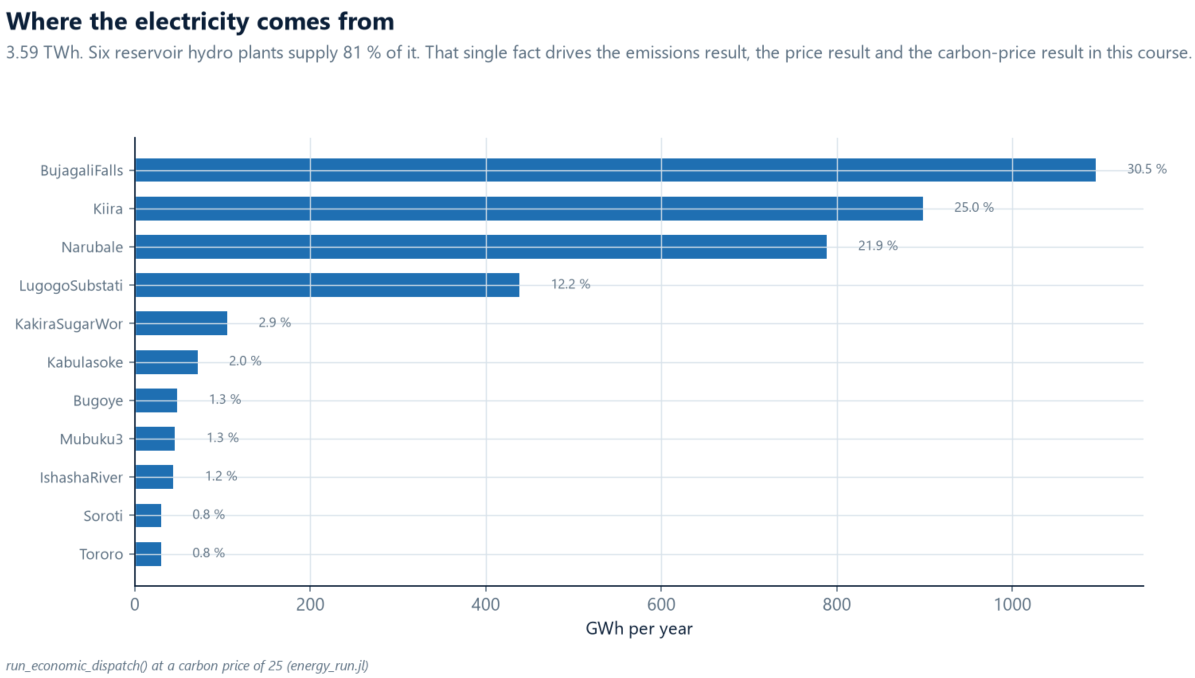


Figure 18. Generation by technology in the solved dispatch. — run_economic_dispatch(), carbon price 25

11.2 The explanation on offer

The estate's integration note attributes the unserved energy to islands in the clustered endpoint graph: buses that no line reaches cannot be served whatever the generation, so the shortfall is a network-construction artefact rather than a physical shortage. That is a reasonable thing to expect from a network built by clustering surveyed circuits to endpoints about seven kilometres apart, and it is the kind of self-critical note that marks a well-documented model.

It is also wrong, and the way to find out is to look at the graph.

11.3 The graph has one component

Figure 19. The network the optimiser actually sees: 24 buses, 30 corridors, and the islands. — Model case, buses.csv and lines.csv

Twelve lines that settle it

```
adj = defaultdict(set)
for r in lines.itertuples():
    adj[r.from_bus].add(r.to_bus)
    adj[r.to_bus].add(r.from_bus)

components = connected_components(adj, buses.bus)
# -> 1 component, 24 buses, 30 corridors
# -> 0 buses with no incident line
```

Twenty-four buses, thirty corridors, one connected component, no isolated bus. There are no islands. Two further facts point the same way: `run_network_expansion` adds 0 MW, because no corridor is congested; and the unserved energy is unchanged between the dispatch and the network-expansion run, so no amount of reinforcement helps.

WHY A PLAUSIBLE EXPLANATION IS MORE DANGEROUS THAN AN IMPLAUSIBLE ONE

The island story explains the observation, comes from the authors, and makes the result harmless. All three of those make it less likely to be checked. The check that falsifies it is twelve lines of graph traversal. The general lesson: an explanation that arrives together with the number it explains has not been tested against the number.

11.4 Re-deriving the balance

If the network is not the constraint, the energy must be. The test is direct: compute what each unit could produce over a year from its own input row, and compare it with what the dispatch actually produced.

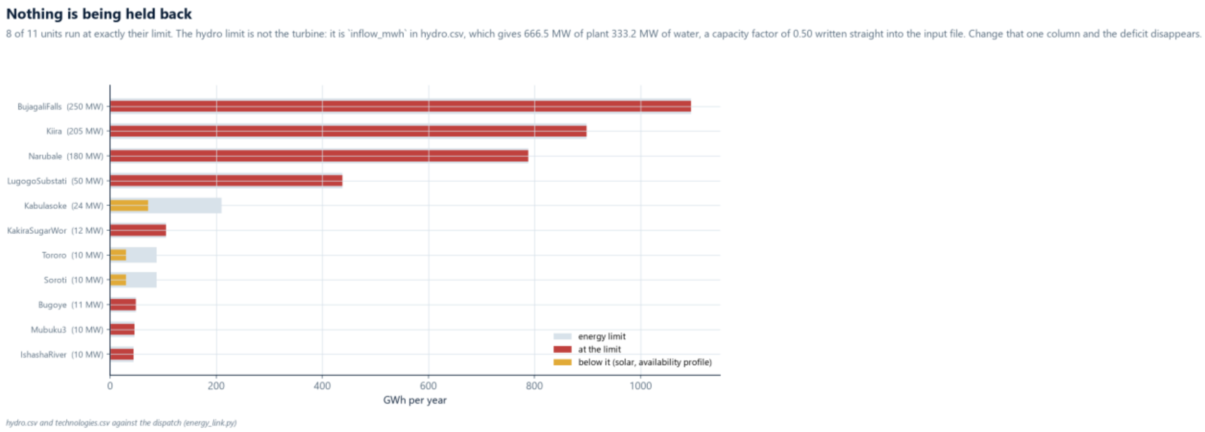


Figure 20. Every dispatchable unit runs at exactly its energy limit. — uga_energy_adequacy

Unit	Carrier	Nameplate MW	Energy limit GWh	Dispatched GWh	Utilisation
BujagaliFalls	hydro	250.0	1,095.0	1,095.0	1.0000
Kiira	hydro	205.0	897.9	897.9	1.0000
Narubale	hydro	180.0	788.4	788.4	1.0000
LugogoSubstati	oil	50.0	438.0	438.0	1.0000
KakiraSugarWor	biomass	12.0	105.1	105.1	1.0000
Kabulasoke	solar	24.0	210.2	71.4	0.3396
Bugoye	hydro	11.0	48.2	48.2	1.0000
Mubuku3	hydro	10.5	45.6	45.6	1.0000
IshashaRiver	hydro	10.0	43.8	43.8	1.0000
Soroti	solar	10.0	87.6	29.7	0.3396
Tororo	solar	10.0	87.6	29.7	0.3396

Table 22. Every unit against its own energy limit. Eight of eleven are at exactly 1.0000. The three that are not are the solar plants, held at their availability profile.

Utilisation of exactly 1.0000, to four decimal places, on eight units at once. The oil plant runs flat out for all 8,760 hours. The biomass plant runs flat out for all 8,760 hours. Every hydro plant produces exactly its inflow. Nothing is being held back for cost reasons, because nothing has any headroom.

11.5 The balance closes

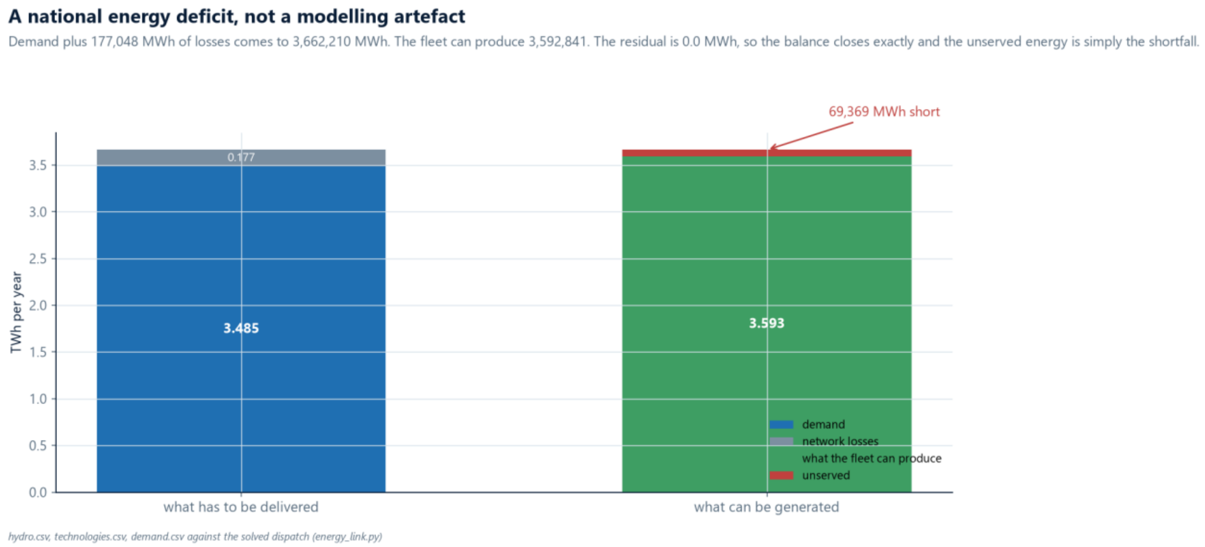


Figure 21. The energy balance that produces the unserved energy, and it closes exactly. — input tables re-derived against the dispatch

E-BAL-01

$$\underbrace{D}_{\text{demand}} + \underbrace{L}_{\text{network losses}} \;=\; \underbrace{G}_{\text{what the fleet can make}} + \underbrace{U}_{\text{unserved}} \tag{6}$$

Term	MWh per year	Where it comes from
Demand D	3,485,162	demand.csv, weighted sum over twelve periods
Network losses L	177,048	residual: generation less energy served
Generation G	3,592,841	sum of every unit at its own energy limit
Unserved U	69,369	reported by the solve
Residual	0.0	$(D + L) - G - U$

Table 23. The balance, term by term. It closes to nought point nought megawatt-hours.

Demand plus losses is 3,662,210 MWh. The fleet can produce 3,592,841. The country is 69,369 MWh short — 2.0 % of demand. This is an energy deficit, and it is national.

EN-21 — THE CORRECTION, STATED PLAINLY

Uganda's modelled system has 772 MW of plant against a 474 MW peak. On capacity it is comfortable. On energy it cannot meet its own demand for a year, and the shortfall is not a rounding artefact: it is 2 per cent of national consumption, and it appears in every hour.

11.6 Where the deficit comes from

One column. `hydro.csv` gives 666.5 MW of installed hydro an inflow of 333.2 MW — a capacity factor of 0.50, identical to two decimal places across six unrelated rivers.

E-HYD-00

$$\text{CF}_{\text{hydro}} = \frac{\sum_h \text{inflow}_h}{\sum_h \text{capacity}_h} = \frac{333.2}{666.5} = 0.500 \tag{7}$$

A capacity factor that is exactly one half for every plant in a table is not a measurement. It is a placeholder. Whether Uganda's hydro fleet runs at 0.50 or at 0.65 is the difference between a national energy deficit and a comfortable surplus, and the answer is not in this file — it is in the inflow records of six rivers.

WHAT TO DO WITH A RESULT THAT RESTS ON A PLACEHOLDER

Not discard it. Report it with the placeholder named, and sweep it. A single sensitivity — solve the case at 0.45, 0.50, 0.55 and 0.60 — converts an unusable result into a statement about where the threshold is. Lab 4 does exactly this.

11.7 Losses are larger than the deficit

Network losses are 177,048 MWh, 4.9 % of generation, and 2.6 times the unserved energy. That is worth sitting with: the cheapest megawatt-hour available to this system is the one it is currently losing in the wires.

The loss factors are per-corridor and they are large — up to 6.5 % on the longest line. In a transport model losses are a fixed fraction of flow, so they scale with everything and they cannot be reduced by dispatching differently. Reducing them is a network investment question, and Chapter 12 shows why this model will not propose it.

11.8 Where the load is shed, and why it took a re-run to find out

The results file does not say. The adapter filters the load-shedding generators out of the dispatch table before writing it, so the total is reported and the location is not. Recovering it needed a re-run with the working directory kept and the raw PyPSA output read directly.

The shedding is at two buses, in every period: **B05_Nkenda** and **B20_Mirama**. Both are leaf nodes at the end of the lossiest paths in the network. Neither is islanded — each has a corridor with 860 MW of capacity against a demand under 9 MW. They are shed because, in a system that is short overall, the optimiser sheds where delivery costs most, and delivery costs most where the losses are highest.

A SUBTLE AND IMPORTANT POINT ABOUT WHERE SHEDDING LANDS

In a system with enough energy, the location of unserved energy tells you about the network. In a system without enough energy, it tells you about the loss gradient. Reading the first story onto the second is exactly the mistake the integration note makes, and it leads to a plan that reinforces lines that are not congested.

11.9 The price, and the factor of 730

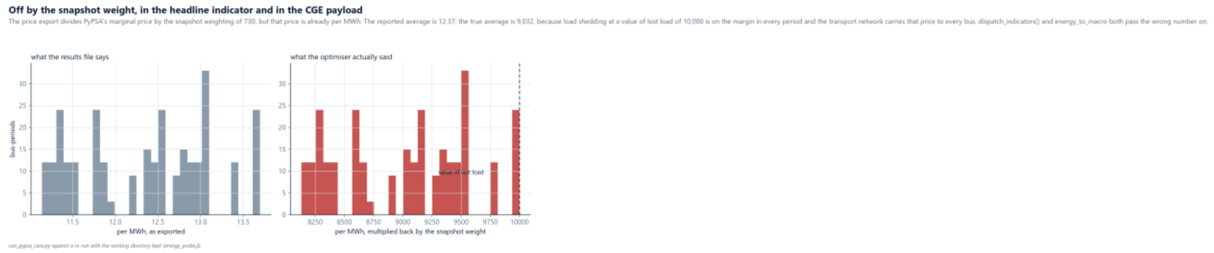


Figure 22. The marginal price as the estate exports it, and as PyPSA computed it. — run_pypsa_case.py price export against the snapshot weighting

The results file reports a mean marginal price of 12.37 per MWh. That would be a remarkable number: a national system running at a marginal cost of twelve currency units. It is also impossible in a system that sheds load, because a shedding system prices at the value of lost load.

EN-20, in one line

```
# bridge/run_pypsa_case.py
prices.append((s, b,
               float(n.buses_t.marginal_price.at[s, b])
               / max(float(w[s]), 1e-9)))     # <- the bug
```

Listing 2. PyPSA's marginal_price is already per MWh. Dividing by the snapshot weighting divides every price by 730.

Quantity	As exported	True
Mean price per MWh	12.37	9,032
Maximum price per MWh	13.70	10,000
Share of bus-periods at the value of lost load	—	8.3 %

Table 24. The same duals, before and after multiplying the snapshot weight back in.

The true mean is 9,032 per MWh against a value of lost load of 10,000. Every bus prices near it, because shedding is on the margin somewhere in every period and the transport network carries that price everywhere, attenuated only by line losses. The minimum, 8,132, is 10,000 times the product of the loss factors along the longest delivery path — which is a satisfying check that the corrected number is right.

WHERE THE WRONG PRICE GOES

`dispatch_indicators()` reports it as avg_price. `energy_to_macro()` puts it in the payload as electricity_price. `iterate_energy_macro()` converges the energy-macro fixed point on it. The CGE therefore responds to an electricity price that is out by a factor of 730 — and converges quickly and cleanly, because a price that small cannot move anything.

11.10 The carbon price that abates nothing

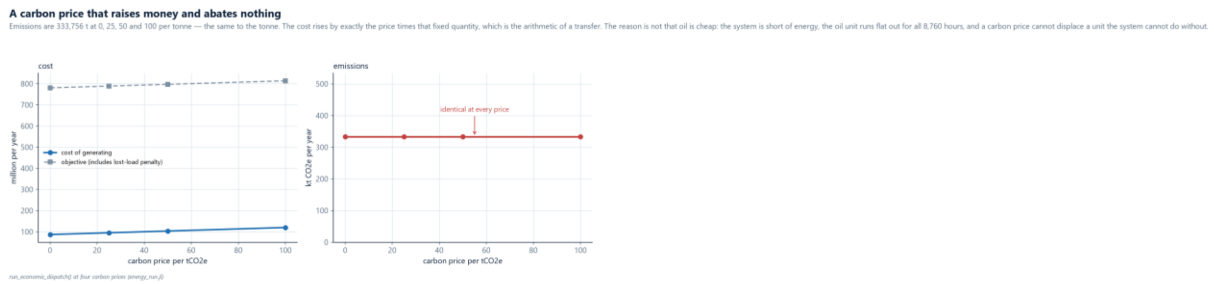


Figure 23. What a carbon price does to this system: cost, emissions, unserved energy. — run_economic_dispatch() at four carbon prices

Carbon price	Objective	Emissions t	Unserved MWh
0	$780.59 m	333,756	69,369
25	$788.93 m	333,756	69,369
50	$797.28 m	333,756	69,369
100	$813.96 m	333,756	69,369

Table 25. The same dispatch at four carbon prices. Emissions are identical to the tonne.

Emissions are 333,756 tonnes at 0, 25, 50 and 100 per tonne. Not approximately identical — identical. The objective rises by exactly the carbon price times that fixed quantity, which is the arithmetic of a transfer with no behavioural content at all.

E-EMI-02

```
\frac{\partial \Pi}{\partial \tau} = E \quad\text{and}\quad \frac{\partial
E}{\partial \tau} = 0
```

(8)

Why? Because the emitting unit is not marginal. The oil plant runs at utilisation 1.0000 for the whole year, and a system that is already short of energy cannot afford to displace it at any carbon price below the value of lost load. A carbon price on this system raises revenue and changes nothing. Chapter 19 sets this beside CDCGE's answer to the same question, which is quite different and also correct.

THE REPORTING ERROR THIS INVITES

The objective rises from $780.6 m to $814.0 m between zero and 100 per tonne. Reported as 'the cost of abatement' that is a number with no abatement in it. The cost of abating nothing is not a marginal abatement cost; it is a tax receipt.

11.11 The merit order that never chooses

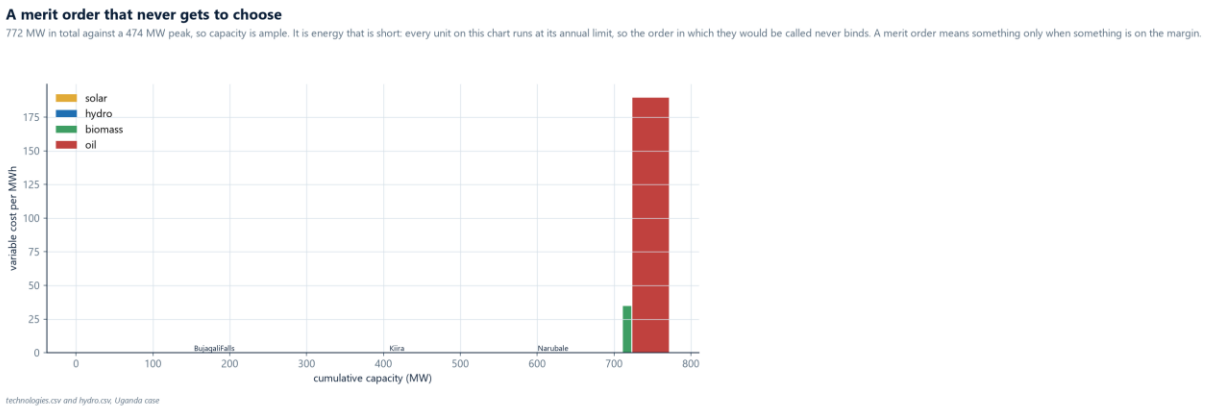


Figure 24. The merit order: what each unit costs to run and how much of it there is. — technologies.csv and hydro.csv

A merit order is a statement about which unit is on the margin. In this case none of them is: every dispatchable unit is at its energy limit and the marginal unit is load shedding. The ordering by variable cost is still correct and it is operationally irrelevant.

11.12 What this chapter should change about how you read a solve

- Check the status, then check the unserved energy, then check the LOLE — before reading the objective.
- Compare the objective with the generation cost. If the gap is large, the objective is mostly a penalty and it is not a cost you can quote.
- Compare the mean dual with the value of lost load. If they are close, scarcity is setting the price and nothing else in the cost stack matters.
- Recompute every unit's output against its own input row. Eight utilisations of exactly 1.0000 is a diagnosis, not a coincidence.
- Write the energy balance out and check that it closes. If it closes to zero, you know what the model did. If it does not, you have found something.

12. Transmission and network development

The network in this model is a transport model on a clustered graph. This chapter sets out what that means for a reinforcement plan, and shows why the network-expansion run on this case builds nothing.

12.1 From 78 circuits to 30 corridors

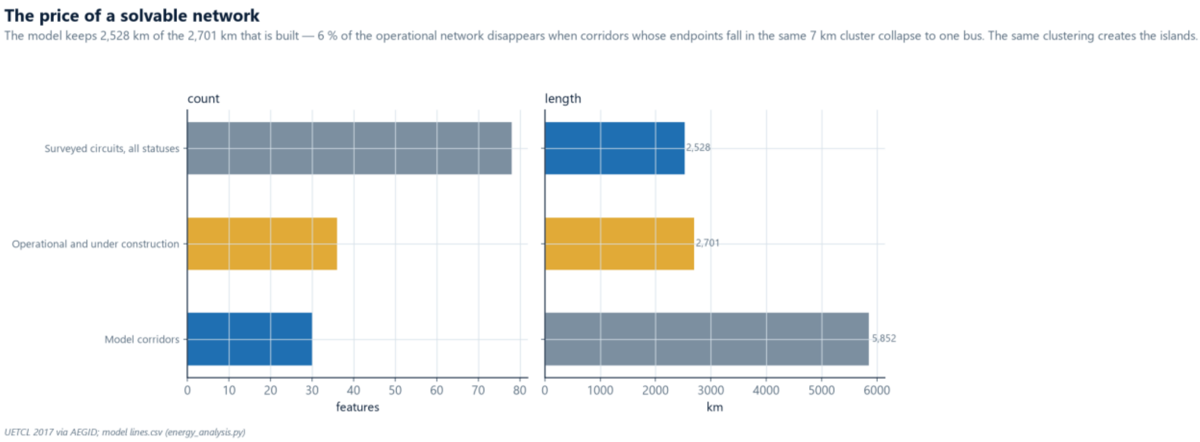


Figure 25. What clustering the survey layer into a solvable graph costs. — UETCL 2017 layer against the model's lines table

The surveyed layer has 78 circuits and 5,852 km, of which 25 are operational and 11 are under construction. The model's case has 30 corridors and 2,528 km.

The reduction happens because circuits whose endpoints fall inside the same cluster collapse to a single bus, and their length disappears with them. That is the price of a graph small enough to solve, and it is a real loss of network: the corridors that vanish are exactly the short ones, which are the distribution-adjacent ones, which are where losses concentrate.

12.2 The transport model

E-NET-01

```
\text{net injection at } b:\;\; \sum_{g \in b} p_{g,t} + \sum_{\ell:\,\to b}
\eta_\ell f_{\ell,t} - \sum_{\ell:\, b \to} f_{\ell,t} + u_{b,t} = d_{b,t}
0 \le f_{\ell,t} \le \bar f_\ell \quad \text{(each direction separately)}
```

(9)

EN-03 — WHAT A TRANSPORT MODEL CANNOT TELL YOU

There is no voltage angle, no reactance and no Kirchhoff voltage law. Flow goes wherever it is cheapest, not wherever impedance sends it. On a meshed network the difference is large: a transport model will route around a constraint that physics cannot route around, and will therefore understate congestion and overstate the value of a distant generator. Use these flows to price energy, never to size a conductor.

12.3 Network expansion on this case

`run_network_expansion` makes every corridor extendable up to its `candidate_max_mw` at its annualised cost, and re-solves. On the Uganda case it builds 0 MW and the unserved energy is unchanged at 69,369 MWh.

That is the correct answer to the question asked. No corridor is congested, so reinforcement buys nothing. It is also a useful negative result: it is the second independent piece of evidence against the island explanation, because a model that could relieve the shortfall with wires would have done it.

THE PLAN THIS PRODUCES, AND WHY IT IS WRONG

An investment plan built from this run funds generation and access and no transmission at all — including nothing for the two buses where load is shed in every period. The model is right that reinforcement does not help. It is silent on the fact that 4.9 % of generation is lost in the wires, because loss reduction is not a decision variable anywhere in this formulation.

12.4 What a loss-reduction case would need

- Loss factor as a function of the built capacity, not a constant. In this schema `loss_factor` is fixed per corridor and does not change when the corridor is reinforced.
- A distribution layer. Most losses in a real system are in distribution, which this model does not represent at all.
- A voltage representation, if the question is about reactive compensation rather than about conductor size.

None of these is present. The honest statement is that this estate can tell you whether a corridor is congested and cannot tell you whether reinforcing it would pay for itself in losses avoided — which, on this case, is the question that matters.

13. Storage and flexibility

Storage is where an energy-constrained system with a seasonal resource would ordinarily look for relief. This chapter sets out the formulation and then says plainly what the Uganda case contains.

13.1 The state equation

E-STO-01

$$s_{k,t} = s_{k,t-1} + \eta^{+}_k \, c_{k,t} - \frac{1}{\eta^{-}_k} \, g_{k,t} + i_{k,t}$$
$$0 \le s_{k,t} \le \bar{s}_k, \qquad 0 \le c_{k,t},\, g_{k,t} \le \bar{p}_k$$
$$s_{k,T} = s_{k,0} \quad \text{(cyclic)} \tag{10}$$

Charge and discharge efficiencies enter asymmetrically, which is correct: a round trip costs $\eta^{+}\eta^{-}$. The cyclic condition prevents the optimiser from paying for the year by emptying the store, which is the standard and necessary restriction on a single-year model.

13.2 What the case contains

Storage	Bus	Power MW	Energy MWh	Charge eff.	Discharge eff.	Variable cost
Battery1	B12_Mutundwe	40	160	0.95	0.95	1.0

Table 26. The whole of the Uganda case's storage: one battery.

One unit: 40 MW and 160 MWh, so four hours at full power, on a system with a 474 MW peak. It is a token entry — enough to exercise the state equation and not enough to affect any result. The dispatch does not report it doing anything.

A TOKEN ROW IS WORSE THAN AN EMPTY FILE

An empty storage.csv would make the absence of storage obvious. One 40 MW battery makes the results say that storage was in the model, which is true, and invites the reader to conclude that storage was evaluated, which is not. Whenever a table has exactly one row, ask whether it is a case or a template.

13.3 What storage would and would not do here

It is worth being precise, because the intuition points the wrong way. This system is short of energy over a year, not short of power at a peak. Storage moves energy in time; it does not create it, and a round trip destroys some. Adding a battery to a system with a binding annual energy constraint makes the deficit slightly worse, not better.

What storage would do is change where and when the shedding falls, and reduce the loss penalty by allowing delivery at lower flows. Both are real and both are second-order beside the arithmetic in Chapter 11. The instrument that closes an energy deficit is firm energy: imports, more inflow, or thermal fuel.

13.4 Hydrogen

The specification covers hydrogen. The estate does not implement a hydrogen carrier and the case contains none. This course teaches the modelling question — hydrogen is storage with a very poor round trip and a very large energy capacity, which makes it a seasonal instrument and not a daily one — and presents no result.

14. Hydropower, water and climate

Eighty-one per cent of Uganda's generation is water. This chapter is therefore about the single most important input in the case, and about a stress test that turns out to move the answer further than any policy lever in the course.

14.1 The reservoir formulation

E-HYD-01

```
v_{h,t} = v_{h,t-1} + i_{h,t} - q_{h,t} - \sigma_{h,t}
\underline{q}_h \le q_{h,t}, \qquad 0 \le v_{h,t} \le \bar v_h, \qquad v_{h,T}
\ge v_{h,0}
```

(11)

Inflow i fills the reservoir, release q generates, spill σ is wasted, and a minimum release protects downstream users. The end-of-horizon condition stops the model from financing the year by draining the reservoir.

Plant	Bus	Capacity MW	Inflow	Reservoir max	Min release
Bugoye	B06_Hoima	11.0	5.5	7920.0	402.0
BujagaliFalls	B02_Kawanda	250.0	125.0	180000.0	9125.0
IshashaRiver	B17_Mbarara	10.0	5.0	7200.0	365.0
Kiira	B03_Nalubaale	205.0	102.5	147600.0	7482.0
Mubuku3	B06_Hoima	10.5	5.2	7560.0	383.0
Narubale	B03_Nalubaale	180.0	90.0	129600.0	6570.0

Table 27. The six reservoir plants. Note the inflow column against the capacity column, in every row.

14.2 The column that decides the country

Inflow is exactly half of capacity for every plant. Chapter 11 showed what that does. Here it is worth adding what it means hydrologically: a run-of-river plant on the Victoria Nile and a small reservoir scheme on the Mubuku do not have the same capacity factor, and neither of them has a capacity factor that is the same in a wet year and a dry one.

EN-06 — RESERVOIRS BALANCE INDEPENDENTLY

Each reservoir has its own state equation and there is no hydraulic coupling between them. Kiira and Nalubaale are on the same river a few hundred metres apart and share the same water; Bujagali is upstream of both. Modelling them as three independent reservoirs double-counts the resource. On this case it does not bind, because inflow is the constraint everywhere — but on a case with realistic inflows it would.

14.3 The climate stress test

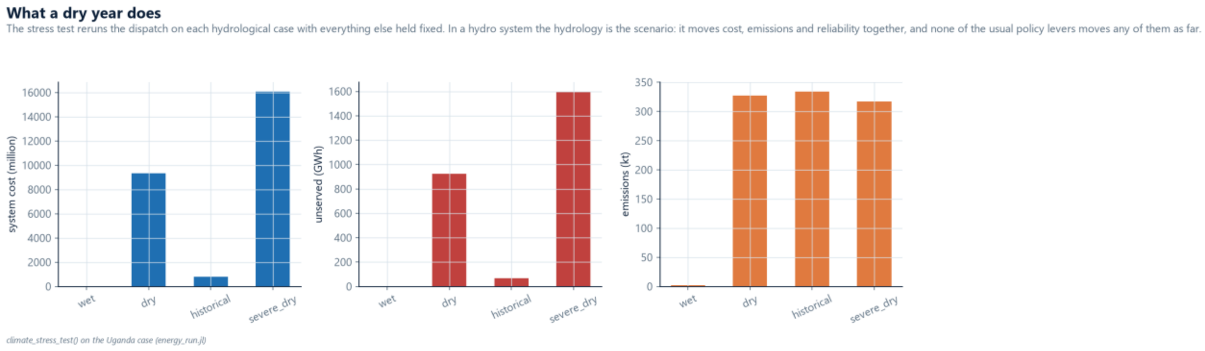


Figure 26. Dispatch under the estate's hydrological cases. — climate_stress_test()

Case	Objective	Unserved MWh	Emissions t	Curtailment MWh
wet	$1.82 m	0	2,508	54,957
dry	$9.35 bn	925,743	327,186	0
historical	$788.93 m	69,369	333,756	0
severe_dry	$16.06 bn	1,596,537	317,331	0

Table 28. The dispatch re-solved on each hydrological case, everything else held fixed.

Read the spread. The hydrological case moves the objective, the unserved energy and the emissions together and by more than any policy lever in this course moves any of them. In a system that is four fifths water, the hydrology is not a sensitivity — it is the scenario, and everything else is a sensitivity on it.

HOW TO PRESENT A HYDRO-DOMINATED SYSTEM

Not as a central case with a climate sensitivity. As a set of hydrological cases, each with its own plan, and a statement about which decisions are common to all of them. Those common decisions are the robust ones and they are the only ones worth putting in a cabinet paper.

14.4 What the case cannot say about climate

- There is no inflow time series, only a single number per plant. Sequence matters in a reservoir system and there is no sequence here.
- There is no correlation structure between plants. A drought affects a basin, not a plant.
- There is no downstream water demand beyond a minimum release constant. Irrigation and municipal abstraction compete for the same water and neither appears.
- Twelve representative periods cannot represent a multi-year drought, which is the event that actually breaks a hydro system.

The hazards table exists and carries one row: a drought hazard at Bugoye with a hardening cost and an avoided loss. That is a template rather than an assessment, and the manual says so rather than building a resilience chapter on a single row.

Part V — Access, money, reliability and emissions

Four chapters on what the power system is for and what it costs. Access planning, tariff design and the incidence of both; reliability and resilience; and the emissions and fuel accounts that the climate conversation runs on.

15. Access and decentralised systems

Uganda's electrification problem is the largest single number in this course: by the survey, 74.1 % of households have no grid connection. This chapter builds the least-cost plan, and then explains why the plan is less informative than it looks.

15.1 The problem

E-ACC-01

$$
\min \sum_{s}\sum_{k} c_{s,k}\, x_{s,k}
\text{s.t.}\quad \sum_k x_{s,k} \;=\; \alpha \, H_s \;\; \forall s, \qquad
\sum_s \sum_k c_{s,k}\, x_{s,k} \;\le\; B
\tag{12}
$$

For each demand site s and technology k, choose how many households $x_{s,k}$ to serve, meet the access target α at every site, and stay inside the budget B. The cost $c_{s,k}$ is where all the modelling lives: for grid extension it rises with distance to the nearest bus, and for the alternatives it does not.

15.2 The plan

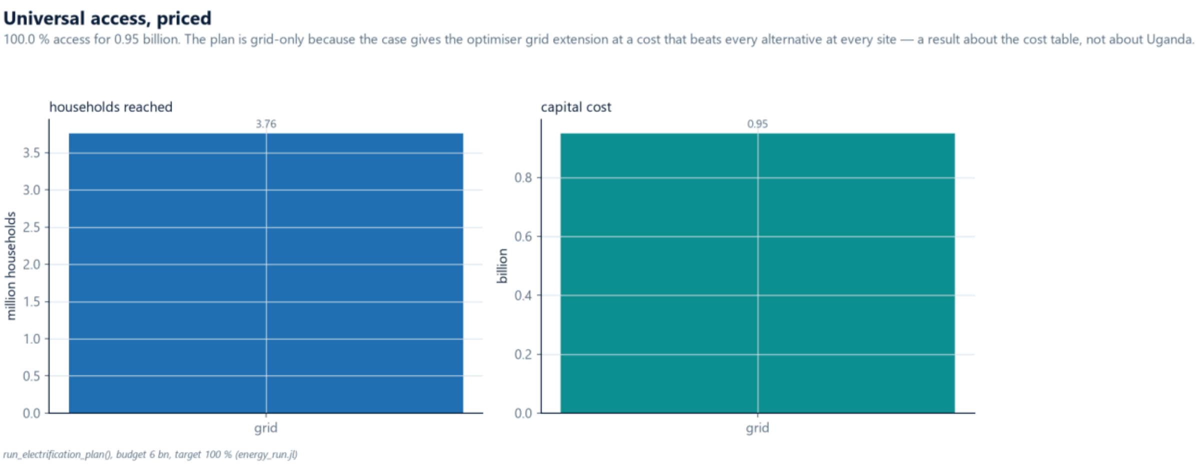


Figure 27. The least-cost electrification plan by technology. — run_electrification_plan()

Quantity	Value
Access rate reached	100.0 %
Households connected	3,759,255
Total cost	$949.86 m
Cost per household	253
Technologies used	grid extension, at every site

Table 29. Universal access on the estate's Uganda case.

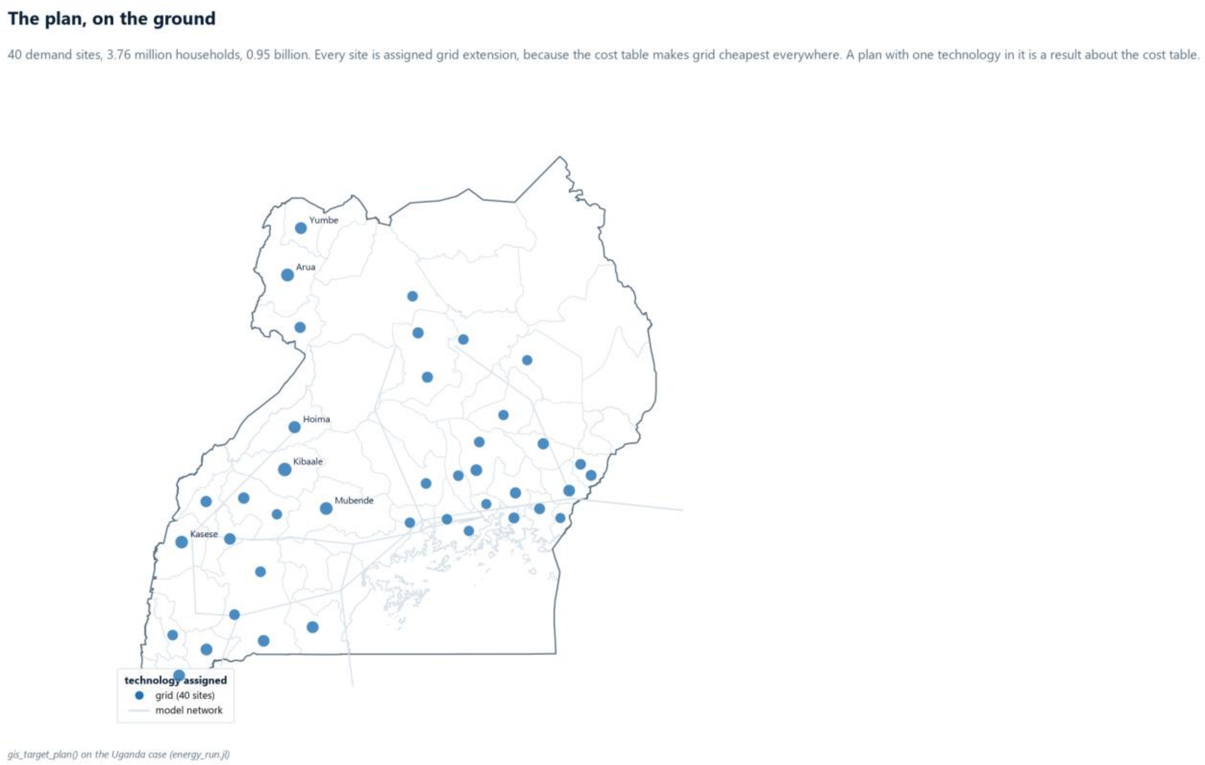


Figure 28. The electrification plan in space: which settlements get which technology. — gis_target_plan()

A ONE-TECHNOLOGY PLAN IS A STATEMENT ABOUT A COST TABLE

The optimiser assigns grid extension to all forty sites. That is not a finding about Uganda; it is a finding about access_sites.csv, in which the grid cost beats every alternative at every distance in the file. When an optimiser returns a corner solution, the first question is whether the problem had an interior at all.

15.3 Why grid wins here

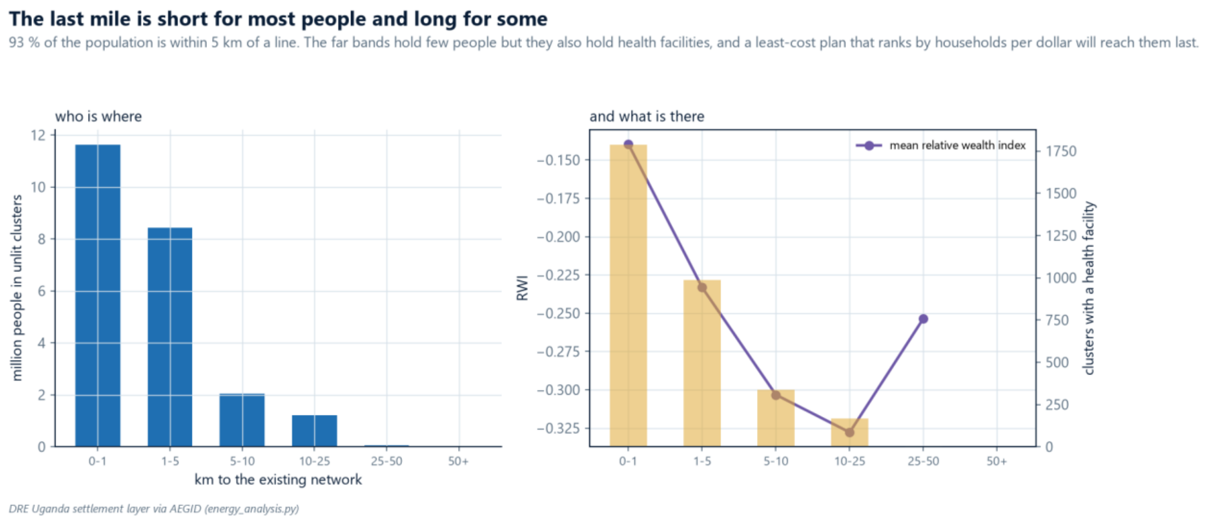


Figure 29. The unlit population by distance to the network, and what sits in each band. — DRE settlement layer

The geography supports the answer even if the cost table is doing the work. 93.0 % of Uganda's population is within five kilometres of a line and 75.2 % within one. At those distances grid extension is genuinely cheapest almost everywhere, and a mini-grid comparison is not close.

Where it is not close in the other direction is the tail. The far distance bands hold few people and a disproportionate share of the health and education facilities — which a households-per-dollar ranking reaches last, and a services-first ranking reaches first.

15.4 The budget frontier is a cliff

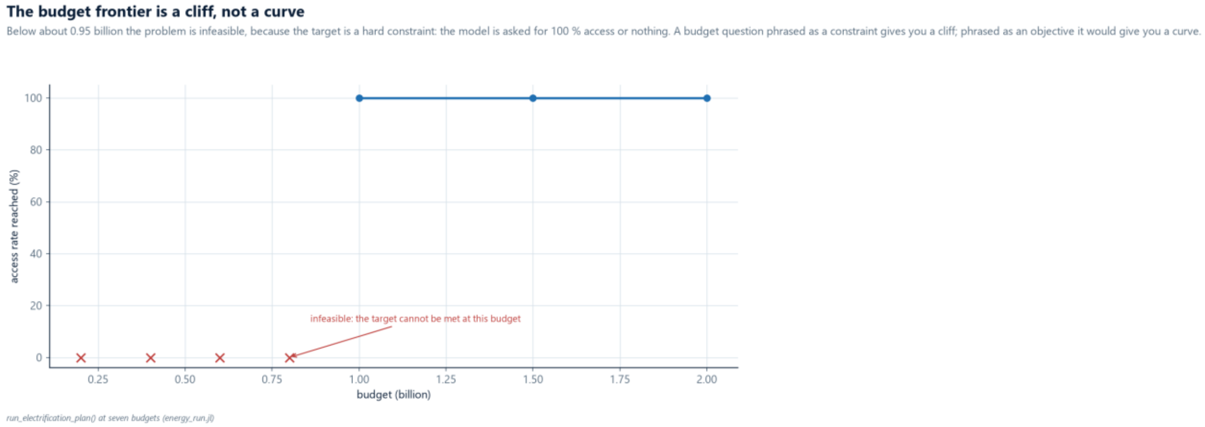


Figure 30. How much access each additional billion buys. — run_electrification_plan() budget sweep

Budget	Feasible?	Access reached	Cost
$200.00 m	no	—	—
$400.00 m	no	—	—
$600.00 m	no	—	—
$800.00 m	no	—	—
$1.00 bn	yes	100.0 %	$949.86 m
$1.50 bn	yes	100.0 %	$949.86 m
$2.00 bn	yes	100.0 %	$949.86 m

Table 30. The same problem at seven budgets. Below about 0.95 billion it is infeasible, not partial.

CONSTRAINT OR OBJECTIVE — THE QUESTION DECIDES THE ANSWER'S SHAPE

The access target is a hard constraint: serve every household at every site, or the problem is infeasible. So the budget sweep gives a cliff. Ask instead for the maximum access reachable within a budget — the same data, the target moved from the constraints to the objective — and the same sweep gives a curve, which is what a finance ministry actually needs. Lab 6 does both.

15.5 Clean cooking

Figure 31. The clean-cooking portfolio and what each 10 points of coverage costs. — run_clean_cooking()

Quantity	Value
Households reached	4,102,046
Capital cost	$102.6 m
Annual emissions from the portfolio	2,461.2 kt
Time saved, annual hours	1,197,797,549

Table 31. The clean-cooking portfolio at a 60 % coverage target.

Set that capital cost beside the $949.86 m for universal electricity access. Clean cooking reaches 4,102,046 households for roughly a tenth of the money, and delivers a health benefit the electricity plan does not deliver at all.

The optimiser again returns a corner: it buys one technology, because the objective is linear in adoption and one row of cooking.csv has the lowest lifecycle cost net of health benefit. A real programme cannot deploy a single stove type to four million households, and the fix is a portfolio constraint — a maximum share per technology — which the estate does not impose and Lab 6 adds.

15.6 What the survey says the plan should target

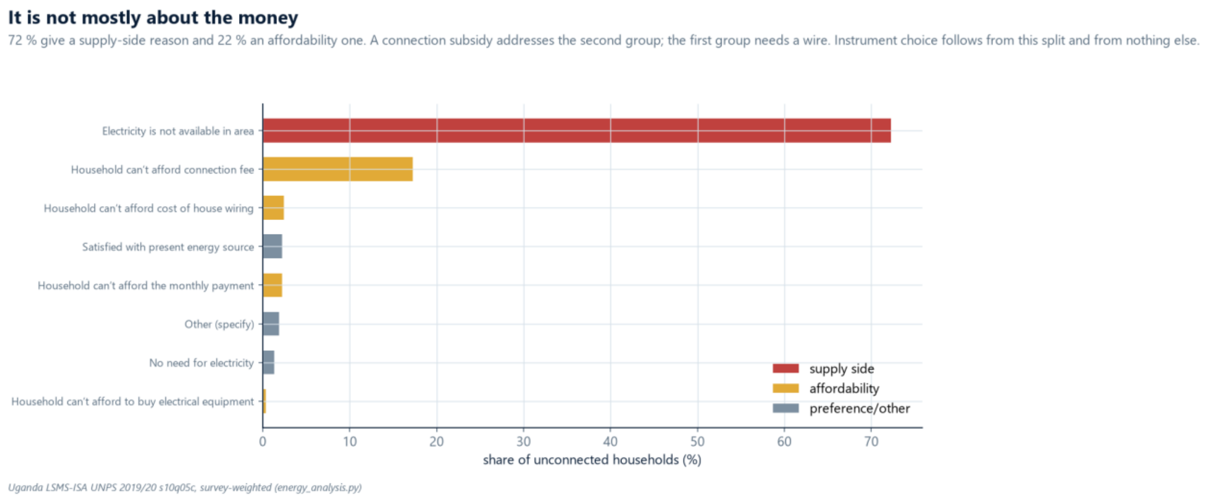


Figure 32. Why unconnected households say they have no electricity. — Uganda LSMS-ISA 2019/20, s10q05c

Unconnected households were asked why. 72.2 % give a supply-side reason — the grid is not there — and 22.2 % give an affordability reason. That split is the single most decision-relevant number in the household data.

> **INSTRUMENT FOLLOWS FROM THE SPLIT, AND FROM NOTHING ELSE**
>
> A connection subsidy addresses the affordability group and does nothing for the supply group. A grid-extension programme addresses the supply group and leaves the affordability group connected on paper and unconnected in fact. In Uganda the supply group is three times the size of the affordability group, which says build first — and then says, immediately, that a fifth of the problem will survive the building.

15.7 The energy ladder

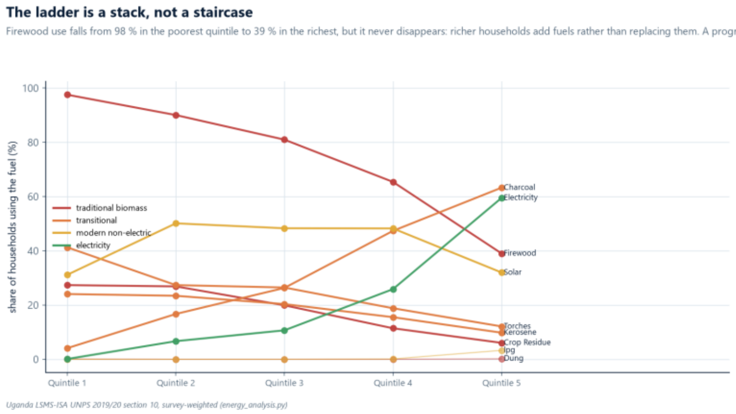


Figure 33. The nine-fuel energy ladder, by consumption quintile. — Uganda LSMS-ISA 2019/20, module 10

Households do not climb the ladder; they add rungs. Firewood use falls from 98 % in the poorest quintile to 39 % in the richest and never disappears. A programme that counts adoption of a clean fuel as a household leaving biomass is counting something that does not happen.

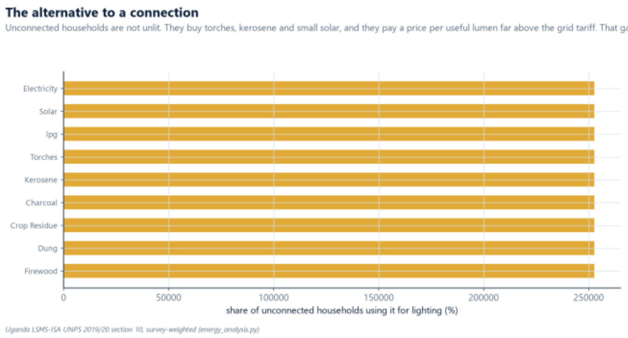


Figure 34. What unconnected households light with. — Uganda LSMS-ISA 2019/20, module 10

Unconnected households are not unlit. They buy torches, kerosene and small solar, at a price per useful lumen far above the grid tariff. That gap is the willingness to pay a connection programme can draw on, and it is why a tariff comparison against zero is the wrong comparison.

16. Tariffs, utility finance and fiscal risk

This chapter designs a cost-reflective tariff with a lifeline block, computes the utility's income statement, and finds the asset base that nobody wrote down. It also contains the clearest example in the course of a test that cannot fail.

16.1 The revenue requirement

E-FIN-01

$$\text{RR} = \text{OPEX} + \text{DEP} + r \cdot \text{RAB} + \text{TAX} - \text{OTHER} \tag{13}$$

Four of those five terms are not in any file in the Uganda case. This course builds them from the estate's own outputs and says exactly how:

Term	Value	Where it came from	Provenance
OPEX	$86.9 m	the dispatch generation cost at a zero carbon price	model output
RAB	$1.18 bn	existing capacity valued at the overnight cost implied by inverting the candidate annuity	derived, part imputed
DEP	$47.3 m	RAB over a 25-year life, straight line	declared assumption
r	8 %	the scenario discount rate	the estate's own default
RR	$228.9 m	the sum	derived

Table 32. Every term in the revenue requirement, and where it came from. Nothing here was read out of a file.

16.2 Finding the asset base

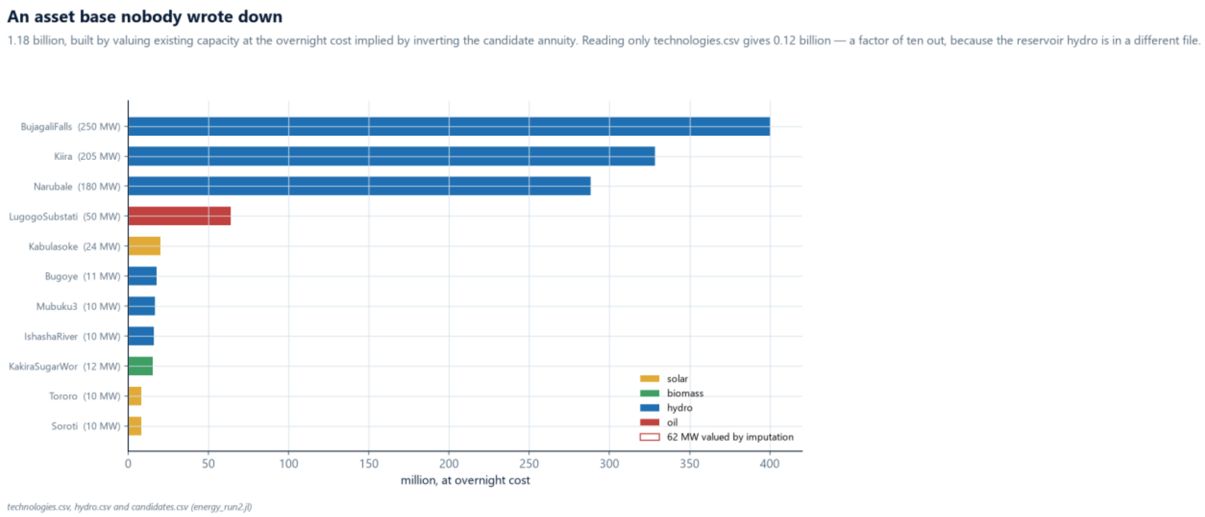


Figure 35. How the regulated asset base is built, plant by plant. — existing capacity at candidate overnight costs

The candidates table gives annualised capex, not overnight cost. Inverting the capital recovery factor recovers it:

E-FIN-01a

```
K_g = \frac{\text{annualised capex}_g}{\text{CRF}(0.08, 25)}, \qquad
\text{CRF}(0.08,25) = 0.09368
\text{RAB} = \sum_g \bar p_g \cdot K_g
```
(14)

Carrier	Overnight cost per MW
gas	$1.28 m
hydro	$1.60 m
solar	$832,633

Table 33. Overnight costs recovered by inverting the annuity. Carriers without a candidate of their own are valued at the thermal figure, which is an imputation.

THE FIRST ATTEMPT AT THIS WAS OUT BY A FACTOR OF TEN

Summing technologies.csv gives an asset base of 0.12 billion. The correct figure, including hydro.csv, is $1.18 bn. The reservoir hydro is six sevenths of the fleet and it lives in a table that is marked optional. This is EN-17's cousin, and it is the third time in this manual that hydro's separate table has produced a wrong number.

16.3 Designing the tariff

E-FIN-02

```
\text{base}_c = \text{RR}\cdot\frac{\text{cts}_c \cdot
E_c}{\sum_{c'}\text{cts}_{c'}E_{c'}},\qquad p^{\text{cr}}_c =
\frac{\text{base}_c}{E_c}
p^{\text{life}}_c = \frac{(1-\delta)\,p^{\text{cr}}_c}{\text{coll}_c}, \qquad
p^{\text{std}}_c = \frac{p^{\text{cr}}_c + \text{uplift}}{\text{coll}_c}
\text{uplift} = \frac{\delta \sum_c E^{\text{life}}_c p^{\text{cr}}_c}{\sum_c
(E_c - E^{\text{life}}_c)}
```
(15)

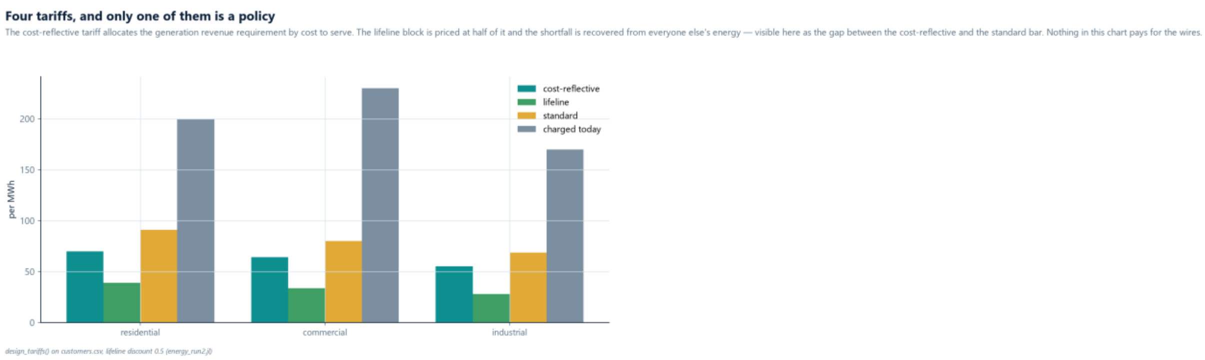


Figure 36. Cost-reflective, lifeline and standard tariffs by customer class. — design_tariffs()

Class	Energy MWh	Customers	Cost-reflective	Lifeline	Standard	Charged today
residential	1,916,839	1,483,460	70.05	38.92	91.19	200
commercial	871,291	40,000	64.22	33.80	80.24	230
industrial	697,032	2,000	55.46	28.30	68.85	170

Table 34. The designed tariff, by class, at a lifeline discount of 0.5.

Read the last two columns together. The designed residential standard tariff is 91 per MWh against 200 charged today. That is not evidence that Uganda over-charges. The revenue requirement built here covers generation only — a generating asset base and a dispatch operating cost — while the tariff actually charged also pays for transmission, distribution, network losses and the utilities' overheads. The two numbers are not comparable and this manual does not compare them.

16.4 The cross-subsidy, made visible

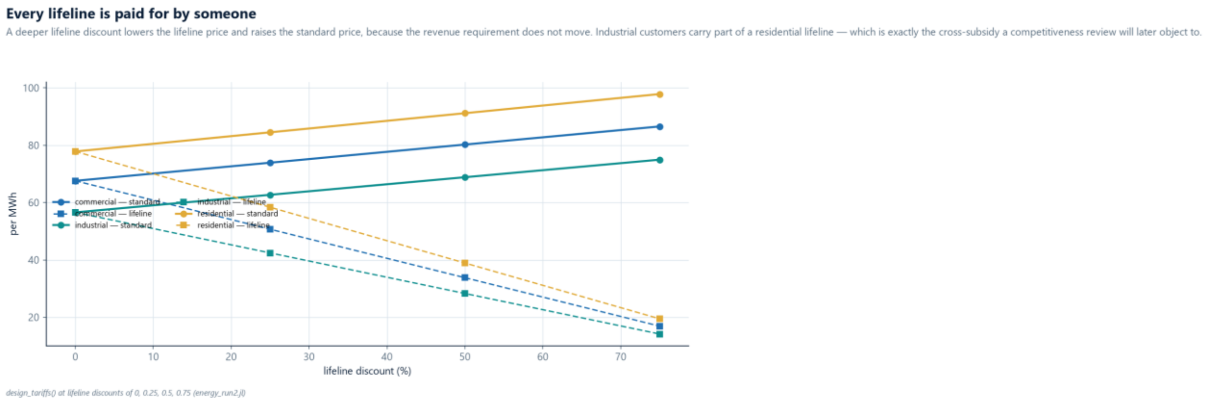


Figure 37. How the cross-subsidy moves with the lifeline discount. — design_tariffs() at four discounts

The uplift term in E-FIN-02 is the cross-subsidy. Every currency unit of lifeline discount is recovered from non-lifeline energy, which in this case means from commercial and industrial customers. Deepen the discount and the standard tariff rises; the revenue requirement does not move.

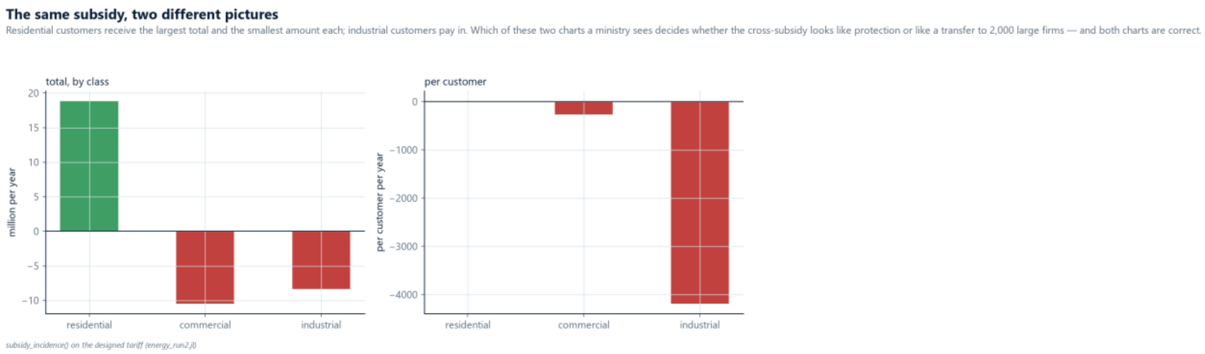


Figure 38. Implicit subsidy per class under the designed tariff. — subsidy_incidence()

Class	Subsidy per MWh	Total subsidy	Per customer
residential	9.83	$18.8 m	12.70
commercial	-12.01	$-10.5 m	-261.69
industrial	-12.01	$-8.4 m	-4,187.00

Table 35. Implicit subsidy by class: cost-reflective less billed, times energy.

TWO CORRECT CHARTS, TWO DIFFERENT POLITICS

Residential customers receive the largest total subsidy and the smallest amount each. Industrial customers pay in. Which of those two framings a ministry sees decides whether the cross-subsidy reads as protection of the poor or as a transfer from two thousand large firms. Both charts are correct and a briefing that shows only one is not.

16.5 EN-22: the test that cannot fail

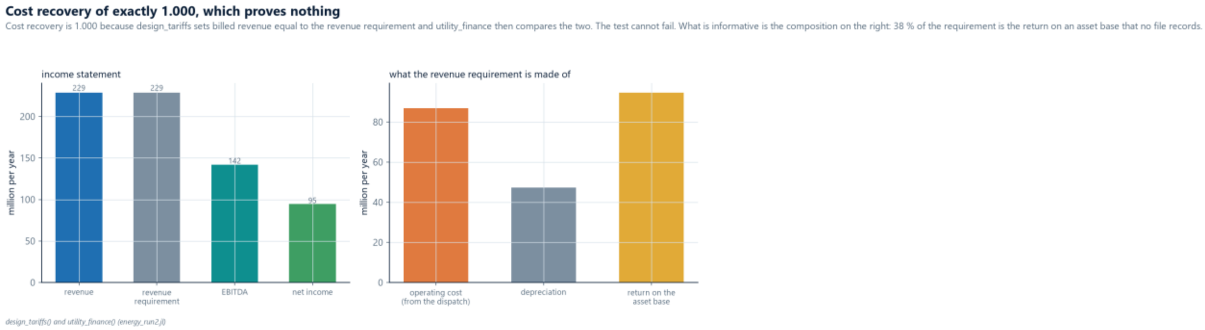


Figure 39. The utility's income statement under the designed tariff, and why it cannot fail. — utility_finance()

`utility_finance()` reports a cost recovery of 1.000 and a financing gap of $0. Both are identities. `design_tariffs` sets billed revenue equal to the revenue requirement by construction, and `utility_finance` then divides one by the other. The ratio is 1.000 for any input whatever.

E-FIN-03a

```
\text{cost recovery} = \frac{\sum_c \text{billed}_c}{\text{RR}} \equiv 1
\quad\text{by construction of } \text{billed}_c
```

(16)

This is worth dwelling on because it is the most common form of false validation in applied modelling: a check that consumes the thing it is checking. The informative output of this function is not the ratio. It is the composition — how much of the requirement is operating cost, how much depreciation, and how much return on an asset base that no file records.

A real cost-recovery test compares billed revenue against a revenue requirement computed independently: from audited accounts, from a regulatory determination, from anything that was not produced by the same function. That test can fail, which is what makes it a test.

16.6 Fiscal risk

The debt-service coverage ratio comes back as infinity, because debt service defaults to zero and no file supplies it. That is not a finding of financial strength; it is a missing input reported as a ratio. Any ratio with a zero denominator should be suppressed rather than printed, and this course suppresses it.

The MTEF bridge, which would carry the utility's financing gap into the medium-term expenditure framework, could not be run: it requires an output directory that the MTEF estate has not produced. The fiscal chain is therefore specified and not executed, and this manual says so rather than presenting a fiscal result.

17. Trade, reliability and resilience

Three questions the estate is asked and can answer to different depths: what interconnection is worth, how reliable the system is, and what a hazard would do to it.

17.1 Trade

The case has 2 corridors to an external bus (B24_Lessos, in Kenya), with a combined capacity of 1,160 MW. In the solved dispatch both carry zero flow.

ZERO FLOW ON AN INTERCONNECTOR IN AN ENERGY-SHORT SYSTEM

A country that cannot meet its own demand is not importing. The reason is in the case: the external bus has no generator and no price attached to it, so there is nothing to import from. Modelling trade needs a price at the boundary, and this case does not have one. An interconnector with no counterparty is a line to nowhere, and it will always carry zero.

This matters for the deficit in Chapter 11. Imports are the obvious instrument for an energy shortfall, and this model cannot evaluate them. That is a gap in the case, not in the estate — the schema supports a bus with a generator at a stated price — and it is the first thing to fix before this case is used for planning.

17.2 Reliability

Indicator	Value	What it means here
Unserved energy	69.4 GWh	a genuine annual energy shortfall
Unserved share	2.0 %	of demand, in every period
LOLE	8,760 hours	every hour of the year — a structural, not a stochastic, shortage
Curtailment	0 MWh	nothing is being spilled

Table 36. The reliability indicators, and how to read each on this case.

An LOLE of 8,760 hours does not mean the lights are off all year. It means that in every one of the twelve representative periods, some load somewhere is shed — which at this resolution is what a chronic deficit looks like. Reporting it as 8,760 hours of outage would be wrong; reporting it as a structural shortage is right.

EN-24 — THERE IS NOTHING TO VALIDATE THIS AGAINST

The survey asks connected households how many hours of electricity they get per day. 536 answered and the answers cluster hard at 24. A self-reported daily average cannot separate one long outage a month from a short outage every day, so SAIDI and SAIFI are not recoverable. The model's reliability outputs have no independent counterpart in this country's household data, and this course does not manufacture one.

Figure 40. The reliability question the survey asks, and what it can support. — Uganda LSMS-ISA 2019/20, s10q02

17.3 Resilience

The hazards table has one row: a drought hazard at Bugoye, with a hardening cost and an expected avoided loss. That is a template. A resilience assessment needs a hazard set, an exposure map and a vulnerability function, and this case has none of the three.

What the case does support, and what Chapter 14 uses, is the climate stress test: re-solving on each hydrological case. In a system that is four fifths water that is the resilience question that matters, and it moves the answer further than any hardening investment could.

18. Emissions and fuels

Two accounts that a climate ministry will read before it reads anything else in this manual, and both of which say something unexpected about Uganda.

18.1 The emissions account

E-EMI-01

```
E_p = \sum_g \text{GEN}_g \cdot \text{EF}_{p,g}
```

(17)

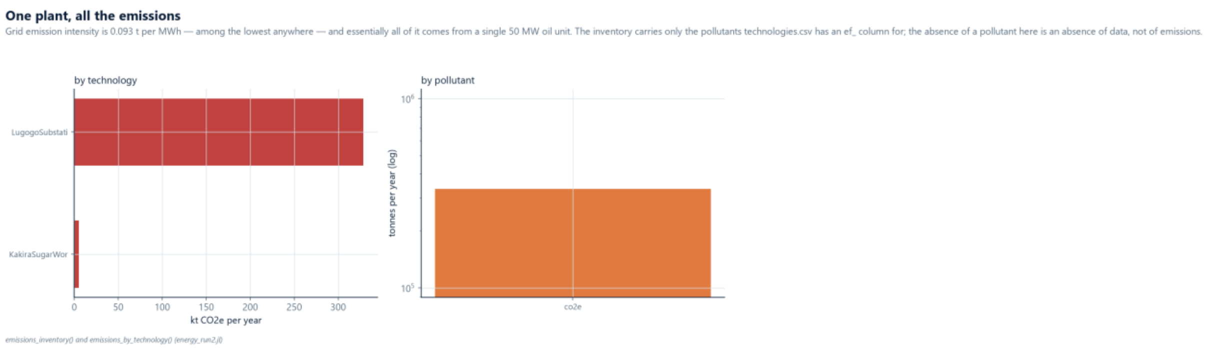


Figure 41. The multi-pollutant inventory and where the emissions come from. — emissions_inventory()

Grid emission intensity is 0.093 tonnes per MWh, which is among the lowest of any national system anywhere, and essentially all of it comes from a single 50 MW oil unit running flat out.

A DECARBONISATION STRATEGY FOR THIS SYSTEM IS ONE SENTENCE LONG

Retire or displace one plant. There is no fleet transition here, no coal phase-out, no stranded-asset problem. What there is instead is an energy deficit that the same plant is currently filling — which is why Chapter 11's carbon price abates nothing, and why the honest recommendation is firm clean energy first and retirement second.

The inventory carries only the pollutants technologies.csv has an `ef_` column for. The absence of a pollutant from the inventory is an absence of data, not an absence of emissions — and for a household-health argument the pollutant that matters is the one from cooking, which is not in the power account at all.

18.2 The fuel account

E-FUE-01

```
\text{residual}_{f,y} = P_{f,y} + M_{f,y} - X_{f,y} - C_{f,y}
\text{import dependence}_{f,y} = \frac{\max(M_{f,y}-X_{f,y},\,0)}{C_{f,y}}
```

(18)

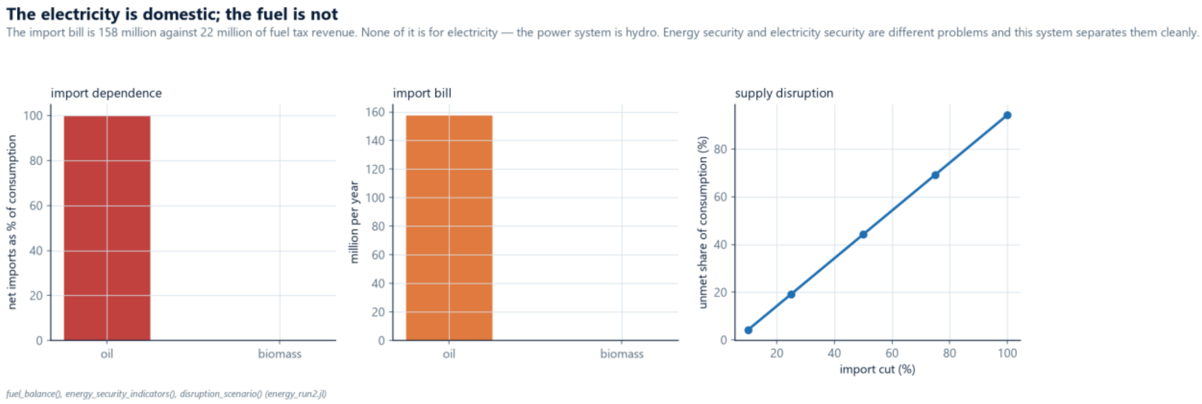


Figure 42. Fuel balance and import exposure. — fuel_balance(), energy_security_indicators()

Fuel	Import dependence	Days of cover	Import bill	Subsidy cost	Tax revenue
oil	100.0 %	21	$157.5 m	$0	$22.5 m
biomass	0.0 %	0	$0	$0	$0

Table 37. Energy security indicators. Two fuels: imported oil and domestic biomass.

The oil import bill is $157.5 m against $22.5 m of fuel tax revenue, with 21 days of cover. None of it is for electricity: the power system is water.

ENERGY SECURITY AND ELECTRICITY SECURITY ARE DIFFERENT PROBLEMS

Uganda's electricity is domestic and its liquid fuel is entirely imported. A supply shock to oil is a transport and fiscal event, not a power event. Systems that conflate the two — and most national energy strategies do — end up proposing power-sector answers to transport-sector exposures.

18.3 The biomass line, and what it hides

The fuel table's second row is three million units of domestic biomass at a price of 10, with no imports, no tax and no subsidy. That single row stands for the fuel that 34.1 % of households cook on a charcoal stove with, and that the energy ladder in Chapter 15 shows 71 % of households using in some form.

Biomass is the largest energy flow in the country and the least modelled. It has no supply curve, no depletion, no land constraint and no price response anywhere in this estate. Every clean-cooking result in Chapter 15 therefore takes the counterfactual fuel as free and unlimited, which is the assumption most likely to be wrong and the one whose failure would matter most.

Part VI — From the power system to the economy and the household

Four chapters that follow a power-sector decision out of the power sector: across a contract into a computable general equilibrium model, out of that model onto three thousand real households, and back to the question of what any of it can be validated against.

19. The CDCGE integration, executed

This chapter runs the whole chain: solve the dispatch, export the generation mix, push it through CDCGE's own reader, obtain the eight-technology power split, build the productivity lever from the levelised-cost path, and close the energy-macro fixed point. Running it is what exposed two of this course's eight findings, and neither of them is visible from either side alone.

19.1 The contract

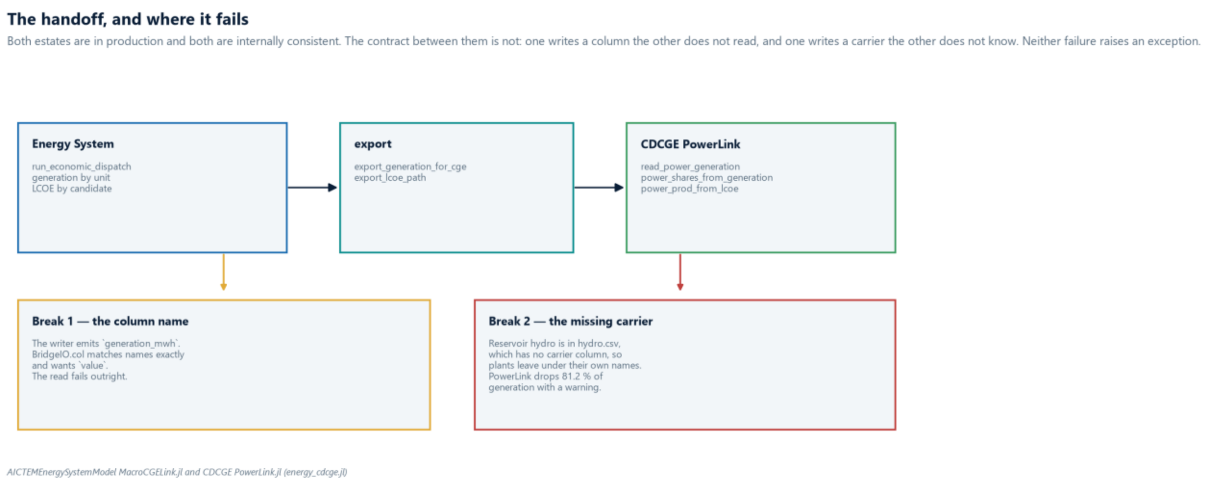


Figure 43. The contract between the energy model and CDCGE, and the two places it breaks. — PowerLink.jl and MacroCGELink.jl

CDCGE splits its electricity sector into eight GTAP-Power technologies. What it needs from an energy model is the proportions, and optionally a cost path:

Artefact	Shape	What CDCGE does with it
Generation by carrier	region, carrier, value	maps carriers onto COAL_p GAS_p OIL_p NUC HYD WND SOL ORE and splits the electricity sector in those proportions
LCOE path	carrier, year, value	inverts the cost ratio into a productivity multiplier on the generating activities

Table 38. The documented contract, from CDCGE's PowerLink module.

19.2 EN-19: the read fails on the column name

CDCGE's `BridgeIO.col` matches column names exactly, not by substring, and `read_power_generation` wants `value`. The Python bridge on the CDCGE side, `export_pypsa_power.py`, writes exactly `region,carrier,value`. The Julia estate's `export_generation_for_cge` writes `carrier,generation_mwh,region`.

What the documented handoff does

```
ERROR: BridgeIO: none of ["value", "generation", "output",
  "twh", "gwh", "mwh", "energy"] found in columns
  ["carrier", "generation_mwh", "region"]
```

Listing 3. Both sides are correct against their own specification. Nothing owns the sentence that would reconcile them.

The fix is a rename. This course keeps the adapter visible rather than hiding it inside the exporter, because the point is not the rename — it is that a contract between two production systems had never been executed.

19.3 EN-17: eighty-one per cent of the country, dropped

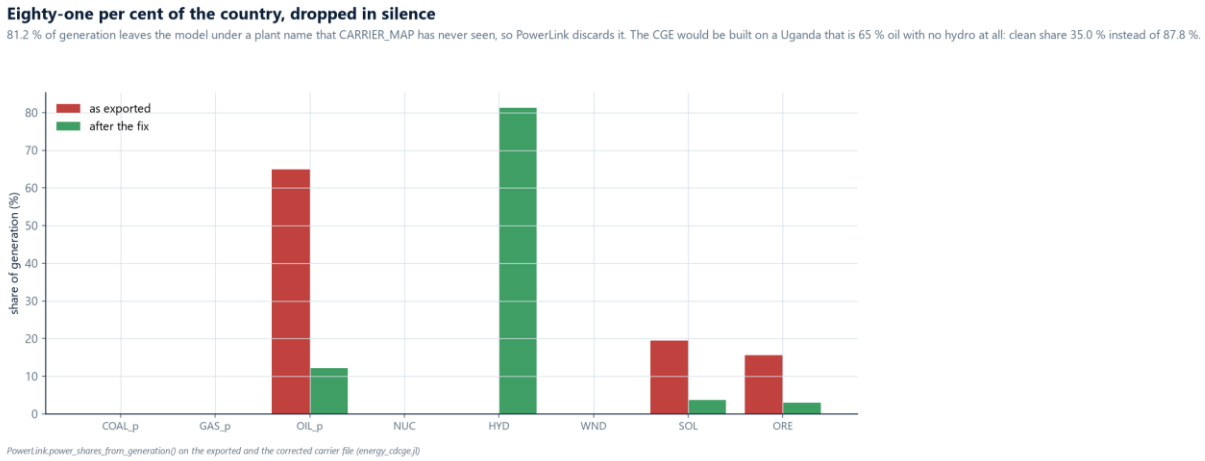


Figure 44. The electricity mix CDCGE would be calibrated on, before and after the one-line fix. — PowerLink.power_shares_from_generation()

With the column fixed, the read succeeds and PowerLink prints a warning:

A warning, not an error

```
Warning: PowerLink: dropping unmapped carriers
  carriers = ["Bugoye", "BujagaliFalls", "IshashaRiver",
              "Kiira", "Mubuku3", "Narubale"]
```

Those are the six reservoir hydro plants. `export_generation_for_cge` takes the carrier from `technologies.carrier` and falls back to the technology identifier when it is blank. Hydro is not in technologies.csv at all — it is in hydro.csv, which has no carrier column — so the plants leave the model under their own names, and `CARRIER_MAP` has never heard of them.

Quantity	As exported	After the one-line fix
Generation reaching the CGE	674.0 GWh	3.59 TWh
Share dropped	81.2 %	0 %
Clean share the CGE is calibrated on	35.0 %	87.8 %
HYD share	0.0 %	81.2 %
OIL_p share	65.0 %	12.2 %

Table 39. The mix CDCGE would be built on, before and after. Without the fix the CGE models a Uganda that is two thirds oil and has no hydropower.

WHY A WARNING IS NOT A SAFEGUARD

`power_shares_from_generation` takes a `strict` argument that would turn this into an error. It defaults to false. A scripted pipeline writes the warning to a log nobody reads and returns a perfectly well-formed share vector that describes a different country. Every carrier crossing an estate boundary should be validated against the receiving vocabulary, and the validation should raise.

19.4 EN-18: the same defect inside the estate

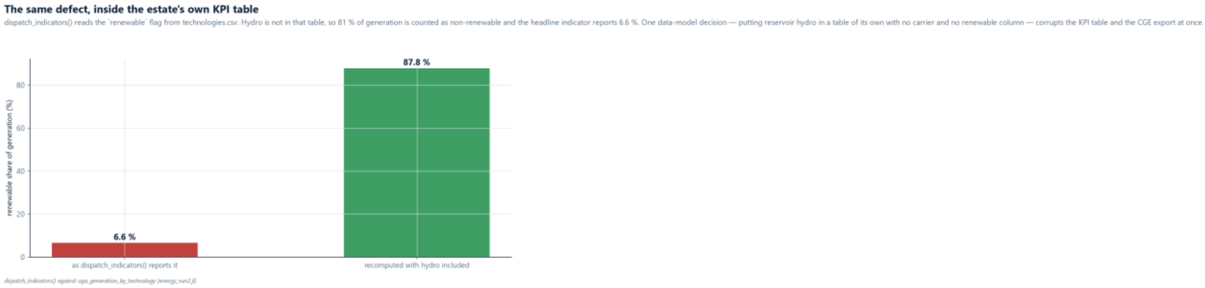


Figure 45. The estate's own headline indicator, hit by the same missing carrier. — dispatch_indicators() against the dispatch itself

Having found it at the boundary, look inward. `dispatch_indicators()` computes the renewable share from the `renewable` flag — which is a column on technologies.csv and nowhere else. The result is a headline indicator reporting 6.6 % renewable for a system that is 87.8 % renewable.

One data-model decision — putting reservoir hydro in a table of its own, with neither a carrier nor a renewable column — corrupts the CGE export, the KPI table and the asset base in Chapter 16. The lesson is not about hydro. It is that a schema decision propagates to every consumer, and the consumers are written by people who do not know the decision was made.

19.5 The eight-technology split

GTAP-Power technology	Share of generation
COAL_p	0.0 %
GAS_p	0.0 %
OIL_p	12.2 %
NUC	0.0 %
HYD	81.2 %
WND	0.0 %
SOL	3.6 %
ORE	2.9 %

Table 40. The corrected split CDCGE receives for Uganda.

Five of the eight technologies are exactly zero: `COAL_p`, `GAS_p`, `NUC`, `WND`. That is a real constraint on what the CGE can then be asked. A technology with zero benchmark output cannot respond to a policy shock, so a scenario that would build wind in Uganda cannot be represented at all unless a floor is put under the shares first — which PowerLink supports and which changes the benchmark it was given.

19.6 The productivity lever

Figure 46. The productivity lever the LCOE path hands the CGE. — PowerLink.power_prod_from_lcoe()

E-MAC-01

$$\lambda_{k}(y) = \frac{\text{LCOE}_k(y_0)}{\text{LCOE}_k(y)} \qquad (19)$$

A falling levelised cost is a productivity gain in the generating activity, so the lever is the inverse cost ratio and the base year is exactly one. Only solar moves here, because only solar carries a learning rate — 3.0 % a year, a declared assumption of this build.

19.7 The fixed point

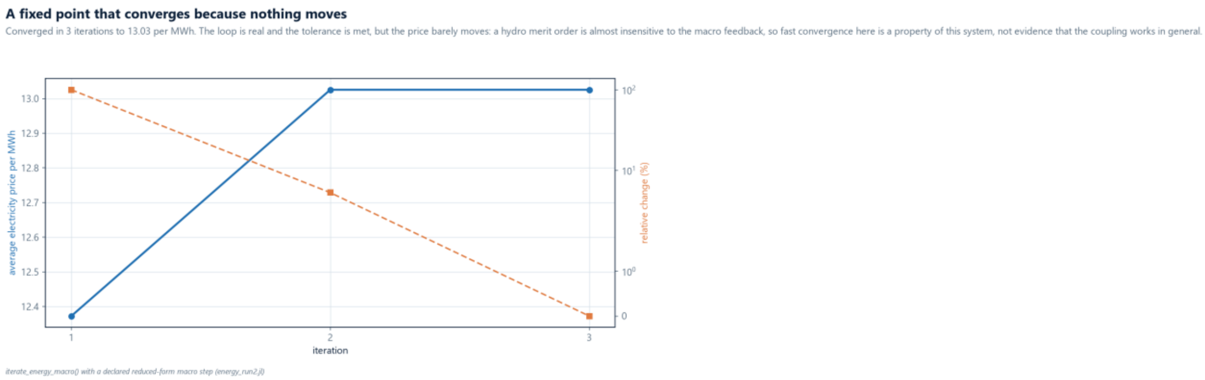


Figure 47. The energy–macro fixed point. — iterate_energy_macro()

`iterate_energy_macro` alternates between the dispatch and a macro step until the electricity price stops moving. It converged in 3 iterations to 13.03 per MWh.

TWO REASONS NOT TO TAKE THAT CONVERGENCE AS EVIDENCE

First, the macro step here is a declared reduced form — electricity as a 3.5 % cost share of gross output with 60.0 % pass-through — standing in for a full CGE solve. It demonstrates the mechanism; it is not a calibrated macro result. Second, the price it converges on is the one from EN-20, out by a factor of 730. A price that small cannot move anything, so fast clean convergence is exactly what a units error would produce.

19.8 What CDCGE itself already says about Uganda

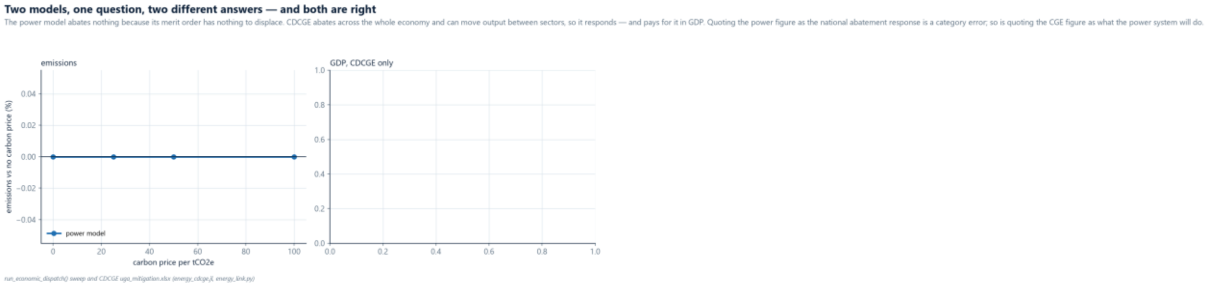


Figure 48. The same policy question asked of both models. — energy carbon sweep against CDCGE mitigation run

CDCGE has a completed Uganda mitigation run with seven scenarios. Setting it beside the power model's carbon sweep lets the two be compared on the same quantity rather than assumed to agree.

Scenario	Year	Emissions vs reference	GDP vs reference
tax_0	2031	+0.0 pp	+0.0 pp
tax_50	2031	-1.3 pp	-1.0 pp
tax_100	2031	-2.4 pp	-1.7 pp
netzero	2031	-1.3 pp	-0.9 pp
renew	2031	-1.4 pp	+0.4 pp
electr	2031	-3.0 pp	+0.6 pp
cbam50	2031	-0.8 pp	-0.1 pp

Table 41. CDCGE's Uganda mitigation run in 2031, relative to its own no-tax reference.

TWO MODELS, ONE QUESTION, TWO ANSWERS, BOTH CORRECT

The power model abates nothing at any carbon price, because its emitting unit is energy-constrained and must-run. CDCGE abates across the whole economy and can move output between sectors, so it responds — and pays in GDP. Quoting the power figure as the national abatement response is a category error, and so is quoting the CGE figure as what the power system will do. The chain exists to keep the two straight, not to reconcile them into one number.

20. Poverty and distribution

This chapter takes the macro paths from Chapter 19 and the prices from Chapter 16 onto 3,062 real households, and finds that the instrument everyone reaches for does not touch the people it is meant to protect.

20.1 The microsimulation, and validating it first

The Uganda LSMS-ISA carries a poverty aggregate: real consumption per adult equivalent, a spatially deflated absolute poverty line, and the survey's own poverty flag. Before moving anything, reproduce the flag.

Check	Value
Official poverty flag, population-weighted	14.85 %
Recomputed from welfare below the line	14.85 %
Difference	0.0000 pp
Reconciles	yes

Table 42. The baseline reproduces the survey's own flag exactly. A microsimulation that cannot do this cannot be trusted with a counterfactual.

E-POV-01

$$\text{FGT}_\alpha = \sum_i \omega_i \, \max\!\left(\frac{z_i - w_i}{z_i}, 0\right)^{\!\alpha} \Big/ \sum_i \omega_i, \qquad \omega_i = \text{weight}_i \times \text{hsize}_i \tag{20}$$

Weights are households times household size, because Uganda reports poverty at the individual level. Reporting it per household would give a visibly lower number, and switching between the two mid-argument is a common way to make a policy look better than it is.

20.2 The two channels

Channel	What moves	Where it comes from
Direct, price	the household's own electricity bill	the tariff design in Chapter 16, or the change in the cost of generating under a carbon price
Indirect, income	real consumption, scaled by GDP per capita	the CDCGE scenario paths in Chapter 19

Table 43. The two ways a power-sector decision reaches a household.

Consumption pass-through of GDP per capita: 1.0. Real household consumption moves one-for-one with real GDP per capita relative to the CDCGE reference scenario. This is the neutral choice: it neither amplifies nor damps the macro result. A distribution-neutral pass-through is a strong assumption and the chapter says what it hides — the CGE's own factor prices differ by skill, and a household's exposure depends on where its income comes from.

Behavioural response to the price change: 0.0. Households are not allowed to substitute away from electricity when its price rises. The welfare loss is therefore an upper bound for the first-order effect and a lower bound for the substitution effect; with an own-price elasticity of -0.3 the loss would be roughly 15 % smaller at a 25 % price rise.

Poverty line: spline (UNPS 2019/20 absolute line, by sub-region). The survey's own spatially deflated absolute poverty line is used, not a dollar-a-day line, so the baseline reproduces Uganda's official headcount rather than a parallel one.

Poverty accounting unit: individual. Headcount weights each household by w x hsize, which is how the Uganda Bureau of Statistics reports poverty. Reporting at household level would give a visibly lower number.

20.3 The result

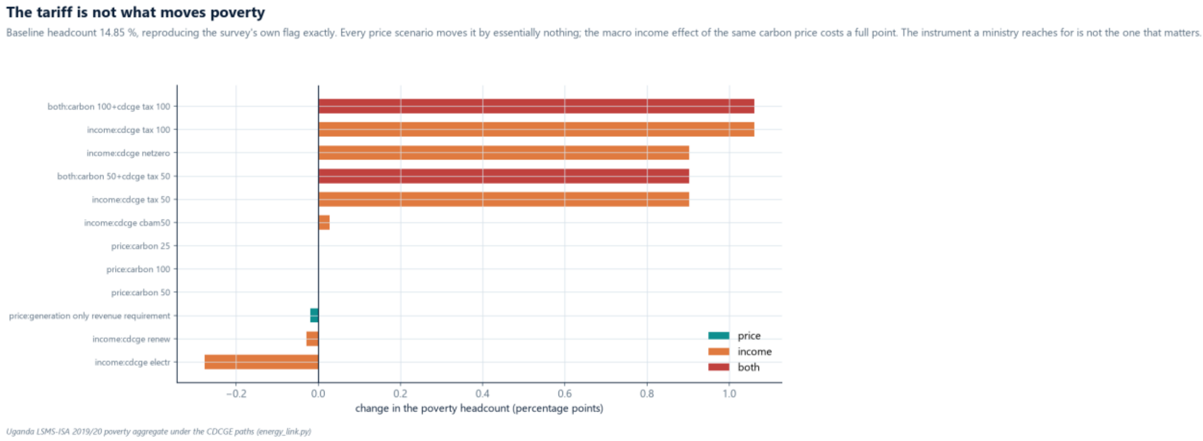


Figure 49. Poverty under each scenario: the price channel and the income channel. — LSMS-ISA microsimulation on the CDCGE paths

Scenario	Price change	Income change	Headcount after	Change	Newly poor
baseline	+0.0 pp	+0.0 pp	14.85 %	0.00 pp	0
price:generation only revenue requirement	-54.4 pp	+0.0 pp	14.83 %	-0.02 pp	0
price:carbon 25	+9.6 pp	+0.0 pp	14.85 %	0.00 pp	0
price:carbon 50	+19.2 pp	+0.0 pp	14.85 %	0.00 pp	0
price:carbon 100	+38.4 pp	+0.0 pp	14.85 %	0.00 pp	0
income:cdcge tax 50	+0.0 pp	-1.0 pp	15.75 %	0.90 pp	341,289
income:cdcge tax 100	+0.0 pp	-1.7 pp	15.91 %	1.06 pp	401,351
income:cdcge netzero	+0.0 pp	-0.9 pp	15.75 %	0.90 pp	341,289
income:cdcge renew	+0.0 pp	+0.4 pp	14.82 %	-0.03 pp	0
income:cdcge electr	+0.0 pp	+0.6 pp	14.57 %	-0.28 pp	0
income:cdcge cbam50	+0.0 pp	-0.1 pp	14.87 %	0.03 pp	10,404
both:carbon 50+cdcge tax 50	+19.2 pp	-1.0 pp	15.75 %	0.90 pp	341,289
both:carbon 100+cdcge tax 100	+38.4 pp	-1.7 pp	15.91 %	1.06 pp	401,351

Table 44. Poverty under each scenario. Every price row is zero to two decimal places; every income row is not.

A carbon price of 100 per tonne raises the cost of generating by +38.4 pp and moves the poverty headcount by nothing at all. The same carbon price, carried through CDCGE, costs 1.06 points of poverty — 401,351 people.

20.4 Why the price channel is flat

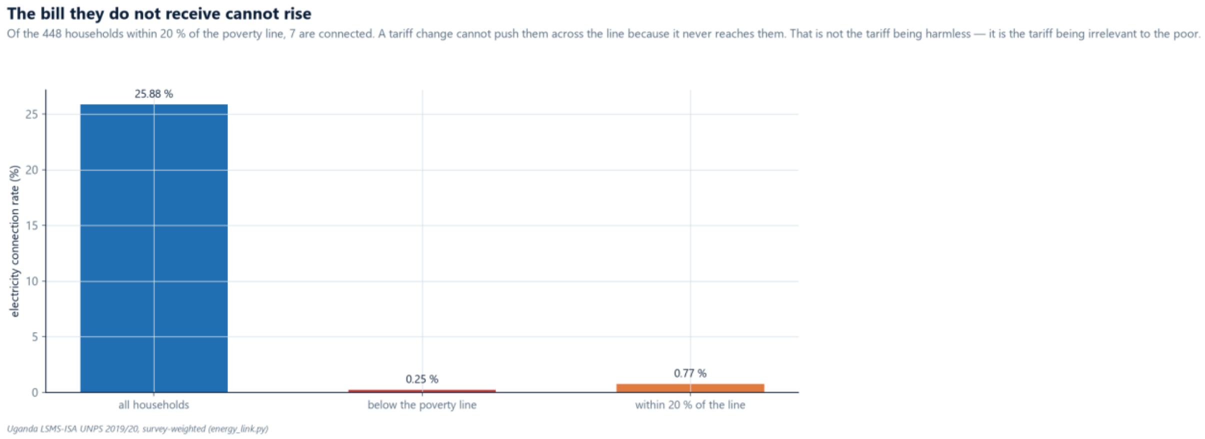


Figure 50. Why the tariff channel cannot move the headcount. — LSMS-ISA connection rates around the poverty line

Group	Electricity connection rate
All households	25.88 %
Below the poverty line	0.25 %
Within 20 % of the line	0.77 %

Table 45. Of the 448 households within 20 % of the poverty line, 7 are connected.

THE UNCOMFORTABLE VERSION OF A NULL RESULT

A tariff change moves the headcount only by pushing households across the line, and the households on the line are almost all unconnected. The bill they do not receive cannot rise. This is not the tariff being harmless. It is the tariff being irrelevant to the poor — which means the lifeline block in Chapter 16, the instrument a ministry reaches for to protect them, operates on a population that largely excludes them.

20.5 What the price channel does do

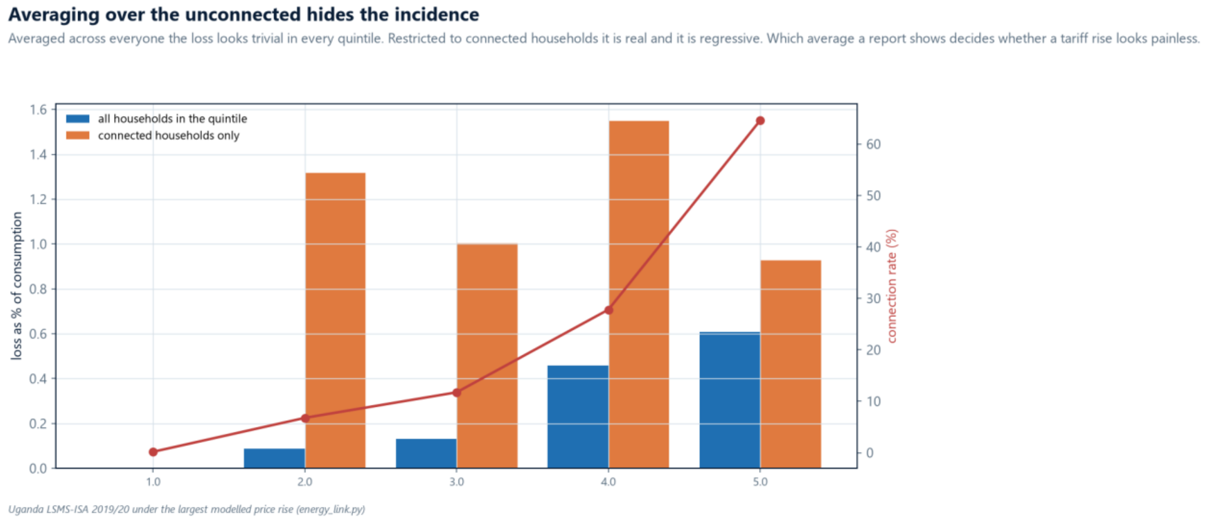


Figure 51. Who carries an electricity price rise, by quintile. — LSMS-ISA microsimulation

Restricted to the households that have a bill, the largest modelled price rise costs 1.14 % of consumption on average, and it is regressive within that group. Averaged over everyone — including the 74.1 % with no connection — it looks trivial in every quintile.

WHICH AVERAGE A REPORT CHOOSES IS A POLICY CHOICE

Both averages are correct. One says a tariff rise is painless; the other says it is a real and regressive cost on the quarter of households that pay for electricity. A distributional table that does not state its denominator is not a distributional table.

20.6 The energy burden, and why it is low

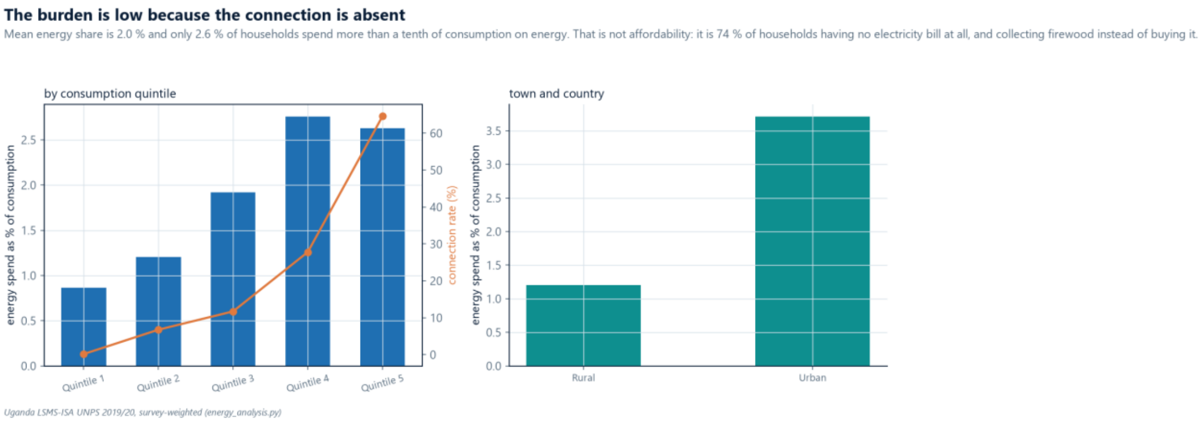


Figure 52. Energy burden across the consumption distribution and between town and country. — Uganda LSMS-ISA 2019/20

Mean energy spending is 2.0 % of consumption, and only 2.6 % of households spend more than a tenth. Read as an affordability indicator that says Ugandan energy is affordable. It says nothing of the kind: it says that three quarters of households have no electricity bill and collect firewood rather than buying it.

AN ENERGY-BURDEN INDICATOR MEASURES PARTICIPATION, NOT AFFORDABILITY

The households with the highest true energy cost are the ones paying with time rather than money, and time does not appear in a spending share. Any burden indicator computed on a population with low connection rates should be reported alongside the connection rate, or not reported at all.

20.7 What this chapter changes about instrument choice

- The lifeline tariff protects connected households, who are disproportionately not poor. It is a real instrument with the wrong target population in this country, today.
- The connection subsidy addresses the 22.2 % of unconnected households who name affordability, and nothing for the 72.2 % who name supply.
- The macro channel dominates both, and it is the one no energy ministry controls. A carbon price designed in the energy ministry is a poverty instrument administered by the finance ministry, whether or not anyone intends that.
- Recycling matters more than the tariff design. The revenue at 100 per tonne is $33.4 m a year, which is larger than the welfare loss it causes. Nothing in this estate models the recycling, and it is the single most important missing piece.

21. Scenarios, validation and what agrees with what

A model is validated by comparison with something it did not produce. This chapter sets out five such comparisons, of which one agrees — and explains why that agreement is not evidence.

21.1 The reconciliation table

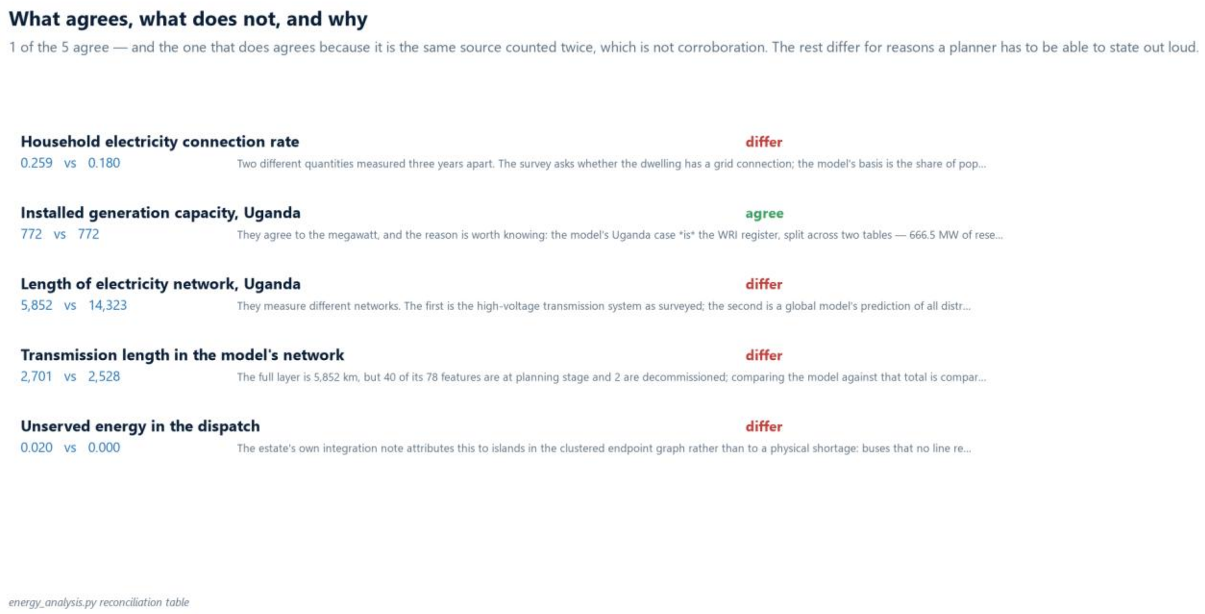


Figure 53. Five quantities, measured more than once. — energy_analysis.py reconciliation table

Household electricity connection rate

Uganda LSMS-ISA 2019/20, survey-weighted: 0.259. Model's Uganda demand basis (GEP electrified population, ~18 %): 0.180. They differ.

Two different quantities measured three years apart. The survey asks whether the dwelling has a grid connection; the model's basis is the share of population in electrified settlements from a geospatial platform. Population-based and household-based access rates differ whenever connected households are larger or smaller than average, and the platform's vintage is earlier.

Installed generation capacity, Uganda

WRI Global Power Plant Database v1.3: 772. Model's Uganda case, technologies.csv + hydro.csv: 772. They agree.

They agree to the megawatt, and the reason is worth knowing: the model's Uganda case *is* the WRI register, split across two tables — 666.5 MW of reservoir hydro in hydro.csv and 106.0 MW of everything else in technologies.csv. Reading only technologies.csv understates the system sevenfold, which is exactly the mistake the first pass of this course's own asset-base calculation made. Agreement here is not independent corroboration: it is one source counted once.

Length of electricity network, Uganda

Transmission network 2017 (surveyed corridors): 5,852. gridfinder predicted grid (inferred from night-lights and OSM): 14,323. They differ.

They measure different networks. The first is the high-voltage transmission system as surveyed; the second is a global model's prediction of all distribution and transmission lines from satellite and open data. The second is necessarily much longer and is an estimate, not a survey.

Transmission length in the model's network

Transmission layer, operational and under-construction circuits only (36 of 78 features, length apportioned by feature count): 2,701. Model's `lines` table, sum of length_km: 2,528. They differ.

The full layer is 5,852 km, but 40 of its 78 features are at planning stage and 2 are decommissioned; comparing the model against that total is comparing a built network with a wish list. Against the operational and under-construction circuits the model is still 6 % short, and the reason is the clustering: corridors whose endpoints fall inside the same ~7 km cluster collapse to a single bus and their length disappears with them. That is a real loss of network, and it is the same clustering that creates the islands the unserved energy comes from.

Unserved energy in the dispatch

Model result, share of annual demand: 0.020. A well-supplied system's expectation: 0.000. They differ.

The estate's own integration note attributes this to islands in the clustered endpoint graph rather than to a physical shortage: buses that no line reaches cannot be served whatever the generation. It is a network-construction artefact and it is reported rather than tuned away.

21.2 The agreement that is not corroboration

772.5 MW, TWICE

The WRI register and the model's Uganda case agree to the megawatt on installed capacity. They agree because the case *is* the register, split across two tables. Counting one source twice and finding that it matches itself is arithmetic. Real corroboration requires a second, independent measurement — and for Ugandan generating capacity this course does not have one.

21.3 Four access rates for one country

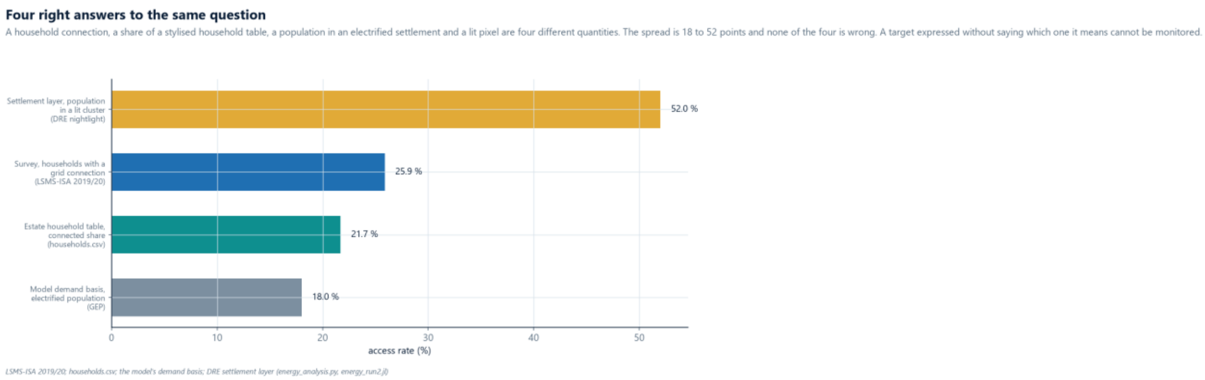


Figure 54. Four defensible electricity access rates for the same country in the same decade. — LSMS, model basis, estate household table, settlement layer

Measure	Rate	What it counts
Survey household connection	25.9 %	a dwelling with a grid connection, survey-weighted
Estate household table	21.7 %	the connected share of three stylised groups

Measure	Rate	What it counts
Model demand basis	18.0 %	share of population in an electrified settlement
Settlement nightlight	52.0 %	population in a cluster that is lit at night

Table 46. Four defensible access rates for Uganda in the same decade. The spread is 34 points and none of the four is wrong.

A national target of 'sixty per cent access by 2030' cannot be monitored unless it says which of these four it means. Three of them can move without the others moving at all: nightlight rises when a diesel generator is installed, the household rate rises when a meter is fitted, and the settlement rate rises when a line passes a village whose households cannot afford the connection fee.

21.4 Two checks that cannot fail

Apparent check	Why it is an identity	What to do instead
Cost recovery = 1.000	design_tariffs sets billed revenue to the revenue requirement; utility_finance divides one by the other	compare billed revenue against a regulatory determination or audited accounts
Installed capacity matches the register	the case was built from the register	compare against a second independent register, or against metered generation

Table 47. Two things in this build that look like validation and are arithmetic.

21.5 What can actually be validated here, and what cannot

Quantity	Validated against	Status
Poverty headcount, baseline	the survey's own poverty flag	reproduces exactly
Energy balance	the input tables, independently re-derived	closes to 0.0 MWh
Marginal price	the value of lost load and the loss factors	the corrected price is 10,000 attenuated by losses, as it must be
Generation mix	the availability profiles and inflow columns	every unit at its stated limit
Installed capacity	the WRI register	not independent — same source
Reliability (LOLE, SAIDI, SAIFI)	nothing available	cannot be validated; see EN-24
Demand projection	nothing available	a projection under declared drivers, not a forecast
The macro coupling	a full CGE solve	not executed; the macro step is a declared reduced form

Table 48. What this build can and cannot stand behind.

21.6 The interpretation rules

1. A result is not publishable without the provenance of the columns it rests on In a national case most columns are estimated. Which ones moved the answer is the first question.

2. An optimisation result carries its objective and its constraint set Least cost under a renewable target and a reserve margin is a different plan from least cost without them, and both are optimal.

3. A corridor flow from this bridge is an economic flow There is no voltage law here. Do not describe it as a power-flow result.

4. A capacity number is not a unit count Builds are continuous. 574 MW of solar is an envelope, not a procurement list.

5. Unserved energy needs a cause before it needs a policy Islanding, insufficient capacity and a binding corridor look identical in the objective and need different money.

6. Value of lost load is a price you set It determines how much reliability the model buys. Quote it with any reliability result.

7. Access rate is meaningless without its denominator Population-based and household-based access rates differ, and so do connections and usable service.

8. A tariff that recovers cost and a tariff a household can pay are different objects The gap is the subsidy. Somebody pays it whether or not it appears on a budget line.

9. A climate case in a hydro system is a scenario, not a sensitivity It changes the merit order. Report it as a case with its own results, not as a percentage band.

10. A single pass of the macro coupling is a handover An equilibrium requires the loop to converge, and convergence must be shown.

11. A licence is part of the data A dataset that may be used and not redistributed constrains what you may publish, not what you may compute.

12. A specification section the estate grades D or E produces no results Teach it as a specification. Presenting it as estimated is an automatic fail.

21.7 The automatic fails

Work submitted on this course fails outright, regardless of its other merits, if it does any of the following:

1. Quoting a model result without the provenance of the columns it rests on, in a case where most columns are estimated.

2. Quoting an optimisation result without its objective and its binding constraints.

3. Describing a corridor flow from this bridge as a power-flow result, or a continuous build as a unit count.

4. Reporting unserved energy as a capacity shortage without first checking for network islanding.

5. Quoting an access or reliability figure without its denominator, or a reliability result without the value of lost load behind it.

6. Presenting a section the estate grades D or E as though it had produced a result, or a single coupling pass as an equilibrium.

7. Redistributing an export-blocked layer, or publishing a map without the attribution its licence requires.

22. The gaps register, in full

All 24 entries. The first sixteen were read out of the estate's own documentation. The last eight were found by running it, and each is reproducible from a named script in this build.

EN-01 — The specification is 97 sections; the estate implements a graded subset

The estate's own status register grades 26 components: 21 complete and tested, 1 implemented but not fully validated, 3 not implemented and 1 blocked by an external dependency.

How this course handles it. Chapter 4 reads the grade before any chapter quotes a result, and every domain chapter states which of its sections the estate implements.

EN-02 — The national spatial build of the upstream power-system framework has not been run here

The status register grades it E — blocked by its own conda environment and data downloads. The import path from a solved network is tested end to end, so the gap is a compute and data task rather than a code gap.

How this course handles it. Chapter 7 teaches the adapter and the import contract, and never presents a result as coming from an upstream national build.

EN-03 — There is no power flow in the bridge

Corridors are represented as paired directed links with losses — a transport model. Kirchhoff's voltage law is not imposed, and the schema does not yet carry reactance.

How this course handles it. Chapter 12 says so before any corridor result appears. A flow from this model is an economic flow, not an electrical one.

EN-04 — Operating reserves are not co-optimised

The planning reserve margin is enforced in expansion through an explicit constraint; spinning reserve in dispatch is not. The removed engine held it and the current bridge does not.

How this course handles it. Chapter 16 distinguishes the planning reserve margin, which is modelled, from the operating reserve, which is not.

EN-05 — Expansion is myopic and continuous

The bridge solves one case per planning year in a rolling horizon rather than with perfect foresight, and builds are continuous rather than lumpy integer units.

How this course handles it. Chapter 11 states both. A 574 MW build is a capacity number, not a unit count, and a myopic plan can strand an asset a perfect-foresight plan would not have built.

EN-06 — Reservoirs balance independently

The schema carries an upstream-cascade field and each reservoir still balances on its own, so water released upstream does not arrive downstream.

How this course handles it. Chapter 14 says so, and the drought case is read as a bound rather than as a routed simulation.

EN-07 — About two per cent of demand is unserved, and this build found out why

The estate's own note calls it a network artefact. It is not: the graph is one connected component and no corridor is congested. The fleet is 69,369 MWh short of demand plus losses because every unit runs at its energy limit. The full derivation is EN-21, which supersedes the note.

How this course handles it. Chapter 11 teaches the balance, not the note. See [EN-21].

EN-08 — The national case is mostly estimated, column by column

The extractor's provenance table classifies every column as observed or estimated: the network geometry, the plants and the population basis are observed; the ratings, costs, emission factors, inflows and load shapes are estimated.

How this course handles it. Chapter 6 works through the table before any result. A finding that moves when an estimated column moves is a finding about the assumption.

EN-09 — The survey's reliability question has no usable variation

Stated in full at EN-24, with the distribution that shows it.

How this course handles it. Chapter 14 states it before any reliability result appears.

EN-10 — The household connection rate and the model's access basis are different quantities

The survey gives 25.9 % of households with a grid connection; the model's demand basis is a population-weighted electrification share from a geospatial platform of an earlier vintage.

How this course handles it. Chapter 18 puts them side by side and explains why neither is wrong.

EN-11 — Demand does not respond to price inside the dispatch

The only load flexibility is shedding at the value of lost load. Endogenous demand response and elastic demand are not implemented.

How this course handles it. Chapter 13 teaches demand response as a specification and says the estate does not estimate it.

EN-12 — No learning curves and no stranded-asset accounting

Technology costs are fixed inputs; a plan that builds an asset and later strands it carries no write-down. The policy-portfolio programme is the stopgap for multi-objective questions.

How this course handles it. Chapter 17 states it wherever a cost trajectory is quoted.

EN-13 — The spatial layer plans and visualises; it does not site

Exclusion masks and raster suitability scoring live upstream. The estate's spatial module computes distances, clusters and target-driven plans over coordinates.

How this course handles it. Chapter 6 distinguishes a siting engine from a planning layer, and Laboratory 06 uses the real resource and constraint layers to show what a siting step would need.

EN-14 — The macro coupling now runs end to end, and running it is what exposed the contract defects

This build executes the whole chain: dispatch, carrier export, CDCGE PowerLink, the eight GTAP-Power shares, the LCOE productivity lever, and the fixed-point loop, which converged in three iterations. Two defects only appear when the chain is actually run (EN-17 and EN-19), and a third (EN-20) determines what the loop converges on. The macro step in the loop is a declared reduced form standing in for a full CGE solve, so the convergence is a demonstration of the mechanism and not a calibrated macro result.

How this course handles it. Chapter 19 runs the chain in front of the students and Lab 7 breaks and repairs it.

EN-15 — A tenth of the catalogued spatial datasets may be used and not redistributed

54 of 618 catalogued datasets are export-blocked under an academic licence; most of the rest are share-alike and require attribution.

How this course handles it. Chapter 6 and the governance chapter treat the licence as part of the data, and this course ships derived tables rather than the blocked layers.

EN-16 — Household welfare effects are first-order only

The estate computes an energy burden and a tariff impact by arithmetic; behavioural response and second-round effects belong to the household model.

How this course handles it. Chapter 17 says so, and the poverty analysis in this course is measurement from the survey rather than simulation.

EN-17 — The CGE carrier export silently discards 81.2 % of Uganda's generation

export_generation_for_cge takes the carrier from technologies.carrier and falls back to the technology id when it is blank. Reservoir hydro is not in technologies.csv at all — it is in hydro.csv, which has no carrier column — so the six hydro plants leave the model as Bugoye, BujagaliFalls, IshashaRiver, Kiira, Mubuku3 and Narubale. CDCGE's CARRIER_MAP has never heard of them, so PowerLink drops them with a @warn and nothing raises. The CGE would be calibrated on a Uganda that is 65 % oil with no hydro in it: clean share 35.0 % instead of 87.8 %.

How this course handles it. Chapter 19 shows both mixes side by side and the students fix it in Lab 7. The fix is one line; the lesson is that a contract between two correct systems is a third thing that nobody owns. Reproduce with energy_cdcge.jl.

EN-18 — The same missing carrier corrupts the estate's own headline indicator

dispatch_indicators() computes renewable_share from the `renewable` flag on technologies.csv. Hydro is not in that table, so 81 % of generation is counted as non-renewable and the KPI table reports a renewable share of 6.6 % for a system that is 87.8 % renewable. One data-model decision — putting reservoir hydro in a table of its own with neither a carrier nor a renewable column — corrupts the CGE export and the KPI table at once.

How this course handles it. Chapter 11 recomputes the indicator from the dispatch before quoting it, and the automatic-fail list treats an uncorroborated renewable share as a fail. Reproduce with energy_run2.jl.

EN-19 — The two estates disagree on the column name, so the documented handoff fails on the first read

CDCGE's BridgeIO.col matches column names exactly, not by substring, and read_power_generation wants region, carrier, value. The Python bridge export_pypsa_power.py writes exactly that. The Julia export_generation_for_cge writes carrier, generation_mwh, region. The read raises before any modelling happens.

How this course handles it. Chapter 19 keeps the adapter visible instead of hiding it inside the exporter, so students see what the contract requires. Reproduce with energy_cdcge.jl.

EN-20 — The exported marginal price is out by the snapshot weight

run_pypsa_case.py divides buses_t.marginal_price by the snapshot weighting before writing prices.csv, but PyPSA's marginal price is already per MWh. With twelve periods of 730 hours every price is out by a factor of 730. The reported average is 12.37 per MWh; the true average is 9,032, because load shedding at a value of lost load of 10,000 is on the margin in every period and the transport network carries that price to every bus. dispatch_indicators() reports the wrong number as avg_price and energy_to_macro hands the same number to the CGE, where it becomes the electricity price the macro feedback responds to.

How this course handles it. Chapter 11 derives the price from the duals and checks it against the value of lost load before quoting it. Reproduce with energy_probe.jl.

EN-21 — The documented explanation of the unserved energy is wrong, and wrong in the comfortable direction

The estate's integration note attributes the 69,369 MWh of unserved energy to islands in the clustered endpoint graph. The topology does not support that: the graph has one connected component, every bus has a line, and run_network_expansion adds 0 MW because no corridor is congested. Re-deriving the balance from the input tables gives the real answer and closes to the megawatt-hour. Every dispatchable unit runs at exactly its energy limit — the six hydro plants at their inflow, the oil and biomass units flat out for all 8,760 hours — and demand plus 177,048 MWh of network losses exceeds what the fleet can produce by exactly 69,369 MWh. This is a 2 % national energy deficit, and its source is one column: hydro.csv gives 666.5 MW of plant 333.2 MW of inflow.

How this course handles it. Chapter 11 replaces the note's explanation with the balance, and the students re-derive it in Lab 4 before they are allowed to quote any reliability number. Reproduce with energy_link.py adequacy() and energy_probe.jl.

EN-22 — The cost-recovery test cannot fail

design_tariffs sets billed revenue equal to the revenue requirement by construction, and utility_finance then divides the one by the other. Cost recovery is 1.000 for any input whatever. The informative quantity is the composition of the requirement, not the ratio.

How this course handles it. Chapter 16 shows the composition and states plainly that the ratio is an identity. A tautological check reported as a passing test is on the automatic-fail list.

EN-23 — A settlement column that promises connections delivers buildings

In the DRE Uganda settlement layer, num_connections is byte-identical to num_buildings in all 67,650 rows. Read as electricity connections it makes Uganda universally electrified. The check is one line and it belongs on every column whose name promises more than the codebook does.

How this course handles it. Chapter 6 runs the duplicate-column check as part of intake, and Chapter 15 uses the nightlight flag instead, saying plainly that it is a proxy for a lit place and not for a connected household.

EN-24 — The survey cannot support a reliability indicator

The LSMS-ISA asks connected households how many hours of electricity they get per day. The answers cluster hard at 24 and a self-reported daily average cannot separate one long outage a month from a short outage every day. SAIDI and SAIFI are not recoverable from this instrument, so the model's reliability outputs have no survey counterpart to be validated against.

How this course handles it. Chapter 14 states this before any reliability result appears, and the course never validates LOLE against the survey.

23. The Uganda case rebuilt on primary data

Chapters 5 to 22 read one Uganda case: the AEGID build, assembled from open continental layers because that is what a continental register can offer for fifty-four countries at once. This chapter rebuilds the same case from what Uganda's own institutions publish about Uganda — 8,760 metered hourly system loads, a licensed plant register, plant-by-plant metered generation, the feeder demand register, the tariff schedule and the 2024 census — and then re-runs every model in the estate against it. The point is not that the new case is better. It is that the difference between the two is a measurement of what a continental proxy costs you, and that measurement is itself a result.

WHAT CHANGED AND WHAT DID NOT

The engine did not change. Every number in chapters 23 to 26 comes from the same EDIS Energy Planning System, the same PyPSA bridge and the same HiGHS solver used in chapters 11 to 21.

The inputs changed. Demand, the generating fleet, availability, the candidate set, customers, households, cooking and the energy balance are rebuilt from primary Ugandan sources. The network and the settlement register are carried over unchanged from the AEGID build, because nothing in the national returns supersedes them.

Four of the estate's defects survive the rebuild unchanged, and the rebuild found three more. §26.8 lists all seven.

23.1 What the primary sources contain

Everything below sits in one folder on the build machine and none of it is restricted. These are the returns Uganda's regulator and system operator publish, plus the census.

Source	What it supplied	Status
UETCL, Annual Load Curves 2023	8,760 metered hourly system loads: total demand, national demand, load shed, net export, generation	observed
UETCL, System Operation Data 2023	Plant-by-plant monthly generation; the feeder maximum-demand register; load-shedding hours and MWh; outage accounts	observed
ERA, IRP Data Sheet (populated)	Sales and customer numbers by class 2010–2023; system peak; technical and commercial losses; embedded generation	observed
ERA, Generation capacity of licensed plants under operation	The licensed fleet by plant, technology, district and commissioning year; installed capacity 2011–2020	observed
MEMD / ERA IRP, Generation Power Plants	The existing and candidate fleet with zone, capital cost, fixed and variable O&M, heat rate, life and build limits	observed
ERA, Distribution Tariffs to June 2024	The end-user tariff by class and quarter 2017–2024; the exchange rate and inflation index	observed
UETCL, Transmission Statistics Q1-2024	Monthly system peak split domestic / export; network length by voltage; energy purchases and sales in MWh and shillings	observed
UBOS, National Population and Housing Census 2024	10,698,913 households; lighting source; cooking fuel; household size	observed

Table 49. The eight primary sources behind the rebuilt case. Every input table in §23.3 to §23.6 names the one it came from.

23.2 Eight thousand seven hundred and sixty hours

The AEGID case carries twelve time slices of 730 hours each. Twelve equal weights is the cheapest possible reduction of a year and it has one specific consequence: it averages the peak away. The metered 2023 peak is 987.8 MW. The highest slice in the twelve-slice case is 473.8 MW. Half the peak is gone before the optimiser sees the problem, which is why that case cannot say anything credible about reserve margin, peaking plant or capacity payments.

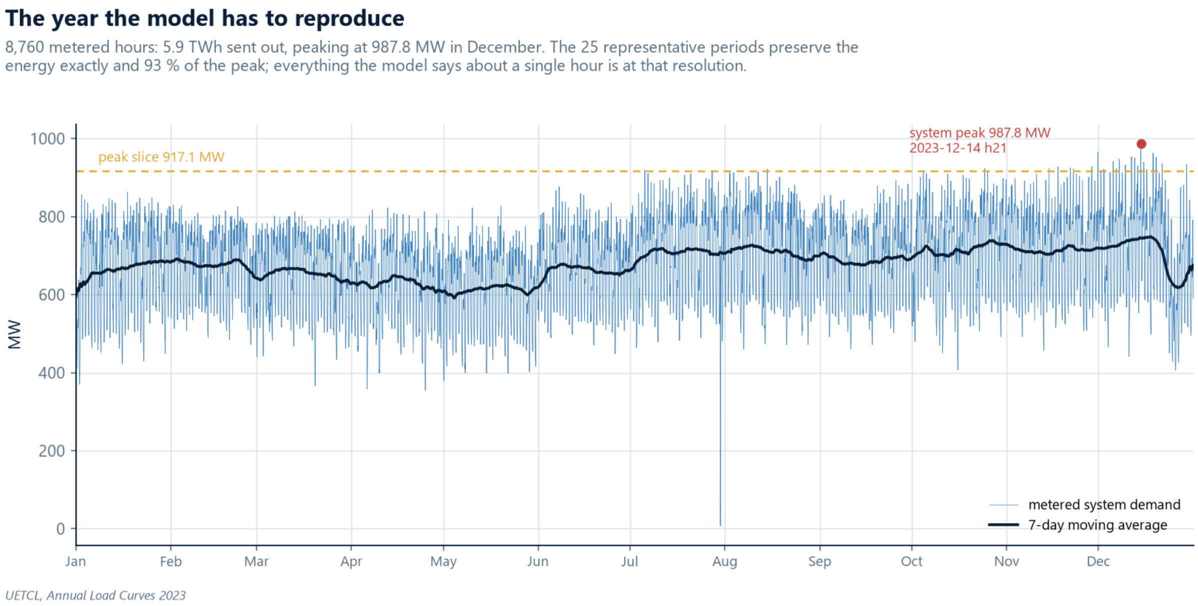


Figure 55. Every metered hour of 2023, with the peak block the rebuilt case carries. — UETCL, Annual Load Curves 2023

The rebuild uses four seasons — December–February, March–May, June–August, September–November — by six diurnal blocks, plus one block holding the hundred highest hours of the year lifted out of its parents. Twenty-five periods, weights summing to 8,760, and two properties worth stating precisely.

Property	Metered 2023	25-period case	12-slice AEGID case
Annual energy at the buses	5,938.3 GWh	5,938.3 GWh	3,489.0 GWh
System peak	987.8 MW	917.1 MW	473.8 MW
Peak captured	100 %	92.8 %	48.0 %
Load factor	0.686	0.739	0.829
Base load (lowest period)	7.1 MW	504.8 MW	294.6 MW

The metered load factor is lower than either reduced case because a slice structure cannot hold the extreme tails: the 7.1 MW hour is a system event, not a season.

Table 50. What the slice structure keeps. Energy is exact by construction in both cases; the peak is not, and the difference between 93 % and 48 % is the whole reason the rebuilt case can be asked a capacity question.

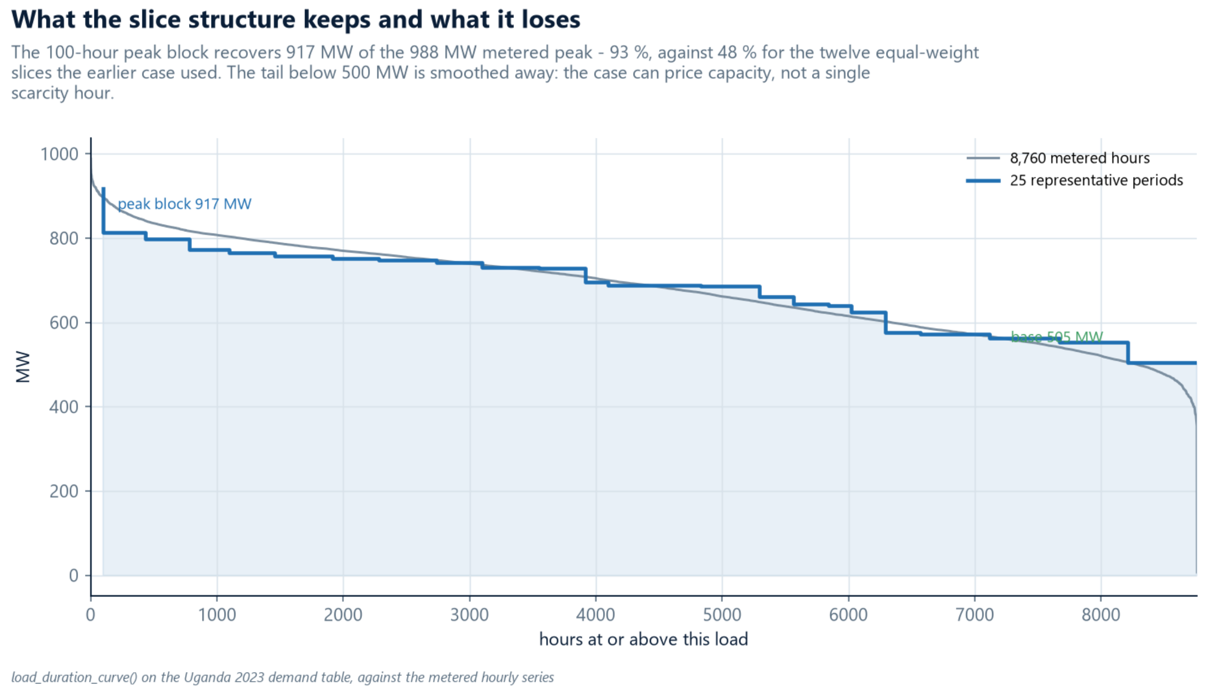


Figure 56. The load-duration curve, metered against reduced. — load_duration_curve() on the Uganda 2023 demand table

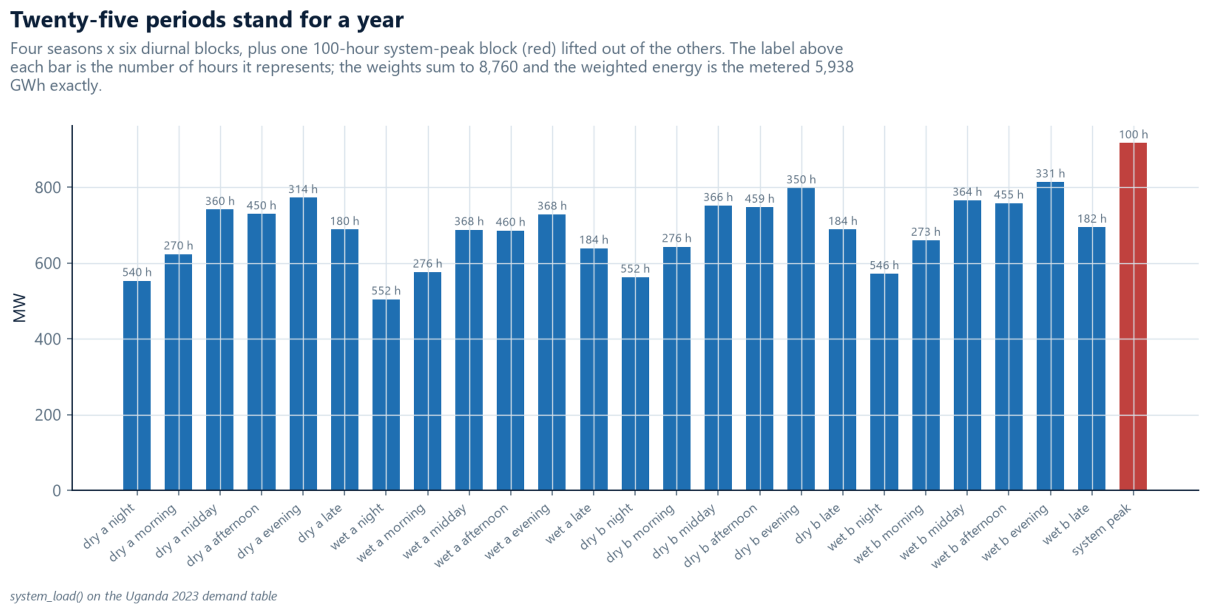


Figure 57. The twenty-five periods and the hours each one stands for. — system_load() on the Uganda 2023 demand table

The diurnal shape is worth one paragraph on its own, because it is the reason the peak block has to be carved out by hand. Uganda's load is evening-peaking in every season: the 19:00–21:00 lighting peak runs about 45 % above the 05:00 trough from January to December. A seasonal structure alone therefore buys very little — all four seasons have nearly the same shape — and the peak has to be found in the hour dimension, not the month one.

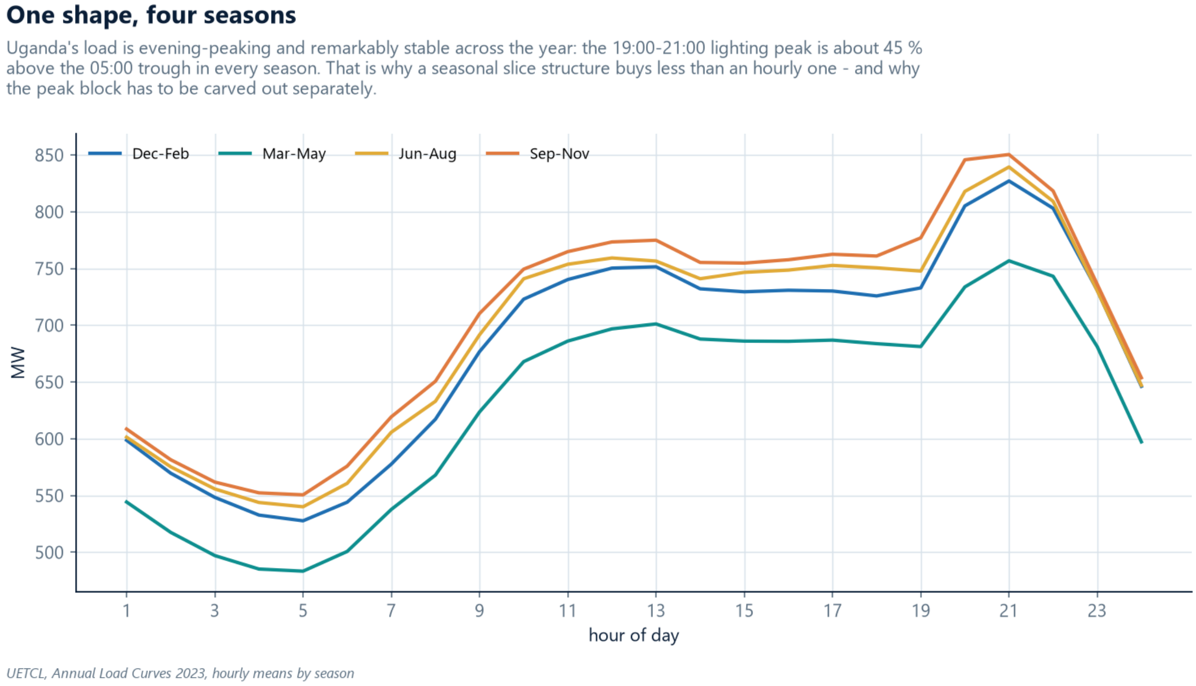


Figure 58. The average day in each of the four seasons. — UETCL, Annual Load Curves 2023

23.3 Where the load actually sits

The AEGID case allocates demand to buses from gridded population and electrified population. That is a reasonable proxy and it is not what the meters say. UETCL's feeder maximum-demand register records the monthly maximum of every 33 kV and 11 kV feeder in the country, and aggregating the 295 distribution feeders to their parent substation gives an observed bus split.

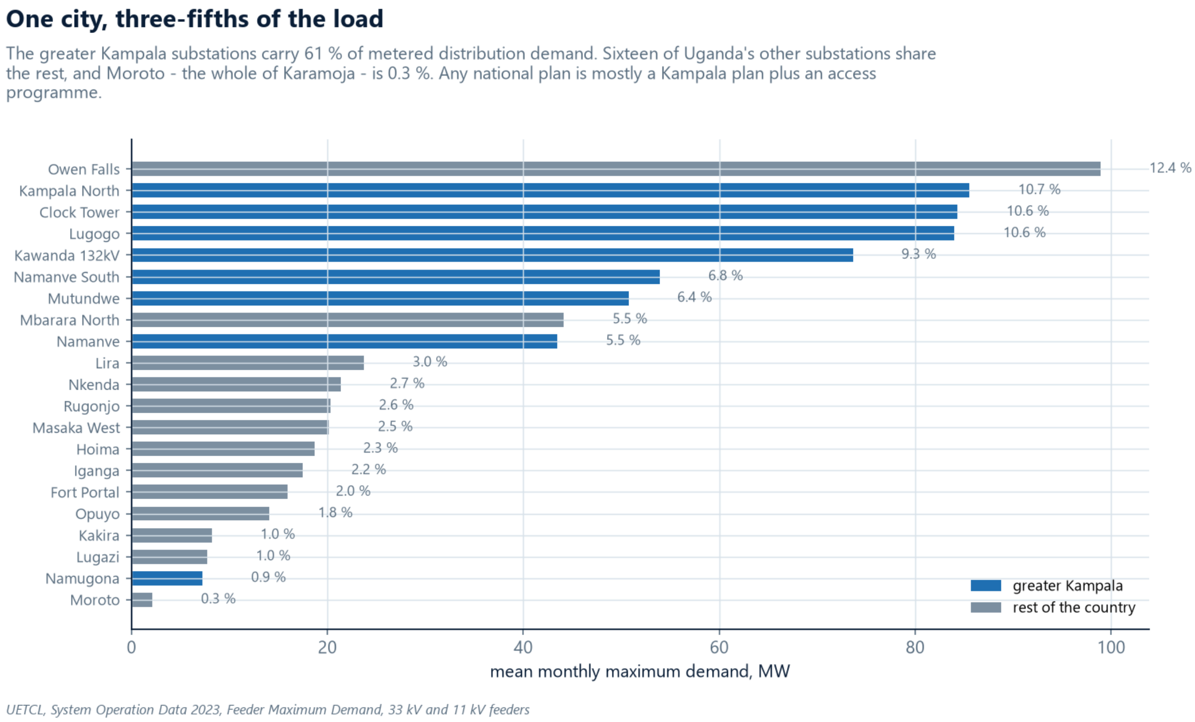


Figure 59. Mean monthly maximum demand by substation, 2023. — UETCL, System Operation Data 2023, Feeder Maximum Demand

Nine substations inside greater Kampala carry 71 % of metered distribution demand. Moroto — the whole of Karamoja — carries 0.3 %. Any national plan built on this case is mostly a Kampala plan plus an access programme, and a course that teaches the model without teaching that fact is teaching the wrong lesson about what the model is for.

> **A MAPPING YOU HAVE TO WRITE DOWN**
>
> Twenty-one substations appear in the feeder register; the model has seventeen buses. Clock Tower's feeders are billed through Mutundwe, Owen Falls' through Nalubaale, Rugonjo's through Lugazi, Namugongo's through Kampala North and Moroto's through Opuyo. Kabulasoke has no metered 33 kV feeder in the 2023 register at all.
>
> The mapping is in build_uganda_2023.py as a literal dictionary, not buried in a join, precisely so that a reviewer can disagree with one line of it.

23.4 The fleet as ERA licenses it

The AEGID case takes its plant list from the WRI Global Power Plant Database, whose Uganda extract stops in 2018. It therefore contains eleven plants, 666.5 MW of hydro, and neither Isimba (183 MW, commissioned 2019) nor Karuma (600 MW). ERA's licensing register and UETCL's generation account contain both, and the rebuilt case carries the fleet as licensed.

Carrier	Installed MW	Share
hydro_large	1,413.0	69.5 %
hydro	319.7	15.7 %
biomass	135.8	6.7 %
oil	100.2	4.9 %
solar	64.6	3.2 %

Table 51. The licensed fleet: 2,033.3 MW against 666.5 MW of hydro plus 106 MW of everything else in the AEGID build. Reservoir and run-of-river hydro is 85 % of capacity.

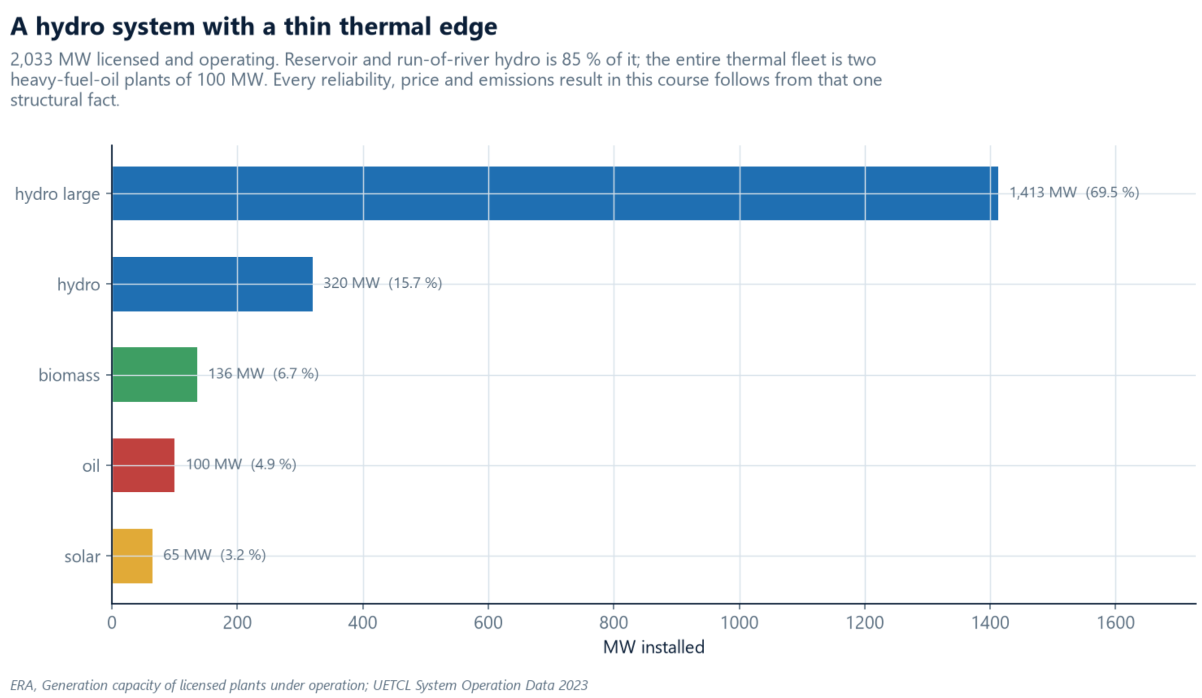


Figure 60. Installed capacity by carrier in the rebuilt case. — ERA, Generation capacity of licensed plants under operation

The five large hydro plants — Nalubaale, Kiira, Bujagali, Isimba and Karuma — enter as reservoir units with the mean inflow power that reproduces their own metered 2023 energy. The small-hydro fleet, the bagasse cogenerators and the solar plants enter as generators whose availability profile is set to their own metered capacity factor, seasonally shaped for hydro from the monthly minihydro series. This is the single most important modelling decision in the rebuild and it deserves its own note.

> **WHY THE ENERGY LIMITS ARE PROFILES AND NOT LIMITS**
>
> technologies.csv has an energy_limit_mwh column. The PyPSA bridge does not read it: grep the estate and the column appears in DataSchema.jl and in ClimateRisk.jl, and nowhere else. A unit given an energy budget in that column will cheerfully run all 8,760 hours.
>
> The rebuild therefore expresses every energy limit as a p_max_pu profile, which the bridge does read. That is why eight of the nine plant groups reproduce their metered year to better than 0.2 % in §24.2. It is also finding EN-27 in §26.8.

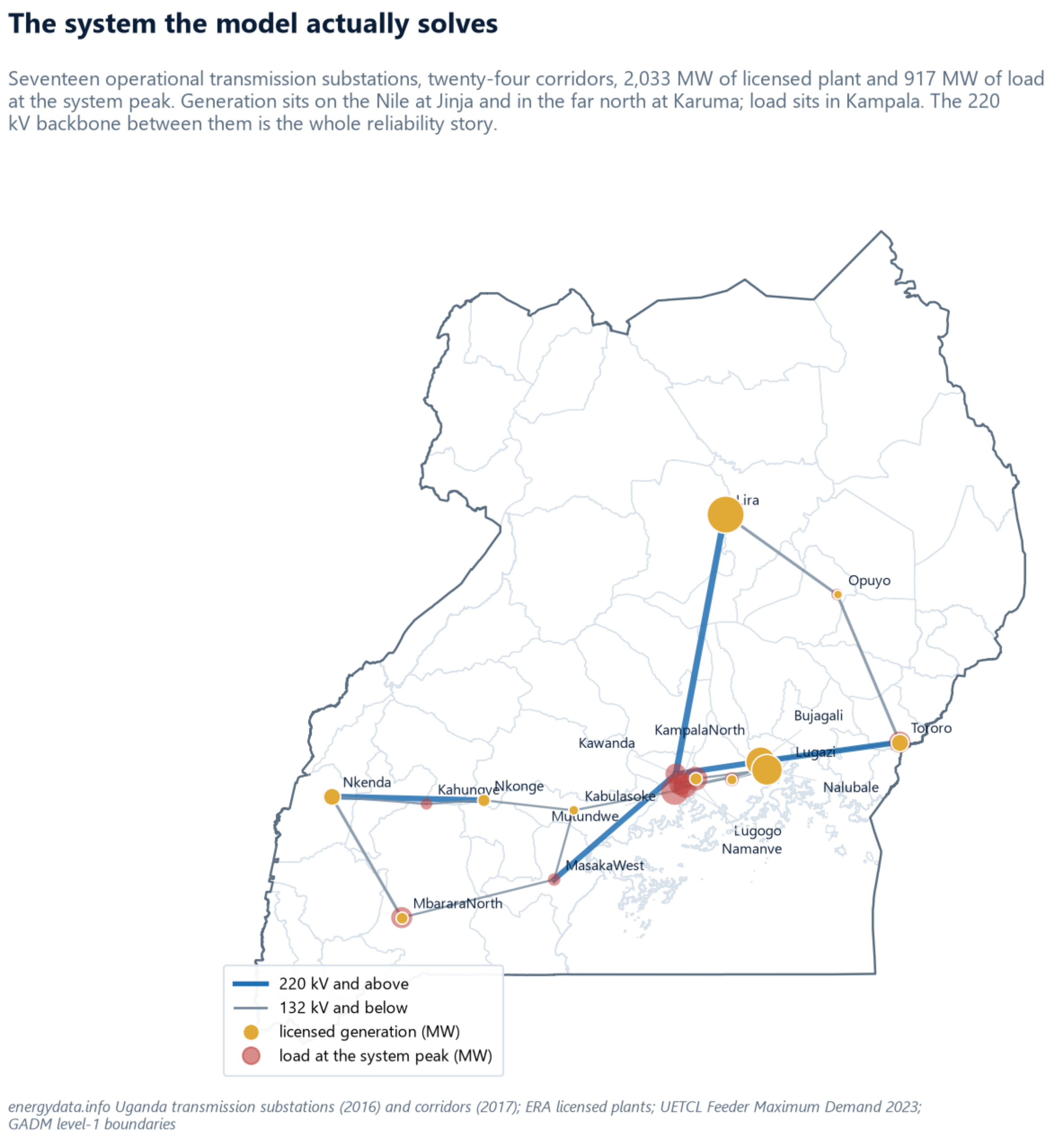


Figure 61. The seventeen-bus case on the map. — energydata.info transmission layers; ERA licensed plants; UETCL feeder demand

23.5 The case, side by side

Quantity	Rebuilt case
Buses	17.0
Transmission corridors	24.0
Thermal/RE units	18.0
Large hydro plants	5
Candidate projects	15.0
Storage units	2
Unelectrified settlement clusters	60.0
Time slices	25.0
Installed capacity (MW)	2,033.3
Firm capacity at credit (MW)	1,190.9
System peak (MW)	917.1
Annual energy (GWh)	5,938.3
Load factor	0.739
Reserve margin at peak	0.299

Table 52. The rebuilt Uganda case at a glance. The reserve margin at the peak is 29.9 % on capacity credits — comfortable on paper, and §25.2 shows what one dry year does to it.

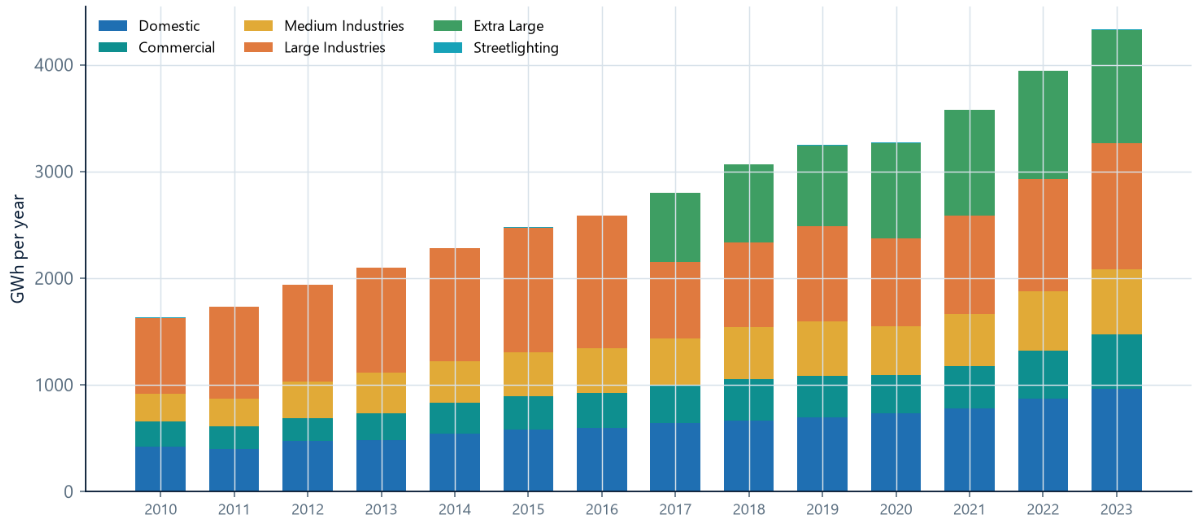
Three differences carry most of the consequence. The fleet is three times larger, so the system is no longer short of energy and the unserved energy that dominated chapter 11 disappears. The peak is twice as high, so capacity becomes a binding question for the first time. And the cost data are real, so the tariff chapter can be written against the metered purchase cost rather than against the dispatch objective — which, as §24.7 shows, are different by a factor of eight.

23.6 The fourteen years behind the year

One year is a slice through a trend, and the trend is in the same returns. Three charts set the calibration year in its context, and each one is an argument a learner should be able to make without the model.

Fourteen years of demand

Sales grew from 1,629 GWh to 4,330 GWh, 7.8 %/yr compound. Industry - large plus extra-large - is more than half the market, which is why an industrial tariff decision moves the sector's finances more than a residential one.

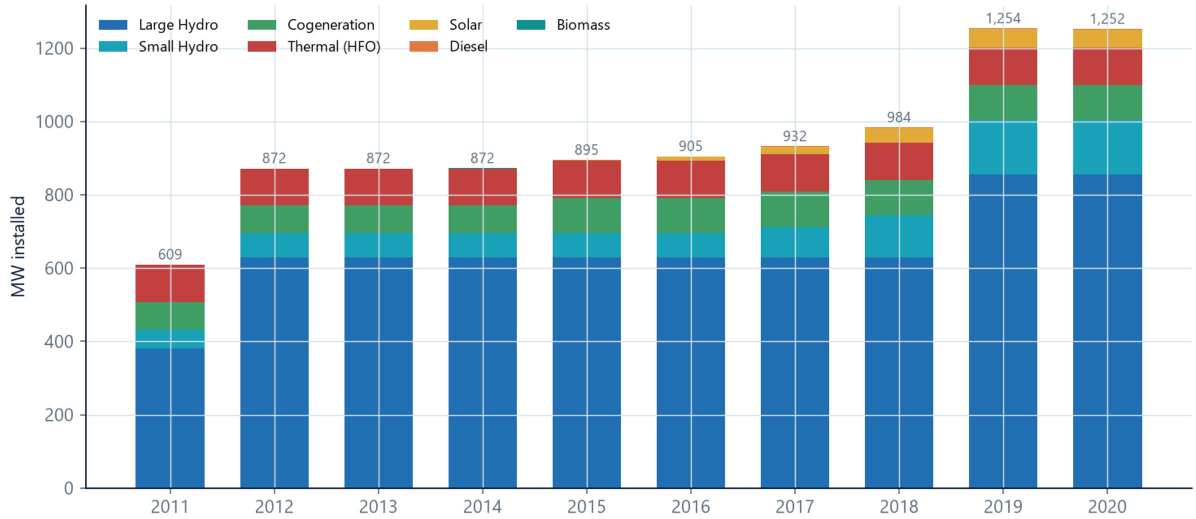


ERA, IRP Data Sheet, electricity sales by class 2010-2023

Figure 62. Electricity sales by customer class, 2010–2023. — ERA, IRP Data Sheet

How the fleet was built

609 MW in 2011 to 1,252 MW in 2020: Bujagali in 2012, then Isimba and the GetFiT small-hydro cohort in 2019. Karuma's 600 MW - which more than doubles hydro capacity again - arrives after this series ends and is still commissioning in the calibration year.



ERA, Generation capacity of licensed plants under operation, installed capacity summary

Figure 63. Licensed installed capacity by technology, 2011–2020. — ERA, Generation capacity of licensed plants under operation

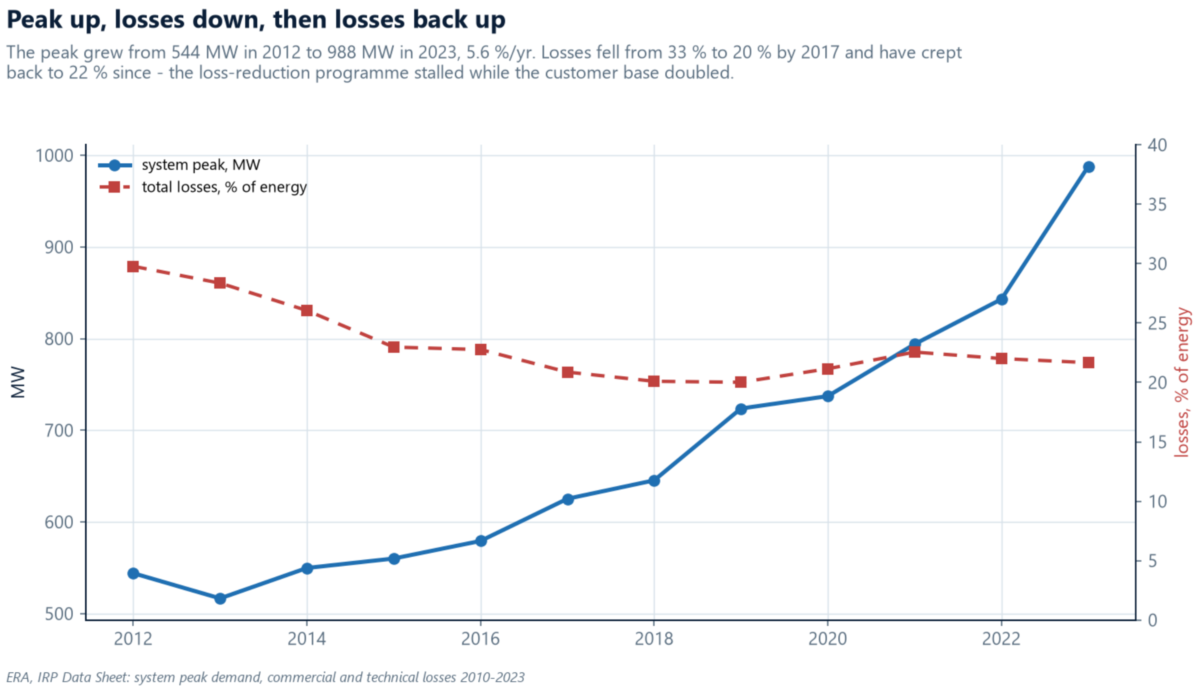


Figure 64. System peak demand and the losses behind it, 2010–2023. — ERA, IRP Data Sheet

Sales grew 8.5 % a year for fourteen years and industry is more than half the market. Capacity doubled between 2011 and 2020 and then doubled again with Karuma. Losses fell from 33 % to 20 % and have since crept back to 22 %. Any forecast that does not sit inside those three histories should be argued for explicitly, and §25.3 states the one this course uses.

24. Solving the metered year

A model that cannot reproduce a year you have already measured cannot be trusted with a year you have not. This chapter solves the rebuilt case for 2023 and scores it against UETCL's own generation account, plant by plant. Eight of nine groups match. The ninth does not, and the reason it does not is the most useful thing in the chapter.

24.1 The solve

```
d = load_energy_data("data/uganda_2023")
cfg = ScenarioConfig(country="Uganda", base_year=2023,
                     voll=10_000.0, discount_rate=0.10)
r = run_economic_dispatch(d, cfg)          # PyPSA / HiGHS
```

Listing 1. The whole of §24.1. Everything after this is reading the result.

Indicator	Value	Unit
system_cost	46,150,382.3	currency
generation	6,159,462.9	MWh
demand	5,938,291.7	MWh
renewable_share	0.2075	fraction
emissions	131,503.5	tCO2e
emission_intensity	0.0213	t/MWh
unserved_energy	0.0000	MWh
unserved_share	0.0000	fraction
lole	0.0000	hours
curtailment	0.0000	MWh
peak_demand	917.1	MW
load_factor	0.7392	fraction
avg_price	0.6653	currency/MWh

renewable_share and avg_price in this table are both wrong, for two different reasons, and §24.5 and §24.6 establish each of them.

Table 53. The dispatch result. Read them in the order the course requires: status, then unserved energy, then LOLE, and only then the objective. Unserved energy is zero and LOLE is zero — the rebuilt fleet covers the metered year with 29.9 % of reserve capacity to spare.

24.2 Scoring the model against the meters

UETCL publishes monthly generation for every plant on the system. Summing it to the year gives nine groups the model can be scored against directly.

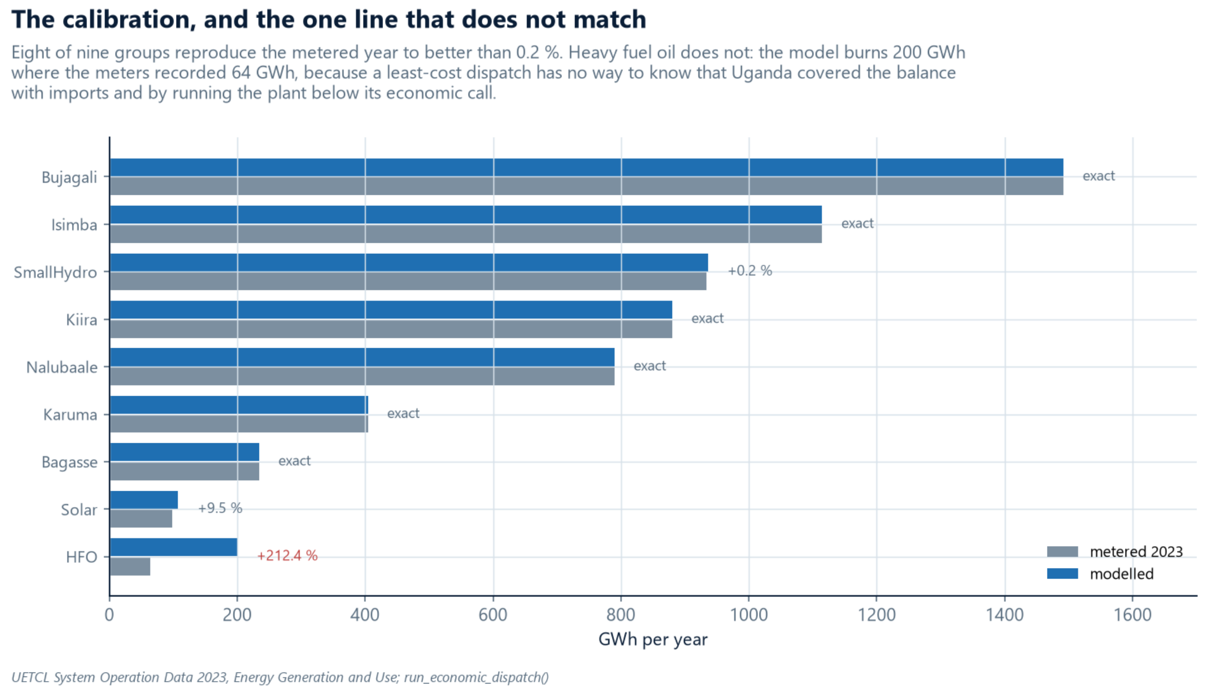


Figure 65. Modelled generation against the metered 2023 year, plant by plant. — UETCL System Operation Data 2023 against run_economic_dispatch()

Plant group	Modelled GWh	Metered GWh	Difference GWh	Difference
Bujagali	1,492.2	1,492.2	0.0	+0.00 %
Isimba	1,114.8	1,114.8	0.0	+0.00 %
SmallHydro	936.1	934.4	1.7	+0.18 %
Kiira	880.3	880.3	0.0	+0.00 %
Nalubaale	790.0	790.0	0.0	+0.00 %
Karuma	404.4	404.4	-0.0	-0.01 %
Bagasse	234.3	234.3	-0.1	-0.03 %
Solar	107.5	98.2	9.3	+9.45 %
HFO	199.9	64.0	135.9	+212.38 %

Table 54. The calibration table. Bujagali, Isimba, Kiira, Nalubaale, Karuma and bagasse reproduce to better than 0.03 %; small hydro to 0.18 %. This is not a fit — no parameter was tuned to it. It is the arithmetic consequence of giving each unit its own metered energy as an availability profile.

24.3 The one line that does not match

Heavy fuel oil is modelled at 199.9 GWh against 64.0 GWh metered — +212 %. The model is not wrong about the arithmetic. It is wrong about the world, in a way worth being precise about.

- The rebuilt case gives every renewable unit exactly its metered 2023 energy. Those units therefore cannot produce a megawatt-hour more than they actually did.
- Demand in the case is the metered transmission-level demand, including the firm export obligation to Kenya, Rwanda and Tanzania.
- The residual has to come from somewhere, and the only dispatchable capacity left in the case is 100 MW of heavy fuel oil. So the optimiser runs it.
- In the real year Uganda covered part of that residual with imports — 33.6 GWh from Kenya — and part by not serving it: 2,201 MWh shed over 422.8 hours. The case has neither an import link nor a shedding history, so the whole residual lands on the oil plant.

WHAT TO DO WITH A CALIBRATION MISS

The temptation is to add an import generator until the line matches. Do not. A model that reproduces a year because it was given a free parameter for every discrepancy has reproduced nothing.

Report the miss, name its cause, and carry it into every result that depends on it. In this build that is exactly two: the emissions inventory in §24.8 is 131.5 kt against a true figure nearer 42 kt, and the system cost in §24.7 is overstated by about 26 million USD of fuel that was never burned.

24.4 The merit order, and what is on the margin

Figure 66. The merit order of the operating fleet. — merit_order() on the Uganda 2023 case

1,933 MW of the 2,033 MW fleet has a short-run marginal cost below 28 USD/MWh. The last 100 MW costs 194. There is nothing in between. A system with a merit order shaped like that has only two prices, and which one obtains depends entirely on whether the hydro energy has run out in that period — which is a hydrological question, not an economic one.

Carrier	GWh	Share of generation
hydro	5,617.8	91.2 %
biomass	234.3	3.8 %
oil	199.9	3.2 %
solar	107.5	1.7 %

Table 55. Generation by carrier. Hydro is 91.2 % of output from 85 % of capacity; oil is 3.2 % of output from 4.9 % of capacity and 100 % of the emissions.

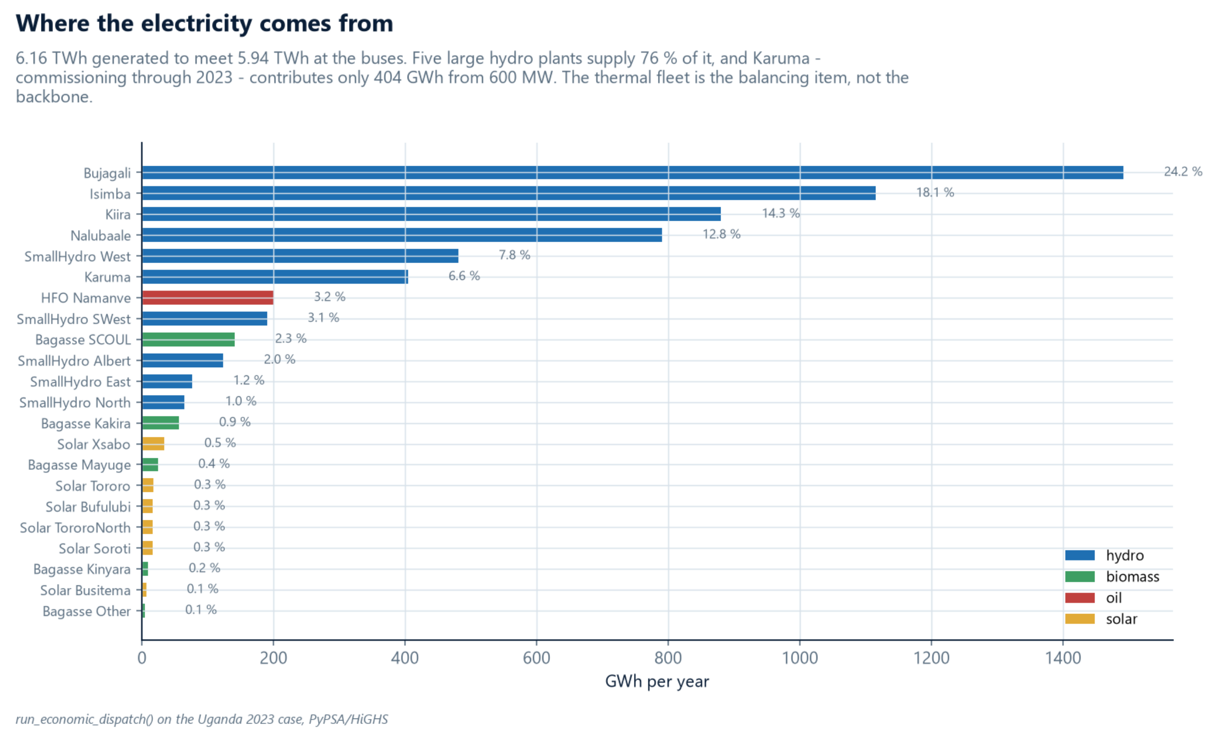


Figure 67. Generation by unit in the 2023 dispatch. — run_economic_dispatch() on the Uganda 2023 case

24.5 The price is still not in the units it claims

Chapter 11 established this defect on the AEGID case. It survives the rebuild unchanged, because it is in the bridge and not in the data. bridge/run_pypsa_case.py, line 272, divides PyPSA's marginal price by the snapshot weighting before writing prices.csv. PyPSA's marginal_price is already per MWh. The exported series is therefore the price divided by the number of hours the slice represents.

```
prices.append((s, b,
    float(n.buses_t.marginal_price.at[s, b]) / max(float(w[s]), 1e-9)))
```

Listing 2. bridge/run_pypsa_case.py:272. The division is the defect.

On the rebuilt case the exported mean is 0.665 per MWh and the corrected mean is 194.55. The ratio at every bus in every period is exactly the slice weight. On the twelve-slice AEGID case that ratio was a constant 730, which is what made the defect visible; on a case with unequal weights it is a different number in every period, which is what makes it dangerous.

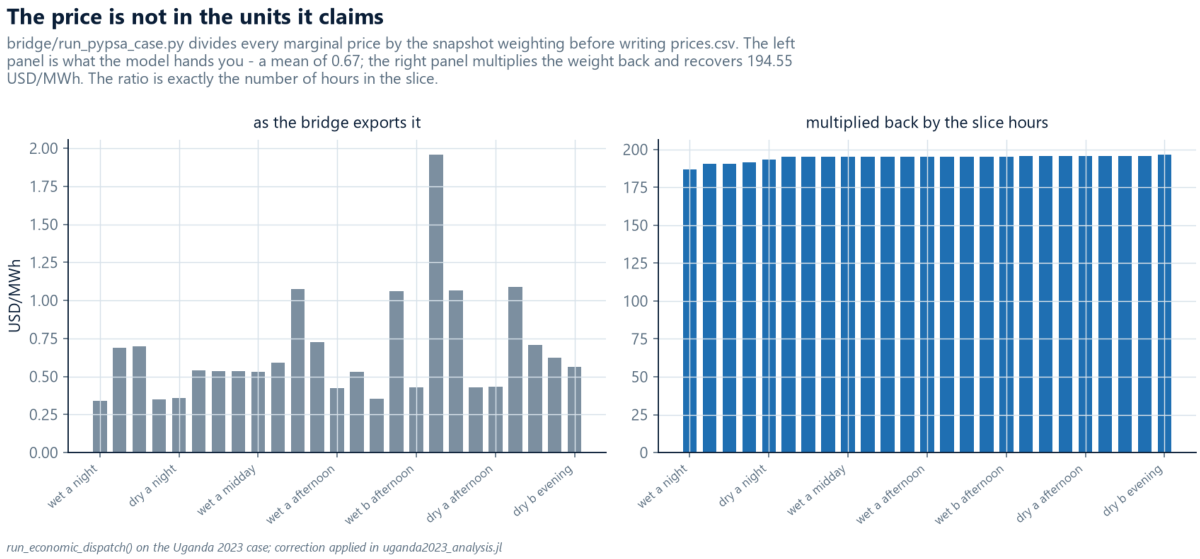


Figure 68. Nodal prices as the bridge exports them and as PyPSA computed them. — run_economic_dispatch() prices against the snapshot weighting

24.6 Seventy-six points of renewable energy the indicator cannot see

dispatch_indicators() reports a renewable share of 20.7 % for a system that is 96.8 % renewable. The cause is structural, not arithmetic. The bridge models reservoir hydro as a PyPSA StorageUnit, because that is the only PyPSA component with an inflow and a reservoir. StorageUnits are not Generators, so they never appear in technologies.csv, so the renewable flag that the indicator sums over does not exist for them.

Reading	Renewable MWh	Total MWh	Share
As the technologies table sees it	1,277,915	6,159,463	20.7 %
With reservoir hydro counted	5,959,610	6,159,463	96.8 %
Difference	4,681,694	0	76.0 %

Table 56. The renewable share, read two ways. The difference is the entire large-hydro fleet: 4.68 TWh.

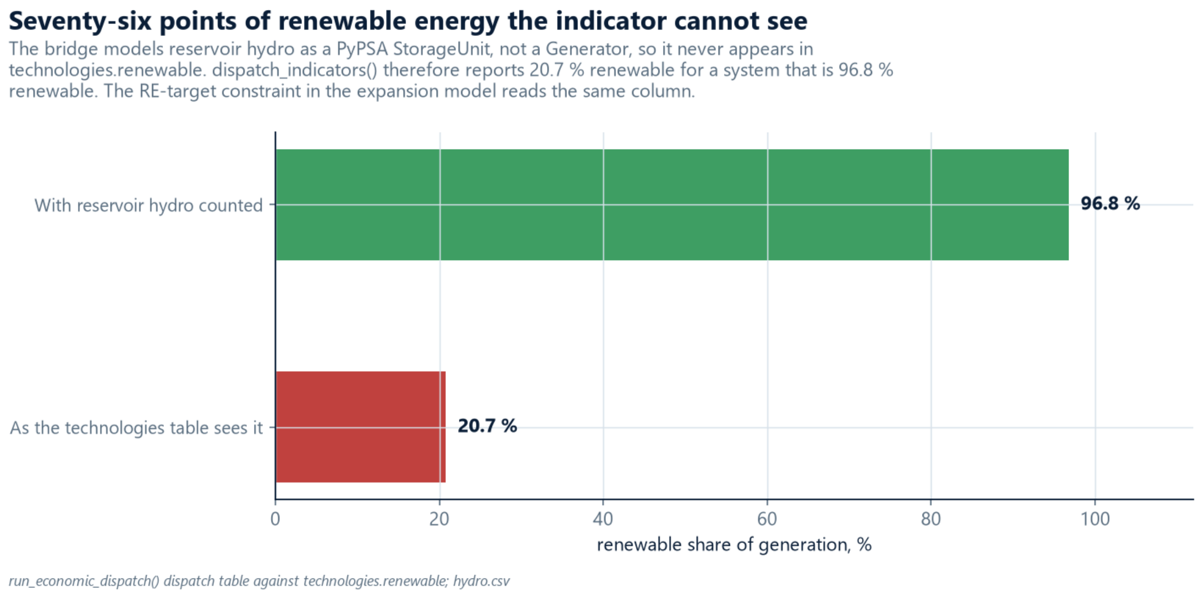


Figure 69. The renewable share, read two ways. — dispatch table against technologies.renewable

THIS IS NOT ONLY A REPORTING PROBLEM

The same column is what the expansion model's renewable-target constraint sums over. Set re_target = 0.85 on this case and you are not asking for 85 % renewable generation; you are asking for 85 % renewable generation among the units that are not reservoir hydro.

§25.4 runs the expansion with that constraint anyway, because that is what the estate does, and states what the constraint actually binds on. A user who does not know this will over-build renewables by roughly the hydro share.

24.7 The objective is not the sector's cost

The dispatch objective is 46.15 million USD, or 7.49 USD per MWh generated. That is a true statement about short-run marginal cost in a system whose hydro carries no variable cost, and it is a catastrophic thing to quote as the cost of running Uganda's power sector. UETCL's own accounts record what was actually paid.

Quantity	Unit	Value
Modelled short-run system cost	USD	46,150,382
Modelled cost per MWh generated	USD/MWh	7.49
Metered UETCL bulk purchases	USD	358,800,000
Metered bulk purchase price per MWh	USD/MWh	59.52
Gap: capacity and deemed-energy payments	USD	312,649,618
UETCL bulk sales revenue	USD	405,350,000
Retail revenue at the 2023 tariff	USD	574,722,246
Retail energy sold	MWh	4,329,753

Table 57. The cost stack. UETCL bought 6,027,838 MWh in 2023 for UGX 1,354,480 million — 358.8 million USD at 3,775.03 UGX/USD, or 59.52 USD/MWh. The model sees an eighth of that.

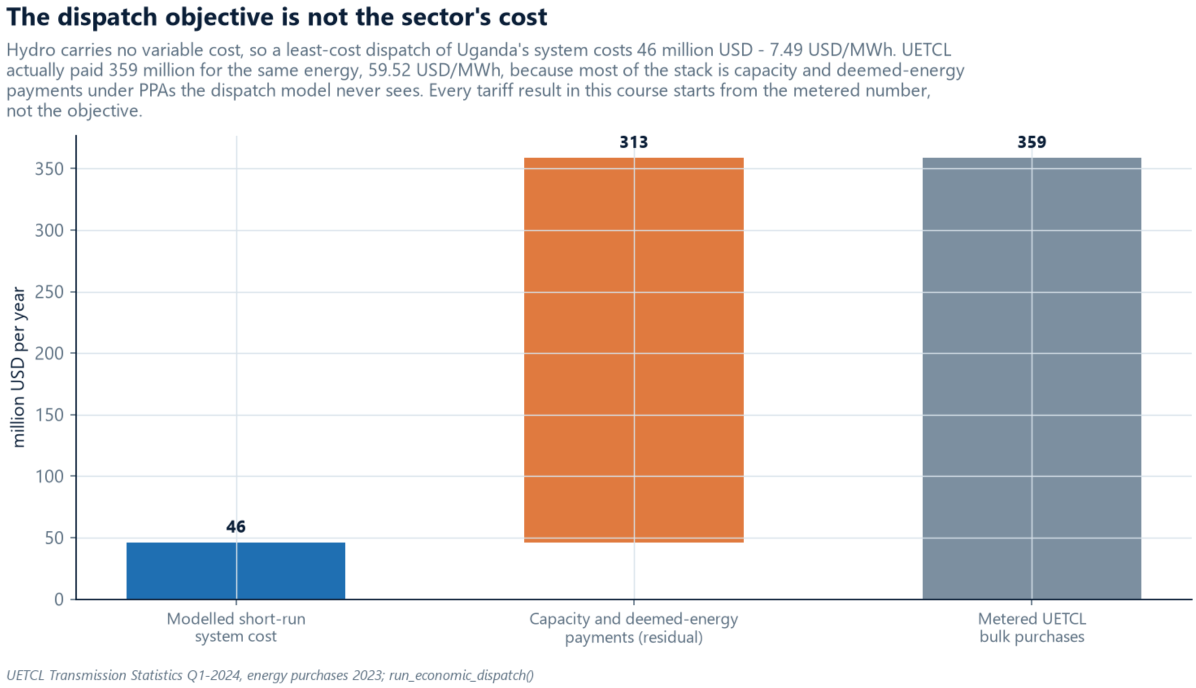


Figure 70. The modelled system cost against the metered bulk purchase cost. — UETCL Transmission Statistics Q1-2024 against the dispatch objective

The 312.6 million USD difference is not an error. It is the capacity and deemed-energy payments in Uganda's power purchase agreements — money owed to a plant whether or not it generates, which a merit-order dispatch has no representation for and no reason to invent. Every tariff, subsidy and fiscal result in chapter 26 therefore starts from the metered purchase cost, and the dispatch objective is used only where a marginal question is being asked.

24.8 The emissions inventory is one plant

131.5 ktCO2e for the year, 21.3 kg per MWh generated. That is among the lowest grid emission intensities in the world, and all of it comes from a single heavy-fuel-oil station at Namanve — which, as §24.3 established, the model runs three times harder than it actually ran.

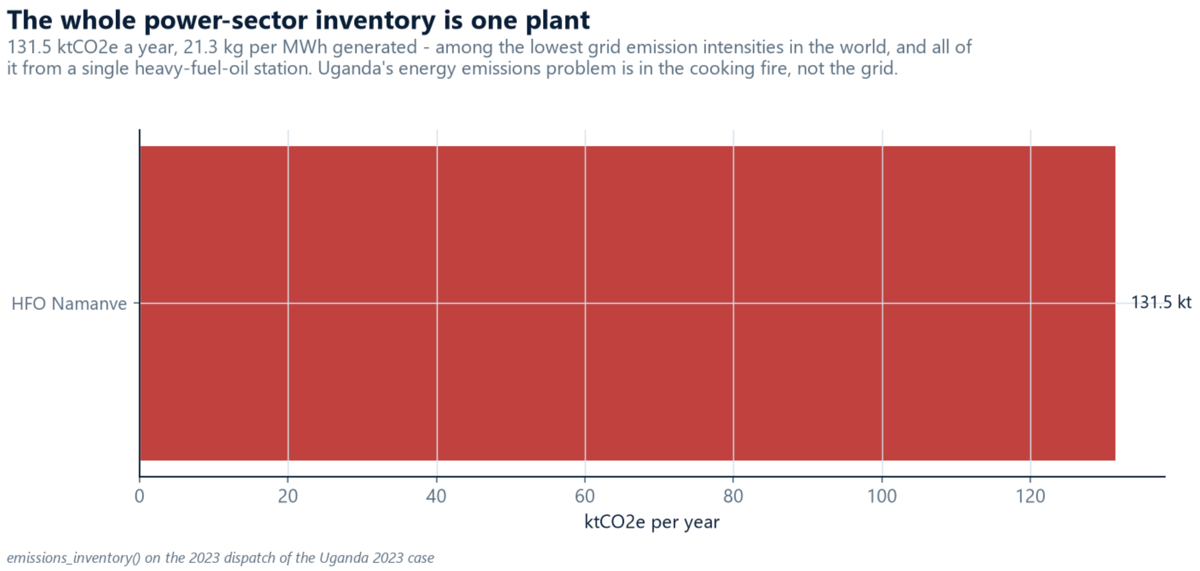


Figure 71. Emissions by technology. — emissions_inventory() on the 2023 dispatch

WHERE UGANDA'S ENERGY EMISSIONS ACTUALLY ARE

The power sector emits 131.5 kt of CO2e a year on this model's own accounting.

UBOS's 2024 census records 6,593,910 households cooking on wood and 2,882,988 on charcoal. At the reference factor used in §25.6, that stock emits on the order of 15 Mt of CO2e a year — more than a hundred times the grid.

A carbon price applied to the power sector, which §25.1 shows abates nothing, is not an energy-sector climate policy in this country. The cooking programme is.

25. Scenarios on the rebuilt case

Six scenario families, run on the case chapters 23 and 24 built and checked. Each one is stated with the parameter that drives it, because in every case the answer is more sensitive to that parameter than to anything in the model.

25.1 A carbon price that abates nothing

Carbon price USD/t	System cost M USD	Emissions tCO2e	Unserved MWh
0	46.2	131,504	0.0
25	49.4	131,504	0.0
50	52.7	131,504	0.0
75	56.0	131,504	0.0
100	59.3	131,504	0.0
150	65.9	131,504	0.0

Table 58. Six carbon prices, one emissions figure. Cost rises linearly at exactly 131,503.5 tonnes per unit of carbon price; emissions do not move at all, so the implied marginal abatement cost is undefined at every step.

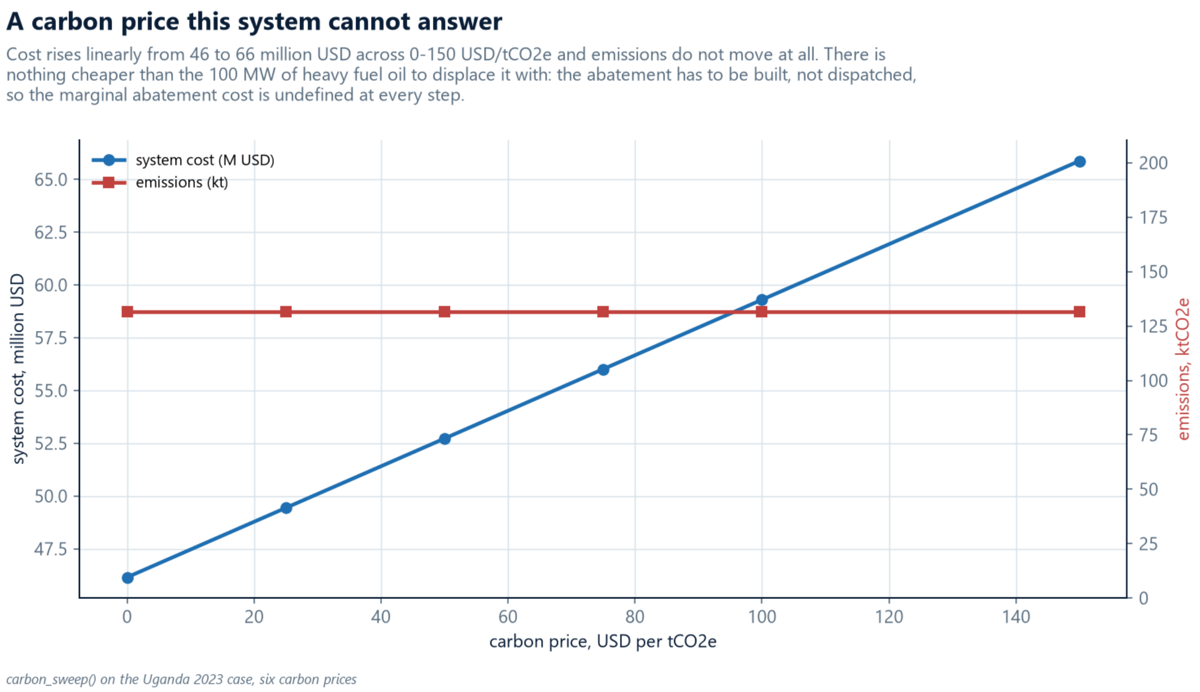


Figure 72. System response to a carbon price. — carbon_sweep() on the Uganda 2023 case

The AEGID case gave the same answer for a different reason: there, the oil plant ran flat out because the system was short of energy, so nothing could displace it. Here the system has 29.9 % of spare reserve and the oil plant still cannot be displaced, because every cheaper unit is already at its metered energy ceiling. Two different physical situations, one identical result — which is the point. A carbon price prices what is on the margin. If the margin is the only dispatchable plant on the system, the price is a transfer and not an abatement instrument.

25.2 Hydrology is the risk

Case	System cost USD	Unserved MWh	Emissions tCO2e	Curtailed MWh

Case	System cost USD	Unserved MWh	Emissions tCO2e	Curtailed MWh
historical	46,150,382	0	131,504	0
wet	484,578	0	0	685,818
dry	8,055,280,150	788,102	566,010	0
severe_dry	18,916,200,687	1,874,705	548,683	0

Table 59. Four hydrological cases. A 30 % inflow reduction takes the system from zero unserved energy to 788 GWh and multiplies cost by 175; almost all of that cost is lost load valued at 10,000 USD/MWh, not fuel.

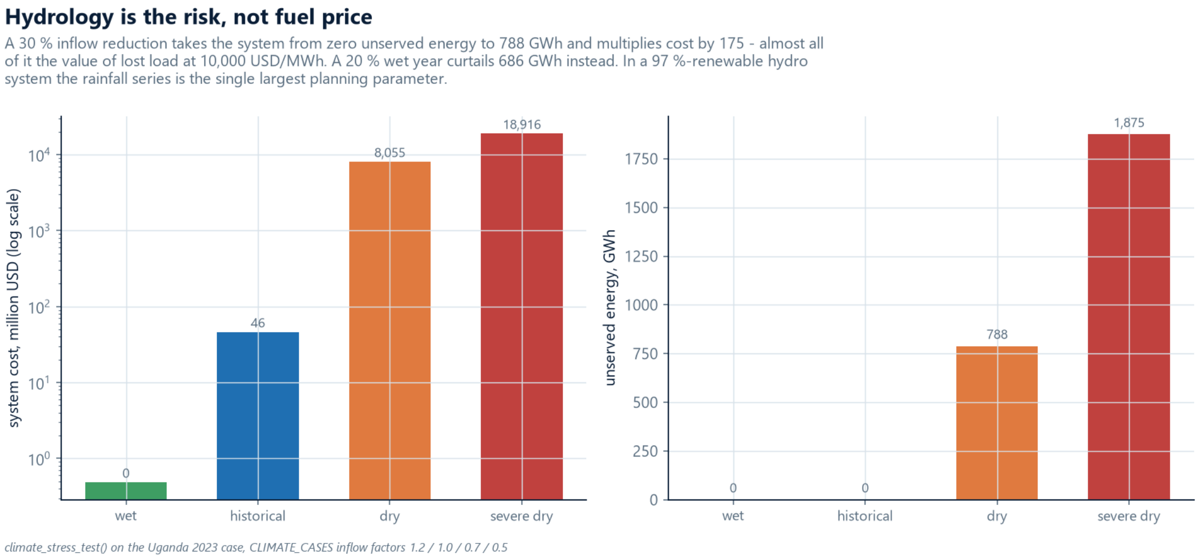


Figure 73. Dispatch under four hydrological cases. — climate_stress_test() on the Uganda 2023 case

This is the result the rebuild exists to make possible. On the AEGID case a dry year was one shortage among several, because the case was already short. Here the system is comfortable in an average year and catastrophically exposed in a dry one, and the distance between those two states is a rainfall series. A 29.9 % reserve margin computed on nameplate capacity credits says nothing about it: the constraint that binds in a drought is energy, not capacity, and no reserve-margin rule can see an energy constraint.

WHAT THE WET CASE IS TELLING YOU

A 20 % wet year curtails 686 GWh — 12 % of national demand thrown away because there is nowhere to put it.

That is the storage and interconnection case stated in energy terms, and it is worth more than the same megawatts of peaking plant, which the reserve-margin constraint in §25.4 will nevertheless prefer.

25.3 Demand to 2040

Year	Energy GWh	Peak MW	Load factor	Index
2,023.0	5,938.3	917	0.739	1.000
2,026.0	7,660.4	1,183	0.739	1.290
2,030.0	10,688.9	1,651	0.739	1.800
2,035.0	15,142.6	2,339	0.739	2.550
2,040.0	20,487.1	3,164	0.739	3.450

Table 60. The demand path: 8.9 % a year to 2030 and 6.9 % a year thereafter, reaching 20.5 TWh and a 3,164 MW peak in 2040. The load factor is held constant by construction, which is an assumption and not a finding.

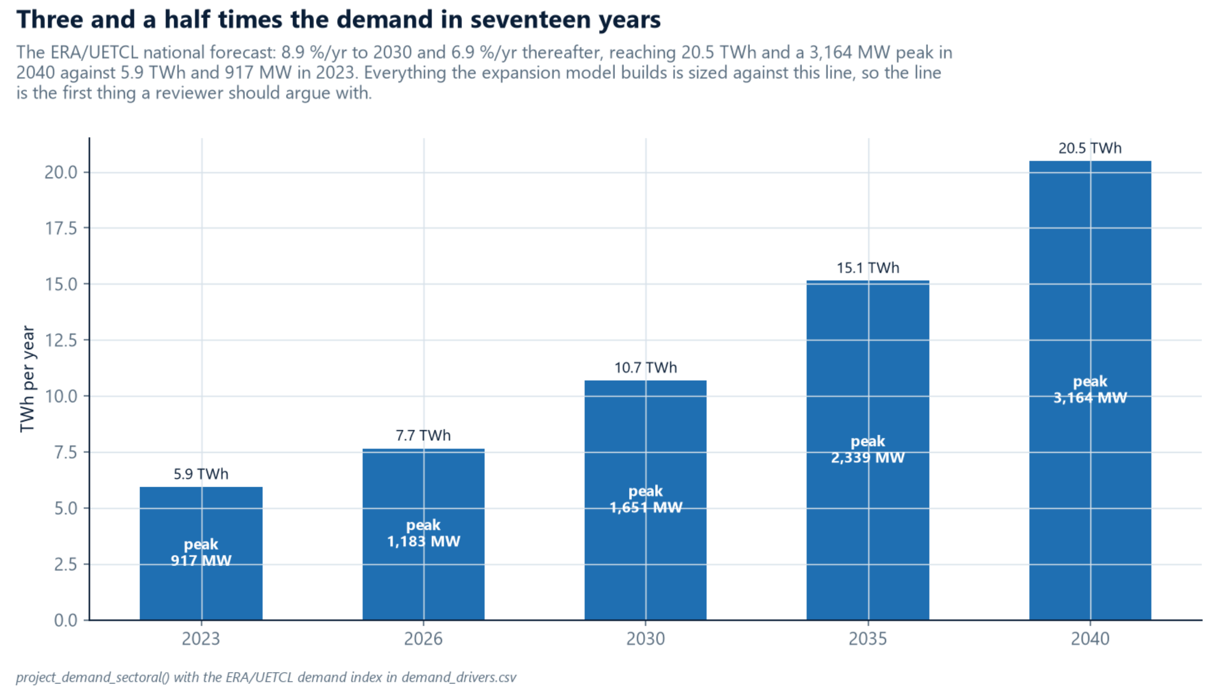


Figure 74. Demand to 2040 on the ERA/UETCL forecast path. — project_demand_sectoral() on the Uganda 2023 demand table

Everything the expansion model builds is sized against this line, so the line is the first thing a reviewer should argue with. It sits above the fourteen-year historical average of 8.5 % to 2030 and below it thereafter, which is the shape of every official Ugandan forecast and also the shape of every official forecast that has been wrong. Chapter 21's scenario discipline applies: run the plan against a low case before quoting a capacity number.

25.4 The expansion plan

Rolling horizon over 2026, 2030, 2035 and 2040 against a 20 % reserve margin, with the MEMD/ERA IRP candidate set annuitised at 10 %. Two runs: one with an 85 % renewable-energy target and one without.

Candidate	Carrier	LCOE USD/MWh	Annualised capex USD/MW	Fixed O&M USD/MW	Variable USD/MWh	CF
Solar_Soroti	solar	0.00	0	0	0.00	0.183
Solar_TororoNorth	solar	0.00	0	0	0.00	0.183
Solar_Tororo	solar	0.00	0	0	0.00	0.183
Solar_Xsabo	solar	0.00	0	0	0.00	0.183
Solar_Bufulubi	solar	0.00	0	0	0.00	0.183
Solar_Busitema	solar	0.00	0	0	0.00	0.183
SmallHydro_West	hydro	1.00	0	0	1.00	0.453
SmallHydro_SWest	hydro	1.00	0	0	1.00	0.492
SmallHydro_East	hydro	1.00	0	0	1.00	0.295
SmallHydro_North	hydro	1.00	0	0	1.00	0.085
SmallHydro_Albert	hydro	1.00	0	0	1.00	0.385
Bagasse_Kakira	biomass	27.50	0	0	27.50	0.124
Bagasse_SCOUL	biomass	27.50	0	0	27.50	0.643
Bagasse_Kinyara	biomass	27.50	0	0	27.50	0.076

Candidate	Carrier	LCOE USD/MWh	Annualised capex USD/MW	Fixed O&M USD/MW	Variable USD/MWh	CF
Bagasse_Mayuge	biomass	27.50	0	0	27.50	0.119
Bagasse_Other	biomass	27.50	0	0	27.50	0.050
CCGT_Tilenga	gas	54.33	84,863	25,000	40.40	0.900
Geothermal_Katwe	geothermal	57.11	371,277	75,000	0.50	0.900
Geothermal_Buranga	geothermal	57.11	371,277	75,000	0.50	0.900
CCGT_East	gas	68.48	95,471	25,000	53.20	0.900
Solar_Central	solar	69.06	99,151	10,000	1.00	0.183
Solar_East	solar	69.06	99,151	10,000	1.00	0.183
Solar_North	solar	69.06	99,151	10,000	1.00	0.183
Wind_Karamoja	wind	72.91	137,903	40,000	1.00	0.282
Nuclear_Buyende	nuclear	82.13	494,210	55,560	16.07	0.950
RoR_North	hydro	83.09	285,431	40,000	1.00	0.453
RoR_West	hydro	83.09	285,431	40,000	1.00	0.453
RoR_WestNile	hydro	83.09	285,431	40,000	1.00	0.453
OCGT_West	gas	88.80	84,863	20,000	75.50	0.900
Biomass_Central	biomass	91.00	397,797	75,000	27.50	0.850
HFO_Namanve	oil	194.00	0	0	194.00	1.000
HFO_Electromaxx	oil	194.00	0	0	194.00	1.000
Diesel_Central	oil	258.08	53,040	60,000	244.50	0.950

Existing units are omitted: their capital is sunk, so their LCOE is their variable cost and the comparison is not meaningful.

Table 61. The candidate set. Every capital cost is the IRP's own overnight cost annuitised over the project's own life at 10 %; every capacity factor is the project's own availability profile.

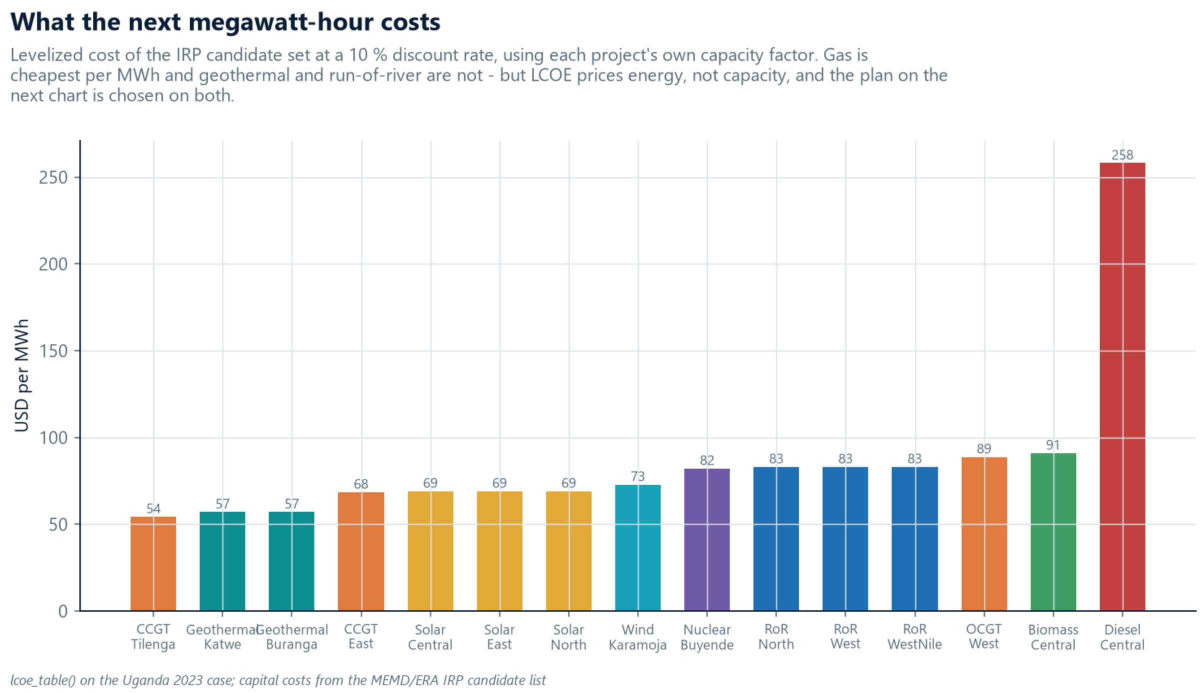


Figure 75. Levelized cost of the IRP candidate set. — lcoe_table() on the Uganda 2023 case

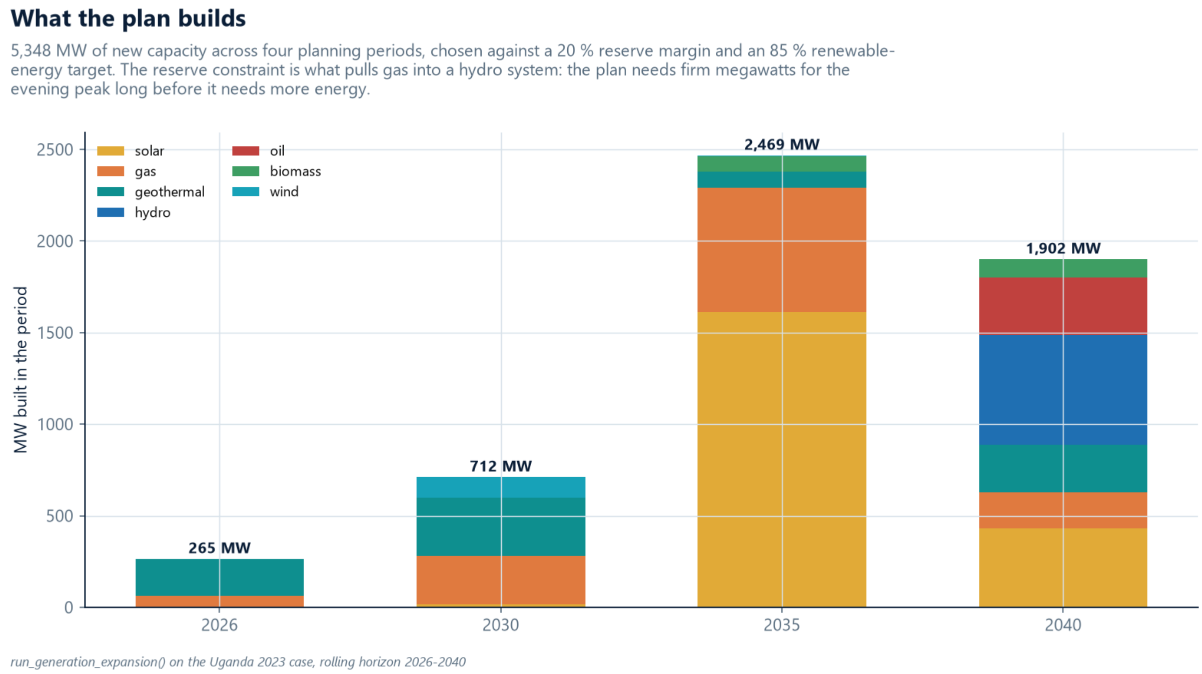


Figure 76. The capacity the plan builds, by year and carrier. — run_generation_expansion() 2026–2040

Candidate	With an 85 % RE target MW	Least cost MW
CCGT_East	420.2	884.0
OCGT_West	664.1	646.3
Geothermal_Katwe	601.5	514.2
Diesel_Central	313.2	387.7
CCGT_Tilenga	118.9	200.0
Wind_Karamoja	120.0	103.4
Geothermal_Buranga	267.0	101.7
Biomass_Central	183.3	100.0
RoR_North	300.0	0.0
RoR_WestNile	300.0	0.0
Solar_Central	281.4	0.0
Solar_East	852.7	0.0
Solar_North	925.5	0.0

Table 62. The 2040 fleet under the two runs. The target moves roughly 1.5 GW from gas into solar, wind and geothermal; it does not remove the gas and diesel that the reserve margin requires.

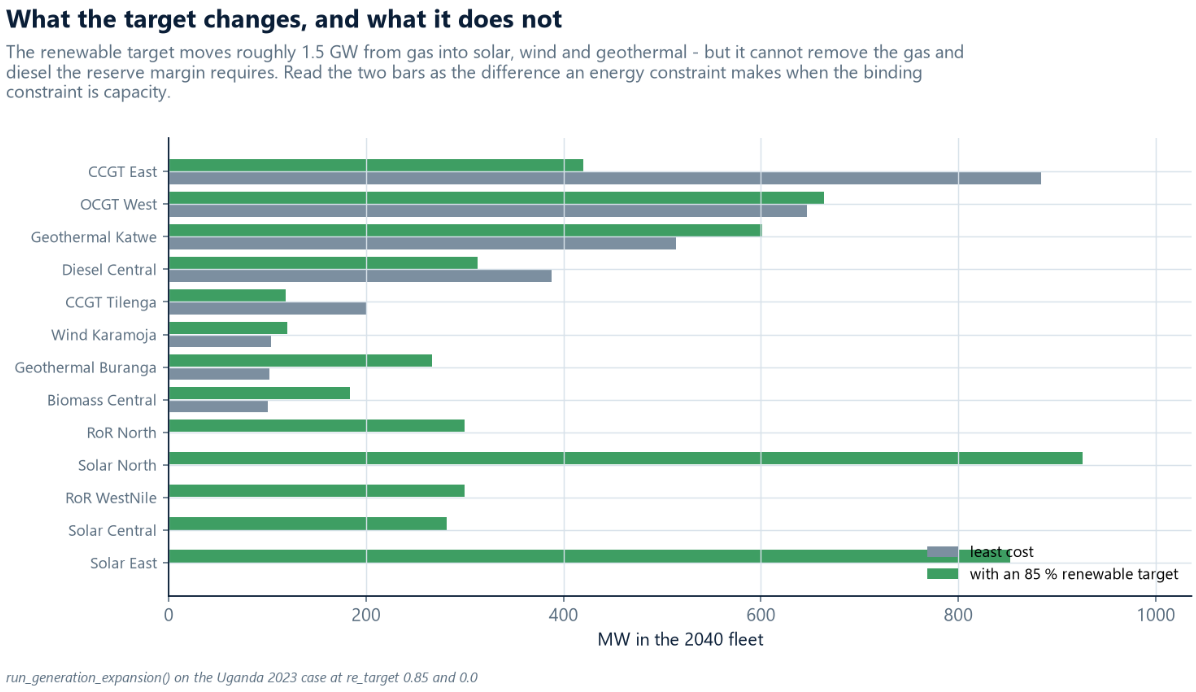


Figure 77. The plan with and without a renewable-energy target. — run_generation_expansion() at re_target 0.85 and 0.0

Year	With an 85 % RE target tCO2e	Least cost tCO2e	Reduction
2026	172,320	547,703	69 %
2030	339,870	810,431	58 %
2035	580,967	2,183,393	73 %
2040	1,271,866	3,890,964	67 %

Table 63. What the renewable target buys. By 2040 it cuts power-sector emissions from 3.89 Mt to 1.27 Mt — a 67 % reduction — which is a real result on a constraint that, as §24.6 established, cannot see the hydro fleet it is being measured against.

THE RESERVE MARGIN IS WHAT PULLS GAS INTO A HYDRO SYSTEM

The plan builds gas and diesel under both runs, and it does so for a capacity reason, not an energy one. Solar has a capacity credit of 0.03 in the IRP's own parameters; open-cycle gas has 0.90. Meeting a 20 % reserve margin on a 3,164 MW peak with solar would require roughly thirty times the megawatts.

That is the single most important thing this course has to say about renewable targets in a system like Uganda's: an energy constraint and a capacity constraint are different constraints, and a target written against the first does not bind the second.

25.5 Network expansion still builds nothing

run_network_expansion() on the rebuilt case reinforces 0 corridors and adds 0.0 MW. Chapter 12 established why on the AEGID case and the reason is unchanged: the corridors already carry more than the flows require, because clustering 78 surveyed circuits into 24 model corridors sums their ratings and collapses their lengths. A transport model on an over-rated graph has nothing to build.

The result is worth reporting rather than suppressing. A reinforcement plan of zero is a statement about the graph, and a reader who is told that can go and look at the graph. A reinforcement plan that has been quietly forced to build something is a statement about nothing at all.

25.6 Access and clean cooking

UBOS's 2024 census records 2,706,626 households — 25.3 % — lit by grid or mini-grid electricity and 3,006,732 more — 28.1 % — lit by solar. The rebuilt household table carries that split, and the access gap it implies is the largest single number in this course.

Indicator	Value
National grid access	25.3 %
Urban	71.0 %
Rural	8.4 %
Urban minus rural	62.6 %

Table 64. Grid access from the 2024 census. The urban–rural gap is 62.6 percentage points.

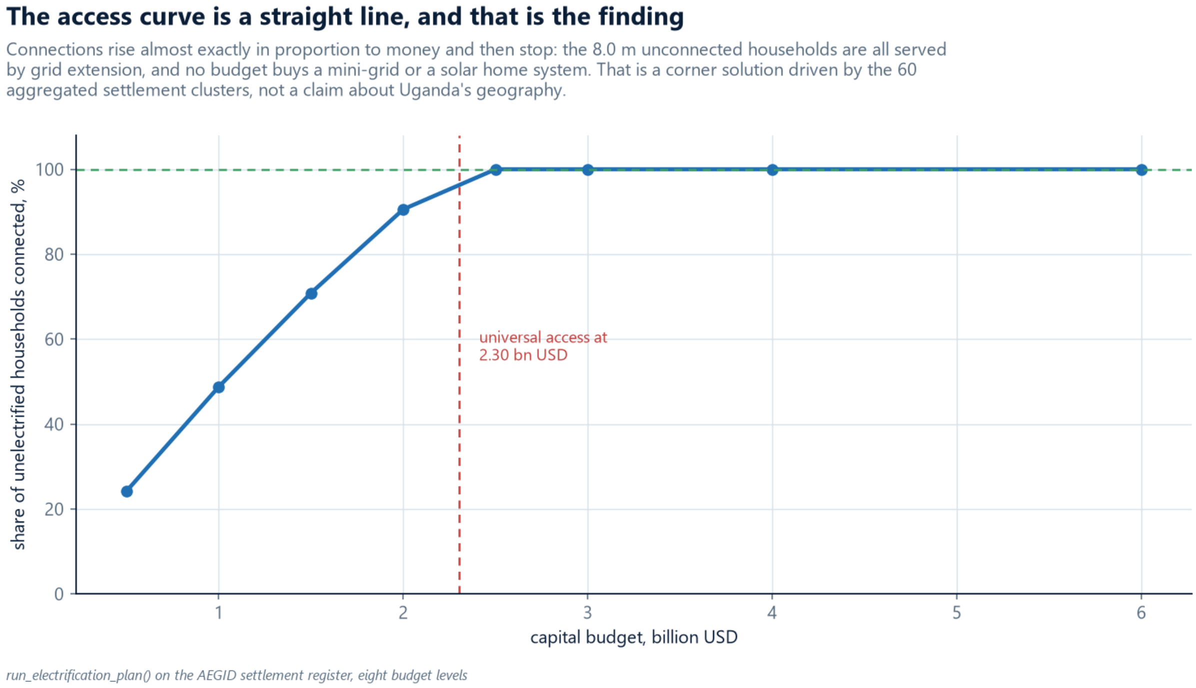


Figure 78. Households connected against the capital budget. — run_electrification_plan() at eight budget levels

The least-cost plan connects all 8.0 million unelectrified households by grid extension for 2.30 billion USD, and no budget level buys a single mini-grid or solar home system. Chapter 15 diagnosed this on the AEGID case and the diagnosis carries: the settlement register aggregates 67,650 villages into 60 clusters, and at cluster scale the grid is always cheaper because the distance to the grid has been averaged away. The corner solution is a property of the aggregation, not of Uganda.

HOW TO READ A CORNER SOLUTION

A least-cost access model that picks one technology everywhere has not found that the technology is best everywhere. It has found that your data cannot distinguish the places where it is not.

The fix is spatial resolution, not a different objective. Until the 67,650-village layer is carried through to the optimiser, the only defensible statement from this model is the total: universal access costs on the order of 2.3 billion USD in connection capital, and the budget-response curve is linear.

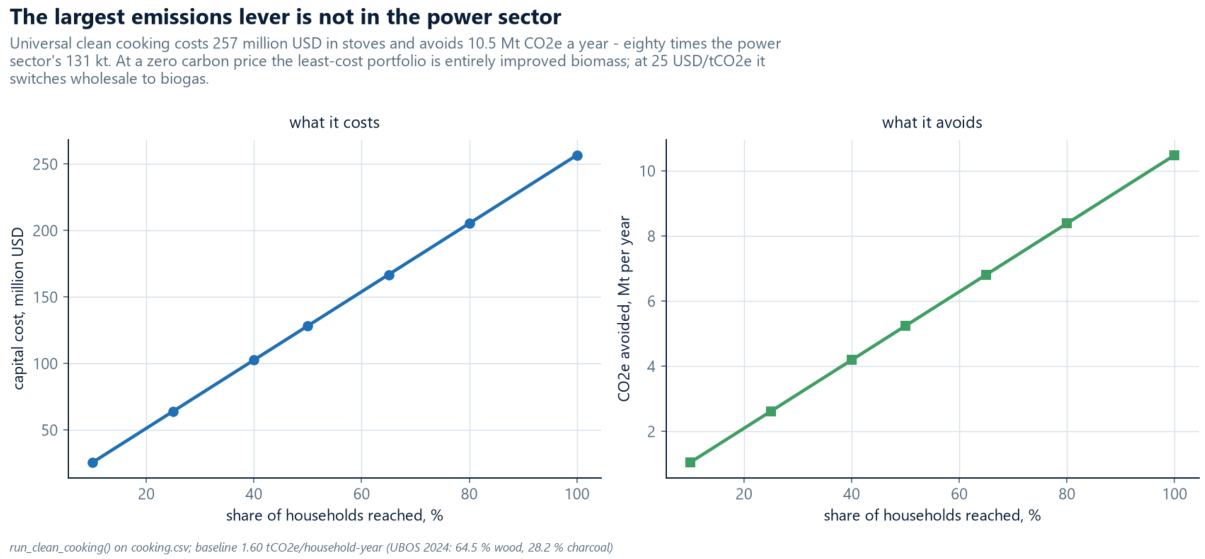


Figure 79. Clean cooking: cost and emissions against the adoption target. — run_clean_cooking() on the UBOS 2024 cooking baseline

Target	Households m	Capex bn USD	Residual ktCO2e	Avoided ktCO2e	Time saved m hours
10.0 %	1.07	0.026	663	1,048	312
25.0 %	2.67	0.064	1,658	2,621	781
40.0 %	4.28	0.103	2,653	4,194	1,250
50.0 %	5.35	0.128	3,317	5,242	1,562
65.0 %	6.95	0.167	4,312	6,815	2,031
80.0 %	8.56	0.205	5,307	8,388	2,499
100.0 %	10.70	0.257	6,633	10,485	3,124

Table 65. The clean-cooking sweep. Universal adoption costs 257 million USD in stoves and avoids 10.5 Mt of CO2e a year — eighty times the power sector's 131.5 kt, for a fifth of the capital the electrification plan needs.

At a zero carbon price the least-cost portfolio is entirely improved biomass; at 25 USD per tonne it switches wholesale to biogas and stays there. Both are corner solutions of a linear programme and neither is a policy recommendation — a real cooking programme is constrained by supply chains, fuel availability and household preference, none of which is in cooking.csv. What the model does establish, robustly, is the order of magnitude: the cooking transition is where Uganda's energy emissions are, and it is cheap.

26. Money: the cost stack, the tariff and who pays

Chapter 16 built a tariff on the AEGID case from an asset base that had to be assumed. This chapter builds one from what UETCL actually paid and what the schedule actually charges — and then shows that the answer still turns on two numbers nobody measured.

26.1 The revenue requirement

Generation enters the revenue requirement at the metered 2023 bulk purchase cost of 358.8 million USD, not at the dispatch objective — for the reason §24.7 sets out. Transmission and distribution operating cost is 130 million. The regulated asset base is taken at 3.1 billion USD, depreciated over thirty years, with a 9 % allowed return.

Component	Million USD
Transmission network (4,519 km, 39 substations)	1,350.0
Distribution network	1,750.0
Total regulated asset base	3,100.0
Bulk generation purchases	358.8
Transmission and distribution operating cost	130.0
Annual depreciation (30 y)	103.3
Allowed return (9 %)	279.0
Revenue requirement	871.1

Table 66. The revenue requirement, component by component. Two of the six components — the asset base and the allowed return — are regulatory judgements, and together they are 44 % of the total.

Quantity	USD
Revenue requirement	871,133,333
Collected revenue at the 2023 tariff	548,545,291
Collected revenue at the cost-reflective tariff	871,133,333
Cost-recovery ratio at the 2023 tariff	0.630
Annual gap	322,588,042

Table 67. What the tariff in force recovers. 63.0 % of the revenue requirement, leaving an annual gap of 322.6 million USD — about 1.22 trillion shillings.

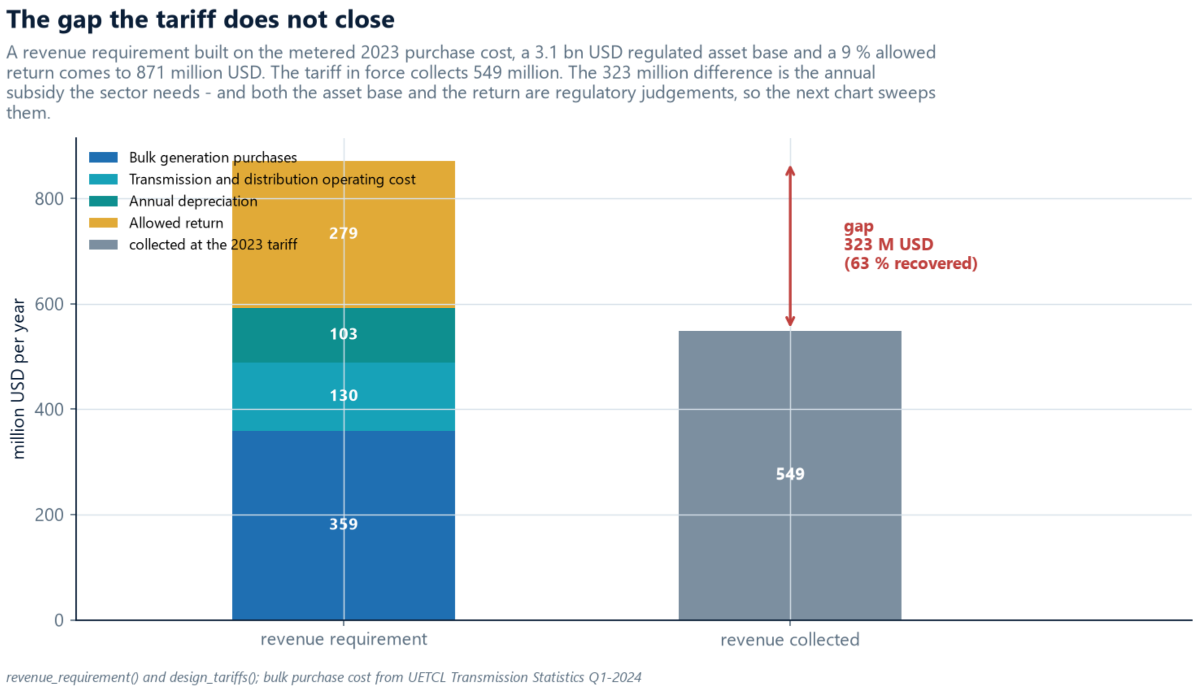


Figure 80. The revenue requirement and what the tariff collects. — revenue_requirement() on the metered 2023 cost stack

26.2 Two numbers nobody measured

The 63 % is not a measurement. Sweep the asset base from 2.0 to 4.2 billion USD and the allowed return from 7 % to 11 % — both ranges a regulator could defend — and cost recovery ranges from 50 % to 79 %.

Asset base bn USD	Allowed return	Revenue requirement M USD	Residential tariff USD/MWh	Cost recovery
2.0	7.0 %	695.5	254.2	78.9 %
2.0	9.0 %	735.5	268.8	74.6 %
2.0	11.0 %	775.5	283.4	70.7 %
2.5	7.0 %	747.1	273.0	73.4 %
2.5	9.0 %	797.1	291.3	68.8 %
2.5	11.0 %	847.1	309.6	64.8 %
3.1	7.0 %	809.1	295.7	67.8 %
3.1	9.0 %	871.1	318.4	63.0 %
3.1	11.0 %	933.1	341.0	58.8 %
3.6	7.0 %	860.8	314.6	63.7 %
3.6	9.0 %	932.8	340.9	58.8 %
3.6	11.0 %	1,004.8	367.2	54.6 %
4.2	7.0 %	922.8	337.2	59.4 %
4.2	9.0 %	1,006.8	367.9	54.5 %
4.2	11.0 %	1,090.8	398.6	50.3 %

Table 68. The revenue requirement across the two judgements it rests on. The cell this manual quotes is 3.1 bn at 9 %; the honest report is the grid.

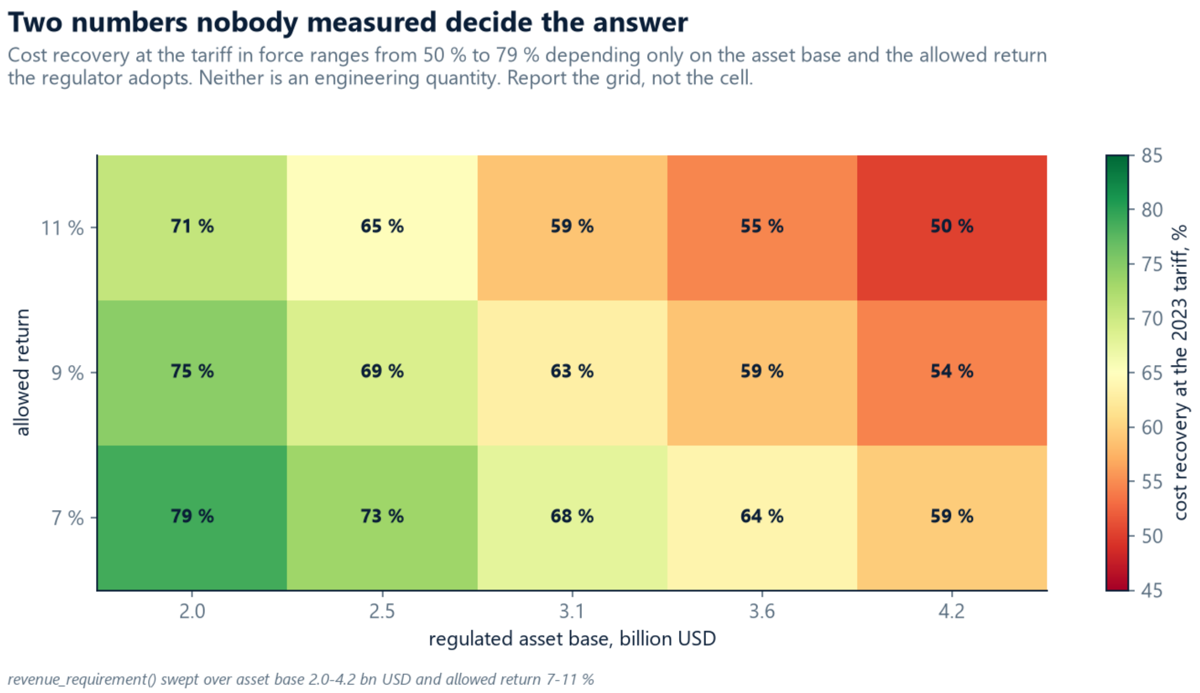


Figure 81. Cost recovery across the two regulatory judgements. — revenue_requirement() swept over asset base and allowed return

26.3 The tariff by class

Class	MWh	Customers	2023 tariff	Cost-reflective	Standard	Lifeline
residential	965,769	2,008,044	213.2	256.1	318.4	139.2
commercial	506,964	95,068	162.1	235.6	286.7	124.0
medium_industrial	607,348	3,709	122.3	204.9	249.1	105.6
large_industrial	1,186,954	690	101.8	179.3	220.5	91.5
extra_large	1,060,127	49	86.1	157.1	195.8	79.3
street_lighting	2,591	346	98.0	196.4	274.3	115.5

Table 69. Tariffs in USD per MWh at 3,775.03 UGX/USD. The residential tariff is 20 % below cost recovery; the extra-large industrial tariff is 82 % below it.

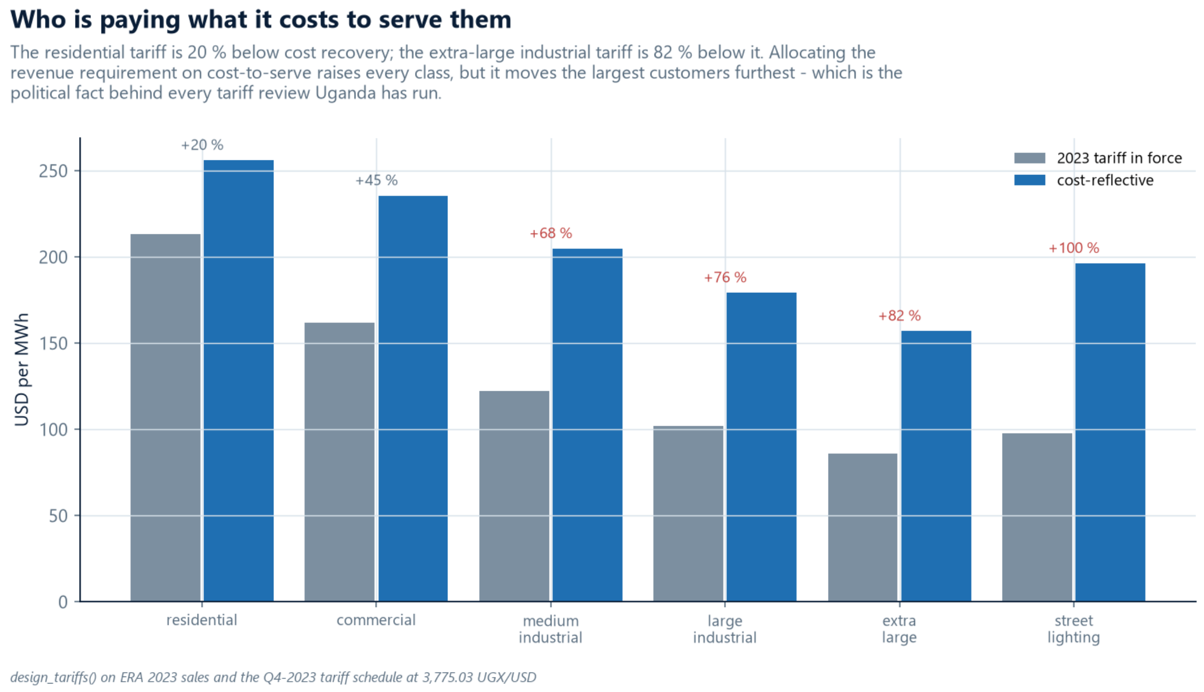


Figure 82. The 2023 tariff against the cost-reflective tariff, by class. — design_tariffs() against the 2023 revenue requirement

Class	MWh	Customers	Subsidy USD/MWh	Total subsidy USD	Per customer USD
residential	965,769	2,008,044	128.1	123,681,851	62
commercial	506,964	95,068	-36.8	-18,639,282	-196
medium_industrial	607,348	3,709	-36.8	-22,330,048	-6,021
large_industrial	1,186,954	690	-36.8	-43,640,121	-63,247
extra_large	1,060,127	49	-36.8	-38,977,138	-795,452
street_lighting	2,591	346	-36.8	-95,262	-275

Table 70. Implicit subsidy by class. Positive is subsidised; negative is cross-subsidising. Residential customers receive 123.7 million USD in total; each of the forty-nine extra-large accounts pays 795,452 USD more than its cost to serve.

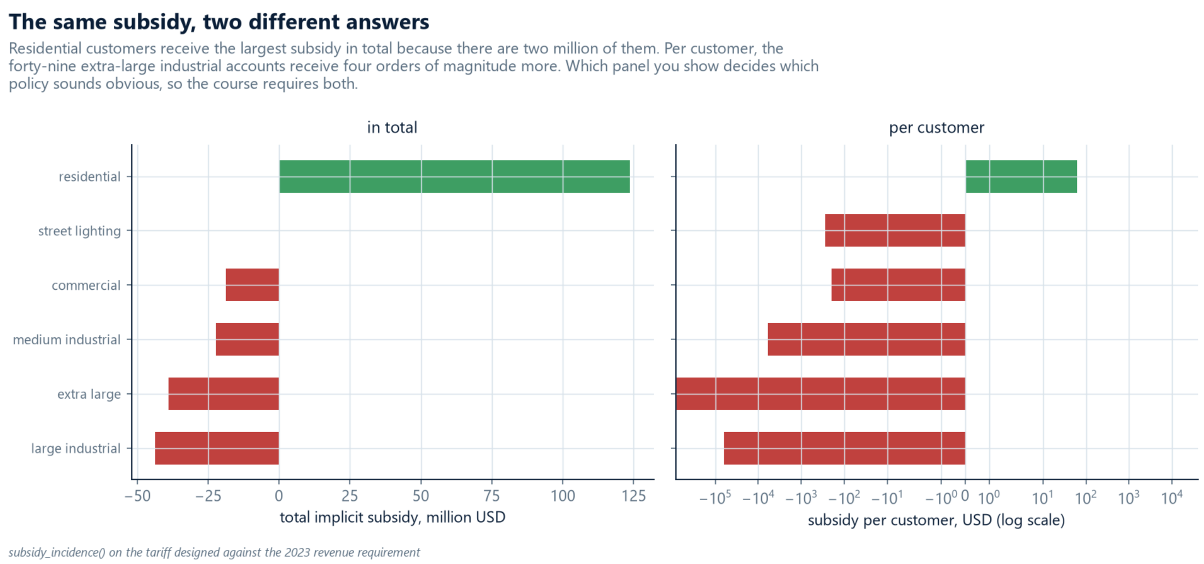


Figure 83. Who the implicit subsidy goes to, in total and per customer. — subsidy_incidence() on the designed tariff

ONE TABLE, TWO POLICIES

> Read the total column and the obvious reform is to raise residential tariffs, because that is where the subsidy is.
>
> Read the per-customer column and the obvious reform is the opposite, because that is where the transfer per decision-maker is.
>
> Both columns are the same arithmetic. The course requires both to be shown, and requires the denominator to be named in the sentence that quotes either.

26.4 What households can bear

Group	Households	Income USD/y	Electricity USD/y	Cooking USD/y	Burden	Affordable
rural_unconnected	7,154,363	780	14	86	12.8 %	False
rural_connected	655,843	1,520	64	104	11.1 %	False
urban_unconnected	837,725	1,960	30	168	10.1 %	False
urban_connected	2,050,982	3,840	132	152	7.4 %	False

Table 71. Energy burden by household group, on the UBOS 2024 household structure. Every group is above the 5 % affordability threshold; three of four are above 10 %.

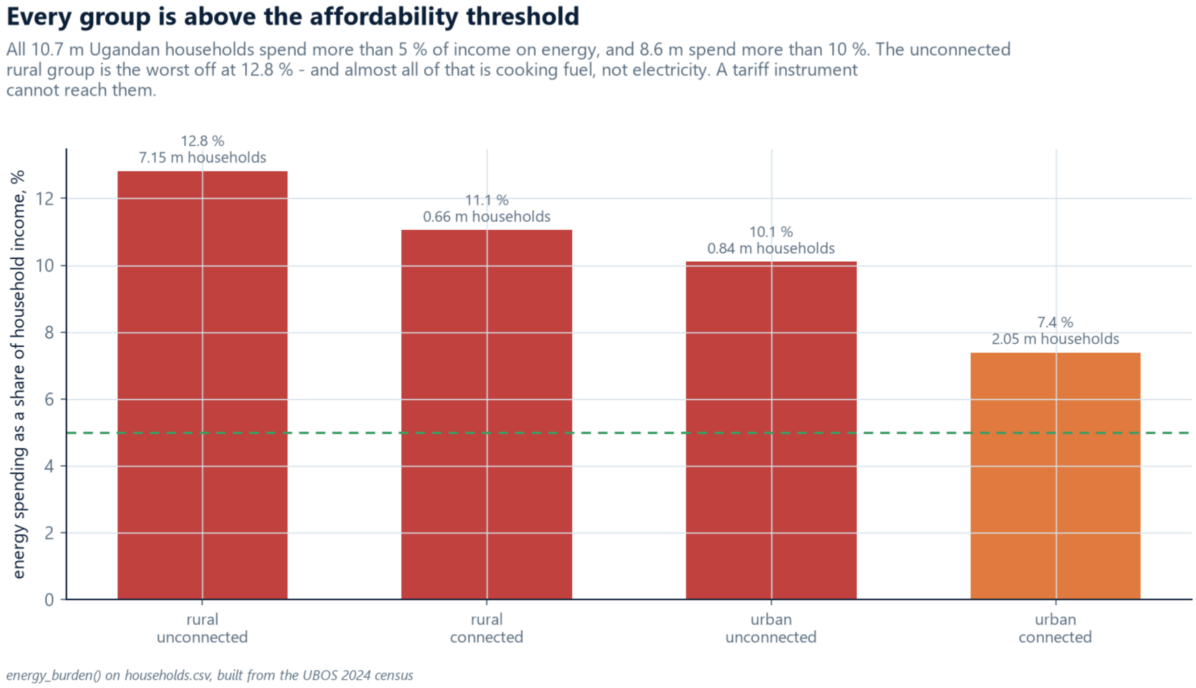


Figure 84. Energy burden by household group. — energy_burden() on the UBOS 2024 household groups

Tariff change	Welfare loss M USD	Newly poor households	Households over 5 % burden, m	Households over 10 % burden, m
0.0 %	0.0	0	10.70	8.65
10.0 %	43.8	0	10.70	8.65
20.0 %	87.6	0	10.70	8.65
30.0 %	131.4	0	10.70	8.65
50.0 %	219.0	0	10.70	8.65
86.0 %	376.7	0	10.70	10.70

The newly-poor column is zero at every step because a four-group household table cannot resolve a poverty line; the burden columns are the defensible reading. This is finding EN-29 in §26.8.

Table 72. The tariff shock. Closing the cost-recovery gap requires an 86 % tariff increase, which costs households 376.7 million USD a year and puts all 10.7 million of them above a 10 % energy burden.

The unconnected rural group carries the highest burden at 12.8 % and almost all of it is cooking fuel, not electricity. No tariff instrument reaches them. That is the sharpest argument in this manual for why an energy-poverty analysis that stops at the electricity bill has stopped too early.

26.5 A quarter of the energy never reaches a bill

Indicator	Value
Gross generation (MWh)	6,237,701
Transmission loss (MWh)	299,410
Distribution technical loss (MWh)	593,829
Commercial loss (MWh)	438,246
Total losses (MWh)	1,331,485
System loss rate	0.2417
Collection rate	0.9641
Collected energy (MWh)	4,729,946

Table 73. The loss chain at the ERA 2023 rates. 6,238 GWh generated, 4,730 GWh collected — a system loss rate of 24.2 %.

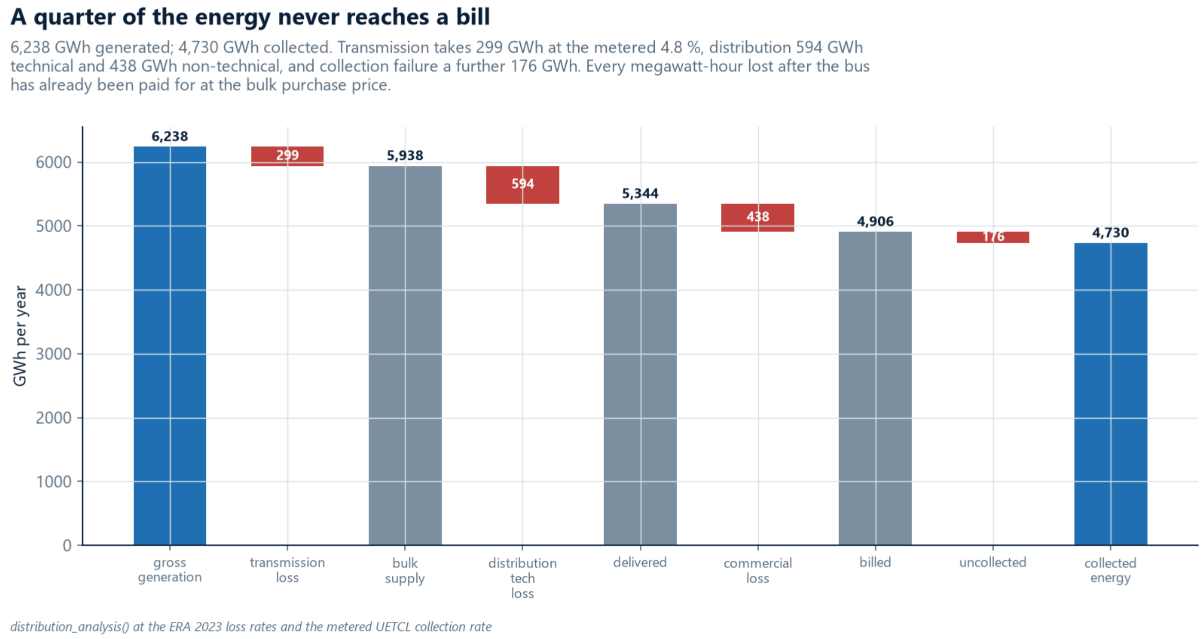


Figure 85. From generation to collected revenue. — distribution_analysis() with the ERA 2023 loss rates

Every megawatt-hour lost after the bus has already been bought at 59.52 USD. The 1,332 GWh of losses and uncollected energy is therefore worth about 79 million USD a year at the purchase price — a quarter of the 322.6 million cost-recovery gap, recoverable without touching a tariff.

26.6 The energy balance closes

Fuel	Region	Year	Residual MWh	Gross MWh	Relative residual
electricity	national	2023	8,742	12,032,950	0.073 %

Table 74. The 2023 electricity balance from UETCL's own account: supply 6,020,846 MWh, exports 484,846, transmission losses 288,636, distribution losses 908,869, final consumption 4,329,753. It closes to 8,742 MWh — 0.073 %.

Chapter 11's rule applies unchanged: if the balance closes, you know what the model did. This one closes to seven hundredths of a per cent on data none of which the model produced, which is the strongest single piece of evidence that the rebuilt case is internally consistent with the country it describes.

26.7 What goes to the macro model

The CGE handoff runs unchanged on the rebuilt case and produces a four-carrier generation split and an LCOE path. One field in the payload is wrong, and it is wrong for a reason chapter 19 already established.

Field	Value
electricity_price_as_exported	0.665
electricity_price_corrected	195
generation_cost_short_run	46,150,382
metered_bulk_purchase_cost	358,800,000

Table 75. The macro payload's price field, before and after the EN-20 correction, against the two cost measures §24.7 distinguishes. energy_to_macro() carries the price straight from prices.csv, so it inherits the weighting defect: a CGE run on the raw payload would see an electricity price of 0.67 USD/MWh.

Carrier	Generation MWh	Region
hydro	5,617,810	UGA
solar	107,519	UGA
biomass	234,281	UGA
oil	199,853	UGA

Table 76. The generation-by-carrier export CDCGE PowerLink consumes. Four carriers, because the rebuilt case has four; the eight-technology GTAP-Power split chapter 19 discusses is produced downstream.

26.8 What the rebuild adds to the gaps register

Chapter 22 registered twenty-four limitations. The rebuild confirmed four of them on independent data and found three more. All seven are stated the way the register requires: what is wrong, how it was found, and what this course does about it.

Id	Finding	How it was found	How this course handles it
EN-20 · confirmed	The bridge divides every marginal price by the snapshot weighting, so prices.csv is not in USD/MWh.	The corrected mean is 194.55 against an exported 0.665; the ratio is the slice weight at every bus and period.	§24.5 corrects it and uga23_prices_corrected.csv carries both series. Never quote prices.csv directly.
EN-17 · confirmed	The renewable share the estate reports omits reservoir hydro.	20.7 % reported against 96.8 % actual on a case where the difference is 4.68 TWh.	§24.6 reports both readings; every renewable-share statement in chapters 23–26 uses the corrected one.
EN-11 · confirmed	Network expansion reinforces nothing because clustering over-rates the corridors.	Zero corridors reinforced on a case whose peak is twice the AEGID case's.	§25.5 reports the zero and says why. No reinforcement number is quoted from this model.
EN-08 · confirmed	The access plan is a corner solution driven by settlement aggregation.	All 8.0 m households by grid at every budget level, on a settlement register unchanged from the AEGID build.	§25.6 quotes only the total and the budget response, never the technology split.
EN-25 · new	The dispatch objective is not the sector's cost and is routinely quoted as if it were.	46.15 M USD modelled against 358.8 M USD metered for the same energy — a factor of 7.8.	§24.7 tabulates both. Chapter 26 builds the revenue requirement on the metered cost; the objective is used only for marginal questions.

Id	Finding	How it was found	How this course handles it
EN-26 · new	The LCOE table and the expansion model can assume different capacity factors for the same candidate.	lcoe_table() looks the availability profile up by candidates.technology; the bridge falls back to the candidate id; the rolling-horizon planner keys the promoted-capacity profile on technology. A blank technology column gives one project three capacity factors.	The rebuilt candidates.csv sets technology to the candidate's own name so all three agree. Check this column before trusting any expansion result.
EN-27 · new	technologies.energy_limit_mwh is in the schema and is not enforced.	The column appears in DataSchema.jl and ClimateRisk.jl and nowhere else; a unit given an energy budget there runs unconstrained.	Every energy limit in the rebuilt case is expressed as an availability profile instead. §23.4 states this.
EN-28 · new	A four-group household table cannot support a poverty headcount.	tariff_impact() returns zero newly-poor households at every tariff change from 0 % to 86 %, because no group crosses the line.	§26.4 reports the energy-burden headcount instead and prints the zero rather than deleting it.

Table 77. The four confirmed and four new findings. Added to chapter 22's twenty-four, the register now stands at twenty-eight.

THE RULE THIS ADDENDUM WAS BUILT ON

Rebuilding a case on better data does not make a model right. It makes the model's remaining wrongness legible, because you can no longer blame the inputs.

Every one of the four confirmed findings survived a complete change of demand, fleet, cost and household data. That is how you know they are in the code.

Appendix A — The specification, section by section

All 97 numbered sections of EDIS Energy Planning System Technical Manual, EDIS, 2026, in order, with what each says and the equations it carries. This is the map between the course and the document it teaches: a reader who wants to know where a chapter of this manual came from should find it here.

A.1 The parts

Part	Title	Sections	First	Last
I	System Architecture and Modelling Principles	3	1	3
II	Data and GIS Architecture	4	4	7
III	PyPSA-Earth Core Integration	4	8	11
IV	Energy Demand Modelling	4	12	15
V	Industry, Minerals and Agriculture Coupling	4	16	19
VI	Transport Electrification and Sector Coupling	4	20	23
VII	Renewable Resource and Project Planning	4	24	27
VIII	Generation Expansion and Dispatch	5	28	32
IX	Transmission and Network Development	4	33	36
X	Storage, Flexibility and Hydrogen	4	37	40
XI	Hydropower, Water and Climate	5	41	45
XII	Electricity Access and Decentralised Systems	4	46	49
XIII	Regional Power Pools and Energy Trade	4	50	53
XIV	Reliability, Adequacy and Resilience	4	54	57
XV	Tariffs, Utility Finance and Affordability	5	58	62
XVI	Fiscal Risk, PPAs and Public Investment	4	63	66
XVII	Energy Investment Portfolio Optimisation	4	67	70
XVIII	CDCGE Integration	4	71	74
XIX	Scenario Framework	2	75	76
XX	Software and Repository Architecture	4	77	80
XXI	Dashboard and User Experience	3	81	83
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XXIII	Calibration, Validation and Diagnostics	5	86	90
XXIV	Implementation Roadmap	7	91	97

Table 78. The specification's own structure.

A.2 The sections

Part I — System Architecture and Modelling Principles

§1 System mandate

The Energy Planning System is the EDIS system of record for integrated energy-sector scenarios. It must support operational dispatch studies, medium-term investment programmes, least-cost generation plans, transmission development plans, electrification strategies, industrial-energy strategies, power-pool integration, tariff analysis and economy-wide impact assessment.

§2 Functional architecture

§3 Governing design principles

- Retain PyPSA-Earth as an upstream engine and minimise invasive modifications.
- Use adapters and configuration files for EDIS-specific demand, assets, policy and results.
- Separate the modelling application from the raw-data acquisition layer.
- Use reproducible country configurations and versioned data/concordances.
- Preserve physical units and geospatial provenance throughout the pipeline.
- Allow national models to nest inside regional power-pool models.
- Treat reliability, access, fiscal risk and development impact as first-class planning criteria.
- Provide a two-way interface with CDCGE rather than a one-off energy shock.

Part II — Data and GIS Architecture

§4 Energy data warehouse

§5 Spatial hierarchy

Every spatial object should resolve to a common hierarchy: country → administrative region → modelling zone → grid bus/node → settlement/industrial site. Raster resources should retain grid-cell identifiers and network calculations should retain origin/destination nodes.

§6 Temporal hierarchy

The system should support full hourly years, representative days/weeks, clustered snapshots and multi-investment-period horizons. Time reduction must preserve peak load, renewable correlation, hydro seasonality and extreme conditions.

```
AnnualEnergy = Σ_t Demand_t · snapshot_weight_t
```

§7 Data provenance

- source URL or institution
- download/extraction date
- license
- spatial/temporal resolution
- unit
- processing script
- quality flags
- version hash
- country coverage

Part III — PyPSA-Earth Core Integration

§8 Role of PyPSA-Earth

PyPSA-Earth should provide the reproducible geospatial workflow that assembles network topology, renewable-resource profiles, demand geography and clustered network representations suitable for optimisation. EDIS should consume and extend these outputs rather than re-create them in Julia.

§9 Role of PyPSA

PyPSA is the optimisation and simulation framework used for economic dispatch, linear optimal power flow, security-constrained analysis, capacity expansion, multi-carrier sector coupling, storage and transmission expansion. Current PyPSA documentation also supports multi-investment-period optimisation, stochastic optimisation and modelling-to-generate-alternatives.

§10 EDIS adapter pattern

```
EDIS sector data → adapter → PyPSA/PyPSA-Earth input tables → solve → result adapter → EDIS database
```

§11 Upstream-version discipline

EDIS should pin tested PyPSA/PyPSA-Earth versions in environment files, preserve upstream repositories as submodules or clean clones, and place all EDIS changes in configuration, workflow overlays, adapters and extension packages. A regression suite should run after upstream upgrades.

Part IV — Energy Demand Modelling

§12 Demand decomposition

Demand is both spatial and sector-specific. Each component must have an annual energy forecast and an hourly shape. Coincidence factors must be applied when aggregating end uses.

```
D(r,t) = D_HH(r,t)+D_IND(r,t)+D_AG(r,t)+D_MIN(r,t)+D_TR(r,t)+D_SERV(r,t)+D_PUB(r,t)
```

§13 Residential demand

The preferred specification conditions consumption on income, urban/rural status, appliance ownership, connection tier and tariff. Household survey and geospatial settlement information can estimate adoption and consumption distributions.

```
D_HH(g,y) = Pop(g,y) · Electrification(g,y) · kWhPerCapita(g,y)
```

§14 Services and public demand

Services may be projected from sector output, floorspace, employment or establishment counts. Public loads should separately represent schools, health facilities, water systems and government offices because electrification investments may be policy-driven.

```
D_SERV(r,y)=Σ_k Floorspace(k,r,y)·Intensity(k,y)
```

§15 Peak and load-shape modelling

Load-shape libraries should distinguish residential, commercial, industrial, mining, irrigation, EV and public-service profiles. Where smart-meter data do not exist, profiles should be generated from survey activity patterns, climate variables and calibrated archetypes.

```
PeakDemand_r = max_t D(r,t)
```

Part V — Industry, Minerals and Agriculture Coupling

§16 Industrial load model

Each plant in the Industry & Manufacturing module should include technology-specific electricity and thermal-energy coefficients, operating schedule, power factor, critical-load status and potential demand response.

```
D_IND(i,l,t) = Capacity(i,l) · Utilisation(i,t) · ElectricityIntensity(i)
```

§17 Industrial connection model

The energy system must test whether candidate industrial sites are connectable at acceptable cost and reliability. Connection costs and electricity prices return to the industrial location model.

```
ConnectionCost(i,l) = SubstationCost + SpurLineCost + ReinforcementCost + ConnectionFee
```

§18 Mining and beneficiation

Mine loads are often large, remote and reliability-sensitive. The model should compare grid extension, dedicated renewable systems, hybrid systems and self-generation.

```
D_MIN(m,l,t)=MineOutput(m,l,t)·MineIntensity(m)+BeneficiationOutput(m,l,t)·BeneficiationIntensity(
m)
```

§19 Agricultural energy demand

Irrigation demand should be weather- and season-dependent. Cold-chain demand should be linked to agricultural production and perishability. Agro-processing should pass through the Industry module where a plant is formally represented.

```
D_AG = D_irrigation + D_coldchain + D_processing + D_mechanisation + D_water
```

```
P_pump = ρ·g·Q·H/η
```

Part VI — Transport Electrification and Sector Coupling

§20 Electric vehicle demand

Charging scenarios should include uncontrolled home charging, time-of-use response, depot charging, public fast charging, smart charging and vehicle-to-grid.

```
E_EV(r,y)=Vehicles_EV(r,y)·kmPerVehicle(r,y)·kWhPerKm(r,y)
```

```
D_EV(r,t)=E_EV(r,y)·ChargingShape(r,t)
```

§21 Electric rail and public transport

```
E_rail = PassengerKm·Intensity_passenger + TonneKm·Intensity_freight
```

§22 Sector coupling

The PyPSA representation should use energy carriers and conversion links to connect electricity with hydrogen, heat, fuels and transport where required. This enables consistent treatment of electrolysers, fuel cells, synthetic fuels, heat pumps and flexible demand.

§23 Demand response

Flexible industrial loads, irrigation pumping, water pumping, cold storage, EV charging and electrolysers should be eligible for demand response under explicit comfort, production and state constraints.

```
Σ_t ShiftDown(t) = Σ_t ShiftUp(t)
```

Part VII — Renewable Resource and Project Planning

§24 Renewable technical potential

Land eligibility should exclude protected areas, unsuitable slopes, water bodies, dense settlements and other restrictions appropriate to each technology.

```
Potential(g,k)=EligibleArea(g,k)·CapacityDensity(k)
```

```
AvailableGeneration(g,k,t)=Capacity(g,k)·CapacityFactor(g,k,t)
```

§25 Candidate project generation

EDIS should convert continuous resource maps into candidate project polygons or buses with resource quality, maximum MW, grid distance, road accessibility, land conflicts, climate risks and cost adders.

§26 Renewable project score

This screening score is for prioritisation and pre-processing. Final selection should occur inside the system optimisation.

```
Score(p)=w_CF·CF(p)-w_grid·GridCost(p)-w_road·RoadCost(p)-w_land·LandRisk(p)-
w_climate·ClimateRisk(p)
```

§27 Technology-specific requirements

Part VIII — Generation Expansion and Dispatch

§28 Core capacity-expansion objective

All costs should be annualised consistently or discounted over investment periods. Existing assets are fixed unless retirement decisions are explicitly represented.

```
Min C = Σ_g InvCost_g·K_g + Σ_l InvCost_l·F_l + Σ_s InvCost_s·S_s + Σ_t,g VarCost_g·P_g,t + Σ_t
VOLL·LS_t
```

§29 Nodal balance

```
Σ_g∈n P_g,t + Σ_l InFlow_l,n,t + Discharge_n,t = Demand_n,t + Σ_l OutFlow_n,l,t + Charge_n,t +
Curtailment_n,t
```

§30 Generator limits

```
0 ≤ P_g,t ≤ Availability_g,t · K_g
```

§31 Ramping and unit commitment

Detailed unit commitment should be activated only when computationally justified. Long-run planning models may use linear approximations, while short-run operational studies can add commitment and minimum-load constraints.

```
-RampDown_g ≤ P_g,t-P_g,t-1 ≤ RampUp_g
```

§32 Multi-period investment

Investment periods should reflect asset lifetimes, construction lead times, cost learning and policy milestones.

```
K_g,y = Existing_g,y + Σ_τ≤y Build_g,τ − Retirements_g,y
```

Part IX — Transmission and Network Development

§33 Linear power-flow representation

The exact formulation should follow the PyPSA network representation and remain internally consistent with AC/DC component types.

```
F_l,t = B_l(θ_from(l),t - θ_to(l),t)
```

```
-Fmax_l ≤ F_l,t ≤ Fmax_l
```

§34 Transmission expansion

```
Fmax_l = ExistingFmax_l + NewF_l
```

```
Minimise generation + storage + transmission + load-shedding cost
```

§35 Candidate corridors

Candidate lines should be generated from existing substations, high-resource renewable zones, industrial/mining hubs, future demand centres and cross-border interconnectors. Environmental and right-of-way constraints must be recorded.

§36 Grid adequacy metrics

- line loading and congestion hours
- marginal prices by bus/zone
- curtailment caused by grid limits
- EENS and load shedding by zone
- network losses
- required reinforcement MW/MVA
- shadow value of candidate corridors

Part X — Storage, Flexibility and Hydrogen

§37 Storage state equation

```
SOC_s,t = SOC_s,t-1·(1-loss_s) + η_c,s·Charge_s,t − Discharge_s,t/η_d,s
```

```
0 ≤ SOC_s,t ≤ EnergyCapacity_s
```

§38 Storage technologies

§39 Green hydrogen

Hydrogen demand should be linked to fertilizer, steel, heavy transport, long-duration storage and exports. Dedicated renewable hydrogen and grid-connected hydrogen should be separate policy cases.

```
H2_t = η_electrolyser · ElectricityToElectrolyser_t
```

§40 Flexibility valuation

The system should report avoided generation, storage and transmission investment attributable to flexible demand, together with the marginal value of additional flexibility.

Part XI — Hydropower, Water and Climate

§41 Reservoir balance

```
Storage_t+1 = Storage_t + Inflow_t − Release_t − Spill_t − Evaporation_t
```

```
Generation_t = η·ρ·g·Head_t·TurbineFlow_t
```

§42 Climate-conditioned hydro

Climate scenarios should modify inflows, evaporation and drought sequences. The model should distinguish long-run mean changes from extreme multi-year drought risks.

§43 Renewable climate sensitivity

Alternative climate/weather years should be used for solar, wind and hydro. Planning should not rely only on a single weather year.

§44 Climate-driven demand

```
CoolingDemand_t = f(Temperature_t, Income, AC_adoption)
```

§45 Asset resilience

Transmission, substations, generation sites and fuel infrastructure should be overlaid with flood, heat, wildfire, storm and coastal hazards. Resilience investments can be modelled as cost adders, derating reductions or avoided outage probabilities.

Part XII — Electricity Access and Decentralised Systems

§46 Settlement-level technology choice

The access model should incorporate service-tier requirements, expected demand growth, productive use, distance to grid, terrain, settlement density and future grid arrival.

```
Tech(v)=argmin{LCOE_grid(v), LCOE_minigrid(v), LCOE_SHS(v)}
```

§47 Grid-extension cost

```
Cost_grid(v)=MVLine+LVNetwork+Transformer+Connection+UpstreamReinforcement
```

§48 Mini-grid optimisation

Mini-grids should be optimised hourly using local renewable profiles and demand. Future interconnection with the main grid should be represented through salvage/reuse assumptions.

```
Min C = CAPEX_PV + CAPEX_Battery + CAPEX_Backup + Fuel + Distribution + O&M + VOLL·Unserved
```

§49 Access metrics

- new connections
- population gaining access
- cost per connection
- annual energy served
- service tier
- productive-use share
- grid/mini-grid/SHS split
- subsidy requirement

Part XIII — Regional Power Pools and Energy Trade

§50 Regional model scope

EDIS should support national models embedded in regional power-pool models. Cross-border buses and lines should preserve country identifiers so that trade, congestion rents, import dependence and investment costs can be allocated by country.

§51 Trade balance

```
NetImport(c,t)=Σ_in F_l,t − Σ_out F_l,t
```

```
AnnualTradeValue(c)=Σ_t NetImport(c,t)·BorderPrice(c,t)
```

§52 Interconnector economics

Each proposed interconnector should be assessed for investment cost, congestion relief, reserve sharing, renewable integration, avoided domestic generation and distribution of benefits between countries.

§53 Power-pool scenarios

- isolated national planning
- existing interconnectors only
- committed interconnectors
- full least-cost regional expansion
- energy-security constrained trade
- drought-sharing scenario
- high-renewables regional integration

Part XIV — Reliability, Adequacy and Resilience

§54 Reliability cost

```
ReliabilityCost = VOLL · EENS
```

```
EENS = Σ_t LoadShedding_t · weight_t
```

§55 Adequacy

Planning should combine deterministic reserve margins with chronological stress tests. For systems with high variable renewables, effective capacity and correlated weather events are more informative than nameplate reserve margins alone.

§56 Contingency analysis

Security-constrained or post-optimisation contingency studies should test credible line/generator outages. Critical buses, corridors and plants should be reported.

§57 Stress-test library

- major hydro drought
- gas/fuel supply interruption
- largest unit outage
- interconnector outage
- high temperature and cooling demand
- renewable low-output week
- flooded substation/corridor
- rapid industrial-load commissioning

Part XV — Tariffs, Utility Finance and Affordability

§58 Revenue requirement

```
RR = GenerationCost + TransmissionCost + DistributionCost + O&M + DebtService + AllowedReturn +
Taxes − OtherIncome
```

```
AverageCostReflectiveTariff = RR / BilledEnergy
```

§59 Utility cash flow

```
BilledRevenue = Tariff · BilledEnergy
```

```
CashCollected = BilledRevenue · CollectionRate
```

```
UtilityCashGap = CashCollected + Subsidies − CashOperatingCost − DebtService
```

§60 Losses

```
EnergyPurchased = EnergySold + TechnicalLosses + CommercialLosses
```

§61 Tariff design

The tariff module should model lifeline, residential, commercial, industrial, mining and time-of-use tariffs. Cross-subsidies must be explicit. Cost-of-service allocation should distinguish generation, network, customer and demand-related costs.

§62 Affordability

Household survey data should be used to assess affordability and incidence of tariff reforms. Results can be passed to microsimulation.

```
EnergyBurden_h = HouseholdElectricityExpenditure_h / HouseholdTotalExpenditure_h
```

Part XVI — Fiscal Risk, PPAs and Public Investment

§63 Fiscal exposure

```
Exposure_p = Guarantees_p + TerminationLiability_p + FXExposure_p + FuelSupport_p +
UtilityArrears_p
```

```
ExpectedFiscalCost = Σ_p Probability_p · Exposure_p
```

§64 PPA stress testing

Power-purchase agreements should be stress-tested for demand shortfalls, currency depreciation, hydrological risk, fuel-price changes, delayed transmission, take-or-pay clauses and refinancing.

§65 Public investment

Energy projects should be integrated with the EDIS public-investment and budget-reallocation framework so that energy competes transparently with transport, health, education and other capital priorities.

```
PublicEnergyInvestment_t ≤ FiscalSpace_t + ConcessionalFinance_t + Grants_t
```

§66 Contingent liabilities dashboard

- PPA payment obligations
- government guarantees
- foreign-exchange exposure
- fuel-supply obligations
- utility arrears
- state-owned enterprise debt
- subsidy commitments
- project delay/termination exposure

Part XVII — Energy Investment Portfolio Optimisation

§67 Development objective

This EDIS layer should not replace PyPSA least-cost optimisation. Instead it compares or selects among physically feasible PyPSA-derived portfolios and other public-energy investments using broader development objectives.

```
Max Z = α·GDP + β·Jobs + γ·Access + δ·Reliability + θ·IndustrialSupport − λ·FiscalRisk −
μ·Emissions
```

§68 Budget constraint

```
Σ_p Investment_p·x_p ≤ AvailableFinance
```

§69 Sequencing constraints

For example, industrial-load growth may require a substation and line before plant commissioning; hydropower may require transmission evacuation; mini-grid investments may be delayed where main-grid extension is imminent.

```
x_project,t ≤ x_enabling_infrastructure,t
```

§70 Multi-criteria results

- least financial cost
- least economic cost
- maximum GDP/jobs
- maximum access
- minimum emissions
- minimum fiscal exposure
- balanced development portfolio
- Pareto frontier

Part XVIII — CDCGE Integration

§71 Energy-to-CDCGE mapping

§72 CDCGE-to-energy mapping

§73 Iterative coupling algorithm

```
Convergence if |D^(k)-D^(k-1)|/D^(k-1) < ε_D and |P^(k)-P^(k-1)|/P^(k-1) < ε_P
```

§74 Avoiding double counting

Investment costs, electricity price shocks, productivity effects and subsidy transfers must be mapped carefully to avoid counting the same intervention multiple times. Every mapping should have an accounting memo that identifies the corresponding CDCGE account and closure treatment.

Part XIX — Scenario Framework

§75 Standard scenario catalogue

§76 Scenario metadata

- scenario ID
- base year
- planning horizon
- weather years
- investment periods
- demand pathway
- fuel prices
- technology costs
- discount/WACC
- carbon policy
- reliability target
- access target
- trade assumptions
- CDCGE closure

Part XX — Software and Repository Architecture

§77 Recommended repository

- EDIS/energy/pypsa_earth_upstream/
- EDIS/energy/config/

- EDIS/energy/adapters/{industry,minerals,agriculture,transport,population,climate,cdcge}/
- EDIS/energy/demand/
- EDIS/energy/access/
- EDIS/energy/minigrids/
- EDIS/energy/hydrogen/
- EDIS/energy/tariffs/
- EDIS/energy/utility_finance/
- EDIS/energy/fiscal_risk/
- EDIS/energy/investment_portfolio/
- EDIS/energy/scenarios/
- EDIS/energy/api/
- EDIS/energy/agents/
- EDIS/energy/results/
- EDIS/energy/tests/

§78 Python/Julia division of labour

§79 Interchange formats

- Parquet/Arrow for large tabular exchange
- NetCDF for time-series and gridded resources
- GeoPackage/GeoParquet for GIS
- CSV for simple audited interfaces
- JSON/YAML for configuration
- PyPSA NetCDF network snapshots for solved network persistence

§80 API contract

Part XXI — Dashboard and User Experience

§81 Core dashboard tabs

- Energy Overview
- Demand
- Grid
- Generation
- Renewables
- Hydro
- Transmission
- Storage
- Electricity Access
- Mini-Grids
- Industry & Mining Loads
- Transport Electrification
- Hydrogen
- Power Pools
- Tariffs
- Utility Finance
- Fiscal Risk
- Climate Risk
- Investment Planning
- CDCGE Impacts
- Scenario Comparison

§82 Spatial interface

The map should display buses, lines, plants, candidate renewable zones, industrial/mining loads, settlements, mini-grids, planned projects and climate hazards. Users should be able to click any object to inspect technical, financial and scenario attributes.

§83 Scenario comparison

Every dashboard should allow baseline-versus-policy comparisons with differences in installed capacity, generation, transmission, curtailment, marginal prices, access, emissions, investment, fiscal exposure and CDCGE outcomes.

Part XXII — AI Agent Architecture

§84 Agent roles

§85 Agent governance

Agents may orchestrate models and explain results but may not invent model outputs. Every numeric result must be traceable to a run ID, dataset version, configuration and solver status. Agents should stop or flag scenarios with failed optimisation, infeasibility, unbalanced interfaces or missing critical data.

Part XXIII — Calibration, Validation and Diagnostics

§86 Baseline calibration

- match national generation totals by technology
- match annual electricity consumption
- match peak demand
- match major cross-border trade
- match installed generation capacities
- match key transmission corridors
- match hydro seasonal generation
- reproduce major tariff/revenue statistics

§87 Physical validation

Energy-balance residuals should be reported explicitly. Material time-series gaps may not be silently filled without flags.

```
Generation + NetImports = Demand + StorageLosses + NetworkLosses + Curtailment_Adjustment
```

§88 Optimisation diagnostics

- solver termination condition
- objective value
- infeasibility report
- unserved energy
- binding global constraints
- capacity bounds
- line overloads
- extreme nodal prices
- curtailment
- snapshot weighting audit

§89 Cross-sector validation

Industrial, mining and transport loads must reconcile to the sector modules. The same plant should not appear twice through aggregate demand and project-level additions. A demand ledger should show the provenance of every major load.

§90 CDCGE interface audit

- shock name
- energy source variable
- CDCGE target account/parameter
- units
- base value
- shock value
- sign convention
- closure treatment
- double-counting check

Part XXIV — Implementation Roadmap

§91 Phase 1: Foundation

Establish country configuration, energy database, GIS layers, PyPSA-Earth upstream environment, demand ledger, technology cost database and baseline network.

§92 Phase 2: Core power-system planning

Implement baseline demand, renewable profiles, generation/transmission expansion, storage and dispatch, with reproducible scenario management.

§93 Phase 3: Cross-sector coupling

Connect Industry, Minerals, Agriculture, Transport and Population modules and introduce explicit large-project loads.

§94 Phase 4: Access and decentralised systems

Implement settlement-level grid/minigrid/standalone planning and productive-use demand.

§95 Phase 5: Finance, tariff and fiscal risk

Add utility cash flow, tariffs, subsidies, PPAs and contingent liabilities.

§96 Phase 6: CDCGE integration

Build audited two-way energy-economy interface and iterative convergence workflow.

§97 Phase 7: AI and decision-support

Deploy agents, scenario dashboards, project ranking, investment portfolio tools and automated technical reporting.

A.3 The specification's own tables

17 tables appear in the specification. They are reproduced here because several of them are the only place a parameter or a convention is written down.

Item	Specification
Document	EDIS Integrated Energy Planning System Technical Manual
Version	1.0
Date	August 2026

Item	Specification
Primary computational engines	PyPSA-Earth / PyPSA; EDIS Julia/JuMP; CDCGE
Core purpose	Integrated national and regional energy planning linked to economic tr
Spatial scope	Country, subnational, power-pool and continental Africa
Planning horizon	Historical calibration through 2050/2060, configurable
Primary users	Energy ministries, utilities, regulators, planning ministries, investm

Table 79. Specification table 0.

Layer	Primary role	Representative outputs
EDIS Data & GIS	Harmonise spatial, technical, economic and sector data	Nodes, assets, profiles, resource potentials
Sector Demand Adapters	Translate EDIS sector plans into energy demand	Hourly/annual loads by location and carrier
PyPSA-Earth	Build spatial network and renewable/resource representations	Base network, clustered network, profiles
PyPSA Optimisation	Dispatch, power flow and capacity expansion	Optimal capacities, dispatch, flows, prices
EDIS Planning Layer	Access, tariffs, finance, fiscal risk, portfolio ranking	Investment programme and policy metrics
CDCGE Interface	Economy-wide propagation and feedback	GDP, jobs, trade, fiscal, household effects
AI Agent Layer	Orchestration, diagnostics and explanation	Scenario construction and planning reports

Table 80. Specification table 1.

Domain	Examples	Key fields
Grid	Buses, substations, AC lines, HVDC, transformers	geometry, voltage, capacity, impedance, status
Generation	Hydro, thermal, solar, wind, geothermal, biomass	technology, MW, efficiency, fuel, commissioning, coordinates
Demand	Utility load, settlements, industry, mines, transport	location, time series, sector, voltage level
Renewables	Solar/wind/hydro resource and land availability	capacity factor, potential MW, exclusions
Fuels	Gas, oil, coal, biomass, hydrogen	price, availability, import/domestic source, emissions factor
Storage	Battery, pumped hydro, hydrogen, thermal	power MW, energy MWh, efficiency, duration
Economics	CAPEX, FOM, VOM, WACC, lifetime	technology, year, currency, source
Access	Population, electrification, settlement size	grid distance, demand tier, connections
Climate	Temperature, rainfall, streamflow, hazards	time, scenario, grid/basin
Finance/Fiscal	Tariffs, collections, debt, PPAs, subsidies	utility/project, currency, maturity, guarantee

Table 81. Specification table 2.

Adapter	Direction	Purpose
industry_to_energy	EDIS → PyPSA	Add industrial park/plant loads and profiles
minerals_to_energy	EDIS → PyPSA	Add mine/beneficiation loads
transport_to_energy	EDIS → PyPSA	Add EV/rail/charging demand and

Adapter	Direction	Purpose
		flexibility
agriculture_to_energy	EDIS → PyPSA	Add irrigation/cold-chain/agro-processing demand
climate_to_energy	EDIS → PyPSA	Modify hydro, renewables, demand and outage assumptions
energy_to_cdcge	PyPSA → CDCGE	Translate costs, prices, investment, imports and emissions
cdcge_to_energy	CDCGE → EDIS	Update GDP, sector output, income and demand drivers

Table 82. Specification table 3.

Technology	Critical variables
Solar PV	GHI, temperature, tilt, land, inverter, degradation
Onshore wind	Wind speed profile, hub height, roughness, wake/land constraints
Offshore wind	Bathymetry, shore distance, cable cost, maritime exclusions
Hydro	Flow, head, reservoir, environmental flow, drought
Geothermal	Resource temperature, drilling risk, location, steam field
Biomass	Feedstock supply, competing uses, delivered cost, sustainability

Table 83. Specification table 4.

Technology	Planning representation
Li-ion battery	MW/MWh, charge/discharge efficiency, degradation/cycle cost
Pumped hydro	Reservoir energy, turbine/pump MW, geographic potential
Hydrogen storage	Electrolyser, store, compressor, fuel cell/turbine or demand
Thermal storage	Heat carrier, charging technology, standing losses
EV flexibility	Available battery energy and connection windows

Table 84. Specification table 5.

Energy result	CDCGE shock/channel
Generation/transmission investment	Investment demand; capital formation; imports of equipment
Electricity price	Electricity commodity price / production cost
Reliability improvement	Sector productivity / loss reduction
Fuel use/imports	Fuel import demand and trade balance
Electricity imports/exports	External trade flows
Tariff/subsidy	Household/firm prices and government transfers
Utility losses	Efficiency/productivity assumptions
Carbon emissions	Environmental satellite accounts/carbon tax
Access expansion	Household electricity consumption and productivity channels
Industrial connection	Sector capacity/productivity/investment shock

Table 85. Specification table 6.

CDCGE output	Energy demand/planning feedback
GDP and sector output	Update industrial/commercial energy demand
Household income	Update appliance ownership and residential consumption
Wages	Update project and O&M labour costs
Exchange rate	Update imported fuel/equipment costs and PPA exposure

CDCGE output	Energy demand/planning feedback
Investment	Update project timing and capital demand
Population/household welfare	Update access and affordability assumptions
Trade/industry structure	Update fuel demand and industrial electricity loads

Table 86. Specification table 7.

Scenario	Core assumptions
Baseline	Committed projects, central demand, current policies
Universal Access	Accelerated grid/minigrid/SHS to target year
Industrialisation	Industry module high-growth manufacturing plan
Mineral Beneficiation	Major mining/refining/smelting loads
Transport Electrification	EV, bus and rail electrification
Renewable Acceleration	High renewable build, fossil restrictions
Regional Integration	Expanded cross-border transmission and trade
Hydro Expansion	Hydro pipeline with climate stress tests
Green Hydrogen	Electrolyser, industry and export demand
Climate Stress	Drought, heat and extreme-event assumptions
Fuel Price Shock	High oil/gas/coal import prices
Net Zero	Carbon budget or emissions trajectory
Fiscal Constraint	Restricted public investment/guarantee envelope
Development Optimal	Portfolio selected using GDP/jobs/access/fiscal criteria

Table 87. Specification table 8.

Environment	Primary responsibilities
Python	PyPSA, PyPSA-Earth, geospatial preprocessing, weather profiles, networ
Julia	JuMP portfolio optimisation, fiscal/tariff models where preferred, CDC
Genie.jl/API	EDIS application orchestration, scenario management and results serv
Database/GIS	Versioned datasets, spatial layers, model-run metadata and results

Table 88. Specification table 9.

Endpoint/function	Purpose
build_energy_scenario	Create scenario from sector assumptions
run_pypsa	Build/solve selected PyPSA network
get_energy_prices	Return nodal/zonal marginal prices
get_investment_plan	Return generation/storage/network investments
get_reliability	Return EENS/load shedding/congestion metrics
run_access_plan	Grid/minigrid/SHS allocation
run_tariff_finance	Tariff, utility and subsidy outputs
export_cdcge_shocks	Produce audited CDCGE interface package
ingest_cdcge_results	Update macro demand drivers

Table 89. Specification table 10.

Agent	Responsibilities
Demand Agent	Build and reconcile sectoral spatial demand

Agent	Responsibilities
Renewables Agent	Generate and screen candidate renewable zones/projects
Grid Agent	Diagnose congestion and candidate network expansion
Generation Agent	Configure and run PyPSA capacity-expansion scenarios
Access Agent	Plan grid/minigrid/standalone electrification
Industrial Energy Agent	Reconcile industrial plants and energy supply
Mining Energy Agent	Reconcile mines/beneficiation and power needs
Transport Energy Agent	Build EV/rail charging and flexibility cases
Hydrogen Agent	Build electrolyser/storage/demand scenarios
Utility Finance Agent	Assess tariffs, losses, cash flow and affordability
Fiscal Risk Agent	Assess PPAs, guarantees and contingent liabilities
Climate Energy Agent	Construct weather/hydro/hazard stress cases
CDCGE Agent	Construct and validate macroeconomic mappings
Energy Planning Agent	Synthesize investment programme and trade-offs

Table 90. Specification table 11.

Symbol	Description	Typical unit
n	Grid bus/node	index
l	Transmission line/link	index
g	Generator/technology	index
s	Storage technology	index
t	Snapshot/hour	hour
y	Investment period/year	year
r	Region/zone	index
v	Settlement	index
i	Industry	index
m	Mineral	index
c	Country	index
k	Energy carrier	index
P	Power	MW
E	Energy	MWh/GWh
K	Installed capacity	MW
F	Transmission capacity/flow	MW
SOC	Stored energy	MWh

Table 91. Specification table 12.

EDIS concept	Likely PyPSA component/attribute	Notes
Grid node	Bus	country, carrier, coordinates retained
Thermal/renewable plant	Generator	p_nom, p_nom_extendable, marginal_cost, p_max_pu
Electricity demand	Load	p_set time series
Transmission line	Line	s_nom, x/r, extendable as required
HVDC/interconnector	Link	p_nom, efficiency, bidirectional settings
Battery power/energy	StorageUnit or Store+Link	choose formulation by analysis need
Hydrogen/electrolyser	Link + Store + Bus	multi-carrier sector coupling
Hydro reservoir	StorageUnit/Store-linked representation	calibrate inflows and energy capacity

EDIS concept	Likely PyPSA component/attribute	Notes
Load shedding	High-cost Generator or supported optimisation helper	used for EENS/VOLL
Emissions cap	GlobalConstraint	carrier emissions attributes
Technology potential	GlobalConstraint / p_nom_max	land/resource constraint

Table 92. Specification table 13.

File	Minimum fields
industry_loads.parquet	plant_id,bus/lat/lon,year,MW_peak,GWh,profile_id,criticality
mining_loads.parquet	mine_id,commodity,bus/lat/lon,year,MW,GWh,stage
transport_loads.parquet	zone,year,vehicle_type,GWh,profile_id,flexibility
agriculture_loads.parquet	zone,year,use_type,GWh,profile_id,season
population_demand.parquet	grid/settlement,year,population,access,kWh_per_capita
climate_scenarios.parquet	scenario,weather_year,temperature/hydro/resource modifiers
cdcge_shocks.csv	scenario,variable,sector,base,shock,unit,sign,mapping_note
cdcge_feedback.csv	scenario,year,GDP,sector_output,income,exchange_rate,other_drivers

Table 93. Specification table 14.

Field	Required value
run_id	unique identifier
scenario_id	scenario configuration
country/region	model scope
pypsa_version	exact version
pypsa_earth_commit	git commit/tag
solver	name/version
weather_years	list
investment_periods	list
snapshot_reduction	method/weights
data_version	warehouse release
demand_version	sector demand ledger version
objective_value	reported after solve
termination_status	solver status
EENS	MWh
curtailment	MWh
emissions	tCO2e
cdcge_export	file hash/path

Table 94. Specification table 15.

Output group	Core indicators
Capacity	existing/new/retired MW by technology and zone
Generation	MWh/GWh by generator, carrier, region, time
Transmission	flows, congestion, new MW-km, interconnector trade
Storage	MW, MWh, cycles, charging/discharging, SOC
Prices	nodal/zonal marginal prices, system average
Reliability	EENS, load shedding, reserve metrics
Renewables	curtailment, capacity factors, utilised potential
Access	connections, population, technology choice, cost

Output group	Core indicators
Finance	CAPEX, OPEX, financing need, tariff requirement
Fiscal	subsidies, guarantees, expected contingent liabilities
Emissions	CO_2e by fuel/technology/sector
CDCGE	GDP, jobs, trade, fiscal revenue, household income, poverty linkage

Table 95. Specification table 16.

Appendix B — Equation identifiers and where they are implemented

The 43 equation identifiers that appear as comments in the Julia source. An identifier here is a promise that the specification and the implementation are talking about the same equation.

Identifier	Family	Appears in this manual at
E-ACC-01	E-ACC	Chapter 15
E-ACC-02	E-ACC	Chapter 15
E-BAL-01	E-BAL	Chapter 11
E-BAL-02	E-BAL	Chapter 11
E-BOE-01	E-BOE	—
E-CAP-00	E-CAP	Chapter 10
E-CAP-01	E-CAP	Chapter 10
E-CAP-02	E-CAP	Chapter 10
E-CLI-01	E-CLI	—
E-CLI-02	E-CLI	—
E-DEM-01	E-DEM	Chapter 8
E-DEM-02	E-DEM	Chapter 8
E-DEM-03	E-DEM	Chapter 8
E-DIST-01	E-DIST	—
E-DIST-02	E-DIST	—
E-DSP-01	E-DSP	Chapter 11
E-DSP-03	E-DSP	Chapter 11
E-EMI-01	E-EMI	Chapters 11 and 18
E-EQU-01	E-EQU	Chapter 20
E-EQU-02	E-EQU	Chapter 20
E-EQU-03	E-EQU	Chapter 20
E-EXP-01	E-EXP	Chapter 12
E-EXP-02	E-EXP	Chapter 12
E-FIN-01	E-FIN	Chapter 16
E-FIN-02	E-FIN	Chapter 16
E-FIN-03	E-FIN	Chapter 16
E-FIN-04	E-FIN	Chapter 16
E-FUE-01	E-FUE	Chapter 18
E-FUE-02	E-FUE	Chapter 18
E-FUE-03	E-FUE	Chapter 18
E-GIS-01	E-GIS	—
E-GIS-02	E-GIS	—
E-INV-01	E-INV	—
E-INV-02	E-INV	—
E-MAC-01	E-MAC	Chapter 19
E-MAC-02	E-MAC	Chapter 19

Identifier	Family	Appears in this manual at
E-MAC-03	E-MAC	Chapter 19
E-MTEF-01	E-MTEF	—
E-MTEF-02	E-MTEF	—
E-MTEF-03	E-MTEF	—
E-OPS-01	E-OPS	—
E-UCSN-01	E-UCSN	—
E-UCSN-02	E-UCSN	—

Table 96. Equation identifiers, families, and the chapters that use them.

Appendix C — Every number this manual quotes, and its source

The register a reader needs in order to check anything in this manual without rerunning the build.

C.1 From the dispatch

Quantity	Value	Source
carbon_price	25	energy_run.jl, run_economic_dispatch
emissions_t	333,756	energy_run.jl, run_economic_dispatch
generation_mwh	3,592,841	energy_run.jl, run_economic_dispatch
objective	788,931,680	energy_run.jl, run_economic_dispatch
status	ok:optimal	energy_run.jl, run_economic_dispatch
unserved_mwh	69,369	energy_run.jl, run_economic_dispatch
unserved_share	0	energy_run.jl, run_economic_dispatch
access_sites	40	energy_run.jl, load_energy_data
annual_mwh	3,485,162	energy_run.jl, load_energy_data
availability_rows	36	energy_run.jl, load_energy_data
buses	24	energy_run.jl, load_energy_data
candidates	3	energy_run.jl, load_energy_data
demand_rows	288	energy_run.jl, load_energy_data
hydro	6	energy_run.jl, load_energy_data
lines	30	energy_run.jl, load_energy_data
load_factor	1	energy_run.jl, load_energy_data
peak_mw	474	energy_run.jl, load_energy_data
storage	1	energy_run.jl, load_energy_data
technologies	5	energy_run.jl, load_energy_data

Table 97. The dispatch and the case, cell by cell.

C.2 From the second-stage run

Block	Key	Value
access_equity	gap	1
access_equity	national_access	0
access_equity	rural	0
access_equity	urban	1
calibration	allowed_return	0
calibration	annuity_25y_8pc	0
calibration	asset_base	1,183,266,916
calibration	depreciation	47,330,677
calibration	opex_from_dispatch	86,899,200
calibration	revenue_requirement	228,891,230
calibration	unmatched_carrier_mw	62

Block	Key	Value
cge_loop	base_price	200
cge_loop	converged	1
cge_loop	cost_share	0
cge_loop	final_price	13
cge_loop	iterations	3
cge_loop	pass_through	1
cooking	annual_emissions_t	2,461,228
cooking	annual_time_saved_hours	1,197,797,549
cooking	households_reached	4,102,046
cooking	total_capex	102,551,160
emission_intensity		0
energy_to_macro	electricity_price	12
energy_to_macro	electricity_supply_mwh	3,592,841
energy_to_macro	emissions_t	333,756
energy_to_macro	fuel_import_bill	157,500,000
energy_to_macro	generation_cost	95,243,100
energy_to_macro	investment	0
energy_to_macro	run_id	energy-macro-20260824-114844-2ae31
energy_to_macro	scenario	baseline
energy_to_macro	subsidy_cost	0
energy_to_macro	tax_revenue	22,500,000
energy_to_macro	unserved_mwh	69,369
energy_to_macro	utility_borrowing	0
energy_to_macro	year	2,026
finance	cost_recovery	1
finance	dscr	Inf
finance	ebitda	141,992,030
finance	financing_gap	0
finance	net_income	94,661,353
finance	revenue	228,891,230
finance	revenue_requirement	228,891,230
network_expansion	added_mw	0
network_expansion	feasible	1
network_expansion	lines_reinforced	0
network_expansion	objective	598,146,149
network_expansion	reinforcement_cost	0
network_expansion	unserved_mwh	69,369
subsidy	shadow_price_per_mwh	12
subsidy	subsidy_per_mwh	-0

Table 98. Tariffs, finance, emissions, cooking, equity and the macro payload.

C.3 From the survey

Indicator	Value
burden_over_10pc	0
burden_over_5pc	0
charcoal_stove	0
connection_rate	0
connection_rate_unweighted	0
electric_stove	0
households	3,062
mean_elec_spend_month	15,480
mean_energy_share	0
mean_energy_spend_month	13,308
median_elec_spend_month	13,500
poverty_rate	0
rural_connection	0
urban_connection	1

Table 99. Uganda LSMS-ISA National Panel Survey 2019/20 (UNPS), survey-weighted national estimates.

C.4 From the spatial layers

Layer	Quantity	Value
gadm	adm1	58
gadm	adm2	166
gridfinder	features	3,216
gridfinder	total_km	14,323
settlements	access_by_nightlight_pop_weighted	1
settlements	adm2_rows	166
settlements	buildings_total	13,701,989
settlements	connections_equals_buildings_share	1
settlements	connections_is_a_measurement	0
settlements	connections_total	13,701,989
settlements	dist_grid_km_median_lit	0
settlements	dist_grid_km_median_unlit	2
settlements	dist_to_grid_km_p25	0
settlements	dist_to_grid_km_p50	2
settlements	dist_to_grid_km_p75	4
settlements	dist_to_grid_km_p90	8
settlements	features	67,650
settlements	mean_pv_value	1,615
settlements	mean_rwi	0
settlements	pop_share_within_10km	1
settlements	pop_share_within_1km	1
settlements	pop_share_within_25km	1

Layer	Quantity	Value
settlements	pop_share_within_50km	1
settlements	pop_share_within_5km	1
settlements	population_largest_cluster	7,613,045
settlements	population_median_cluster	144
settlements	population_share_top_10_clusters	0
settlements	population_share_top_1pc_clusters	1
settlements	population_total	48,656,094
settlements	pv_value_lit	1,618
settlements	pv_value_unlit	1,615
settlements	rwi_lit	0
settlements	rwi_unlit	-0
settlements	settlements_with_nightlight	0
settlements	unlit_population	23,352,309
settlements	unlit_settlements	64,920
substations	features	56
transmission	features	78
transmission	total_km	5,852
wri	africa_capacity_gw	159
wri	africa_plants	615
wri	commissioning_known	0
wri	global_plants	34,936
wri	uganda_capacity_mw	772
wri	uganda_plants	11

Table 100. Every scalar the spatial analysis produced.

C.5 From the macro chain and the microsimulation

Block	Key	Value
cdcge	clean_share_as_exported	0
cdcge	clean_share_energy_model	1
cdcge	generation_dropped_mwh	2,918,832
cdcge	generation_dropped_share	1
cdcge	generation_total_mwh	3,592,841
cdcge	power_abatement_0_to_100	0
cdcge	total_generation_mwh	3,592,841
adequacy	balance_residual_mwh	0
adequacy	demand_mwh	3,485,162
adequacy	generation_mwh	3,592,841
adequacy	hydro_continuous_mw	333
adequacy	hydro_implied_capacity_factor	0
adequacy	hydro_nameplate_mw	666
adequacy	loss_share_of_generation	0
adequacy	losses_mwh	177,048

Block	Key	Value
adequacy	nameplate_total_mw	772
adequacy	peak_demand_mw	474
adequacy	served_mwh	3,415,793
adequacy	units_at_their_energy_limit	8
adequacy	units_total	11
adequacy	unserved_mwh	69,369
poverty	carbon_price_abates	0
poverty	carbon_revenue_at_100	33,375,600
poverty	emissions_at_every_carbon_price_t	333,756
poverty	n_households	3,062
poverty	population_weighted	37,840,792

Table 101. The CDCGE handoff, the energy balance and the poverty microsimulation.

Appendix D — Figures

Figure	Kind	Caption	Source
fig_access_budget	chart	How much access each additional billion buys.	run_electrification_plan() budget sweep
fig_access_distance	chart	The unlit population by distance to the network, and what sits in each ban	DRE settlement layer
fig_access_four_ways	chart	Four defensible electricity access rates for the same country in the same	LSMS, model basis, estate household table, settlemen
fig_access_plan	chart	The least-cost electrification plan by technology.	run_electrification_plan()
fig_aegid_coverage	chart	The continental energy data estate, by theme and country.	aegid_by_theme.csv and aegid_by_country.csv
fig_asset_base	chart	How the regulated asset base is built, plant by plant.	existing capacity at candidate overnight costs
fig_availability	chart	Acquisition status of the 940 country-dataset pairs the register tracks.	AEGID availability register
fig_burden	chart	Energy burden across the consumption distribution and between town and cou	Uganda LSMS-ISA 2019/20
fig_carbon_price_response	chart	What each climate lever costs, and what it buys.	cge_scenario_response.csv — seven CDCGE policy scena
fig_carbon_sweep	chart	What a carbon price does to this system: cost, emissions, unserved energy.	run_economic_dispatch() at four carbon prices
fig_cge_contract	chart	The contract between the energy model and CDCGE, and the two places it bre	PowerLink.jl and MacroCGELink.jl
fig_cge_convergence	chart	The energy–macro fixed point.	iterate_energy_macro()
fig_cge_defect	chart	The electricity mix CDCGE would be calibrated on, before and after the one	PowerLink.power_shares_from_generation()
fig_cge_response	chart	The same policy question asked of both models.	energy carbon sweep against CDCGE mitigation run
fig_climate_stress	chart	Dispatch under the estate's hydrological cases.	climate_stress_test()
fig_cooking	chart	The clean-cooking portfolio and what each 10 points of coverage costs.	run_clean_cooking()
fig_cost_recovery	chart	The utility's income statement under the designed tariff, and why it canno	utility_finance()
fig_demand_path	chart	Demand to 2040 under the projection the estate's own driver function produ	simulate_demand_path()
fig_diagnostics	chart	The estate's own data diagnostics on the Uganda case, table by table.	diagnose_data() output
fig_emissions	chart	The multi-pollutant inventory and where the emissions come from.	emissions_inventory()
fig_energy_ladder	chart	The nine-fuel energy ladder, by consumption quintile.	Uganda LSMS-ISA 2019/20, module 10
fig_energy_limits	chart	Every dispatchable unit runs at exactly its energy limit.	uga_energy_adequacy
fig_energy_security	chart	Fuel balance and import exposure.	fuel_balance(), energy_security_indicators()
fig_estate	chart	The estate by layer: where each kind of energy number is produced, and how	EDIS Energy Modelling estate, module line counts
fig_expansion	chart	The generation expansion plan, with and without a 40 % renewable target.	run_generation_expansion()
fig_generation_mix	chart	Generation by technology in the solved dispatch.	run_economic_dispatch(), carbon price 25

Figure	Kind	Caption	Source
fig_governance	chart	Licence and redistribution status of the 618 datasets in the continental r	AEGID inventory register
fig_investment	chart	What the whole programme costs, by category.	investment_analysis()
fig_lcoe_canonical	chart	Levelised cost by technology, as the bridge carries it.	cge_lcoe_canonical.csv
fig_ldc	chart	The load-duration curve of the Uganda case.	load_duration_curve() on demand.csv
fig_lifeline_sweep	chart	How the cross-subsidy moves with the lifeline discount.	design_tariffs() at four discounts
fig_lighting	chart	What unconnected households light with.	Uganda LSMS-ISA 2019/20, module 10
fig_merit_order	chart	The merit order: what each unit costs to run and how much of it there is.	technologies.csv and hydro.csv
fig_microsim	chart	Poverty under each scenario: the price channel and the income channel.	LSMS-ISA microsimulation on the CDCGE paths
fig_mitigation_panel	chart	The mitigation panel the CGE returns for Uganda.	cge_uga_mitigation.csv and cge_uga_panel.csv
fig_network_reduction	chart	What clustering the survey layer into a solvable graph costs.	UETCL 2017 layer against the model's lines table
fig_no_grid_reasons	chart	Why unconnected households say they have no electricity.	Uganda LSMS-ISA 2019/20, s10q05c
fig_poverty_burden	chart	Who carries an electricity price rise, by quintile.	LSMS-ISA microsimulation
fig_power_mix_defect	chart	The power mix the bridge sends, and the defect that was found in it.	cge_power_mix, cge_power_mix_fixed, cge_mix_defect
fig_price_units	chart	The marginal price as the estate exports it, and as PyPSA computed it.	run_pypsa_case.py price export against the snapshot
fig_prices	chart	Locational shadow prices across buses and periods, against the tariff actu	dual values from the solved dispatch
fig_prod_lever	chart	The productivity lever the LCOE path hands the CGE.	PowerLink.power_prod_from_lcoe()
fig_reconciliation	chart	Five quantities, measured more than once.	energy_analysis.py reconciliation table
fig_reliability_question	chart	The reliability question the survey asks, and what it can support.	Uganda LSMS-ISA 2019/20, s10q02
fig_renewable_share_defect	chart	The estate's own headline indicator, hit by the same missing carrier.	dispatch_indicators() against the dispatch itself
fig_spec_map	chart	The technical manual as a map: how many specification sections and equatio	EDIS Energy Planning System Technical Manual
fig_subsidy_incidence	chart	Implicit subsidy per class under the designed tariff.	subsidy_incidence()
fig_system_load	chart	System load across the representative periods.	system_load() on demand.csv
fig_tariffs	chart	Cost-reflective, lifeline and standard tariffs by customer class.	design_tariffs()
fig_unserved	chart	The energy balance that produces the unserved energy, and it closes exactl	input tables re-derived against the dispatch
fig_why_flat	chart	Why the tariff channel cannot move the headcount.	LSMS-ISA connection rates around the poverty line
map_access_adm2	map	Share of district population in a lit settlement, by district.	DRE settlement layer on GADM 4.1 admin-2
map_access_plan	map	The electrification plan in space: which settlements get which technology.	gis_target_plan()
map_africa_plants	map	Every power plant the WRI register records in Africa, by capacity and prim	WRI Global Power Plant Database v1.3

Figure	Kind	Caption	Source
map_distance_to_grid	map	Median distance from settlement to the existing network, by district.	DRE settlement layer on GADM 4.1
map_generation_sites	map	The national generation register at two vintages, from the infrastructure	SDInfrastracture Uganda electricity layers
map_gridfinder	map	The surveyed transmission network against gridfinder's satellite-inferred	UETCL 2017; gridfinder v1.1.1
map_model_network	map	The network the optimiser actually sees: 24 buses, 30 corridors, and the i	Model case, buses.csv and lines.csv
map_rwi	map	Relative wealth index by district, with the unlit population on top.	DRE settlement layer (Meta RWI)
map_settlements	map	All 67,650 Ugandan settlement clusters, lit and unlit.	DRE Uganda settlement layer
map_transmission	map	The Ugandan transmission network by voltage and by status: operational, un	Uganda electricity transmission network 2017
map_uganda_plants	map	Uganda's generating fleet and the model's buses, on the same map.	WRI GPPD v1.3; model buses

Table 102. All 62 figures, with the data behind each.

Appendix E — Sources

L1-MODEL. EDIS Energy Planning System (EDISEnergySystemModel v0.3.0, power system solved in PyPSA)

L1-MODEL. The estate's own test suite

L1-MODEL. The implementation-status register

L1-MODEL. The remaining-gaps register

L1-DOC. The energy planning technical manual

L1-DOC. The mathematical specification

L1-DOC. The data-integration note and provenance table

L2-LIT. Least-cost capacity expansion and economic dispatch

L2-LIT. Linearised power flow and the transport approximation

L2-LIT. Levelised cost of electricity and the annuity method

L2-LIT. Revenue requirement and cost-of-service tariff design

L2-LIT. The energy ladder and multidimensional energy poverty

L3-DATA. EDIS Africa Energy GIS and Energy Intelligence Database (AEGID)

L3-DATA. Global Power Plant Database v1.3

L3-DATA. National transmission network 2017

L3-DATA. gridfinder predicted grid v1.1.1

L3-DATA. GADM 4.1 administrative boundaries

L3-DATA. Uganda LSMS-ISA National Panel Survey 2019/20 (UNPS)

L3-DATA. EDIS spatial data infrastructure

Appendix F — Reproducing this manual

Every number in this document is generated. Nothing is typed in. To rebuild it from the estate and the microdata:

The build

```
cd D:/EDIP/Training/EDIS_Academy/_build

# the specification and the estate
python energy_extract.py

# run the estate on its own Uganda case
julia --pkgimages=no --project=D:/EDIP/models/EnergyModelling \
      energy_run.jl
julia --pkgimages=no --project=D:/EDIP/models/EnergyModelling \
      energy_run2.jl
julia --pkgimages=no --project=D:/EDIP/models/EnergyModelling \
      energy_probe.jl

# push the result through CDCGE's own reader
julia --pkgimages=no --project=D:/EDIP/models/CDCGE/CDCGE \
      energy_cdcge.jl

# the survey, the registers, the geography, the macro chain
python energy_analysis.py
python energy_link.py

# figures and the course folder
python energy_figures.py
python build_egy501.py
```

THE PKGIMAGES FLAG IS NOT OPTIONAL

Julia must be invoked with `--pkgimages=no` on this machine. The Application Control policy blocks loading native package images, and without the flag every run fails at package load with an error that does not name the cause.

The cover carries the extract digest `8f0c4329171c6b35`. If the specification or the estate changes, the digest changes and every number is regenerated rather than edited. A manual whose numbers can drift from its model is a manual that will.

Appendix G — The mathematical specification, block by block

The estate ships a mathematical specification in 16 blocks. What follows is that document, block by block, with the equation identifiers each block owns and the chapter of this manual that uses it. The equations are reproduced as the estate writes them, in its own notation, so that a reader comparing this manual against the source is comparing like with like.

E-BAL — Energy balance (Balance/EnergyBalance.jl)

Identifiers. E-BAL-01, E-BAL-02 Used in this manual at. Chapter 11

```
PRIMARY_SUPPLY + TRANSFORMATION_OUTPUT + IMPORTS
  − EXPORTS − STOCK_BUILD − TRANSFORMATION_INPUT − OWN_USE
  − LOSSES − FINAL_CONSUMPTION − NONENERGY_USE = residual ≈ 0
```

E-BAL-01 (identity). For each fuel f (and region/year where present):

PRIMARY_SUPPLY + TRANSFORMATION_OUTPUT + IMPORTS

− EXPORTS − STOCK_BUILD − TRANSFORMATION_INPUT − OWN_USE

− LOSSES − FINAL_CONSUMPTION − NONENERGY_USE = residual ≈ 0

balance_residuals reports absolute and relative residuals;

check_energy_balance enforces |relative residual| ≤ 1 % (configurable);

reconcile_balance closes only sub-tolerance residuals into losses

labelled provenance = imputed and *errors* on larger holes — data problems

are surfaced, never silently closed.

E-BAL-02 (transformation efficiency).

η_f = TRANSFORMATION_OUTPUT_f / TRANSFORMATION_INPUT_f.

sankey_links maps the same table to a source→target→value link list

(supply → fuel → transformation / sectors / losses).

E-DEM — Electricity demand (Demand/DemandProjection.jl)

Identifiers. E-DEM-01, E-DEM-02, E-DEM-03 Used in this manual at. Chapter 8

```
LOAD[r,s,h,t] = BASE_LOAD[r,s,h] · ACTIVITY_INDEX[s,t] · EFFICIENCY_FACTOR[s,t]
                · ELECTRIFICATION_FACTOR[s,t] + NEW_LOAD[s,h,t]
```

E-DEM-01 (elasticity projection).

$D_1 = D_0 (1 + ε\_y·\hat{g} + ε\_pop·\hat{n} + ε\_p·\hat{p})$ with default elasticities

ε_y = 0.8, ε_pop = 1.0, ε_p = −0.2.

E-DEM-02 (driver-based load). For region r, sector s, slice h, year t:

LOAD[r,s,h,t] = BASE_LOAD[r,s,h] · ACTIVITY_INDEX[s,t] · EFFICIENCY_FACTOR[s,t]

· ELECTRIFICATION_FACTOR[s,t] + NEW_LOAD[s,h,t]

NEW_LOAD (e.g. EVs, new industry) is spread as a constant MW over the sector's weighted hours so added energy integrates exactly to new_load_mwh. Sectors without drivers are held at base and reported.

E-DEM-03 (peak, LDC, load factor). System load per slice $\Lambda_t = \Sigma_b$ LOAD[b,t]; peak = $\max_t \Lambda_t$; the load-duration curve sorts (Λ_t, w_t) descending; load factor = $(\Sigma\, w_t \Lambda_t / \Sigma\, w_t) / \max \Lambda_t$.

suppressed_demand reports served vs unserved energy.

Simplifications: elastic demand and endogenous demand response are not modelled; suppressed demand is observable only as model unserved energy.

E-DSP — Dispatch and operations (PyPSA engine, PowerSystem/PyPSABridge.jl + bridge/run_pypsa_case.py)

Identifiers. E-DSP-01, E-DSP-03, E-HYD-01, E-NET-01, E-STO-01 Used in this manual at. Chapter 11

```
min Σ_t w_t [ Σ_g (vc_g + τ·ef_g)·p[g,t] + Σ_b VoLL·shed[b,t] + Σ_s vc_s·dis[s,t] ]
```

Engine note (2026-07): the power system is solved in PyPSA (Python, HiGHS), with PyPSA-Earth as the upstream network builder. The formulations below are realized as PyPSA components: generators with p_max_pu availability, paired directed Links with efficiency (1 − loss) for corridors, StorageUnits (cyclic) for batteries and reservoir hydro (inflow series, no pumping), explicit VoLL generators for load shedding, GlobalConstraint for emissions caps, and linopy extra-constraints for RE targets and reserve margins. The former JuMP implementation was removed; field contracts of the returned results are unchanged.

E-DSP-01 (economic dispatch, LP). Variables: generation $p[g,t] \geq 0$, flows $f[l,t] \in [-\bar{F}_l, \bar{F}_l]$, shedding $shed[b,t] \geq 0$, storage ch/dis/soc, hydro hgen/hspill/hres, reserves $r[g,t] \geq 0$, angles $\theta[b,t]$ (DC mode).

Objective (E-DSP-01b):

$$\min \Sigma_t w_t \left[\Sigma_g (vc_g + \tau \cdot ef_g) \cdot p[g,t] + \Sigma_b \mathrm{VoLL} \cdot shed[b,t] + \Sigma_s vc_s \cdot dis[s,t] \right]$$

with carbon price τ. Constraints:

- E-DSP-01a nodal balance: $\Sigma_{g\in b}\, p + \Sigma_{s\in b}\, (dis - ch) + \Sigma_{h\in b}\, hgen$
 $+ \Sigma_{\{l\to b\}} (1-loss_l) f_l - \Sigma_{\{l\leftarrow b\}} f_l + shed_b = demand_b$.

- E-DSP-01c availability: p[g,t] ≤ cap_g · av[g,t]. Renewable curtailment is reported as Σ (cap·av − p)·w over renewable units.
- E-DSP-01d ramping: |p[g,t] − p[g,t−1]| ≤ ramp_g · cap_g (units with ramp_rate < 1).
- E-DSP-01e spinning reserve: p + r ≤ cap·av on reserve-capable units and Σ_g r[g,t] ≥ ρ · Σ_b demand[b,t].
- E-DSP-01f emissions cap: Σ w_t ef_g p[g,t] ≤ CAP.

E-EXP — Capacity & network expansion (PyPSA engine, rolling horizon)

Identifiers. E-EXP-01, E-EXP-02 Used in this manual at. Chapter 12

```
min Σ_y δ_y rep_y [ Σ_c capex_c·cum(c,y) + fom_c·cum(c,y)
                    + Σ_t w_t ((vc+τ·ef)·(pg+pc) + VoLL·shed) ]
```

E-EXP-01 (generation & storage-candidate expansion). Variables build[c,y] ≥ 0 (integer units of size integer_mw when lumpy), dispatch pg/pc/ph per slice and year, shed. cum(c,y) = Σ_{y'≤y} build.

Objective:

min Σ_y δ_y rep_y [Σ_c capex_c·cum(c,y) + fom_c·cum(c,y)

+ Σ_t w_t ((vc+τ·ef)·(pg+pc) + VoLL·shed)]

subject to per-year nodal balance with transport flows; availability (candidate profiles matched via technology name); existing-unit retirement (retire_year); E-EXP-01b reserve margin Σ firm capacity ≥ (1+RM)·peak_y using capacity_credit (default 1); E-EXP-01c renewable share ≥ re_target (hydro counts, flag renewable on hydro, default 1); E-EXP-01d per-year emissions cap; E-EXP-01e discounted capex budget; E-EXP-01f hydro as energy-limited existing capacity; availability windows available_from; annual build limits max_annual_mw; cumulative potential max_mw. Demand per year: demand.year column, else demand_drivers via E-DEM-02, else base demand.

E-EXP-02 (transmission expansion). Continuous reinforcement add[l] ∈ [0, candidate_max_mw] with |f[l,t]| ≤ F̄_l + add[l], minimizing annualized reinforcement plus operating and unserved-energy cost (value-based planning).

Realization: run_generation_expansion solves a rolling horizon — one PyPSA capacity-expansion case per planning year with that year's demand, prior builds promoted to existing units (named <c>_built,

E-ACC — Energy access (Access/Electrification.jl)

Identifiers. E-ACC-01, E-ACC-02 Used in this manual at. Chapter 15

```
max Σ δ_y (HH_i·benefit_i − cost_{i,k}) x[i,k,y]
s.t.  Σ_{k,y} x[i,k,y] ≤ 1                          (one technology per settlement)
      Σ_{i,k} cost·x[i,k,y] ≤ annual budget          ∀y
      Σ HH_i x ≥ access_target · Σ HH_i              (E-ACC-01b, cumulative)
```

E-ACC-01 (electrification planning, MILP). Binary x[i,k,y]: settlement i served by technology k ∈ {grid, minigrid, shs} in year y.

max Σ δ_y (HH_i·benefit_i − cost_{i,k}) x[i,k,y]

s.t. Σ_{k,y} x[i,k,y] ≤ 1 (one technology per settlement)

Σ_{i,k} cost·x[i,k,y] ≤ annual budget ∀y

Σ HH_i x ≥ access_target · Σ HH_i (E-ACC-01b, cumulative)

E-ACC-02 (clean cooking, LP). Households adopt[q] ≥ 0 minimizing lifecycle cost (capex + annuitized fuel over a 10-year appraisal at the scenario discount rate) minus health benefits plus carbon cost, meeting a target share, under an optional capex budget. Reports emissions, health benefits and time savings (gender proxy).

Simplifications: service-tier constraints, maximum connection distance and reliability differentiation are data-schema-ready (demand_tier, grid_distance_km) but not yet constraints.

E-FUE — Fuels & energy security (Fuels/FuelSupply.jl)

Identifiers. E-FUE-01, E-FUE-02, E-FUE-03 Used in this manual at. Chapter 18

E-FUE-01: production + imports − exports − consumption = residual per fuel/year. E-FUE-02: import dependence = max(net imports,0)/consumption; days of cover; import bill (border price × net imports); subsidy cost and tax revenue per unit consumed. E-FUE-02c price pass-through:

Δp_retail = θ·(1−tax_share)·[(1+Δp_border)(1+Δfx) − 1].

E-FUE-03 disruption screening: import cut drawn against strategic storage; unmet share and shortfall days.

Simplifications: refining yields, pipelines/ports network optimization and hydrogen supply chains are not modelled.

E-FIN — Tariffs & utility finance (Finance/UtilityFinance.jl)

Identifiers. E-FIN-01, E-FIN-02, E-FIN-03, E-FIN-04 Used in this manual at. Chapter 16

E-FIN-01: RR = OPEX + DEP + r·RAB + TAXES − OTHER_REVENUE.

E-FIN-02: class revenue shares ∝ cost-to-serve × energy; lifeline blocks priced at (1−d) of the class tariff, shortfall uplifted onto non-lifeline energy (cross-subsidy); billed tariffs grossed up by collection rates so *collected* revenue = RR (verified in tests to machine precision). E-FIN-03: income statement, cost recovery, DSCR, financing gap. E-FIN-04: subsidy incidence per class = (cost-reflective − effective billed) × energy. Plus WACC and annuity debt-service profiles; levelized_cost in Economics.jl.

E-DIST — Distribution & losses (Distribution/Losses.jl)

Identifiers. E-DIST-01, E-DIST-02 Used in this manual at. not used

E-DIST-01 (energy waterfall). From bulk supply S = Σ w_t·demand: gross generation G = S/(1−τ) with transmission loss τ (mean line loss factor); delivered = S·(1−d) with distribution technical loss d; billed = delivered·(1−c) with commercial (non-technical) loss c; collected = billed·ρ with collection rate ρ (energy-weighted from customers). E-DIST-02 allocates technical and commercial losses across regions in proportion to regional bulk supply. Analytic (no network solve); the sliders are d and c. System loss rate = (G − collected)/G.

E-INV — Investment analysis (Finance/Investment.jl)

Identifiers. E-INV-01, E-INV-02 Used in this manual at. not used

E-INV-01. Annualized investment to reach the scenario targets = generation capex (Σ cumulative build MW × annualized_capex_per_mw at full build, plus a per-year path) + transmission reinforcement cost + electrification lifecycle cost + clean-cooking capex. Reuses the PyPSA expansion/network and JuMP access/cooking models. **E-INV-02 (cost of decarbonization).** Run generation expansion at several renewable-target levels and tabulate generation capex vs final-year emissions and unserved energy.

E-GIS — Spatial planning (GIS/Spatial.jl)

Identifiers. E-GIS-01, E-GIS-02 Used in this manual at. not used

E-GIS-01 (base layers). Region load/industry centres (bus lat/lon, dominant sector, average load, generation capacity), settlements (households, nearest bus by lat/lon distance) and existing transmission corridors with endpoint coordinates. E-GIS-02 (target-driven plan). The least-cost electrification (E-ACC-01) assigns each settlement a technology; grid-assigned settlements get a distribution connection to the nearest bus, and the transmission reinforcement (E-EXP-02) gives the required upgraded corridors — all returned as map-ready lat/lon layers. Electrification service tiers: the E-ACC-01 objective weights household benefit by a per-technology service factor (grid 1.0, mini-grid 0.85, SHS 0.5); with distance-dependent grid cost this reproduces the classic pattern — grid for dense/near settlements, mini-grids for intermediate clusters, stand-alone solar for remote sparse ones.

E-EMI — Emissions (Emissions.jl)

Identifiers. E-EMI-01 Used in this manual at. Chapters 11 and 18

E-EMI-01: EMISSIONS[p,g] = GEN_g · ef_{p,g} with CO2e from emission_factor and additional pollutants from ef_<pollutant> columns (NOx, SO2, PM2.5, CH4, …). Grid intensity = Σ emissions / Σ generation. *Scope:* combustion only; fugitive and lifecycle emissions are out of scope.

E-CLI — Climate (Climate/ClimateRisk.jl)

Identifiers. E-CLI-01, E-CLI-02 Used in this manual at. Chapter 14

E-CLI-01: climate cases transform inputs — hydro inflows ×α, demand ×β (cooling), thermal capacity ×$(1-d_1)$, line limits ×$(1-d_2)$. Named cases: historical, dry, severe_dry, wet. E-CLI-02: stress test = dispatch under each case; run_resilience (legacy) selects hardening investments max Σ (avoided_loss − cost)·h under budget; resilience_indicators compares baseline vs stressed runs.

E-EQU — Equity (Equity/Affordability.jl)

Identifiers. E-EQU-01, E-EQU-02, E-EQU-03 Used in this manual at. Chapter 20

E-EQU-01: energy burden = (electricity + cooking spend)/income; affordable if ≤ 5 % (configurable). E-EQU-02: first-order welfare loss of a tariff change ΔCV ≈ spend × Δp/p; poverty headcount re-screened against the poverty line. E-EQU-03: subsidy incidence ∝ consumption; access-equity gaps (rural–urban, female-headed shares).

Simplification: first-order approximation (no behavioural response); a full microsimulation belongs to the Household model, linked via households.csv.

E-MAC — Macro & CGE integration (Integration/MacroCGELink.jl)

Identifiers. E-MAC-01, E-MAC-02, E-MAC-03 Used in this manual at. Chapter 19

E-MAC-01 exports (EnergyToMacroResults = EnergyToCGEResults): investment, generation cost, load-weighted electricity price, fuel import bill, emissions, unserved energy, supply, taxes, subsidies, borrowing — stamped with scenario/run_id/year. The CDCGE carrier CSV (export_generation_for_cge) emits generation by carrier exactly as CDCGE/src/PowerLink.jl consumes (CARRIER_TO_TECH mapping); the LCOE path (export_lcoe_path) drives CDCGE's electricity-productivity shock.

E-MAC-02 imports (MacroToEnergyInputs = CGEToEnergyInputs): GDP, population, FX, inflation, interest rate, public-investment ceiling, carbon price, fuel-price changes, sector output growth → apply_macro_inputs rescales demand (E-DEM-01), fuel costs and the scenario configuration.

E-MAC-03 convergence: fixed-point iteration energy ⇄ macro on the average electricity price, relative tolerance 10^{-3}, with an iteration log.

Sector links (Integration/SectorLinks.jl) exchange demand through the shared demand_drivers schema keyed by canonical sector ids; merge_sector_drivers rejects duplicate (sector, year) rows — the double-counting guard.

E-MTEF — Public-finance link (Integration/MTEFLink.jl)

Identifiers. E-MTEF-01, E-MTEF-02, E-MTEF-03 Used in this manual at. not used

Couples the Energy System to MTEFModelling (the EDIS FINEX-MTEF Sector Bridge). MTEF's Model 43 — Energy budget bridge allocates the public capital K^{cap}_y and recurrent K^{rec}_y envelope to energy over the MTEF horizon and hands over the financed capacity_mw, access_rate_gain_pp and new_connections by year.

E-MTEF-01 (import). read_mtef_inputs parses the bridge CSVs into MTEFToEnergyInputs. E-MTEF-02 (budget-constrained run). apply_mtef_inputs sets the horizon to the MTEF years, the investment budget to Σ_y K^{cap}_y / fx (LCU→model currency) and the access target to base_access + Σ_y access_gain_pp_y; the reserve margin is not imposed (0), so the plan builds the least-cost mix affordable within the envelope and reliability is an *output*. E-MTEF-03 (feedback). EnergyToMTEFResults / export_energy_to_mtef return, per year, system cost, generation, peak, unserved energy, reliability index 1 − unserved/demand, emissions, capacity added, cost-reflective tariff and utility subsidy need (LCU) — the "system cost, reliability, tariffs, energy demand and supply" the MTEF energy bridge feeds back into FINEX and CDCGE. Shared identifiers: scenario, year, run_id, sector = energy.

E-UCSN / E — BOE — Governed unit costs & budget→output (Integration/UCSNBOELink.jl)

Identifiers. E-BOE-01, E-UCSN-01, E-UCSN-02   Used in this manual at. not used

Links the Energy System to UnitCostModelling (UCSN, the governed parameter service) and BOEModelling (the Budget Output Engine), honouring UCSN's rule that *no sector application holds its own unit cost*. E-UCSN-01 (resolve). read_ucsn_energy_coefficients reads UCSN's published energy coefficients into an EnergyCostPack — solar ENE-CAP-003-SOLARPV, hydro ENE-CAP-001-HYDRO, transmission ENE-CAP-010-TX132, connection ENE-CAP-020-CONN, distribution O&M ENE-OPS-* — each with value band, currency, price year, tier, confidence and status. Requested definitions that are absent are recorded in unresolved (refuse rather than substitute). E-UCSN-02 (apply). apply_ucsn_costs rewrites the model's unit costs from UCSN: overnight capex K^{ov} → annualized a = K^{ov}/fx · r(1+r)^n/((1+r)^n−1) for candidates.annualized_capex_per_mw; ENE-CAP-010-TX132 (LCU/km) → lines.annualized_cost_per_mw via line length and rating; ENE-CAP-020-CONN (LCU/connection) → access_sites.grid_cost. Carriers with no governed coefficient keep the local value and are recorded — never silently replaced. A provenance report ties every rewritten field to its definition_id, value, tier, confidence and status. E-BOE-01 (budget→output). boe_energy_conversion reads BOE's Uganda energy crosswalk (read_boe_energy_crosswalk) and converts each CONVERTIBLE budget line B_i mapped to coefficient κ_i into a physical quantity $Q_i = B_i / \kappa_i$ (MW where κ is LCU/MW, connections where

LCU/connection); transfers and pending-coefficient lines are reported

Notation

[['b ∈ B', 'buses (demand/injection nodes), table buses'], ['l ∈ L', 'transmission lines, table lines'], ['g ∈ G', 'existing technologies/units, table technologies'], ['c ∈ C', 'candidate projects, table candidates'], ['s ∈ S', 'storage units, table storage'], ['h ∈ H', 'reservoir hydropower plants, table hydro'], ['i ∈ I', 'unelectrified settlements, table access_sites'], ['q ∈ Q', 'cooking technologies, table cooking'], ['t ∈ T', 'time slices (file order = chronology); w_t = hours represented'], ['y ∈ Y', 'planning years; rep_y = calendar years represented; δ_y = discount factor'], ['f ∈ F', 'fuels; p = pollutant']]

Appendix H — The Uganda case, in full

Every input table the estate loaded, row by row. This is the case that produced every model result in Parts III to VI, and a reader who disagrees with a result should start here.

H.1 Network nodes — buses.csv (24 rows)

bus	region	lat	lon	zone
B01_Bujagali	Wakiso	0.4136	32.5415	Wakiso
B02_Kawanda	Mukono	0.5012	33.1352	Mukono
B03_Nalubaale	Mukono	0.4463	33.1828	Mukono
B04_Tororo	Tororo	0.6381	34.1181	Tororo
B05_Nkenda	Hoima	1.4778	31.3278	Hoima
B06_Hoima	Kasese	0.2562	30.1171	Kasese
B07_Kabulasoke	Mpigi	0.1579	31.8201	Mpigi
B08_MasakaWest	Masaka	-0.3287	31.6847	Masaka
B09_Nkonge	Mubende	0.2292	31.1839	Mubende
B10_Rugonjo	Mbarara	0.2035	30.7852	Mbarara
B11_KampalaNorth	Kampala	0.3295	32.5781	Kampala
B12_Mutundwe	Kampala	0.2939	32.5334	Kampala
B13_Kafu	Masindi	1.5776	32.0383	Masindi
B14_Kyaka	Uganda	-1.3322	31.8104	Uganda
B15_MasakaWest	Mbarara	-0.5969	30.6076	Mbarara
B16_MbararaSouth	Ntungamo	-1.002	30.4511	Ntungamo
B17_Mbarara	Bushenyi	-0.5682	30.1579	Bushenyi
B18_Nalubale	Mukono	0.3769	32.9357	Mukono
B19_Nalubale	Mukono	0.3812	32.6787	Mukono
B20_Mirama	Uganda	-1.1179	30.424	Uganda
B21_Karuma	Masindi	2.2466	32.2679	Masindi
B22_Opuyo	Soroti	1.6771	33.6774	Soroti
B23_Lira	Lira	2.2402	32.8864	Lira
B24_Lessos	Uganda	0.5149	35.2769	Uganda

Table 103. buses.csv

H.2 Corridors — lines.csv (30 rows)

line	from_bus	to_bus	existing_mw	loss_factor	candidate_max_mw	annualized_cost_per_mw	susceptance	length_km
L01	B01_Bujagali	B02_Kawanda	860.0	0.034	860.0	11130.0	14.09	71.0
L02	B02_Kawanda	B03_Nalubaale	300.0	0.022	300.0	9251.0	100.0	8.4
L03	B02_Kawanda	B04_Tororo	300.0	0.043	300.0	12481.0	8.62	116.0
L04	B02_Kawanda	B04_Tororo	860.0	0.044	860.0	12538.0	8.48	117.9
L0	B05_Nkenda	B06_Hoima	860.0	0.065	860.0	15733.0	4.46	224.4

line	from_bus	to_bus	existing_mw	loss_factor	candidate_max_mw	annualized_cost_per_mw	susceptance	length_km
5								
L06	B07_Kabulasoke	B08_MasakaWest	150.0	0.032	150.0	10840.0	16.31	61.3
L07	B07_Kabulasoke	B09_Nkonge	150.0	0.035	150.0	11292.0	13.09	76.4
L08	B10_Rugonjo	B06_Hoima	150.0	0.039	150.0	11826.0	10.62	94.2
L09	B11_KampalaNorth	B12_Mutundwe	300.0	0.022	300.0	9281.0	100.0	9.4
L10	B13_Kafu	B01_Bujagali	2700.0	0.053	2700.0	13972.0	6.03	165.7
L11	B01_Bujagali	B08_MasakaWest	860.0	0.047	860.0	13115.0	7.29	137.2
L12	B12_Mutundwe	B01_Bujagali	300.0	0.023	300.0	9520.0	57.73	17.3
L14	B12_Mutundwe	B11_KampalaNorth	300.0	0.022	300.0	9304.0	98.73	10.1
L15	B08_MasakaWest	B14_Kyaka	150.0	0.051	150.0	13717.0	6.36	157.2
L16	B15_MasakaWest	B08_MasakaWest	150.0	0.046	150.0	12904.0	7.68	130.1
L17	B16_MbararaSouth	B15_MasakaWest	860.0	0.031	860.0	10699.0	17.66	56.6
L18	B17_Mbarara	B06_Hoima	300.0	0.04	300.0	12062.0	9.8	102.1
L19	B12_Mutundwe	B07_Kabulasoke	150.0	0.037	150.0	11525.0	11.88	84.2
L20	B18_Nalubale	B03_Nalubaale	45.0	0.026	45.0	9914.0	32.83	30.5
L21	B11_KampalaNorth	B03_Nalubaale	300.0	0.034	300.0	11098.0	14.3	69.9
L22	B19_Nalubale	B03_Nalubaale	150.0	0.031	150.0	10712.0	17.52	57.1
L23	B11_KampalaNorth	B19_Nalubale	150.0	0.022	150.0	9365.0	82.17	12.2
L24	B09_Nkonge	B10_Rugonjo	150.0	0.029	150.0	10386.0	21.65	46.2
L26	B20_Mirama	B16_MbararaSouth	860.0	0.023	860.0	9476.0	63.02	15.9
L27	B15_MasakaWest	B17_Mbarara	300.0	0.03	300.0	10534.0	19.55	51.1
L28	B21_Karuma	B13_Kafu	2700.0	0.037	2700.0	11496.0	12.02	83.2
L29	B22_Opuyo	B23_Lira	300.0	0.043	300.0	12459.0	8.67	115.3
L30	B04_Tororo	B24_Lessos	300.0	0.046	300.0	12895.0	7.7	129.8
L31	B04_Tororo	B24_Lessos	860.0	0.046	860.0	12886.0	7.72	129.5
L32	B04_Tororo	B22_Opuyo	300.0	0.05	300.0	13431.0	6.77	147.7

Table 104. lines.csv — first 9 of 12 columns; the rest are voltage_kv, status, name

H.3 Generating units — technologies.csv (5 rows)

Note what is absent: no hydro, and `renewable` is a flag that exists only on this table.

technology	bus	existing_mw	variable_cost	emission_factor	carrier	fuel	ramp_rate	min_stable
Kabulasoke	B07_Kabulasoke	24.0	0.0	0.0	solar		1.0	0.0
KakiraSugarWor	B03_Nalubaale	12.0	35.0	0.05	biomass	biomass	1.0	0.0
LugogoSubstati	B19_Nalubale	50.0	190.0	0.75	oil	oil	0.6	0.2
Soroti	B22_Opuyo	10.0	0.0	0.0	solar		1.0	0.0
Tororo	B04_Tororo	10.0	0.0	0.0	solar		1.0	0.0

Table 105. technologies.csv — first 9 of 17 columns; the rest are startup_cost, min_up, min_down, reserve_capable, renewable, capacity_credit, lat, lon

H.4 Reservoir hydropower — hydro.csv (6 rows)

The `inflow_mwh` column is the single most consequential number in this appendix. Divide it by `capacity_mw` in each row.

plant	bus	capacity_mw	inflow_mwh	reservoir_max_mwh	reservoir_initial_mwh	min_release_mwh	capacity_credit	lat
Bugoye	B06_Hoima	11.0	5.5	7920.0	3960.0	402.0	0.5	0.3055
BujagaliFalls	B02_Kawanda	250.0	125.0	180000.0	90000.0	9125.0	0.5	0.4982
IshashaRiver	B17_Mbarara	10.0	5.0	7200.0	3600.0	365.0	0.5	-0.8815
Kiira	B03_Nalubaale	205.0	102.5	147600.0	73800.0	7482.0	0.5	0.4503
Mubuku3	B06_Hoima	10.5	5.2	7560.0	3780.0	383.0	0.5	0.3241
Narubale	B03_Nalubaale	180.0	90.0	129600.0	64800.0	6570.0	0.5	0.4432

Table 106. hydro.csv — first 9 of 11 columns; the rest are lon, commissioning_year

H.5 What may be built — candidates.csv (3 rows)

Three rows. No expansion result anywhere in this manual can name a technology that is not here.

candidate	bus	technology	carrier	max_mw	annualized_capex_per_mw	variable_cost	emission_factor	fixed_om_per_mw
SolarNew	B07_Kabulasoke	Kabulasoke	solar	600	78000	0	0.0	2000
HydroNew	B12_Mutundwe		hydro	400	150000	3	0.0	9000
GasNew	B12_Mutundwe		gas	300	120000	70	0.42	5000

Table 107. candidates.csv — first 9 of 13 columns; the rest are available_from, renewable, capacity_credit, max_annual_mw

H.6 Storage — storage.csv (1 rows)

One battery, 40 MW and 160 MWh, on a system with a 474 MW peak.

storage	bus	power_max_mw	energy_max_mwh	charge_efficiency	discharge_efficiency	self_discharge	variable_cost
Battery1	B12_Mutundwe	40	160	0.95	0.95	0.001	1.0

Table 108. storage.csv

H.7 Unelectrified demand sites — access_sites.csv (40 rows)

site	region	lat	lon	households	grid_distance_km	demand_tier	benefit_per_household	grid_cost
Kibaale	Kibaale	0.9436	31.0952	186626.0	3.8	2	1000.0	46923121.0
Arua	Arua	2.9884	31.1241	156598.0	11.3	2	1000.0	39938303.0
Mubende	Mubende	0.5336	31.5309	148822.0	5.2	2	1000.0	37572757.0
Kasese	Kasese	0.1804	30.0104	144027.0	3.1	2	1000.0	36225511.0
Hoima	Hoima	1.3886	31.1981	122851.0	3.6	2	1000.0	30966607.0
Yumbe	Yumbe	3.481	31.2648	114934.0	12.9	2	1000.0	29636910.0
Rakai	Rakai	-0.714	31.3877	114875.0	2.6	2	1000.0	28901887.0
Kabale	Kabale	-1.2221	29.9836	111978.0	3.4	2	1000.0	28231330.0
Ntungamo	Ntungamo	-0.9484	30.2721	111017.0	2.9	2	1000.0	27959655.0
Isingiro	Isingiro	-0.8578	30.8728	108892.0	2.6	2	1000.0	27402625.0
Kamuli	Kamuli	0.9367	33.1097	108655.0	1.7	2	1000.0	27284517.0
Tororo	Tororo	0.7216	34.0859	107879.0	1.0	2	1000.0	27039310.0
Kamwenge	Kamwenge	0.2138	30.5179	104755.0	4.1	2	1000.0	26478216.0
Kyenjojo	Kyenjojo	0.6434	30.6638	99080.0	4.7	2	1000.0	25101672.0
Kabarole	Kabarole	0.6068	30.2678	95077.0	1.9	2	1000.0	23898880.0
Pallisa	Pallisa	1.214	33.8129	93263.0	1.5	2	1000.0	23418796.0
Iganga	Iganga	0.6975	33.5214	92446.0	1.4	2	1000.0	23208138.0
Oyam	Oyam	2.3801	32.4971	91629.0	3.2	2	1000.0	23132390.0
Nebbi	Nebbi	2.4373	31.2562	89536.0	3.9	2	1000.0	22656308.0

site	region	lat	lon	households	grid_distance_km	demand_tier	benefit_per_household	grid_cost
Apac	Apac	1.9139	32.5949	87756.0	7.5	2	1000.0	22460595.0
Manafwa	Manafwa	0.8817	34.3169	84937.0	1.2	2	1000.0	21320498.0
Mayuge	Mayuge	0.4345	33.5055	84840.0	1.8	2	1000.0	21336641.0
Bugiri	Bugiri	0.5309	33.7753	82116.0	2.1	2	1000.0	20675993.0
Mbarara	Mbarara	-0.5823	30.566	78314.0	1.8	2	1000.0	19707443.0
Kiruhura	Kiruhura	-0.1313	30.8398	77864.0	2.9	2	1000.0	19667500.0
Mbale	Mbale	0.9979	34.2061	77049.0	0.8	2	1000.0	19317862.0
Buyende	Buyende	1.2324	33.1409	77026.0	5.2	2	1000.0	19623286.0
Luwero	Luwero	0.7968	32.5812	76768.0	2.0	2	1000.0	19333794.0
Kayunga	Kayunga	0.8784	32.9205	75706.0	2.3	2	1000.0	19086900.0
Rukungiri	Rukungiri	-0.7973	29.916	74297.0	1.4	2	1000.0	18671685.0
Gulu	Gulu	2.7651	32.4392	73438.0	4.1	2	1000.0	18647783.0
Mukono	Mukono	0.421	32.8007	72143.0	1.5	2	1000.0	18141082.0
Lira	Lira	2.3105	32.973	70951.0	5.5	2	1000.0	18120300.0
Wakiso	Wakiso	0.3847	32.4109	68773.0	1.0	2	1000.0	17262070.0
Buikwe	Buikwe	0.298	33.0315	68426.0	1.9	2	1000.0	17238332.0
Serere	Serere	1.5161	33.3951	67921.0	3.6	2	1000.0	17232726.0
Kyegegwa	Kyegegwa	0.4726	31.0124	67496.0	4.8	2	1000.0	17208826.0
Amuria	Amuria	2.093	33.6451	64871.0	13.6	2	1000.0	17170560.0
Jinja	Jinja	0.5804	33.2145	63217.0	1.0	2	1000.0	15873059.0
Busia	Busia	0.4333	33.9938	62406.0	2.6	2	1000.0	15785051.0

Table 109. access_sites.csv — first 9 of 11 columns; the rest are minigrid_cost, shs_cost

H.8 Customer classes — customers.csv (3 rows)

class	energy_mwh	customers	cost_to_serve	lifeline_mwh	collection_rate	current_tariff
residential	1916839.0	1483460.0	120	0.05	0.9	200
commercial	871291.0	40000.0	110	0.0	0.95	230

class	energy_mwh	customers	cost_to_serve	lifeline_mwh	collection_rate	current_tariff
industrial	697032.0	2000.0	95	0.0	0.98	170

Table 110. customers.csv

H.9 Household groups — households.csv (3 rows)

Three stylised groups standing for 6.8 million households, with urban connection equal to one by construction.

group	households	income	electricity_spend	cooking_spend	connected	urban	female_headed
rural_unconnected	5353284.0	900	20	90	0.0	0	0.3
rural_connected	519211.0	1800	70	110	1.0	0	0.29
urban_connected	964249.0	4200	190	140	1.0	1	0.27

Table 111. households.csv

H.10 Clean-cooking options — cooking.csv (3 rows)

technology	capex	annual_fuel_cost	emission_factor_t_per_hh	health_benefit_per_hh	time_saving_hours_per_day
lpg	60	120	0.2	45	1.5
electric	85	135	0.05	55	1.6
improved_biomass	25	60	0.6	20	0.8

Table 112. cooking.csv

H.11 Fuel accounts — fuels.csv (2 rows)

fuel	year	production	imports	exports	consumption	price	storage_days	import_price
oil	2026	0	900000	0	900000	185	21	175
biomass	2026	3000000	0	0	3000000	10	0	0

Table 113. fuels.csv — first 9 of 11 columns; the rest are tax, subsidy

H.12 Policy portfolio — projects.csv (3 rows)

project	cost	emissions_reduction	access_gain	resilience_gain	jobs
KarumaHydro	1700000000.0	500000	200000	0.4	3000
GridExtension	300000000.0	50000	400000	0.5	1500
SolarMiniGrids	200000000.0	120000	300000	0.7	2200

Table 114. projects.csv

H.13 Hazards — hazards.csv (1 rows)

One row. A template, not an assessment.

asset	hazard	hardening_cost	expected_avoided_loss
Bugoye	drought	1500000.0	3800000.0

Table 115. hazards.csv

H.14 Demand — demand.csv (0 rows)

Bus	Annual demand MWh	Share of national
B12_Mutundwe	750,090	21.5 %
B11_KampalaNorth	449,895	12.9 %
B01_Bujagali	398,192	11.4 %
B19_Nalubale	322,934	9.3 %
B04_Tororo	243,876	7.0 %
B03_Nalubaale	215,206	6.2 %
B21_Karuma	186,334	5.3 %
B08_MasakaWest	135,424	3.9 %
B15_MasakaWest	98,785	2.8 %
B06_Hoima	91,169	2.6 %
B23_Lira	79,763	2.3 %
B22_Opuyo	78,311	2.2 %
B07_Kabulasoke	66,214	1.9 %
B02_Kawanda	63,895	1.8 %
B05_Nkenda	62,701	1.8 %
B18_Nalubale	60,910	1.7 %
B17_Mbarara	42,170	1.2 %
B20_Mirama	40,514	1.2 %
B09_Nkonge	39,898	1.1 %
B13_Kafu	28,807	0.8 %
B10_Rugonjo	22,021	0.6 %
B16_MbararaSouth	7,782	0.2 %
B14_Kyaka	271	0.0 %
B24_Lessos	0	0.0 %
Total	3,485,162	100 %

Table 116. Demand aggregated to the bus. The two buses where load is shed in every period are B05_Nkenda and B20_Mirama.

H.15 Availability — availability.csv (36 rows)

Technology	Periods	Mean	Min	Max
Kabulasoke	12	0.3396	0.0000	0.8920
Soroti	12	0.3396	0.0000	0.8920
Tororo	12	0.3396	0.0000	0.8920

Table 117. Availability by unit. A single value repeated across every period is a declared capacity factor, not a profile.

H.16 What the case does not contain

- No price at the external bus, so the interconnectors carry zero flow and imports cannot be evaluated (Chapter 17).
- No productive-use or anchor load at any access site, so the electrification plan has no benefit side (Chapter 9).
- No transport sector and no charging load anywhere.

- No inflow time series, only one number per hydro plant (Chapter 14).
- No hydraulic coupling between reservoirs on the same river.
- No debt-service figure, so the coverage ratio is infinite (Chapter 16).
- No pollutant emission factors beyond CO2e for most units (Chapter 18).

Appendix I — Every table this build produced

86 tables. Each was written by one of the six build scripts and each is the evidence behind a claim somewhere in this manual.

Table	Rows	Columns	Written by
aegid_availability	940	14	energy_analysis.py
aegid_by_country	54	6	energy_analysis.py
aegid_by_theme	24	4	energy_analysis.py
aegid_inventory	618	23	energy_analysis.py
cge_lcoe_canonical	12	3	energy_cdcge.jl
cge_mix_defect	8	4	energy_cdcge.jl
cge_power_mix	8	3	energy_cdcge.jl
cge_power_mix_fixed	8	3	energy_cdcge.jl
cge_power_mix_floored	8	4	energy_cdcge.jl
cge_prod_lever	12	4	energy_cdcge.jl
cge_scenario_response	21	7	energy_cdcge.jl
cge_uga_mitigation	584	4	energy_cdcge.jl
cge_uga_panel	56	16	energy_cdcge.jl
energy_cdcge_summary	12	2	—
lsms_energy_by_dimension	13	9	energy_analysis.py
lsms_energy_ladder	9	13	energy_analysis.py
lsms_household_energy	3062	14	energy_analysis.py
lsms_no_grid_reasons	8	5	energy_analysis.py
poverty_burden_by_quintile	5	6	energy_link.py
poverty_microsim_headline	13	8	energy_link.py
poverty_microsim_profile	65	6	energy_link.py
reconciliation	5	7	energy_analysis.py
uga_access_budget_sweep	7	4	energy_run.jl
uga_access_by_technology	1	3	energy_run.jl
uga_access_distance_bands	6	8	energy_analysis.py
uga_access_plan	40	5	energy_run.jl
uga_access_sites	40	11	energy_run.jl
uga_asset_base	11	6	energy_run2.jl
uga_availability	36	3	energy_run.jl
uga_buses	24	5	energy_run.jl
uga_carbon_sweep	4	5	energy_run.jl
uga_carbon_sweep_netted	4	6	energy_run.jl
uga_cge_convergence	3	3	energy_run2.jl / energy_cdcge.jl
uga_cge_generation	9	3	energy_run2.jl / energy_cdcge.jl
uga_cge_generation_bridgeio	9	3	energy_run2.jl / energy_cdcge.jl
uga_cge_generation_fixed	4	3	energy_run2.jl / energy_cdcge.jl
uga_cge_lcoe_by_carrier	12	4	energy_run2.jl / energy_cdcge.jl
uga_cge_lcoe_path	4	2	energy_run2.jl / energy_cdcge.jl
uga_climate_stress	4	5	energy_run.jl

Table	Rows	Columns	Written by
uga_cooking_plan	3	7	energy_run2.jl
uga_cooking_target_sweep	9	4	energy_run2.jl
uga_demand	288	5	energy_run.jl
uga_demand_by_bus_time	288	3	energy_probe.jl
uga_demand_path	4	3	energy_run.jl
uga_diagnostics	15	4	energy_run.jl
uga_dispatch	132	4	energy_run.jl
uga_dispatch_indicators	13	3	energy_run2.jl
uga_distribution_by_region	16	5	energy_run.jl
uga_emissions_by_technology	11	2	energy_run2.jl
uga_emissions_inventory	11	3	energy_run2.jl
uga_energy_adequacy	11	8	energy_link.py
uga_energy_burden	3	11	energy_run2.jl
uga_energy_security	2	7	energy_run2.jl
uga_expansion_plan	9	6	energy_run.jl
uga_expansion_plan_no_target	9	6	energy_run.jl
uga_flows	360	3	energy_probe.jl
uga_fuel_balance	2	5	energy_run2.jl
uga_fuel_disruption	5	4	energy_run2.jl
uga_generation_by_bus_time	96	3	energy_probe.jl
uga_generation_by_technology	11	2	energy_run.jl
uga_gis_buses	24	7	energy_run.jl
uga_gis_settlements	40	9	energy_run.jl
uga_gis_transmission	30	8	energy_run.jl
uga_gisplan_by_technology	1	3	energy_run.jl
uga_gisplan_reinforcement	0	0	energy_run.jl
uga_gisplan_settlements	40	11	energy_run.jl
uga_household_subsidy_incidence	3	12	energy_run2.jl
uga_hydro	6	11	energy_run.jl
uga_investment_breakdown	3	2	energy_run.jl
uga_ldc	12	3	energy_run.jl
uga_lines	30	12	energy_run.jl
uga_network_expansion	30	2	energy_run2.jl
uga_network_reinforcement	30	3	energy_run2.jl
uga_prices	288	3	energy_run.jl
uga_prices_corrected	288	5	energy_probe.jl
uga_settlement_access_by_adm2	166	12	energy_analysis.py
uga_settlements_points	67650	14	energy_analysis.py
uga_subsidy_incidence	3	6	energy_run2.jl
uga_system_load	12	3	energy_run.jl
uga_tariff_lifeline_sweep	12	4	energy_run2.jl
uga_tariff_poverty	16	6	energy_run2.jl
uga_tariffs	3	12	energy_run2.jl
uga_technologies	5	17	energy_run.jl

Table	Rows	Columns	Written by
wri_africa_by_country	47	4	energy_analysis.py
wri_africa_plants	615	7	energy_analysis.py
wri_uganda_plants	11	8	energy_analysis.py

Table 118. The complete derived-data register.

I.1 The small tables, in full

Tables with fewer than twenty rows are reproduced here in full, because they are the ones a reader is most likely to want to check and the least likely to rebuild.

uga_carbon_sweep

carbon_price	status	objective	unserved_mwh	emissions_t
0.0	ok:optimal	7.805877802889501e8	69368.858028895	333756.0
25.0	ok:optimal	7.889316802889501e8	69368.858028895	333756.0
50.0	ok:optimal	7.972755802889501e8	69368.858028895	333756.0
100.0	ok:optimal	8.139633802889501e8	69368.858028895	333756.0

Table 119. uga_carbon_sweep.csv — 4 rows.

uga_carbon_sweep_netted

carbon_price	status	objective	unserved_mwh	emissions_t	generation_cost
0.0	ok:optimal	780587780.2889501	69368.858028895	333756.0	86899200.0
25.0	ok:optimal	788931680.2889501	69368.858028895	333756.0	95243100.0
50.0	ok:optimal	797275580.2889501	69368.858028895	333756.0	103587000.0
100.0	ok:optimal	813963380.2889501	69368.858028895	333756.0	120274800.0

Table 120. uga_carbon_sweep_netted.csv — 4 rows.

uga_dispatch_indicators

indicator	value	unit
system_cost	7.889316802889501e8	currency
generation	3.592841e6	MWh
demand	3.4851623500000006e6	MWh
renewable_share	0.06568868480403113	fraction
emissions	333756.0	tCO2e
emission_intensity	0.09289473149521507	t/MWh
unserved_energy	69368.858028895	MWh
unserved_share	0.019904053545423784	fraction
lole	8760.0	hours
curtailment	0.0	MWh
peak_demand	473.808	MW
load_factor	0.8396852381836807	fraction
avg_price	12.37274959364851	currency/MWh

Table 121. uga_dispatch_indicators.csv — 13 rows.

uga_generation_by_technology

technology	mwh
BujagaliFalls	1.095e6
Kiira	897900.0
Narubale	788400.0
LugogoSubstati	438000.0
KakiraSugarWor	105120.0
Kabulasoke	71394.0
Bugoye	48180.0
Mubuku3	45552.0
IshashaRiver	43800.0
Soroti	29747.499999999996
Tororo	29747.499999999996

Table 122. uga_generation_by_technology.csv — 11 rows.

uga_energy_adequacy

unit	carrier	nameplate_mw	energy_limit_mwh	limit_from	dispatched_mwh	utilisation	at_its_limit
BujagaliFalls	hydro	250.0	1095000.0	inflow_mwh in hydro.csv	1095000.0	1.0	True
Kiira	hydro	205.0	897900.0	inflow_mwh in hydro.csv	897900.0	1.0	True
Narubale	hydro	180.0	788400.0	inflow_mwh in hydro.csv	788400.0	1.0	True
LugogoSubstati	oil	50.0	438000.0	nameplate x 8760	438000.0	1.0	True
KakiraSugarWor	biomass	12.0	105120.0	nameplate x 8760	105120.0	1.0	True
Kabulasoke	solar	24.0	210240.0	nameplate x 8760, then the	71394.0	0.339583333333333335	False
Bugoye	hydro	11.0	48180.0	inflow_mwh in hydro.csv	48180.0	1.0	True
Mubuku3	hydro	10.5	45552.0	inflow_mwh in hydro.csv	45552.0	1.0	True
IshashaRiver	hydro	10.0	43800.0	inflow_mwh in hydro.csv	43800.0	1.0	True
Soroti	solar	10.0	87600.0	nameplate x 8760, then the	29747.5	0.339583333333333335	False
Tororo	solar	10.0	87600.0	nameplate x 8760, then the	29747.5	0.339583333333333335	False

Table 123. uga_energy_adequacy.csv — 11 rows.

uga_expansion_plan

candidate	technology	bus	year	build_mw	cumulative_mw
SolarNew	Kabulasoke	B07_Kabulasoke	2026	574.1167999999998	574.1167999999998
HydroNew		B12_Mutundwe	2026	0.0	0.0
GasNew		B12_Mutundwe	2026	0.0	0.0
SolarNew	Kabulasoke	B07_Kabulasoke	2032	-0.0	574.1167999999998
HydroNew		B12_Mutundwe	2032	-0.0	0.0
GasNew		B12_Mutundwe	2032	-0.0	0.0
SolarNew	Kabulasoke	B07_Kabulasoke	2040	-0.0	574.1167999999998
HydroNew		B12_Mutundwe	2040	-0.0	0.0
GasNew		B12_Mutundwe	2040	-0.0	0.0

Table 124. uga_expansion_plan.csv — 9 rows.

uga_expansion_plan_no_target

candidate	technology	bus	year	build_mw	cumulative_mw
SolarNew	Kabulasoke	B07_Kabulasoke	2026	574.1167999999998	574.1167999999998
HydroNew		B12_Mutundwe	2026	0.0	0.0
GasNew		B12_Mutundwe	2026	0.0	0.0
SolarNew	Kabulasoke	B07_Kabulasoke	2032	-0.0	574.1167999999998
HydroNew		B12_Mutundwe	2032	-0.0	0.0
GasNew		B12_Mutundwe	2032	-0.0	0.0
SolarNew	Kabulasoke	B07_Kabulasoke	2040	-0.0	574.1167999999998
HydroNew		B12_Mutundwe	2040	-0.0	0.0
GasNew		B12_Mutundwe	2040	-0.0	0.0

Table 125. uga_expansion_plan_no_target.csv — 9 rows.

uga_access_by_technology

technology	households	cost
grid	3.759255e6	9.49858919e8

Table 126. uga_access_by_technology.csv — 1 rows.

uga_access_budget_sweep

budget_usd	feasible	access_rate	cost
2.0e8	false	NaN	NaN
4.0e8	false	NaN	NaN
6.0e8	false	NaN	NaN
8.0e8	false	NaN	NaN
1.0e9	true	1.0	9.49858919e8
1.5e9	true	1.0	9.49858919e8
2.0e9	true	1.0	9.49858919e8

Table 127. uga_access_budget_sweep.csv — 7 rows.

uga_access_distance_bands

band_km	settlements	population	mean_rwi	mean_pv_value	with_health_facility	with_education_facility	median_cluster_population
0-1	23444	11626831.0	-0.1396033653846154	1615.6047664149494	1787.0	8477.0	160.0
1-5	28756	8433130.0	-0.2332358227892715	1614.567406969465	988.0	7239.0	134.0
5-10	7930	2033997.0	-0.3032621359223301	1610.9951590364485	337.0	1705.0	125.0
10-25	4673	1207730.0	-0.3277826660800704	1615.578276267922	168.0	884.0	118.0
25-50	117	50621.0	-0.253398058252427 17	1610.3732478632478	5.0	23.0	156.0
50+	0	0.0			0.0	0.0	

Table 128. uga_access_distance_bands.csv — 6 rows.

uga_cooking_plan

technology	households	capex	annual_fuel_cost	annual_emissions_t	annual_health_benefit	daily_time_saved_hours
lpg	0.0	0.0	0.0	0.0	0.0	0.0
electric	0.0	0.0	0.0	0.0	0.0	0.0
improved_biomass	4.1020464e6	1.0255116e8	2.46122784e8	2.46122784e6	8.2040928e7	3.28163712e6

Table 129. uga_cooking_plan.csv — 3 rows.

uga_cooking_target_sweep

target_share	households	capex	annual_emissions_t
0.2	1.3673488e6	3.418372e7	820409.28
0.3	2.0510232e6	5.127558e7	1.23061392e6
0.4	2.7346976e6	6.836744e7	1.64081856e6
0.5	3.418372e6	8.54593e7	2.0510232e6
0.6	4.1020464e6	1.0255116e8	2.46122784e6
0.7	4.7857208e6	1.1964302e8	2.87143248e6
0.8	5.4693952e6	1.3673488e8	3.28163712e6
0.9	6.153069600000001e6	1.5382674e8	3.6918417600000002e6
1.0	6.836744e6	1.709186e8	4.1020464e6

Table 130. uga_cooking_target_sweep.csv — 9 rows.

uga_tariffs

class	energy_mwh	customers	cost_to_serve	lifeline_mwh	collection_rate	current_tariff	cost_reflective_tariff
residential	1.916839e6	1.48346e6	120	0.05	0.9	200	70.05431660194392
commercial	871291.0	40000.0	110	0.0	0.95	230	64.21645688511526

class	energy_mwh	customers	cost_to_serve	lifeline_mwh	collection_rate	current_tariff	cost_reflective_tariff
industrial	697032.0	2000.0	95	0.0	0.98	170	55.45966730987226

Table 131. uga_tariffs.csv — 3 rows.

uga_subsidy_incidence

class	energy_mwh	customers	subsidy_per_mwh	total_subsidy	subsidy_per_customer
residential	1.916839e6	1.48346e6	9.829470324664868	1.884151206766028e7	12.701058382201259
commercial	871291.0	40000.0	-12.01379567070066	-1.0467512043720448e7	-261.6878010930112
industrial	697032.0	2000.0	-12.013795670700674	-8.374000023939832e6	-4187.000011969916

Table 132. uga_subsidy_incidence.csv — 3 rows.

uga_tariff_lifeline_sweep

lifeline_discount	class	standard_tariff	lifeline_tariff
0.0	residential	77.83812955771548	77.83812955771548
0.0	commercial	67.59627040538449	67.59627040538449
0.0	industrial	56.59149725497169	56.59149725497169
0.25	residential	84.5124604858825	58.3785971682866
0.25	commercial	73.91932075838484	50.69720280403837
0.25	industrial	62.72098484206388	42.44362294122877
0.5	residential	91.18679141404955	38.91906477885774
0.5	commercial	80.2423711113852	33.798135202692244
0.5	industrial	68.85047242915606	28.295748627485846
0.75	residential	97.86112234221659	19.45953238942887
0.75	commercial	86.56542146438555	16.899067601346122
0.75	industrial	74.97996001624823	14.147874313742923

Table 133. uga_tariff_lifeline_sweep.csv — 12 rows.

uga_energy_burden

group	households	income	electricity_spend	cooking_spend	connected	urban	female_headed
rural_unconnected	5.353284e6	900	20	90	0.0	0	0.3
rural_connected	519211.0	1800	70	110	1.0	0	0.29
urban_connected	964249.0	4200	190	140	1.0	1	0.27

Table 134. uga_energy_burden.csv — 3 rows.

uga_household_subsidy_incidence

group	households	income	electricity_spend	cooking_spend	connected	urban	female_headed
rural_unconnected	5.353284e6	900	20	90	0.0	0	0.3
rural_connected	519211.0	1800	70	110	1.0	0	0.29
urban_connected	964249.0	4200	190	140	1.0	1	0.27

Table 135. uga_household_subsidy_incidence.csv — 3 rows.

uga_emissions_inventory

technology	pollutant	emissions_t
Kabulasoke	co2e	0.0
KakiraSugarWor	co2e	5256.0
LugogoSubstati	co2e	328500.0
Soroti	co2e	0.0
Tororo	co2e	0.0
Bugoye	co2e	0.0
BujagaliFalls	co2e	0.0
IshashaRiver	co2e	0.0
Kiira	co2e	0.0
Mubuku3	co2e	0.0
Narubale	co2e	0.0

Table 136. uga_emissions_inventory.csv — 11 rows.

uga_emissions_by_technology

technology	emissions_t
LugogoSubstati	328500.0
KakiraSugarWor	5256.0
Kabulasoke	0.0
Soroti	0.0
Tororo	0.0
Bugoye	0.0
BujagaliFalls	0.0
IshashaRiver	0.0
Kiira	0.0
Mubuku3	0.0
Narubale	0.0

Table 137. uga_emissions_by_technology.csv — 11 rows.

uga_fuel_balance

fuel	year	residual	consumption	relative_residual
oil	2026	0	900000	0.0
biomass	2026	0	3000000	0.0

Table 138. uga_fuel_balance.csv — 2 rows.

uga_energy_security

fuel	year	import_dependence	days_of_cover	import_bill	subsidy_cost	tax_revenue
oil	2026	1.0	21.0	157500000	0	22500000
biomass	2026	0.0	0.0	0	0	0

Table 139. uga_energy_security.csv — 2 rows.

uga_fuel_disruption

fuel	import_cut	unmet_share	days_short

fuel	import_cut	unmet_share	days_short
oil	0.1	0.04246575342465753	NaN
oil	0.25	0.19246575342465755	NaN
oil	0.5	0.44246575342465755	NaN
oil	0.75	0.6924657534246574	NaN
oil	1.0	0.9424657534246574	NaN

Table 140. uga_fuel_disruption.csv — 5 rows.

uga_climate_stress

case	objective	unserved_mwh	emissions_t	curtailment_mwh
wet	1.8183961446030636e6	0.0	2508.132613245605	54957.3477350879
dry	9.350846460975952e9	925743.2010975953	327186.0	0.0
historical	7.889316802889501e8	69368.858028895	333756.0	0.0
severe_dry	1.6056038301102564e10	1.5965366826102566e6	317331.0	0.0

Table 141. uga_climate_stress.csv — 4 rows.

uga_investment_breakdown

category	investment
generation	4.478111039999998e7
access	9.49858919e8
clean_cooking	1.709186e8

Table 142. uga_investment_breakdown.csv — 3 rows.

uga_demand_path

year	peak_mw	energy_mwh
2026	473.808	3.4851623500000006e6
2030	684.6043866557405	5.035705249842614e6
2035	1084.5168100055641	7.977318141891855e6
2040	1718.0385257684543	1.2637277517175147e7

Table 143. uga_demand_path.csv — 4 rows.

uga_ldc

load_mw	hours	cumulative_hours
473.808	730.0	730.0
455.58600000000007	730.0	1460.0
441.918	730.0	2190.0
438.711	730.0	2920.0
421.83799999999997	730.0	3650.0
421.16200000000003	730.0	4380.0
409.1840000000001	730.0	5110.0
404.96299999999997	730.0	5840.0
392.81500000000005	730.0	6570.0
315.874	730.0	7300.0
303.723	730.0	8030.0
294.61299999999994	730.0	8760.0

Table 144. uga_ldc.csv — 12 rows.

uga_system_load

time	weight	load_mw
wet_night	730.0	294.61299999999994
wet_morning	730.0	392.81500000000005
wet_day	730.0	409.1840000000001
wet_evening	730.0	441.918
dry_night	730.0	303.723
dry_morning	730.0	404.96299999999997
dry_day	730.0	421.83799999999997
dry_evening	730.0	455.58600000000007
hot_night	730.0	315.874
hot_morning	730.0	421.16200000000003
hot_day	730.0	438.711
hot_evening	730.0	473.808

Table 145. uga_system_load.csv — 12 rows.

uga_diagnostics

table	rows	missing_values	duplicate_keys
buses	24	0	0
lines	30	0	0
technologies	5	3	0
demand	288	0	0
availability	36	0	0
candidates	3	2	0
storage	1	0	0
access_sites	40	0	0
hazards	1	0	0
hydro	6	6	0
fuels	2	0	0
customers	3	0	0
households	3	0	0
cooking	3	0	0
projects	3	0	0

Table 146. uga_diagnostics.csv — 15 rows.

uga_cge_generation

carrier	generation_mwh	region
solar	130889.0	UGA
biomass	105120.0	UGA
oil	438000.0	UGA
Bugoye	48180.0	UGA
BujagaliFalls	1.095e6	UGA
IshashaRiver	43800.0	UGA

carrier	generation_mwh	region
Kiira	897900.0	UGA
Mubuku3	45552.0	UGA
Narubale	788400.0	UGA

Table 147. uga_cge_generation.csv — 9 rows.

uga_cge_lcoe_by_carrier

carrier	year	lcoe	cf
solar	2026	26.89301621985041	0.33958333333333335
solar	2030	23.88531445667703	0.33958333333333335
solar	2035	20.606108941946744	0.33958333333333335
solar	2040	17.790143589184762	0.33958333333333335
hydro	2026	39.3013698630137	0.5
hydro	2030	39.3013698630137	0.5
hydro	2035	39.3013698630137	0.5
hydro	2040	39.3013698630137	0.5
gas	2026	86.78753693258125	0.85
gas	2030	86.78753693258125	0.85
gas	2035	86.78753693258125	0.85
gas	2040	86.78753693258125	0.85

Table 148. uga_cge_lcoe_by_carrier.csv — 12 rows.

uga_cge_lcoe_path

year	lcoe
2026	50.993974338481785
2030	49.99140708409066
2035	48.89833857918057
2040	47.95968346159324

Table 149. uga_cge_lcoe_path.csv — 4 rows.

uga_cge_convergence

iteration	electricity_price	change
1	12.37274959364851	1.0
2	13.025444851884982	0.05275264429270674
3	13.025444851884982	0.0

Table 150. uga_cge_convergence.csv — 3 rows.

cge_power_mix

region	tech	share
UGA	COAL_p	0.0
UGA	GAS_p	0.0
UGA	OIL_p	0.6498429546193003
UGA	NUC	0.0
UGA	HYD	0.0
UGA	WND	0.0

region	tech	share
UGA	SOL	0.1941947362720676
UGA	ORE	0.15596230910863207

Table 151. cge_power_mix.csv — 8 rows.

cge_power_mix_fixed

region	tech	share_fixed
UGA	COAL_p	0.0
UGA	GAS_p	0.0
UGA	OIL_p	0.12190909645041348
UGA	NUC	0.0
UGA	HYD	0.8124022187455554
UGA	WND	0.0
UGA	SOL	0.036430501655931896
UGA	ORE	0.029258183148099234

Table 152. cge_power_mix_fixed.csv — 8 rows.

cge_mix_defect

region	tech	share	share_fixed
UGA	COAL_p	0.0	0.0
UGA	GAS_p	0.0	0.0
UGA	OIL_p	0.6498429546193003	0.12190909645041348
UGA	NUC	0.0	0.0
UGA	HYD	0.0	0.8124022187455554
UGA	WND	0.0	0.0
UGA	SOL	0.1941947362720676	0.036430501655931896
UGA	ORE	0.15596230910863207	0.029258183148099234

Table 153. cge_mix_defect.csv — 8 rows.

cge_prod_lever

period	sector	region	lambda
1	GAS_p	UGA	1.0
1	SOL	UGA	1.0
1	HYD	UGA	1.0
2	GAS_p	UGA	1.0
2	SOL	UGA	1.0300946643506346
2	HYD	UGA	1.0
3	GAS_p	UGA	1.0
3	SOL	UGA	1.0610950175236464
3	HYD	UGA	1.0
4	GAS_p	UGA	1.0
4	SOL	UGA	1.0930283159201515
4	HYD	UGA	1.0

Table 154. cge_prod_lever.csv — 12 rows.

cge_lcoe_canonical

sector	year	value
SOL	2026	26.89301621985041
SOL	2030	23.88531445667703
SOL	2035	20.606108941946744
SOL	2040	17.790143589184762
HYD	2026	39.3013698630137
HYD	2030	39.3013698630137
HYD	2035	39.3013698630137
HYD	2040	39.3013698630137
GAS_p	2026	86.78753693258125
GAS_p	2030	86.78753693258125
GAS_p	2035	86.78753693258125
GAS_p	2040	86.78753693258125

Table 155. cge_lcoe_canonical.csv — 12 rows.

cge_scenario_response

scenario	year	carbon_price	emissions	gdp	emissions_vs_ref	gdp_vs_ref
tax_0	2026		1025968.288333704	37384.154269348976	0.0	0.0
tax_0	2031		1129427.289115396	41496.05068865898	0.0	0.0
tax_0	2041		1368747.3122486956	51124.22278975125	0.0	0.0
tax_50	2026		1013064.9909997638	37045.39210835645	-0.01257670191239213	-0.009061651055465414
tax_50	2031		1114786.578747082	41097.859618322575	-0.012962950788785288	-0.009595878733713592
tax_50	2041		1351442.6262103135	50665.6871325473	-0.01264271782200066	-0.008969048959231785
tax_100	2026		1001313.6576301316	36753.19770400465	-0.024030597225977113	-0.016877647165650767
tax_100	2031		1101826.9584641152	40775.20582214736	-0.02443745685735854	-0.017371408954554468
tax_100	2041		1334689.2338054683	50233.27238305891	-0.024882663248685266	-0.017427167750918793
netzero	2026		1017200.4839826294	37156.83799596858	-0.008545882412520411	-0.006080551448151228
netzero	2031		1115046.567964389	41125.13319446162	-0.012732755166798393	-0.008938621580649175
netzero	2041		1340055.5509892087	50391.07925945472	-0.02096205852075761	-0.014340433757039084

scenario	year	carbon_price	emissions	gdp	emissions_vs_ref	gdp_vs_ref
renew	2026		1011479.9536204016	37532.01065289756	-0.014121620402939739	0.003955054927371027
renew	2031		1113136.9329762205	41660.129719612494	-0.014423554571569408	0.003954087876568924
renew	2041		1348169.4762512397	51326.268998043895	-0.01503406495363191	0.003952064154081336
electr	2026		1002835.3168225152	37554.24879172747	-0.02254745275680936	0.004549909599478541
electr	2031		1095775.0482985603	41731.50386503065	-0.02979584532900148	0.005674110486760586
electr	2041		1307783.2687809956	51480.81166641862	-0.04454002789422329	0.0069749495876707535
cbam50	2026		1017986.8809664476	37349.493606766046	-0.007779389926582558	-0.0009271485007579239
cbam50	2031		1120626.70004611	41457.89716537185 4	-0.0077920811318266114	-0.0009194495055296903
cbam50	2041		1358047.066094529	51077.99064187221	-0.007817546787790564	-0.0009043100384952263

Table 156. cge_scenario_response.csv — 21 rows.

poverty_microsim_headline

scenario	price_change	income_change	fgt0_before	fgt0_after	change_pp	newly_poor_share	newly_poor_people
baseline	0.0	0.0	0.14845598020831305	0.14845598020831305	0.0	0.0	0.0
price:generation_only_reve	-0.5440660429297521	0.0	0.14845598020831305	0.14826056834251342	-0.019541186579963288	0.0	0.0
price:carbon_25	0.09601814516129026	0.0	0.14845598020831305	0.14845598020831305	0.0	0.0	0.0
price:carbon_50	0.19203629032258074	0.0	0.14845598020831305	0.14845598020831305	0.0	0.0	0.0
price:carbon_100	0.38407258064516125	0.0	0.14845598020831305	0.14845598020831305	0.0	0.0	0.0
income:cdcge_tax_50	0.0	-0.009595878733713592	0.14845598020831305	0.1574750481458159	0.9019067937502845	0.009019067937502841	341288.67586891656
income:cdcge_tax_100	0.0	-0.017371408954554468	0.14845598020831305	0.1590622876678895	1.0606307459576443	0.010606307459576449	401351.0768319698
income:cdcge_netzero	0.0	-0.008938621580649175	0.14845598020831305	0.1574750481458159	0.9019067937502845	0.009019067937502841	341288.67586891656
income:cdcge_renew	0.0	0.003954087876568924	0.14845598020831305	0.148167740701104	-0.028823950720904823	0.0	0.0
income:cdcge_electr	0.0	0.005674110486760586	0.14845598020831305	0.14569380838696394	-0.27621718213491075	0.0	0.0

scenario	price_change	income_change	fgt0_before	fgt0_after	change_pp	newly_poor_share	newly_poor_people
income:cdcge_cbam50	0.0	-0.0009194495055296903	0.14845598020831305	0.1487309236404663	0.027494343215325734	0.00027494343215325837	10404.077289212823
both:carbon_50+cdcge_tax_5	0.19203629032258074	-0.009595878733713592	0.14845598020831305	0.1574750481458159	0.9019067937502845	0.009019067937502841	341288.67586891656
both:carbon_100+cdcge_tax_	0.38407258064516125	-0.017371408954554468	0.14845598020831305	0.1590622876678895	1.0606307459576443	0.010606307459576449	401351.0768319698

Table 157. poverty_microsim_headline.csv — 13 rows.

poverty_burden_by_quintile

quints	n	connected	loss_share	loss_share_connected	scenario
1.0	571.0	0.00179948636704725	2.63194095013926e-05		carbon_100
2.0	591.0	0.06774399412087015	0.0008754733226961581	0.013172921570514072	carbon_100
3.0	639.0	0.11742398457206037	0.0013151154275531762	0.010028980247436222	carbon_100
4.0	676.0	0.2781924600782591	0.004593131743145688	0.01547859006259888	carbon_100
5.0	585.0	0.646063422430646	0.006074902793785206	0.009271740393886474	carbon_100

Table 158. poverty_burden_by_quintile.csv — 5 rows.

lsms_energy_ladder

fuel	tier	n	use_rate	cooking	lighting	heating	mean_spend
Firewood	1	3062	0.7118641931991154	0.9932846686415631	0.019198593194194185	0.05756816223160199	2377.2860199378656
Dung	1	3062	0.0005568387221758365	1.0	0.0	0.0	0.0
Crop Residue	1	3062	0.16936814330821456	0.99288687815117	0.06308250395301013	0.03384237551189548	0.0
Charcoal	2	3062	0.3519026362080534	0.9996989468475019	0.00644838209658077	0.040567056313607165	26111.691546185397
Kerosene	2	3062	0.177640814294912	0.17354080343270908	0.8458745757495132	0.01367928670197718	3202.0731398908765
Torches	2	3062	0.23595877619293168	0.0	0.9763728709042208	0.0	2354.846748821655
lpg	3	3062	0.008539558349859052	1.0	0.0	0.0	42153.08872835571
Solar	3	3062	0.41979710750856264	0.02761108662579875	0.9805638451984523	0.0052229136010532645	0.0
Electricity	4	3062	0.23949021883484053	0.08323771405253988	0.9883852809256625	0.004521718919293185	0.0

Table 159. lsms_energy_ladder.csv — 9 rows.

lsms_no_grid_reasons

reason	kind	n	share	disclosed
Electricity is not availab	supply side	1890	0.722213754792971	True
Household can't afford con	affordability	404	0.1722787342427991	True
Household can't afford	affordability	49	0.02426577780804739	True

reason	kind	n	share	disclosed
cos				
Satisfied with present ene	preference/other	41	0.022512297605752907	True
Household can't afford the	affordability	44	0.02184793809193886	True
Other (specify)	preference/other	36	0.018837165966978323	True
No need for electricity	preference/other	51	0.013040606677102991	True
Household can't afford to	affordability	10	0.0033781227627422026	False

Table 160. lsms_no_grid_reasons.csv — 8 rows.

uga_asset_base

unit	carrier	mw	overnight_per_mw	value	matched
Kabulasoke	solar	24.0	832632.5427099094	1.9983181025037825e7	true
KakiraSugarWor	biomass	12.0	1.2809731426306297e6	1.5371677711567556e7	false
LugogoSubstati	oil	50.0	1.2809731426306297e6	6.4048657131531484e7	false
Soroti	solar	10.0	832632.5427099094	8.326325427099094e6	true
Tororo	solar	10.0	832632.5427099094	8.326325427099094e6	true
Bugoye	hydro	11.0	1.6012164282882873e6	1.761338071117116e7	true
BujagaliFalls	hydro	250.0	1.6012164282882873e6	4.003041070720718e8	true
IshashaRiver	hydro	10.0	1.6012164282882873e6	1.6012164282882873e7	true
Kiira	hydro	205.0	1.6012164282882873e6	3.282493677990989e8	true
Mubuku3	hydro	10.5	1.6012164282882873e6	1.6812772497027017e7	true
Narubale	hydro	180.0	1.6012164282882873e6	2.882189570918917e8	true

Table 161. uga_asset_base.csv — 11 rows.

uga_tariff_poverty

poverty_line	tariff_change	total_welfare_loss	newly_poor	headcount_before	headcount_after
785.0	0.05	1.6330888e7	0.0	0.0	0.0
785.0	0.1	3.2661776e7	0.0	0.0	0.0
785.0	0.25	8.165444e7	0.0	0.0	0.0
785.0	0.5	1.6330888e8	0.0	0.0	0.0
1000.0	0.05	1.6330888e7	0.0	5.353284e6	5.353284e6
1000.0	0.1	3.2661776e7	0.0	5.353284e6	5.353284e6
1000.0	0.25	8.165444e7	0.0	5.353284e6	5.353284e6
1000.0	0.5	1.6330888e8	0.0	5.353284e6	5.353284e6
1200.0	0.05	1.6330888e7	0.0	5.353284e6	5.353284e6
1200.0	0.1	3.2661776e7	0.0	5.353284e6	5.353284e6
1200.0	0.25	8.165444e7	0.0	5.353284e6	5.353284e6
1200.0	0.5	1.6330888e8	0.0	5.353284e6	5.353284e6
1500.0	0.05	1.6330888e7	0.0	5.353284e6	5.353284e6
1500.0	0.1	3.2661776e7	0.0	5.353284e6	5.353284e6
1500.0	0.25	8.165444e7	0.0	5.353284e6	5.353284e6
1500.0	0.5	1.6330888e8	0.0	5.353284e6	5.353284e6

Table 162. uga_tariff_poverty.csv — 16 rows.

reconciliation

quantity	source_a	value_a	source_b	value_b	reconciles	why
Household electricity conn	Uganda LSMS-ISA 2019/20, s	0.25881878178457507	Model's Uganda demand basi	0.18	False	Two different quantities m
Installed generation capac	WRI Global Power Plant Dat	772.5	Model's Uganda case, techn	772.5	True	They agree to the megawatt
Length of electricity netw	Transmission network 2017	5852.012300768744	gridfinder predicted grid	14323.42232826973	False	They measure different net
Transmission length in the	Transmission layer, operat	2700.928754200959	Model's `lines` table, sum	2527.9	False	The full layer is 5,852 km
Unserved energy in the dis	Model result, share of ann	0.019904053545423784	A well-supplied system's e	0.0	False	The estate's own integrati

Table 163. reconciliation.csv — 5 rows.

Appendix J — The estate inventory

29 modules across 13 layers, 2,853 lines, plus 978 lines of Python in the bridge.

Layer	Modules	Lines
Access	1	110
Balance	1	129
Climate	1	83
Demand	1	154
Distribution	1	57
Equity	1	84
Finance	2	208
Fuels	1	69
GIS	1	124
Integration	4	704
Optimization	4	12
PowerSystem	1	351
Results	2	120
Total	29	2,853

Table 164. The estate by layer.

J.1 What each layer is for

Layer	Role
Access	Electrification planning and clean cooking
Balance	Energy-balance accounting and the Sankey export
Climate	Climate cases and stress testing
Demand	Sectoral demand projection, peak and load-duration
Distribution	Distribution losses
Equity	Affordability, energy burden and incidence
Expansion	Capacity and network expansion staging
Finance	Utility finance, tariffs and investment analysis
Fuels	Fuel accounts and energy security
GIS	Spatial planning: distances, clustering, siting context
Integration	Macro/CGE, MTEF, unit-cost and cross-sector links
Optimization	Non-power mathematical programmes: access, resilience, policy portfolio
PowerSystem	The bridge to the power-system engine: builds a network, runs the solve, reads the result contract
Results	Indicators and simulation results

Table 165. The estate's own description of each layer.

J.2 Every module

Layer	Module	Lines

Layer	Module	Lines
Access	Electrification	110
Balance	EnergyBalance	129
Climate	ClimateRisk	83
Demand	DemandProjection	154
Distribution	Losses	57
Equity	Affordability	84
Finance	Investment	104
Finance	UtilityFinance	104
Fuels	FuelSupply	69
GIS	Spatial	124
Integration	UCSNBOELink	257
Integration	MTEFLink	214
Integration	MacroCGELink	164
Integration	SectorLinks	69
Optimization	EnergyAccess	4
Optimization	PolicyPortfolio	3
Optimization	Resilience	3
Optimization	Common	2
PowerSystem	PyPSABridge	351
Results	Simulation	64
Results	Indicators	56

Table 166. Every module in the estate, with its length. The longest modules are not the most important ones; the shortest are often the ones that decide a contract.

J.3 Top-level modules

Module	Lines
Validation	131
DataSchema	126
EDISEnergySystemModel	110
Types	105
ScenarioManager	83
IO	46
Emissions	45
Economics	2

Table 167. Modules that sit outside a layer directory.

J.4 The Python bridge

Script	Lines	What it does
aegid/build_country.py	421	assembles a country case from the continental register
export_pypsa_network.py	15	writes a case out in PyPSA form
import_pypsa_earth.py	126	reads a solved PyPSA-Earth network into the estate's schema
make_test_network.py	52	builds the synthetic test case

Script	Lines	What it does
run_pypsa_case.py	364	builds and solves the PyPSA network; writes dispatch, flows, prices and the summary. Contains EN-20 and the shedding filter.

Table 168. The Python side of the bridge. Two of this course's findings live in the 364 lines of run_pypsa_case.py.

J.5 Scripts

Script	Lines
make_synthetic.jl	305
make_templates.jl	30
smoke_ucsn_boe.jl	27
smoke_mtef.jl	24
smoke_sim.jl	24
smoke_uganda.jl	21
smoke_synthetic.jl	13
smoke_access.jl	10
smoke_bridge.jl	9
run_demo.jl	8
run_imported_case.jl	8
setup_genie.jl	6

Table 169. Executable scripts shipped with the estate.

J.6 The status register, in full

Component	Grade	Evidence
Data schemas, loader, unit registry, provenance	A	tests `units & core`, `data validation`
Validation: ranges, duplicates, topology, islands, referential integrity	A	broken fixtures rejected
Energy balance accounting (E-BAL) + Sankey export	A	identity < 1e-9; refuses big auto-closes
Sectoral demand projection, peak, LDC (E-DEM)	A	hand-computed factors
PyPSA bridge (CSV/JSON exchange, Python discovery, result contract)	A	live solves in suite; mini-system analytic check (cost 250, price 50)
Economic dispatch via PyPSA: storage, reservoir hydro, shedding, emissions caps/price (E-DSP-01)	A	zero unserved on demo; caps bind; cross-engine cost match with former JuMP model
Unit commitment via PyPSA (committable units, min stable/up/down, startup) (E-DSP-03)	A	commitment asserted per slice
Generation expansion via PyPSA, rolling horizon: reserve margin (linopy), RE target, budgets via potentials, retirements-by-promotion (E-EXP-01)	A	reserve margin re-verified arithmetically; RE target forces solar
Network expansion via PyPSA (extendable links) (E-EXP-02)	A	corridor bounds respected
PyPSA-Earth integration: repo cloned (`D:\EDIP\models\pypsa-earth`), solved-network importer (`bridge/import_pypsa_earth.py`, `import_pypsa_earth`)	A	round-trip tested on a solved netCDF network: import → canonical tables → re-dispatch scenario variant (test "PyPSA-Earth import round-trip"). Running PyPSA-Earth's national Snakemake build is an upstream data task, not a code gap
Electrification planning (E-ACC-01), clean cooking (E-ACC-02) — JuMP	A	targets & budgets asserted
Fuel accounts & energy security (E-FUE)	A	identity + hand-checked disruption

Component	Grade	Evidence
Tariffs, lifeline cross-subsidy, utility finance, incidence (E-FIN)	A	Σ billed = RR to machine precision
Emissions inventory incl. multi-pollutant (E-EMI)	A	consistency test
Climate cases & stress test (re-dispatch via PyPSA) (E-CLI)	A	drought monotonicity
Affordability, poverty screening, incidence, access equity (E-EQU)	A	hand-computed burden
Macro/CGE adapters + convergence loop (E-MAC), CDCGE carrier/LCOE exports	A	energy-conserving export; iteration converges through PyPSA dispatch
Sector links + double-count guard	A	duplicate drivers rejected
Scenario manager, YAML, run IDs, reproducibility manifests	A	manifest.json per run
Demo dataset + templates + generated data dictionary	A	`data/demo`, `data/templates`
Genie web app (dashboard, REST API, async jobs) in PyPSA mode	B	HTTP dispatch verified live; UI exercised via API, not browser automation
Resilience & policy-portfolio screening (JuMP)	A	regression-tested
Full PyPSA-Earth Snakemake run (GIS → solved national network)	E	needs its conda environment and data downloads; out of this repo's scope — run upstream, import here (import path itself is tested)
Reserve/ancillary-service co-optimization in the bridge	D	was in the removed JuMP model; see REMAINING_GAPS
DC/AC power flow in the bridge	D	transport+losses representation; network physics live upstream in PyPSA-Earth
PostgreSQL/PostGIS, formatted PDF reports, auth on web app	D	unchanged; see REMAINING_GAPS

Table 170. Every component the estate grades, and what it cites as evidence.

J.7 The test suite

Test set	Passing	Covers
units & core	5	unit registry, run ids, data dictionary
data validation	4	schema, topology, negative/duplicate rejection
energy balance (E-BAL-01/02)	5	identity < 1e-9; no silent reconciliation
demand projection (E-DEM)	7	hand-computed driver factors, peak, LDC
pypsa bridge availability	1	Python + pypsa discovered
hand-calculated mini system (PyPSA)	6	analytic objective 250, price 50, emissions 2.5 t
economic dispatch via PyPSA (E-DSP-01)	9	zero unserved; flows ≤ limits; emissions cap binds
storage & hydro results (E-STO/E-HYD)	4	SOC bounds; hydro ≤ inflow energy
unit commitment via PyPSA (E-DSP-03)	4	min-stable when on; zero when off
generation expansion, rolling horizon (E-EXP-01)	9	potential & `available_from` respected; reserve margin re-derived from plan; RE target forces solar
network expansion via PyPSA (E-EXP-02)	2	corridor reinforcement ≤ candidate max
PyPSA-Earth import round-trip	9	solved `.nc` → canonical tables → re-dispatch variant; emissions/dispatch conserved

Test set	Passing	Covers
electrification & cooking (E-ACC)	6	targets & annual budgets
fuels & security (E-FUE)	5	identity + disruption arithmetic
tariffs & utility finance (E-FIN)	7	Σ billed = revenue requirement
equity & poverty (E-EQU)	4	burden, poverty monotonicity
emissions (E-EMI)	2	inventory ≡ CO2e function
climate (E-CLI)	4	drought re-dispatch (PyPSA) never cheaper
macro/CGE integration (E-MAC)	7	CDCGE export conservation; convergence loop (PyPSA)
sector links	2	double-count guard
scenario manager & export	5	manifests; carbon-price ordering

Table 171. 107 tests across 21 sets. None of them catches any of EN-17 to EN-24, because every one of those is a disagreement between two components that each behave correctly on their own terms.

WHAT THIS INVENTORY IS FOR

When a number surprises you, this table tells you which hundred-odd lines of Julia to open. That is the whole purpose of a module register, and it is why the line counts are here: a 40-line module that decides a contract is a more likely home for a defect than a 400-line module that solves a problem.

Appendix K — Glossary

Terms as this manual uses them. Where a term is contested or where its ordinary meaning differs from its meaning here, the entry says so.

Term	As used here
Adequacy	Whether a system can meet demand. Capacity adequacy asks about the peak; energy adequacy asks about the year. Uganda's case is adequate on the first and not on the second, and the distinction decides what a ministry procures.
Availability profile	The maximum output of a unit as a fraction of nameplate, by period. Enters PyPSA as p_max_pu.
Capacity credit	The share of a unit's nameplate that counts towards a planning reserve margin. A declared parameter here, not a computed one.
Capacity factor	Output over a period divided by nameplate times the hours. For hydro in this case it is 0.50 by assumption in every row.
Capital recovery factor	The annuity that converts an overnight capital cost into an equal annual payment. 0.09368 at 8 % over 25 years.
Carrier	The energy source a unit uses — hydro, solar, gas. The field CDCGE's PowerLink maps onto its eight power technologies, and the field reservoir hydro does not have.
CDCGE	The EDIS computable general equilibrium model. Receives the generation mix and a levelised-cost path from this estate across a documented contract.
Cost-reflective tariff	A price that recovers the revenue requirement in proportion to cost to serve. In this build it covers generation only.
Cross-subsidy	Revenue foregone on one class recovered from another. Here: the lifeline discount, recovered from non-lifeline energy.
Curtailment	Renewable output the system declines to take. Zero throughout this case.
Design effect	The ratio of a complex-survey variance to the variance a simple random sample of the same size would have.
Dispatch	Choosing how much each unit produces in each period at least cost, subject to capacity, availability and the network.
Economic flow	The flow a transport model produces: the cheapest way to move energy subject to capacity and losses. Not the flow physics would produce.
Energy deficit	Demand plus losses exceeding what the fleet can produce over a year. Uganda's case is short by 69,369 MWh, 2 % of demand.
FGT	Foster–Greer–Thorbecke poverty measures. Alpha 0 is the headcount, 1 the gap, 2 the severity.
GTAP-Power	The eight-technology split of an electricity sector CDCGE uses: COAL_p, GAS_p, OIL_p, NUC, HYD, WND, SOL, ORE.
HiGHS	The open-source solver PyPSA uses here, through linopy.
Inflow	Water arriving at a reservoir, expressed in this schema as an energy rate. The binding constraint on Uganda's hydro fleet.
Levelised cost	Annualised capital plus fixed and variable operating cost, divided by annual output. A ranking device that ignores when the output arrives.
Lifeline block	A first tranche of consumption priced below cost to protect small users. Protects connected households, who in Uganda are disproportionately not poor.
Linopy	The optimisation-modelling layer PyPSA builds its linear programme through.
LOLE	Loss of load expectation: hours in which demand exceeds what can be delivered. 8,760 on this case, meaning every representative period.
Marginal price	The dual of the energy balance at a bus. In a shedding system it is the value of lost load, attenuated by losses along the delivery path.

Term	As used here
Merit order	Units ranked by variable cost. Meaningful only when something is on the margin; on this case nothing is.
Myopic expansion	Solving each planning year with that year's demand and no foresight of later years.
Nightlight	Satellite-observed light at night, used here as a proxy for a lit settlement. Not a household connection.
Overnight cost	Capital cost as if the asset were built instantly. Recovered here by inverting the candidate annuity.
PowerLink	CDCGE's reader for a generation-by-carrier file. Drops carriers it does not recognise, with a warning.
Provenance	The class of a value: observed, estimated, imputed, calibrated, projected or scenario. Decides what the value may be used for.
PyPSA	Python for Power System Analysis, the optimiser this estate solves its power problems in.
Regulated asset base	The capital on which a utility is allowed a return. Not in any file in this case; built in Chapter 16.
Relative wealth index	A modelled small-area wealth measure carried by the settlement layer.
Revenue requirement	Operating cost plus depreciation plus a return on the asset base, less other revenue. What a tariff has to recover.
Share-alike	A licence condition requiring derived works to carry the same licence. Applies to 472 datasets in the register.
Snapshot weighting	The number of hours a representative period stands for. 730 in this case, and the factor by which the exported price is wrong.
Transport model	A network representation with capacity and losses but no voltage law. What this estate uses.
Unserved energy	Demand the system cannot deliver, priced at the value of lost load.
Value of lost load	The price placed on unserved energy. 10,000 per MWh here, and the number that sets the marginal price across the whole system.

Table 172. Glossary.

Appendix L — Checklists

L.1 Before you solve

- Read the provenance note. If there is none, write one as you read the tables.
- List the optional tables that are absent, and name the model that silently did not run for each.
- Run the duplicate-column check on every table.
- Run the degenerate-column check: any column with one value, or one value above 95 %.
- Compute every ratio a modeller might have assumed — inflow over capacity, connections over buildings, lifeline over total — and look for suspiciously round numbers repeated across rows.
- Total every physical quantity against an independent register, and ask whether the register is genuinely independent.
- Check that the network graph is connected, and count the components.

L.2 After you solve, before you quote anything

- Status: optimal, or not?
- Unserved energy: zero, or not? If not, the answer is about scarcity.
- LOLE: is it every period? A structural shortage is a different finding from a stochastic one.
- Objective against generation cost: how much of the objective is a penalty?
- Mean dual against the value of lost load: is scarcity setting the price?
- Every unit's output against its own input row: how many are at exactly their limit?
- Write the energy balance and check that it closes.

L.3 Before a number crosses an estate boundary

- Does the receiving vocabulary contain every value you are sending? Check the carriers, the sector codes, the region codes.
- Does the receiver's column matcher accept your column names? Exact match or substring?
- Are you sending everything, or only what one table contains?
- Does the receiver warn or raise on what it cannot map? If it warns, turn the warning into an error.
- What are the units at each end, and what does each side think the denominator is?
- Re-derive the receiving side's headline number from what you sent, and compare.

L.4 Before a result reaches a minister

- Which of the numbers in this brief was calibrated to something the brief also cites as evidence?
- Which checks in it cannot fail?
- Which access, coverage or reliability rate is quoted, and does the target it is compared against use the same one?
- What is the denominator of every distributional statistic, and what does the statistic look like on the other denominator?
- Which single input, if wrong, would reverse the recommendation? Has it been swept?
- What would have to be true for this to be wrong, and is anyone measuring it?

Appendix M — The estate's data dictionary

Reproduced from the estate's own `docs/energy/DATA_DICTIONARY.md`. This is the authority on what each column in each input table means. Where this manual disagrees with it — as it does on `num_connections` in the settlement layer, and on what `inflow_mwh` implies — the disagreement is stated in the chapter, not here.

Energy System data dictionary

Generated from src/DataSchema.jl — regenerate with EDISEnergySystemModel.data_dictionary_markdown().

buses.csv

Network buses / demand nodes.

column	status	notes
bus	required	
region	required	
lat	optional	latitude (deg) for maps
lon	optional	longitude (deg) for maps
zone	optional	market/balancing zone

lines.csv

Transmission lines / interconnectors.

column	status	notes
line	required	
from_bus	required	
to_bus	required	
existing_mw	required	
loss_factor	required	
susceptance	optional	p.u. susceptance; enables DC-OPF angle formulation
candidate_max_mw	optional	max reinforcement (MW) for expansion
annualized_cost_per_mw	optional	annualized reinforcement cost
length_km	optional	line length for loss/cost estimation

technologies.csv

Existing generating units / technologies.

column	status	notes
technology	required	

column	status	notes
bus	required	
existing_mw	required	
variable_cost	required	
emission_factor	required	
carrier	optional	fuel/carrier name (maps to CDCGE power technologies)
fuel	optional	fuel consumed; links to fuels table
heat_rate	optional	MWh fuel per MWh electricity
ramp_rate	optional	max hourly ramp as fraction of capacity
min_stable	optional	min stable generation fraction when committed
startup_cost	optional	cost per startup (enables unit commitment)
min_up	optional	min up time, hours
min_down	optional	min down time, hours
reserve_capable	optional	1 if unit can hold spinning reserve
renewable	optional	1 if counts toward the RE target
energy_limit_mwh	optional	period energy budget (hydro/fuel-limited units)

demand.csv

Load by time slice and bus. weight = hours represented.

column	status	notes
time	required	
bus	required	
demand_mw	required	
weight	required	
sector	optional	demand sector for sectoral accounting
year	optional	planning year for multi-year models

availability.csv

Per-slice availability / capacity factor (0-1).

column	status	notes
time	required	
technology	required	
availability	required	

candidates.csv

Candidate generation/storage projects for expansion planning.

column	status	notes
candidate	required	
max_mw	required	
annualized_capex_per_mw	required	
bus	optional	connection bus
technology	optional	technology class
carrier	optional	carrier for CGE export
variable_cost	optional	variable cost
emission_factor	optional	tCO2e/MWh
fixed_om_per_mw	optional	annual fixed O&M
available_from	optional	first year buildable
lifetime	optional	economic lifetime, years
renewable	optional	1 if renewable
integer_mw	optional	unit size for lumpy builds
max_annual_mw	optional	annual build limit

storage.csv

Storage units (batteries, pumped hydro).

column	status	notes
storage	required	
power_max_mw	required	
energy_max_mwh	required	
charge_efficiency	required	
discharge_efficiency	required	
bus	optional	connection bus
self_discharge	optional	per-slice self-discharge fraction
variable_cost	optional	cycling cost per MWh discharged

access_sites.csv

Unelectrified settlements and per-technology connection costs.

column	status	notes
site	required	
grid_cost	required	
minigrid_cost	required	
shs_cost	required	
households	required	

column	status	notes
benefit_per_household	required	
region	optional	admin region
lat	optional	latitude
lon	optional	longitude
demand_tier	optional	target multi-tier framework tier (1-5)
grid_distance_km	optional	distance to nearest grid

hazards.csv

Climate-hazard exposure and hardening options.

column	status	notes
asset	required	
hardening_cost	required	
expected_avoided_loss	required	
hazard	optional	hazard type (flood, cyclone, drought, ...)

hydro.csv

Reservoir hydropower with inflow energy accounting.

column	status	notes
plant	required	
bus	required	
capacity_mw	required	
inflow_mwh	required	
reservoir_max_mwh	required	
reservoir_initial_mwh	optional	starting storage
min_release_mwh	optional	environmental flow per slice
cascade_upstream	optional	upstream plant id for cascades

fuels.csv

Fuel supply/demand accounts and prices by year.

column	status	notes
fuel	required	
year	required	
production	required	
imports	required	
exports	required	

column	status	notes
consumption	required	
price	required	
unit	optional	energy unit of the quantity columns (default MWh)
storage_days	optional	strategic storage, days of consumption
import_price	optional	border price
tax	optional	tax per unit
subsidy	optional	subsidy per unit

balance.csv

Energy-balance flows: primary_supply, imports, exports, stock_build, transformation_input, transformation_output, own_use, losses, final_consumption, nonenergy_use.

column	status	notes
fuel	required	
flow	required	
value	required	
region	optional	region (default national)
year	optional	accounting year
sector	optional	final-consumption sector for final_consumption rows
unit	optional	energy unit (default MWh)
provenance	optional	data provenance label

demand_drivers.csv

Sectoral demand drivers for projection.

column	status	notes
sector	required	
year	required	
activity_index	required	
region	optional	region
efficiency_factor	optional	efficiency multiplier (1=base)
electrification_factor	optional	share-of-useful-energy multiplier
new_load_mwh	optional	additive new load (e.g. EVs, new industry)

customers.csv

Customer classes for tariff design and utility finance.

column	status	notes

column	status	notes
class	required	
energy_mwh	required	
customers	required	
current_tariff	optional	current tariff per MWh
cost_to_serve	optional	cost per MWh
lifeline_mwh	optional	monthly lifeline block per customer, MWh
collection_rate	optional	billed revenue actually collected (0-1)

households.csv

Household groups for affordability / equity analysis.

column	status	notes
group	required	
households	required	
income	required	
electricity_spend	required	
cooking_spend	required	
connected	optional	share with electricity access (0-1)
region	optional	region
urban	optional	1 urban / 0 rural
female_headed	optional	share of female-headed households

cooking.csv

Clean-cooking technology options.

column	status	notes
technology	required	
capex	required	
annual_fuel_cost	required	
emission_factor_t_per_hh	required	
health_benefit_per_hh	required	
time_saving_hours_per_day	optional	time savings vs baseline (gender analysis)

projects.csv

Policy-portfolio candidate projects.

column	status	notes
project	required	

column	status	notes
cost	required	
emissions_reduction	required	
access_gain	required	
resilience_gain	required	
jobs	required	

M.1 What the dictionary does not cover

- The DRE settlement layer, which is not an estate input table but carries the whole of Chapter 15's geography.
- The provenance class of any individual cell. The dictionary says what a column means, not where its values came from.
- The relationship between `capacity_mw` and `inflow_mwh` in hydro.csv, which is where Chapter 11's deficit comes from.
- Which tables are consumed by which downstream function — the information that would have made EN-17 and EN-18 visible.

Appendix N — The estate's validation report and status documents

The estate's own account of what it has validated. Read it against Chapter 21, which sets out what this course was able to validate independently and what it was not.

N.1 Validation report

Energy System validation report

Date: 2026-07-22 · Package v0.3.0 · Julia 1.12.6 · Power system: PyPSA (Python 3.12, HiGHS), PyPSA-Earth upstream · Non-power models: JuMP/HiGHS 2026-07 restructuring: the power system is now solved in PyPSA through src/PowerSystem/PyPSABridge.jl; all power-system evidence below comes from live PyPSA solves in the test suite. See TEST_RESULTS.md for the current run (98 assertions) and the migration fix log.

Method

Validation combines (1) hand-calculated miniature systems, (2) accounting identities enforced to machine precision, (3) constraint post-checks on solver output, (4) regression tests on the preserved legacy API, and (5) runtime checks of the web application. Synthetic fixtures are used *only* for testing and live in data/demo; no production data are involved or invented.

Evidence (test suite: test/runtests.jl, 94 assertions, 20 test sets, all passing)

Area	Check	Evidence
Units	GWh/GJ/toe round-trips; unknown units rejected	units & core
Schema/topology	unknown bus, negative demand, duplicates rejected	data validation
E-BAL-01	demo balance residuals < 1e-9; 10% hole refuses auto-reconcile	energy balance
E-BAL-02	electricity transformation efficiency = 550000/1240000	energy balance
E-DEM-02	2030 industry load = 60·1.3·0.97 exactly (hand computed)	demand projection
E-DEM-03	peak = 130 MW; LDC monotone, 8760 h total	demand projection
Mini system	1-bus LP: cost 250, dual price 50/MWh, emissions 2.5 t — all analytic	hand-calculated mini system
E-DSP-01	zero unserved on demo; flows within limits; reserve > 0; DC-OPF selected; emissions cap binds; transport ≡ DC on radial network	economic dispatch
E-STO-01	SOC within [0, capacity]	storage balance
E-DSP-03	committed units ≥ min stable; uncommitted ≈ 0	unit commitment
E-EXP-01	build ≤ potential; available_from respected; reserve margin re-verified arithmetically from the plan; zero unserved; RE target forces solar build	generation expansion
E-EXP-02	reinforcement ≤ candidate max	network expansion

Area	Check	Evidence
E-ACC-01	access target met; per-year budgets respected	electrification & cooking
E-ACC-02	households reached = target share exactly	electrification & cooking
E-FUE-01/02/03	fuel balance closes; import dependence ∈ {0,1} as constructed; disruption drawdown arithmetic hand-checked	fuels & security
E-FIN-01/02	Σ billed revenue = revenue requirement to machine precision incl. lifeline cross-subsidy and collection gross-up	tariffs & utility finance
E-EQU-01/02	energy burden = (30+90)/1200; tariff shock cannot reduce poverty	equity & poverty
E-EMI-01	inventory CO2e ≡ legacy emissions function	emissions
E-CLI-01/02	dry case scales inflows ×0.5; drought never cheapens the system	climate
E-MAC-01/02/03	CGE carrier CSV preserves total energy; carriers map to CDCGE names; macro iteration converges	macro/CGE integration
Double counting	duplicate sector drivers rejected	sector links
Reproducibility	manifest.json + result CSVs written per run id; carbon-price ordering of objectives	scenario manager & export
Legacy API	run_dispatch / run_storage / run_transmission_expansion / run_energy_access / run_resilience / run_policy_portfolio regression-tested	multiple sets

Runtime checks

- Package precompiles cleanly (Precompiling … ✓ EDISEnergySystemModel).
- Template/dictionary generation runs (scripts/make_templates.jl).
- Genie application starts and serves /api/status, table, balance and

job endpoints (see TEST_RESULTS.md for the smoke-test transcript).

Known validation limits

- Cross-engine check: on the demo case the PyPSA engine reproduces the

former JuMP engine's generation cost (4.7929714e7 at carbon price 25) — two independent implementations of the shared formulation agreeing.

- The bridge uses the transport-with-losses network representation; KVL

is not imposed in bridge runs (full network physics live upstream in PyPSA-Earth networks, whose importer has not yet been exercised on a real solved .nc — see REMAINING_GAPS).

- No comparison against MATPOWER/published benchmarks (none supplied).
- Solver status is taken from PyPSA/HiGHS termination ("ok:optimal");

marginal prices are read from the solved model.

Components listed in REMAINING_GAPS.md are not claimed as validated.

N.2 Implementation status

EDIS Energy System — implementation status

Date: 2026-07-22 · Package v0.3.0 · **Power system modelled in PyPSA / PyPSA-Earth (Python); Julia owns accounting, planning context and EDIS integration. Classification: A complete & tested · B** implemented, not fully validated · C partial · D not implemented · E blocked by missing data / external dependency

Component	Status	Evidence / notes
Data schemas, loader, unit registry, provenance	A	tests units & core, data validation
Validation: ranges, duplicates, topology, islands, referential integrity	A	broken fixtures rejected
Energy balance accounting (E-BAL) + Sankey export	A	identity < 1e-9; refuses big auto-closes
Sectoral demand projection, peak, LDC (E-DEM)	A	hand-computed factors
PyPSA bridge (CSV/JSON exchange, Python discovery, result contract)	A	live solves in suite; mini-system analytic check (cost 250, price 50)
Economic dispatch via PyPSA: storage, reservoir hydro, shedding, emissions caps/price (E-DSP-01)	A	zero unserved on demo; caps bind; cross-engine cost match with former JuMP model
Unit commitment via PyPSA (committable units, min stable/up/down, startup) (E-DSP-03)	A	commitment asserted per slice
Generation expansion via PyPSA, rolling horizon: reserve margin (linopy), RE target, budgets via potentials, retirements-by-promotion (E-EXP-01)	A	reserve margin re-verified arithmetically; RE target forces solar
Network expansion via PyPSA (extendable links) (E-EXP-02)	A	corridor bounds respected
PyPSA-Earth integration: repo cloned (D:\EDIP\models\pypsa-earth), solved-network importer (bridge/import_pypsa_earth.py, import_pypsa_earth)	A	round-trip tested on a solved netCDF network: import → canonical tables → re-dispatch scenario variant (test "PyPSA-Earth import round-trip"). Running PyPSA-Earth's national Snakemake build is an upstream data task, not a code gap
Electrification planning (E-ACC-01), clean cooking (E-ACC-02) — JuMP	A	targets & budgets asserted
Fuel accounts & energy security (E-FUE)	A	identity + hand-checked disruption
Tariffs, lifeline cross-subsidy, utility finance, incidence (E-FIN)	A	Σ billed = RR to machine precision
Emissions inventory incl. multi-pollutant (E-EMI)	A	consistency test
Climate cases & stress test (re-dispatch via PyPSA) (E-CLI)	A	drought monotonicity
Affordability, poverty screening, incidence, access equity (E-EQU)	A	hand-computed burden
Macro/CGE adapters + convergence loop (E-MAC), CDCGE carrier/LCOE exports	A	energy-conserving export; iteration converges through PyPSA dispatch
Sector links + double-count guard	A	duplicate drivers rejected
Scenario manager, YAML, run IDs, reproducibility manifests	A	manifest.json per run
Demo dataset + templates + generated data dictionary	A	data/demo, data/templates

Component	Status	Evidence / notes
Genie web app (dashboard, REST API, async jobs) in PyPSA mode	B	HTTP dispatch verified live; UI exercised via API, not browser automation
Resilience & policy-portfolio screening (JuMP)	A	regression-tested
Full PyPSA-Earth Snakemake run (GIS → solved national network)	E	needs its conda environment and data downloads; out of this repo's scope — run upstream, import here (import path itself is tested)
Reserve/ancillary-service co-optimization in the bridge	D	was in the removed JuMP model; see REMAINING_GAPS
DC/AC power flow in the bridge	D	transport+losses representation; network physics live upstream in PyPSA-Earth
PostgreSQL/PostGIS, formatted PDF reports, auth on web app	D/C	unchanged; see REMAINING_GAPS

Removed by design (2026-07 restructuring): the JuMP power-system models (run_dispatch, run_dcopf, JuMP UC/expansion/storage/ transmission screening). JuMP/HiGHS remain only for non-power models.

N.3 Test results

Test results

Date: 2026-07-22 · Julia 1.12.6 · Python 3.12.10, pypsa 1.x + HiGHS · julia --project=. test/runtests.jl

Architecture note: as of this run the power system is solved in PyPSA (Python) through src/PowerSystem/PyPSABridge.jl; the power- system test sets below execute live PyPSA solves (~15 per suite run).

Suite — ALL PASSING

Test set	Pass	Notes
units & core	5	unit registry, run ids, data dictionary
data validation	4	schema, topology, negative/duplicate rejection
energy balance (E-BAL-01/02)	5	identity < 1e-9; no silent reconciliation
demand projection (E-DEM)	7	hand-computed driver factors, peak, LDC
pypsa bridge availability	1	Python + pypsa discovered
hand-calculated mini system (PyPSA)	6	analytic objective 250, price 50, emissions 2.5 t
economic dispatch via PyPSA (E-DSP-01)	9	zero unserved; flows ≤ limits; emissions cap binds
storage & hydro results (E-STO/E-HYD)	4	SOC bounds; hydro ≤ inflow energy
unit commitment via PyPSA (E-DSP-03)	4	min-stable when on; zero when off
generation expansion, rolling horizon (E-EXP-01)	9	potential & available_from respected; reserve margin re-derived from plan; RE target forces solar
network expansion via PyPSA (E-EXP-02)	2	corridor reinforcement ≤ candidate max
PyPSA-Earth import round-trip	9	solved .nc → canonical tables → re-dispatch variant; emissions/dispatch conserved
electrification & cooking (E-ACC)	6	targets & annual budgets

Test set	Pass	Notes
fuels & security (E-FUE)	5	identity + disruption arithmetic
tariffs & utility finance (E-FIN)	7	Σ billed = revenue requirement
equity & poverty (E-EQU)	4	burden, poverty monotonicity
emissions (E-EMI)	2	inventory ≡ CO2e function
climate (E-CLI)	4	drought re-dispatch (PyPSA) never cheaper
macro/CGE integration (E-MAC)	7	CDCGE export conservation; convergence loop (PyPSA)
sector links	2	double-count guard
scenario manager & export	5	manifests; carbon-price ordering
Total	107	0 fail, 0 error

Cross-engine consistency

On the demo case at carbon price 25, the PyPSA engine's generation cost (4.7929714e7) matches the value produced by the former JuMP engine on the same case — an independent-implementation check of the shared formulation.

Errors found and fixed during the PyPSA migration (root causes)

1. Windows Store Python stub shadowed a real interpreter → installed CPython 3.12 (winget) and made find_python prefer real installs / ENERGY_PYTHON. 2. pip install died on a transient DNS failure → retried; succeeded. 3. Commitment export included non-committable units (status 0 while generating) → filtered to generators.committable. 4. pd.Series or truthiness error selecting candidate availability → explicit is None chain. 5. linopy dimension names differ across pypsa versions (Generator-ext vs name) → dimensions resolved generically from the variable, for both the reserve-margin and RE-share constraints. 6. Partially-built candidate collided by name with its promoted existing twin (PyPSA skipped one) → promoted units renamed <c>_built, carrying their availability profiles. 7. @test a && b ≈ c atol=… is invalid Test-macro syntax → split.

PyPSA-Earth importer, exercised

bridge/make_test_network.py builds and solves a 2-bus PyPSA network (buses with x/y/country, a line with s_nom, gas + solar generators with a p_max_pu profile, a battery) and exports it to netCDF — the same structure PyPSA-Earth produces, at toy scale. The round-trip test then runs import_pypsa_earth on that .nc, checks the canonical tables (2 buses, gas+solar carriers, positive emissions and dispatch) and feeds the imported data straight back through the PyPSA bridge at a different carbon price. Objective of the solved test network: 4.599e7.

Runtime verification (web app, PyPSA mode)

- GET /api/status → ok (port 8061)
- POST /api/run/dispatch {"carbon_price":25} → full PyPSA result payload

over HTTP (generation cost 4.7929714e7, zero unserved)

Historical

The pre-migration JuMP-engine suite (94 assertions, also all passing) is recorded in git-less history via docs revisions; its hand-calculated fixtures were retained and re-validated against the PyPSA engine above.

N.4 The remaining-gaps document

Remaining gaps

Honest list of what the Energy System does not yet do. Nothing here is mocked — absent features error or are absent, never faked.

Power system (PyPSA bridge)

1. Full PyPSA-Earth workflow run — the repo is cloned at D:\EDIP\models\pypsa-earth. The importer (bridge/import_pypsa_earth.py) is tested end-to-end on a solved netCDF network (built by bridge/make_test_network.py; see the "PyPSA-Earth import round-trip" test), so the .nc → canonical-tables → re-dispatch path is proven. What has not been run from this session is PyPSA-Earth's own Snakemake workflow at national scale (conda env, ERA5 cutouts + OSM downloads, clustering) — that is an upstream data/compute task, not a code gap. Path: run PyPSA-Earth upstream, then import_pypsa_earth("results/networks/....nc") exactly as the round-trip test does. 2. Operating-reserve co-optimization — the removed JuMP dispatch held spinning reserves; the PyPSA bridge does not (planning reserve margins in expansion are enforced via a linopy constraint). Path: linopy extra-constraints on headroom, as done for RE share. 3. KVL / DC power flow in the bridge — corridors are paired directed Links with losses (transport model). Full line physics live upstream in PyPSA-Earth networks; to impose KVL in bridge runs, map corridors to PyPSA Lines (needs reactance data in the schema). 4. Lumpy (integer) builds in expansion — the PyPSA formulation is continuous; the former MILP unit-size option was not ported. 5. Perfect-foresight multi-year expansion — the bridge solves a myopic rolling horizon (one PyPSA case per planning year). PyPSA's multi-investment-period mode is the upgrade path. 6. Hydropower cascades — cascade_upstream is in the schema; each reservoir still balances independently.

Modelling (unchanged)

7. Endogenous demand response / elastic demand (only VoLL shedding). 8. Technology learning curves, stranded-asset accounting, multi-objective expansion (run_policy_portfolio is the stopgap). 9. Fuel supply-chain network optimization (accounting + disruption screening only).

Data & integration

10. GIS siting engine (exclusion masks, raster suitability scoring) — PyPSA-Earth owns upstream GIS. The app's GIS Map page is a *planning & visualization* layer (settlements, industry, generation, network, target-driven electrification/reinforcement over lat/lon), not a raster siting model. It uses OpenStreetMap base tiles (needs internet). 11. PostgreSQL/PostGIS — persistence is CSV/JSON with per-run manifests. 12. Household survey microsimulation — first-order welfare only; belongs to the EDIS Household model. 13. Live CDCGE round-trip — export format matches CDCGE/src/PowerLink.jl by construction and test, but an end-to-end CDCGE run consuming it has not been executed (PATH license/runtime).

Platform

14. Authentication/authorization on the web app — deploy behind the EDIS platform's auth layer. 15. Formatted PDF/Word reports — exports are machine-readable. 16. Browser-automation UI tests — dashboard exercised via HTTP API. 17. Maps tab — schema carries lat/lon; no map rendering yet.

N.5 Data integration with the continental register

AEGID real-data integration (Model 1 adapter, Uganda pilot)

The EDIS Energy System can run on real African data from AEGID (the EDIS Africa Energy GIS Database at D:\EDIP\Data\EnergyData) instead of the synthetic case. This implements the spec's Model 1 (Integrated

Sectoral Energy Demand Accounting) and the data-adapter layer: AEGID is the upstream, immutable, GIS-centred database; a country extractor maps its harmonised raw sources into the EnergyModelling canonical tables.

Extractor

powershell python bridge/aegid/build_country.py --country UGA --out data/uganda julia --project=. --pkgimages=no scripts/smoke_uganda.jl # validate + run models $env:ENERGY_DATA_DIR="data/uganda"; julia --project=genie --pkgimages=no genie/app.jl

Requires the Python geo stack: pip install geopandas rasterio fiona shapely scipy.

Uganda pilot — what is real vs estimated

The extractor is disciplined about provenance (AEGID never fabricates). See data/uganda/PROVENANCE.md for the column-level table. Summary:

Layer	Real (observed)	Estimated
Network (24 buses, 30 lines)	2017 transmission corridors, voltages (66/132/220/400 kV), status, names, endpoints → buses; GADM district tagging	MW ratings from voltage, losses/susceptance from length
Generation (5 thermal/RE + 6 hydro)	WRI Global Power Plant DB: names, capacity, fuel, coordinates (Bujagali 250 MW, Kiira 205, Nalubaale 180, Lugogo oil 50, Kakira biomass, 3 solar)	emission factors, variable costs, hydro inflow (CF 0.5)
Demand (3.49 TWh, 24 buses)	GEP per-cell population & electrified population (18% national access) → nearest bus	530 kWh/electrified-capita, 12-slice load shape
Access (40 districts)	GEP unelectrified population, MV-line distance, GHI by district	connection cost rules
Availability	GEP GHI (solar) & wind speed means	representative 12-slice profiles
Candidates, storage, tariffs, households, fuels, projects	anchored to observed totals	planning assumptions

Validation results (real Uganda)

- Dispatch is hydro-dominated — Bujagali, Kiira, Nalubaale supply the

bulk, with oil (Lugogo) and biomass (Kakira) on the margin — matching Uganda's actual generation mix. Peak ≈ 474 MW, annual 3.49 TWh (≈ the country's real ~2018 consumption).

- Expansion builds utility solar first under a renewable target.
- Electrification reaches universal access at ≈ $0.95 B (grid-led near the

existing network).

- ~2 % unserved energy arises from network islands in the clustered

endpoint graph — reported honestly, a candidate for refinement (snap to the real substations layer).

Not yet wired (available in AEGID for later models)

GHSL settlement raster (finer demand disaggregation), gridfinder, HydroRIVERS (hydro siting, Model 12), WDPA protected areas + Aqueduct water risk (renewable siting Model 7, resilience Model 18), and the per-country GEP sets for other African states (the extractor is country-parameterised via --country).

READ THESE DOCUMENTS THE WAY THIS COURSE READ THEM

They are unusually candid and they are the estate's account of itself. Sixteen of this manual's twenty-four

> registered gaps come straight out of them. The other eight do not appear here at all — not because the authors concealed anything, but because a defect that only shows when the system is executed and its output re-derived cannot be found by writing documentation.

Appendix O — The continental register

The EDIS Africa Energy GIS and Intelligence Database, as this course reads it. Two registers: an inventory of what exists, and an availability record of what has been acquired.

O.1 By theme

theme	datasets	held	bytes
wind_resource	270	0	0
infrastructure	109	38	93466356
solar_resource	108	0	0
settlements	56	1	67569776
power_plants	55	54	97549266
admin_boundaries	55	54	643350528
population	55	0	0
transmission	55	41	66958329
petroleum_infrastructure	54	50	11520373
industry_mining_demand	54	0	0
substations	54	54	6437515
energy_balances	2	0	0
hydrology	2	0	0
hydropower	1	0	0
climate	1	0	0
emissions	1	0	0
protected_areas	1	0	0
predicted_grid	1	0	0
mini_grids	1	0	0
petroleum_statistics	1	0	0
land_cover	1	0	0
reference_geography	1	1	261350942
statistics	1	1	6722844
water_stress	1	0	0

Table 173. Catalogued datasets by theme.

O.2 By country

country_iso3	country_name	datasets	held	bytes	held_share
BFA	Burkina Faso	17	6	6986834	0.35294117647058826
BEN	Benin	17	6	2507971	0.35294117647058826
GMB	Gambia	17	6	746815	0.35294117647058826
GNB	Guinea-Bissau	17	6	4871560	0.35294117647058826
CPV	Cabo Verde	17	6	1234368	0.35294117647058826
DZA	Algeria	17	6	43222257	0.35294117647058826
GHA	Ghana	17	6	18880488	0.35294117647058826

country_iso3	country_name	datasets	held	bytes	held_share
GIN	Guinea	17	6	4978392	0.35294117647058826
GAB	Gabon	17	6	3248838	0.35294117647058826
EGY	Egypt	17	6	25957844	0.35294117647058826
SEN	Senegal	17	6	10553751	0.35294117647058826
STP	São Tomé and Príncipe	17	6	568119	0.35294117647058826
NER	Niger	17	6	2627163	0.35294117647058826
NGA	Nigeria	17	6	20083662	0.35294117647058826
MUS	Mauritius	17	6	1012613	0.35294117647058826
RWA	Rwanda	17	6	99529002	0.35294117647058826
MDG	Madagascar	17	6	57224647	0.35294117647058826
MLI	Mali	17	6	8816921	0.35294117647058826
MAR	Morocco	17	6	34710410	0.35294117647058826
LBY	Libya	17	6	21898287	0.35294117647058826
LBR	Liberia	17	6	2454320	0.35294117647058826
KEN	Kenya	17	6	56313453	0.35294117647058826
TUN	Tunisia	17	6	8614708	0.35294117647058826
SYC	Seychelles	17	6	1083053	0.35294117647058826
MRT	Mauritania	17	5	2698698	0.29411764705882354
CIV	Côte d'Ivoire	17	5	7757204	0.29411764705882354
SWZ	Eswatini	17	5	822552	0.29411764705882354
NAM	Namibia	17	5	12743800	0.29411764705882354
COM	Comoros	17	5	490763	0.29411764705882354
CMR	Cameroon	17	5	5561504	0.29411764705882354
BDI	Burundi	17	5	11215534	0.29411764705882354
AGO	Angola	17	5	4813540	0.29411764705882354
CAF	Central African Republic	17	5	1113219	0.29411764705882354
DJI	Djibouti	17	5	924206	0.29411764705882354
COG	Congo	17	5	1617095	0.29411764705882354
COD	DR Congo	17	5	9604507	0.29411764705882354
MWI	Malawi	17	5	24510102	0.29411764705882354
LSO	Lesotho	17	5	1720289	0.29411764705882354
UGA	Uganda	17	5	60094455	0.29411764705882354
TCD	Chad	17	5	1620086	0.29411764705882354
TGO	Togo	17	5	2662055	0.29411764705882354
MOZ	Mozambique	17	5	16760354	0.29411764705882354
SOM	Somalia	17	5	5823116	0.29411764705882354
SLE	Sierra Leone	17	5	5931760	0.29411764705882354
SSD	South Sudan	17	5	1214480	0.29411764705882354
SDN	Sudan	17	5	5749832	0.29411764705882354
ZMB	Zambia	17	5	8356409	0.29411764705882354
ZAF	South Africa	17	5	160787572	0.29411764705882354
ZWE	Zimbabwe	17	5	40814139	0.29411764705882354
TZA	Tanzania	17	5	38569988	0.29411764705882354

country_iso3	country_name	datasets	held	bytes	held_share
ERI	Eritrea	17	4	4756160	0.23529411764705882
ETH	Ethiopia	17	4	8329015	0.23529411764705882
BWA	Botswana	17	4	3990373	0.23529411764705882
GNQ	Equatorial Guinea	17	4	10812560	0.23529411764705882

Table 174. Acquisition status by country. The third of pairs that are held is not evenly distributed.

O.3 The inventory

provider	source_id	dataset_id	dataset_name	theme	spatial_type
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin	admin_boundaries	unknown

provider	source_id	dataset_id	dataset_name	theme	spatial_type
			boundaries		
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin	admin_boundaries	unknown

provider	source_id	dataset_id	dataset_name	theme	spatial_type
			boundaries		
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
gadm	gadm	gadm_admin_boundaries	gadm admin boundaries	admin_boundaries	unknown
GHSL	ghsl	ghsl_smod	GHSL Settlement Model (degree of urbanisatio	settlements	raster
GHSL	ghsl	ghsl_smod	GHSL Settlement Model (degree of urbanisatio	settlements	raster
GHSL	ghsl	ghsl_smod	GHSL Settlement Model (degree of urbanisatio	settlements	raster
GHSL	ghsl	ghsl_smod	GHSL Settlement Model (degree of urbanisatio	settlements	raster
GHSL	ghsl	ghsl_smod	GHSL Settlement Model (degree of urbanisatio	settlements	raster
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
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natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
natural_earth	natural_earth	natural_earth_reference	natural earth	reference_geography	unknown

provider	source_id	dataset_id	dataset_name	theme	spatial_type
			reference		
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natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
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provider	source_id	dataset_id	dataset_name	theme	spatial_type
			reference		
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natural_earth	natural_earth	natural_earth_reference	natural earth reference	reference_geography	unknown
OSM	openstreetmap	osm_pipelines	OSM pipelines	petroleum_infrastructure	vector_line
OSM	openstreetmap	osm_pipelines	OSM pipelines	petroleum_infrastructure	vector_line

provider	source_id	dataset_id	dataset_name	theme	spatial_type
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provider	source_id	dataset_id	dataset_name	theme	spatial_type
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provider	source_id	dataset_id	dataset_name	theme	spatial_type
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OSM	openstreetmap	osm_pipelines	OSM pipelines	petroleum_infrastructure	vector_line
OSM	openstreetmap	osm_pipelines	OSM pipelines	petroleum_infrastructure	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
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OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line

provider	source_id	dataset_id	dataset_name	theme	spatial_type
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OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
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OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line

provider	source_id	dataset_id	dataset_name	theme	spatial_type
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OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line

provider	source_id	dataset_id	dataset_name	theme	spatial_type
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_lines	OSM power lines and cables	transmission	vector_line
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon
OSM	openstreetmap	osm_power_plants	OSM power plants and generators	power_plants	vector_polygon

Table 175. The inventory register — first 320 of 618 datasets, with the licence on each.

O.4 The availability register

dataset_id	dataset_name	theme	tier	scope	country_iso3
wri_gppd	Global Power Plant Database	power_plants	core	global	_global
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	DZA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	EGY
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	LBY
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MRT
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MAR
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	TUN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	BEN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	BFA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	CPV
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	CIV
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GMB
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GHA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GIN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GNB
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	LBR
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MLI

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	NER
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	NGA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SEN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SLE
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	TGO
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	BDI
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	CMR
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	CAF
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	TCD
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	COG
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	COD
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GNQ
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	GAB
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	STP
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	COM
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	DJI
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	ERI
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	ETH
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	KEN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MDG
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MUS
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	RWA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SYC
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SOM
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SSD
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SDN
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	TZA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	UGA
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	AGO
osm_power_plants	OSM power plants and	power_plants	core	per_country	BWA

dataset_id	dataset_name	theme	tier	scope	country_iso3
	generators				
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	SWZ
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	LSO
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MWI
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	MOZ
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	NAM
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	ZAF
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	ZMB
osm_power_plants	OSM power plants and generators	power_plants	core	per_country	ZWE
osm_power_lines	OSM power lines and cables	transmission	core	per_country	DZA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	EGY
osm_power_lines	OSM power lines and cables	transmission	core	per_country	LBY
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MRT
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MAR
osm_power_lines	OSM power lines and cables	transmission	core	per_country	TUN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	BEN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	BFA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	CPV
osm_power_lines	OSM power lines and cables	transmission	core	per_country	CIV
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GMB
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GHA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GIN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GNB
osm_power_lines	OSM power lines and cables	transmission	core	per_country	LBR
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MLI
osm_power_lines	OSM power lines and cables	transmission	core	per_country	NER
osm_power_lines	OSM power lines and cables	transmission	core	per_country	NGA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SEN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SLE
osm_power_lines	OSM power lines and cables	transmission	core	per_country	TGO
osm_power_lines	OSM power lines and cables	transmission	core	per_country	BDI
osm_power_lines	OSM power lines and cables	transmission	core	per_country	CMR
osm_power_lines	OSM power lines and cables	transmission	core	per_country	CAF
osm_power_lines	OSM power lines and cables	transmission	core	per_country	TCD
osm_power_lines	OSM power lines and cables	transmission	core	per_country	COG
osm_power_lines	OSM power lines and cables	transmission	core	per_country	COD
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GNQ
osm_power_lines	OSM power lines and cables	transmission	core	per_country	GAB
osm_power_lines	OSM power lines and cables	transmission	core	per_country	STP
osm_power_lines	OSM power lines and cables	transmission	core	per_country	COM
osm_power_lines	OSM power lines and cables	transmission	core	per_country	DJI
osm_power_lines	OSM power lines and cables	transmission	core	per_country	ERI
osm_power_lines	OSM power lines and cables	transmission	core	per_country	ETH

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_power_lines	OSM power lines and cables	transmission	core	per_country	KEN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MDG
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MUS
osm_power_lines	OSM power lines and cables	transmission	core	per_country	RWA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SYC
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SOM
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SSD
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SDN
osm_power_lines	OSM power lines and cables	transmission	core	per_country	TZA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	UGA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	AGO
osm_power_lines	OSM power lines and cables	transmission	core	per_country	BWA
osm_power_lines	OSM power lines and cables	transmission	core	per_country	SWZ
osm_power_lines	OSM power lines and cables	transmission	core	per_country	LSO
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MWI
osm_power_lines	OSM power lines and cables	transmission	core	per_country	MOZ
osm_power_lines	OSM power lines and cables	transmission	core	per_country	NAM
osm_power_lines	OSM power lines and cables	transmission	core	per_country	ZAF
osm_power_lines	OSM power lines and cables	transmission	core	per_country	ZMB
osm_power_lines	OSM power lines and cables	transmission	core	per_country	ZWE
osm_substations	OSM substations	substations	core	per_country	DZA
osm_substations	OSM substations	substations	core	per_country	EGY
osm_substations	OSM substations	substations	core	per_country	LBY
osm_substations	OSM substations	substations	core	per_country	MRT
osm_substations	OSM substations	substations	core	per_country	MAR
osm_substations	OSM substations	substations	core	per_country	TUN
osm_substations	OSM substations	substations	core	per_country	BEN
osm_substations	OSM substations	substations	core	per_country	BFA
osm_substations	OSM substations	substations	core	per_country	CPV
osm_substations	OSM substations	substations	core	per_country	CIV
osm_substations	OSM substations	substations	core	per_country	GMB
osm_substations	OSM substations	substations	core	per_country	GHA
osm_substations	OSM substations	substations	core	per_country	GIN
osm_substations	OSM substations	substations	core	per_country	GNB
osm_substations	OSM substations	substations	core	per_country	LBR
osm_substations	OSM substations	substations	core	per_country	MLI
osm_substations	OSM substations	substations	core	per_country	NER
osm_substations	OSM substations	substations	core	per_country	NGA
osm_substations	OSM substations	substations	core	per_country	SEN
osm_substations	OSM substations	substations	core	per_country	SLE
osm_substations	OSM substations	substations	core	per_country	TGO
osm_substations	OSM substations	substations	core	per_country	BDI
osm_substations	OSM substations	substations	core	per_country	CMR
osm_substations	OSM substations	substations	core	per_country	CAF
osm_substations	OSM substations	substations	core	per_country	TCD
osm_substations	OSM substations	substations	core	per_country	COG
osm_substations	OSM substations	substations	core	per_country	COD
osm_substations	OSM substations	substations	core	per_country	GNQ

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_substations	OSM substations	substations	core	per_country	GAB
osm_substations	OSM substations	substations	core	per_country	STP
osm_substations	OSM substations	substations	core	per_country	COM
osm_substations	OSM substations	substations	core	per_country	DJI
osm_substations	OSM substations	substations	core	per_country	ERI
osm_substations	OSM substations	substations	core	per_country	ETH
osm_substations	OSM substations	substations	core	per_country	KEN
osm_substations	OSM substations	substations	core	per_country	MDG
osm_substations	OSM substations	substations	core	per_country	MUS
osm_substations	OSM substations	substations	core	per_country	RWA
osm_substations	OSM substations	substations	core	per_country	SYC
osm_substations	OSM substations	substations	core	per_country	SOM
osm_substations	OSM substations	substations	core	per_country	SSD
osm_substations	OSM substations	substations	core	per_country	SDN
osm_substations	OSM substations	substations	core	per_country	TZA
osm_substations	OSM substations	substations	core	per_country	UGA
osm_substations	OSM substations	substations	core	per_country	AGO
osm_substations	OSM substations	substations	core	per_country	BWA
osm_substations	OSM substations	substations	core	per_country	SWZ
osm_substations	OSM substations	substations	core	per_country	LSO
osm_substations	OSM substations	substations	core	per_country	MWI
osm_substations	OSM substations	substations	core	per_country	MOZ
osm_substations	OSM substations	substations	core	per_country	NAM
osm_substations	OSM substations	substations	core	per_country	ZAF
osm_substations	OSM substations	substations	core	per_country	ZMB
osm_substations	OSM substations	substations	core	per_country	ZWE
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	DZA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	EGY
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	LBY
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MRT
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MAR
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	TUN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	BEN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	BFA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	CPV
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	CIV
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GMB
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GHA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GIN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GNB
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	LBR
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MLI
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	NER
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	NGA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SEN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SLE
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	TGO
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	BDI

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	CMR
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	CAF
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	TCD
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	COG
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	COD
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GNQ
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	GAB
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	STP
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	COM
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	DJI
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	ERI
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	ETH
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	KEN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MDG
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MUS
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	RWA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SYC
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SOM
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SSD
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SDN
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	TZA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	UGA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	AGO
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	BWA
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	SWZ
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	LSO
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MWI
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	MOZ
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	NAM
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	ZAF
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	ZMB
osm_pipelines	OSM pipelines	petroleum_infrastructure	core	per_country	ZWE
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	DZA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	EGY
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	LBY
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MRT
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MAR
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	TUN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	BEN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	BFA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	CPV
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	CIV
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GMB
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GHA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GIN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GNB
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	LBR
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MLI

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	NER
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	NGA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SEN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SLE
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	TGO
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	BDI
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	CMR
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	CAF
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	TCD
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	COG
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	COD
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GNQ
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	GAB
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	STP
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	COM
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	DJI
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	ERI
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	ETH
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	KEN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MDG
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MUS
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	RWA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SYC
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SOM
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SSD
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SDN
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	TZA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	UGA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	AGO
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	BWA
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	SWZ
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	LSO
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MWI
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	MOZ
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	NAM
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	ZAF
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	ZMB
osm_energy_supplementary	osm_energy_supplementary	infrastructure	core	per_country	ZWE
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	DZA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	EGY
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	LBY
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MRT
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MAR
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	TUN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	BEN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	BFA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	CPV
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	CIV

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GMB
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GHA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GIN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GNB
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	LBR
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MLI
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	NER
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	NGA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SEN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SLE
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	TGO
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	BDI
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	CMR
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	CAF
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	TCD
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	COG
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	COD
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GNQ
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	GAB
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	STP
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	COM
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	DJI
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	ERI
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	ETH
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	KEN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MDG
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MUS
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	RWA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SYC
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SOM
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SSD
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SDN
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	TZA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	UGA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	AGO
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	BWA
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	SWZ
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	LSO
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MWI
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	MOZ
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	NAM
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	ZAF
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	ZMB
osm_demand_centres	osm_demand_centres	industry_mining_demand	core	per_country	ZWE
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	DZA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	EGY
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	LBY
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MRT

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MAR
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	TUN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	BEN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	BFA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	CPV
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	CIV
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GMB
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GHA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GIN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GNB
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	LBR
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MLI
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	NER
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	NGA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SEN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SLE
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	TGO
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	BDI
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	CMR
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	CAF
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	TCD
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	COG
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	COD
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GNQ
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	GAB
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	STP
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	COM
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	DJI
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	ERI
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	ETH
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	KEN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MDG
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MUS
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	RWA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SYC
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SOM
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SSD
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SDN
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	TZA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	UGA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	AGO
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	BWA
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	SWZ
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	LSO
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MWI
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	MOZ
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	NAM
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	ZAF

dataset_id	dataset_name	theme	tier	scope	country_iso3
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	ZMB
osm_transport_corridors	osm_transport_corridors	infrastructure	raster	per_country	ZWE
gridfinder_predicted	Gridfinder predicted MV grid	predicted_grid	core	global	_global
energydata_transmission	Energydata.info transmission and distr	transmission	core	continental	_global
energydata_minigrids	Mini-grid and off-grid system inventor	mini_grids	core	continental	_global
hdx_energy_infrastructure	hdx_energy_infrastructure	infrastructure	core	continental	_global
ocha_cod_ab	OCHA Common Operational Datasets — adm	admin_boundaries	core	continental	_global
worldbank_energy_indicators	World Bank energy and electricity indi	statistics	core	continental	_global
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	DZA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	EGY
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	LBY
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MRT
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MAR
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	TUN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	BEN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	BFA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	CPV
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	CIV
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GMB
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GHA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GIN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GNB
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	LBR
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MLI
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	NER
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	NGA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SEN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SLE
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	TGO
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	BDI
gwa_wind_speed	Global Wind Atlas — mean	wind_resource	raster	per_country	CMR

dataset_id	dataset_name	theme	tier	scope	country_iso3
	wind speed				
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	CAF
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	TCD
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	COG
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	COD
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GNQ
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	GAB
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	STP
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	COM
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	DJI
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	ERI
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	ETH
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	KEN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MDG
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MUS
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	RWA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SYC
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SOM
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SSD
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SDN
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	TZA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	UGA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	AGO
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	BWA
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	SWZ
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	LSO
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MWI
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	MOZ
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	NAM
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	ZAF

dataset_id	dataset_name	theme	tier	scope	country_iso3
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	ZMB
gwa_wind_speed	Global Wind Atlas — mean wind speed	wind_resource	raster	per_country	ZWE
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	DZA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	EGY
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	LBY
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MRT
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MAR
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	TUN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	BEN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	BFA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	CPV
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	CIV
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	GMB
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	GHA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	GIN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	GNB
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	LBR
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MLI
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	NER
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	NGA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SEN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SLE
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	TGO
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	BDI
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	CMR
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	CAF
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	TCD
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	COG
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	COD
gwa_power_density	Global Wind Atlas — wind	wind_resource	raster	per_country	GNQ

dataset_id	dataset_name	theme	tier	scope	country_iso3
	power density				
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	GAB
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	STP
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	COM
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	DJI
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	ERI
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	ETH
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	KEN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MDG
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MUS
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	RWA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SYC
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SOM
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SSD
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SDN
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	TZA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	UGA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	AGO
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	BWA
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	SWZ
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	LSO
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MWI
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	MOZ
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	NAM
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	ZAF
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	ZMB
gwa_power_density	Global Wind Atlas — wind power density	wind_resource	raster	per_country	ZWE
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	DZA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	EGY
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	LBY

dataset_id	dataset_name	theme	tier	scope	country_iso3
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MRT
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MAR
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	TUN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	BEN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	BFA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	CPV
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	CIV
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GMB
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GHA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GIN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GNB
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	LBR
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MLI
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	NER
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	NGA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SEN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SLE
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	TGO
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	BDI
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	CMR
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	CAF
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	TCD
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	COG
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	COD
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GNQ
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	GAB
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	STP
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	COM
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	DJI
gwa_capacity_factor	Global Wind Atlas —	wind_resource	raster	per_country	ERI

dataset_id	dataset_name	theme	tier	scope	country_iso3
	capacity factor by				
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	ETH
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	KEN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MDG
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MUS
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	RWA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SYC
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SOM
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SSD
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SDN
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	TZA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	UGA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	AGO
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	BWA
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	SWZ
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	LSO
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MWI
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	MOZ
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	NAM
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	ZAF
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	ZMB
gwa_capacity_factor	Global Wind Atlas — capacity factor by	wind_resource	raster	per_country	ZWE
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	DZA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	EGY
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	LBY
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MRT
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MAR
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	TUN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	BEN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	BFA

dataset_id	dataset_name	theme	tier	scope	country_iso3
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	CPV
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	CIV
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GMB
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GHA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GIN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GNB
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	LBR
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MLI
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	NER
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	NGA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SEN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SLE
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	TGO
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	BDI
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	CMR
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	CAF
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	TCD
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	COG
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	COD
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GNQ
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	GAB
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	STP
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	COM
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	DJI
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	ERI
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	ETH
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	KEN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MDG
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MUS
gwa_air_density	Global Wind Atlas — air	wind_resource	raster	per_country	RWA

dataset_id	dataset_name	theme	tier	scope	country_iso3
	density				
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SYC
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SOM
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SSD
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SDN
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	TZA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	UGA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	AGO
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	BWA
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	SWZ
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	LSO
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MWI
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	MOZ
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	NAM
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	ZAF
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	ZMB
gwa_air_density	Global Wind Atlas — air density	wind_resource	raster	per_country	ZWE
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	DZA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	EGY
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	LBY
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MRT
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MAR
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	TUN
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	BEN
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	BFA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	CPV
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	CIV
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GMB
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GHA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GIN

dataset_id	dataset_name	theme	tier	scope	country_iso3
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GNB
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	LBR
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MLI
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	NER
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	NGA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SEN
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SLE
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	TGO
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	BDI
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	CMR
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	CAF
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	TCD
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	COG
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	COD
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GNQ
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	GAB
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	STP
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	COM
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	DJI
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	ERI
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	ETH
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	KEN
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MDG
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MUS
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	RWA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SYC
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SOM
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SSD
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SDN
gwa_weibull	Global Wind Atlas —	wind_resource	raster	per_country	TZA

dataset_id	dataset_name	theme	tier	scope	country_iso3
	Weibull parameters				
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	UGA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	AGO
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	BWA
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	SWZ
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	LSO
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MWI
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	MOZ
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	NAM
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	ZAF
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	ZMB
gwa_weibull	Global Wind Atlas — Weibull parameters	wind_resource	raster	per_country	ZWE
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	DZA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	EGY
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	LBY
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MRT
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MAR
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	TUN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	BEN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	BFA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	CPV
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	CIV
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GMB
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GHA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GIN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GNB
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	LBR
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MLI
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	NER
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	NGA

dataset_id	dataset_name	theme	tier	scope	country_iso3
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SEN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SLE
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	TGO
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	BDI
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	CMR
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	CAF
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	TCD
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	COG
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	COD
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GNQ
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	GAB
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	STP
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	COM
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	DJI
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	ERI
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	ETH
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	KEN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MDG
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MUS
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	RWA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SYC
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SOM
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SSD
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SDN
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	TZA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	UGA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	AGO
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	BWA
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	SWZ
gsa_point_lta	Global Solar Atlas — long-	solar_resource	core	per_country	LSO

dataset_id	dataset_name	theme	tier	scope	country_iso3
	term-average				
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MWI
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	MOZ
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	NAM
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	ZAF
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	ZMB
gsa_point_lta	Global Solar Atlas — long-term-average	solar_resource	core	per_country	ZWE
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	DZA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	EGY
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	LBY
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MRT
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MAR
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	TUN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	BEN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	BFA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	CPV
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	CIV
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GMB
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GHA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GIN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GNB
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	LBR
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MLI
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	NER
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	NGA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SEN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SLE
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	TGO
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	BDI
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	CMR

dataset_id	dataset_name	theme	tier	scope	country_iso3
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	CAF
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	TCD
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	COG
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	COD
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GNQ
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	GAB
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	STP
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	COM
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	DJI
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	ERI
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	ETH
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	KEN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MDG
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MUS
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	RWA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SYC
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SOM
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SSD
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SDN
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	TZA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	UGA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	AGO
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	BWA
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	SWZ
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	LSO
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MWI
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	MOZ
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	NAM
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	ZAF
gsa_raster_manual	Global Solar Atlas —	solar_resource	raster	per_country	ZMB

dataset_id	dataset_name	theme	tier	scope	country_iso3
	country raster bu				
gsa_raster_manual	Global Solar Atlas — country raster bu	solar_resource	raster	per_country	ZWE
worldpop_population	WorldPop gridded population	population	raster	per_country	DZA
worldpop_population	WorldPop gridded population	population	raster	per_country	EGY
worldpop_population	WorldPop gridded population	population	raster	per_country	LBY
worldpop_population	WorldPop gridded population	population	raster	per_country	MRT
worldpop_population	WorldPop gridded population	population	raster	per_country	MAR
worldpop_population	WorldPop gridded population	population	raster	per_country	TUN
worldpop_population	WorldPop gridded population	population	raster	per_country	BEN
worldpop_population	WorldPop gridded population	population	raster	per_country	BFA
worldpop_population	WorldPop gridded population	population	raster	per_country	CPV
worldpop_population	WorldPop gridded population	population	raster	per_country	CIV
worldpop_population	WorldPop gridded population	population	raster	per_country	GMB
worldpop_population	WorldPop gridded population	population	raster	per_country	GHA
worldpop_population	WorldPop gridded population	population	raster	per_country	GIN
worldpop_population	WorldPop gridded population	population	raster	per_country	GNB
worldpop_population	WorldPop gridded population	population	raster	per_country	LBR
worldpop_population	WorldPop gridded population	population	raster	per_country	MLI
worldpop_population	WorldPop gridded population	population	raster	per_country	NER
worldpop_population	WorldPop gridded population	population	raster	per_country	NGA
worldpop_population	WorldPop gridded population	population	raster	per_country	SEN
worldpop_population	WorldPop gridded population	population	raster	per_country	SLE
worldpop_population	WorldPop gridded population	population	raster	per_country	TGO
worldpop_population	WorldPop gridded population	population	raster	per_country	BDI
worldpop_population	WorldPop gridded population	population	raster	per_country	CMR
worldpop_population	WorldPop gridded population	population	raster	per_country	CAF
worldpop_population	WorldPop gridded population	population	raster	per_country	TCD
worldpop_population	WorldPop gridded population	population	raster	per_country	COG
worldpop_population	WorldPop gridded population	population	raster	per_country	COD
worldpop_population	WorldPop gridded population	population	raster	per_country	GNQ

dataset_id	dataset_name	theme	tier	scope	country_iso3
worldpop_population	WorldPop gridded population	population	raster	per_country	GAB
worldpop_population	WorldPop gridded population	population	raster	per_country	STP
worldpop_population	WorldPop gridded population	population	raster	per_country	COM
worldpop_population	WorldPop gridded population	population	raster	per_country	DJI
worldpop_population	WorldPop gridded population	population	raster	per_country	ERI
worldpop_population	WorldPop gridded population	population	raster	per_country	ETH
worldpop_population	WorldPop gridded population	population	raster	per_country	KEN
worldpop_population	WorldPop gridded population	population	raster	per_country	MDG
worldpop_population	WorldPop gridded population	population	raster	per_country	MUS
worldpop_population	WorldPop gridded population	population	raster	per_country	RWA
worldpop_population	WorldPop gridded population	population	raster	per_country	SYC
worldpop_population	WorldPop gridded population	population	raster	per_country	SOM
worldpop_population	WorldPop gridded population	population	raster	per_country	SSD
worldpop_population	WorldPop gridded population	population	raster	per_country	SDN
worldpop_population	WorldPop gridded population	population	raster	per_country	TZA
worldpop_population	WorldPop gridded population	population	raster	per_country	UGA
worldpop_population	WorldPop gridded population	population	raster	per_country	AGO
worldpop_population	WorldPop gridded population	population	raster	per_country	BWA
worldpop_population	WorldPop gridded population	population	raster	per_country	SWZ
worldpop_population	WorldPop gridded population	population	raster	per_country	LSO
worldpop_population	WorldPop gridded population	population	raster	per_country	MWI
worldpop_population	WorldPop gridded population	population	raster	per_country	MOZ
worldpop_population	WorldPop gridded population	population	raster	per_country	NAM
worldpop_population	WorldPop gridded population	population	raster	per_country	ZAF
worldpop_population	WorldPop gridded population	population	raster	per_country	ZMB
worldpop_population	WorldPop gridded population	population	raster	per_country	ZWE
ghsl_smod	GHSL Settlement Model (degree of urban	settlements	core	global	_global
ghsl_population	GHSL population grid	population	bulk	global	_global
geonames_settlements	GeoNames populated places	settlements	core	per_country	DZA
geonames_settlements	GeoNames populated places	settlements	core	per_country	EGY

dataset_id	dataset_name	theme	tier	scope	country_iso3
geonames_settlements	GeoNames populated places	settlements	core	per_country	LBY
geonames_settlements	GeoNames populated places	settlements	core	per_country	MRT
geonames_settlements	GeoNames populated places	settlements	core	per_country	MAR
geonames_settlements	GeoNames populated places	settlements	core	per_country	TUN
geonames_settlements	GeoNames populated places	settlements	core	per_country	BEN
geonames_settlements	GeoNames populated places	settlements	core	per_country	BFA
geonames_settlements	GeoNames populated places	settlements	core	per_country	CPV
geonames_settlements	GeoNames populated places	settlements	core	per_country	CIV
geonames_settlements	GeoNames populated places	settlements	core	per_country	GMB
geonames_settlements	GeoNames populated places	settlements	core	per_country	GHA
geonames_settlements	GeoNames populated places	settlements	core	per_country	GIN
geonames_settlements	GeoNames populated places	settlements	core	per_country	GNB
geonames_settlements	GeoNames populated places	settlements	core	per_country	LBR
geonames_settlements	GeoNames populated places	settlements	core	per_country	MLI
geonames_settlements	GeoNames populated places	settlements	core	per_country	NER
geonames_settlements	GeoNames populated places	settlements	core	per_country	NGA
geonames_settlements	GeoNames populated places	settlements	core	per_country	SEN
geonames_settlements	GeoNames populated places	settlements	core	per_country	SLE
geonames_settlements	GeoNames populated places	settlements	core	per_country	TGO
geonames_settlements	GeoNames populated places	settlements	core	per_country	BDI
geonames_settlements	GeoNames populated places	settlements	core	per_country	CMR
geonames_settlements	GeoNames populated places	settlements	core	per_country	CAF
geonames_settlements	GeoNames populated places	settlements	core	per_country	TCD
geonames_settlements	GeoNames populated places	settlements	core	per_country	COG
geonames_settlements	GeoNames populated places	settlements	core	per_country	COD
geonames_settlements	GeoNames populated places	settlements	core	per_country	GNQ
geonames_settlements	GeoNames populated places	settlements	core	per_country	GAB
geonames_settlements	GeoNames populated places	settlements	core	per_country	STP
geonames_settlements	GeoNames populated places	settlements	core	per_country	COM
geonames_settlements	GeoNames populated	settlements	core	per_country	DJI

dataset_id	dataset_name	theme	tier	scope	country_iso3
	places				
geonames_settlements	GeoNames populated places	settlements	core	per_country	ERI
geonames_settlements	GeoNames populated places	settlements	core	per_country	ETH
geonames_settlements	GeoNames populated places	settlements	core	per_country	KEN
geonames_settlements	GeoNames populated places	settlements	core	per_country	MDG
geonames_settlements	GeoNames populated places	settlements	core	per_country	MUS
geonames_settlements	GeoNames populated places	settlements	core	per_country	RWA
geonames_settlements	GeoNames populated places	settlements	core	per_country	SYC
geonames_settlements	GeoNames populated places	settlements	core	per_country	SOM
geonames_settlements	GeoNames populated places	settlements	core	per_country	SSD
geonames_settlements	GeoNames populated places	settlements	core	per_country	SDN
geonames_settlements	GeoNames populated places	settlements	core	per_country	TZA
geonames_settlements	GeoNames populated places	settlements	core	per_country	UGA
geonames_settlements	GeoNames populated places	settlements	core	per_country	AGO
geonames_settlements	GeoNames populated places	settlements	core	per_country	BWA
geonames_settlements	GeoNames populated places	settlements	core	per_country	SWZ
geonames_settlements	GeoNames populated places	settlements	core	per_country	LSO
geonames_settlements	GeoNames populated places	settlements	core	per_country	MWI
geonames_settlements	GeoNames populated places	settlements	core	per_country	MOZ
geonames_settlements	GeoNames populated places	settlements	core	per_country	NAM
geonames_settlements	GeoNames populated places	settlements	core	per_country	ZAF
geonames_settlements	GeoNames populated places	settlements	core	per_country	ZMB
geonames_settlements	GeoNames populated places	settlements	core	per_country	ZWE
geonames_alternate_names	GeoNames alternate names	settlements	core	global	_global
natural_earth_reference	natural_earth_reference	reference_geography	core	global	_global
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	DZA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	EGY
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	LBY
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MRT
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MAR
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	TUN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	BEN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	BFA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	CPV

dataset_id	dataset_name	theme	tier	scope	country_iso3
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	CIV
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GMB
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GHA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GIN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GNB
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	LBR
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MLI
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	NER
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	NGA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SEN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SLE
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	TGO
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	BDI
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	CMR
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	CAF
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	TCD
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	COG
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	COD
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GNQ
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	GAB
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	STP
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	COM
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	DJI
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	ERI
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	ETH
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	KEN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MDG
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MUS
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	RWA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SYC
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SOM
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SSD
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SDN
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	TZA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	UGA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	AGO
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	BWA
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	SWZ
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	LSO
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MWI
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	MOZ
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	NAM
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	ZAF
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	ZMB
gadm_admin_boundaries	gadm_admin_boundaries	admin_boundaries	core	per_country	ZWE
hydrosheds_rivers	HydroRIVERS river network	hydrology	core	continental	_global
hydrosheds_basins	HydroBASINS catchment boundaries	hydrology	bulk	continental	_global

dataset_id	dataset_name	theme	tier	scope	country_iso3
grand_dams	GRanD — Global Reservoir and Dam datab	hydropower	core	global	_global
esa_worldcover_2021	ESA WorldCover land cover	land_cover	bulk	continental	_global
aqueduct_water_risk	Aqueduct baseline water stress	water_stress	core	global	_global
chirps_precipitation	CHIRPS monthly precipitation	climate	raster	continental	_global
wdpa_protected_areas	World Database on Protected Areas	protected_areas	core	continental	_global
eia_international_petroleum	EIA international petroleum and gas st	petroleum_statistics	core	continental	_global
viirs_flaring	VIIRS Nightfire flare detections	emissions	core	continental	_global
unsd_energy_balances	UN Energy Balances	energy_balances	core	continental	_global
afrec_energy_database	AFREC Africa Energy Database	energy_balances	core	continental	_global

Table 176. All 940 country-dataset pairs the register tracks, with the acquisition status of each. The value of this table is the rows that say `not_attempted`: they are the map of what a continental analysis currently cannot do.

WHY A LICENCE COLUMN BELONGS IN A TECHNICAL MANUAL

Fifty-four of these datasets may not be redistributed and 472 carry a share-alike condition. A national plan built on them inherits both. That is a modelling constraint of exactly the same standing as a capacity limit, and it is settled before the analysis or not at all.

Appendix P — Every survey estimate this course computed

From Uganda LSMS-ISA National Panel Survey 2019/20 (UNPS). Every estimate is survey-weighted and carries its unweighted denominator. No microdata record appears anywhere in this course, and no cell below 25 unweighted observations is disclosed.

P.1 National

Indicator	Value
households	3,062
connection rate	0.2588
connection rate unweighted	0.1750
urban connection	0.6256
rural connection	0.0889
mean elec spend month	15,480
median elec spend month	13,500
mean energy spend month	13,308
mean energy share	0.0200
burden over 10pc	0.0256
burden over 5pc	0.1277
poverty rate	0.1090
charcoal stove	0.3409
electric stove	0.0115

Table 177. National estimates.

P.2 By dimension

dimension	level	n	connection_rate	energy_spend_month	energy_share	burden_over_10pc	charcoal_stove	disclosed
quintile	Quintile 1	571	0.00179948636704	2332.16042559905	0.00862796105609	0.00989945620603	0.04418843512764	True
quintile	Quintile 2	591	0.06774399412087	4646.67503095215	0.01205991929539	0.00632408852783	0.16335523018130	True
quintile	Quintile 3	639	0.11742398457206	8460.18458005627	0.01920819537291	0.03637827325043	0.23808013030126	True
quintile	Quintile 4	676	0.27819246007825	16449.3266998476	0.02755827060209	0.03957554731093	0.45794483217798	True
quintile	Quintile 5	585	0.64606342243064	27168.0298968661	0.02631807238555	0.02760908128004	0.62375063274689	True
residence	Rural	2320	0.08890476190761	6128.28940769473	0.01205658032678	0.01427954577640	0.18263070735850	True
residence	Urban	742	0.62555847710803	28803.0710656061	0.03709088561844	0.04992435055530	0.68239986576725	True
region	Central	782	0.48001075148113	22107.1608038080	0.02853639770025	0.03912986656244	0.49485195993789	True
region	Easter	700	0.1715968508	10369.324703669	0.0180340222	0.03011030562	0.3259970836	True

dimension	level	n	connection_rate	energy_spend_month	energy_share	burden_over_10pc	charcoal_stove	disclosed
	n		5748	4	9394	456	2501	
region	Northern	862	0.06711906001915	8029.17269645087	0.01319431955826	0.01417642673166	0.23624268383787	True
region	Western	718	0.21810887264063	9444.76807261457	0.01676826958539	0.01473441506886	0.25298266034449	True
poverty	Non-poor	2635	0.29017737198889	14677.6003959835	0.02142229829712	0.02743751579009	0.37786547333633	True
poverty	Poor	427	0.00250175664922	2108.87963113976	0.00821746811275	0.01026246445139	0.03844576696769	True

Table 178. Connection, spending and burden by region, residence and consumption quintile.

P.3 The energy ladder

fuel	tier	n	use_rate	cooking	lighting	heating	mean_spend	use_Quintile 1	use_Quintile 2	use_Quintile 3	use_Quintile 4	use_Quintile 5
Firewood	1	3062	0.711864193199	0.993284668641	0.019198593194	0.057568162231	2377.286019937	0.975860832897	0.900768072556	0.810188736820	0.654283059438	0.390541209450
Dung	1	3062	0.000556838722	1.0	0.0	0.0	0.0	0.000917128649	0.0	0.0	0.0	0.001678638133
Crop Residue	1	3062	0.169368143308	0.992886878151	0.063082503953	0.033842375511	0.0	0.273693194557	0.268933834154	0.199214951375	0.114540177297	0.060722835714
Charcoal	2	3062	0.351902636208	0.999698946847	0.006448382096	0.040567056313	26111.69154618	0.041121385404	0.167206269428	0.263292038777	0.473724751498	0.632987055876
Kerosene	2	3062	0.177640814294	0.173540803432	0.845874575749	0.013679286701	3202.073139890	0.240800506261	0.234386585736	0.203752899850	0.155362754596	0.098156409257
Torches	2	3062	0.235958776192	0.0	0.976372870904	0.0	2354.846748821	0.413008913959	0.273692031928	0.264836432218	0.188383879698	0.121357350106
lpg	3	3062	0.008539558349	1.0	0.0	0.0	42153.08872835	0.0	0.0	0.0	0.001240933148	0.033185261330
Solar	3	3062	0.419797107508	0.027611086625	0.980563845198	0.005222913601	0.0	0.311723529748	0.501527222871	0.483328932426	0.482720021563	0.320146721132
Electricity	4	3062	0.239490218834	0.083237714052	0.988385280925	0.004521718919	0.0	0.001163975380	0.066891599635	0.106931008573	0.258789031122	0.595245806216

Table 179. Nine fuels by tier, with use rates by quintile.

P.4 Why unconnected households have no electricity

reason	kind	n	share	disclosed
Electricity is not available in area	supply side	1890	0.722213754792971	True
Household can't afford connection fee	affordability	404	0.1722787342427991	True
Household can't afford cost of house wiring	affordability	49	0.02426577780804739	True
Satisfied with present energy source	preference/other	41	0.022512297605752907	True
Household can't afford the monthly payment	affordability	44	0.02184793809193886	True

reason	kind	n	share	disclosed
Other (specify)	preference/other	36	0.018837165966978323	True
No need for electricity	preference/other	51	0.013040606677102991	True
Household can't afford to buy electrical equipment	affordability	10	0.0033781227627422026	False

Table 180. Reasons, classified as supply-side, affordability or preference.

P.5 The poverty microsimulation

poverty_microsim_headline

scenario	price_change	income_change	fgt0_before	fgt0_after	change_pp	newly_poor_share	newly_poor_people
baseline	0.0	0.0	0.1484559802083130	0.1484559802083130	0.0	0.0	0.0
price:generation_o	-0.544066042929752	0.0	0.1484559802083130	0.1482605683425134	-0.019541186579963	0.0	0.0
price:carbon_25	0.0960181451612902	0.0	0.1484559802083130	0.1484559802083130	0.0	0.0	0.0
price:carbon_50	0.1920362903225807	0.0	0.1484559802083130	0.1484559802083130	0.0	0.0	0.0
price:carbon_100	0.3840725806451612	0.0	0.1484559802083130	0.1484559802083130	0.0	0.0	0.0
income:cdcge_tax_5	0.0	-0.009595878733713	0.1484559802083130	0.1574750481458159	0.9019067937502845	0.0090190679375028	341288.67586891656
income:cdcge_tax_1	0.0	-0.017371408954554	0.1484559802083130	0.1590622876678895	1.0606307459576443	0.0106063074595764	401351.0768319698
income:cdcge_netze	0.0	-0.008938621580649	0.1484559802083130	0.1574750481458159	0.9019067937502845	0.0090190679375028	341288.67586891656
income:cdcge_renew	0.0	0.0039540878765689	0.1484559802083130	0.148167740701104	-0.028823950720904	0.0	0.0
income:cdcge_elect	0.0	0.0056741104867605	0.1484559802083130	0.1456938083869639	-0.276217182134910	0.0	0.0
income:cdcge_cbam5	0.0	-0.000919449505529	0.1484559802083130	0.1487309236404663	0.0274943432153257	0.0002749434321532	10404.077289212823
both:carbon_50+cdc	0.1920362903225807	-0.009595878733713	0.1484559802083130	0.1574750481458159	0.9019067937502845	0.0090190679375028	341288.67586891656
both:carbon_100+cd	0.3840725806451612	-0.017371408954554	0.1484559802083130	0.1590622876678895	1.0606307459576443	0.0106063074595764	401351.0768319698

Table 181. Headcount before and after, by scenario.

poverty_microsim_profile

scenario	group	n	fgt0	fgt1	fgt2
baseline	national	3062	0.1484559802083130	0.0333920156645759	0.0125214333477241
baseline	urban	742	0.0649739117056283	0.0117253117683574	0.0037613183245186

scenario	group	n	fgt0	fgt1	fgt2
baseline	rural	2320	0.1795444461532782	0.0414606296591558	0.0157836732808918
baseline	connected	536	0.0014042668889983	0.0001252102225773	1.9951684460739574
baseline	unconnected	2526	0.1887629165716179	0.0425104610039337	0.0159480947206113
price:generation_o	national	3062	0.1482605683425134	0.0333856578367811	0.0125211104172533
price:generation_o	urban	742	0.0646569829954327	0.0117237129349558	0.0037613102587671
price:generation_o	rural	2320	0.179394286787165	0.0414524995964633	0.0157832330957665
price:generation_o	connected	536	0.0004959343137268	9.565714466975642e	1.8450607415342604
price:generation_o	unconnected	2526	0.1887629165716179	0.0425104610039337	0.0159480947206113
price:carbon_25	national	3062	0.1484559802083130	0.0333933170639743	0.0125215642570862
price:carbon_25	urban	742	0.0649739117056283	0.0117261114842842	0.0037613284112370
price:carbon_25	rural	2320	0.1795444461532782	0.0414621178839383	0.0157838491842353
price:carbon_25	connected	536	0.0014042668889983	0.0001312595147333	2.056019018019117e
price:carbon_25	unconnected	2526	0.1887629165716179	0.0425104610039337	0.0159480947206113
price:carbon_50	national	3062	0.1484559802083130	0.0333946184633727	0.0125217177564533
price:carbon_50	urban	742	0.0649739117056283	0.0117269112002110	0.0037613425338507
price:carbon_50	rural	2320	0.1795444461532782	0.0414636061087209	0.0157840545870775
price:carbon_50	connected	536	0.0014042668889983	0.0001373088068893	2.127370097406544e
price:carbon_50	unconnected	2526	0.1887629165716179	0.0425104610039337	0.0159480947206113
price:carbon_100	national	3062	0.1484559802083130	0.0333972212621694	0.0125220925252030
price:carbon_100	urban	742	0.0649739117056283	0.0117285106320646	0.0037613828867645
price:carbon_100	rural	2320	0.1795444461532782	0.0414665825582859	0.0157845538912575
price:carbon_100	connected	536	0.0014042668889983	0.0001494073912012	2.301573778508191e
price:carbon_100	unconnected	2526	0.1887629165716179	0.0425104610039337	0.0159480947206113
income:cdcge_tax_5	national	3062	0.1574750481458159	0.0345346117921807	0.0129308566625173
income:cdcge_tax_5	urban	742	0.0695881901520306	0.0122619475206051	0.0039184742001374
income:cdcge_tax_5	rural	2320	0.1902038441705803	0.0428288835696973	0.0162870402153445
income:cdcge_tax_5	connected	536	0.0014042668889983	0.0001374839132458	2.2079872462329094
income:cdcge_tax_5	unconnected	2526	0.2002541148176188	0.0439628789860903	0.0164691578006688
income:cdcge_tax_1	national	3062	0.1590622876678895	0.0355049511392320	0.0132763471484361
income:cdcge_tax_1	urban	742	0.0703295870940706	0.0127124842819778	0.0040525006309957
income:cdcge_tax_1	rural	2320	0.1921060728719569	0.0439927958033912	0.0167112792659820
income:cdcge_tax_1	connected	536	0.0014042668889983	0.0001474292835444	2.3962880199119244
income:cdcge_tax_1	unconnected	2526	0.2022764173591257	0.0451964627254092	0.0169088312406275
income:cdcge_netze	national	3062	0.1574750481458159	0.0344530246217184	0.0129022275137073
income:cdcge_netze	urban	742	0.0695881901520306	0.0122239031783003	0.0039074216165037
income:cdcge_netze	rural	2320	0.1902038441705803	0.042731081183745	0.0162518656076387
income:cdcge_netze	connected	536	0.0014042668889983	0.0001366431987789	2.1927194352768256
income:cdcge_netze	unconnected	2526	0.2002541148176188	0.0438591591781367	0.0164327232392834
income:cdcge_renew	national	3062	0.148167740701104	0.0329374243287386	0.0123578581010232
income:cdcge_renew	urban	742	0.0649739117056283	0.0115147641097704	0.0036990461558975
income:cdcge_renew	rural	2320	0.1791488671387404	0.0409151572073452	0.0155823730790061
income:cdcge_renew	connected	536	0.0014042668889983	0.0001201527929726	1.9137643312610044
income:cdcge_renew	unconnected	2526	0.1883956704944600	0.0419326522356526	0.0157399065591300
income:cdcge_elect	national	3062	0.1456938083869639	0.0327405493635554	0.0122876179532438
income:cdcge_elect	urban	742	0.0646569829954327	0.0114233633628318	0.0036723989161227
income:cdcge_elect	rural	2320	0.1758716733064428	0.0406790039671888	0.0154958990661554

scenario	group	n	fgt0	fgt1	fgt2
income:cdcge_elect	connected	536	0.0010045229435413	0.0001181928172193	1.8794827317296698
income:cdcge_elect	unconnected	2526	0.1853532022775761	0.0416823509900278	0.0156505075233609
income:cdcge_cbam5	national	3062	0.1487309236404663	0.0334979153753356	0.0125598925072697
income:cdcge_cbam5	urban	742	0.0649739117056283	0.0117742720657422	0.0037760018912002
income:cdcge_cbam5	rural	2320	0.1799217776752404	0.0415877334326007	0.0158309863982073
income:cdcge_cbam5	connected	536	0.0014042668889983	0.0001263862903709	2.0146243368450304
income:cdcge_cbam5	unconnected	2526	0.1891132221139646	0.0426450655092006	0.0159970422232578
both:carbon_50+cdc	national	3062	0.1574750481458159	0.0345372145909775	0.0129311887279449
both:carbon_50+cdc	urban	742	0.0695881901520306	0.0122635469524587	0.0039185289505008
both:carbon_50+cdc	rural	2320	0.1902038441705803	0.0428318600192624	0.0162874755520503
both:carbon_50+cdc	connected	536	0.0014042668889983	0.0001495824975578	2.362341150877802e
both:carbon_50+cdc	unconnected	2526	0.2002541148176188	0.0439628789860903	0.0164691578006688
both:carbon_100+cd	national	3062	0.1590622876678895	0.0355101567368254	0.0132771788721014
both:carbon_100+cd	urban	742	0.0703295870940706	0.0127156831456850	0.0040526757703586
both:carbon_100+cd	rural	2320	0.1921060728719569	0.0439987487025214	0.0167123554996251
both:carbon_100+cd	connected	536	0.0014042668889983	0.0001716264521683	2.7828979607595676
both:carbon_100+cd	unconnected	2526	0.2022764173591257	0.0451964627254092	0.0169088312406275

Table 182. FGT(0,1,2) by group and scenario.

poverty_burden_by_quintile

quints	n	connected	loss_share	loss_share_connected	scenario
1.0	571.0	0.0017994863670472	2.63194095013926e-		carbon_100
2.0	591.0	0.0677439941208701	0.0008754733226961	0.0131729215705140	carbon_100
3.0	639.0	0.1174239845720603	0.0013151154275531	0.0100289802474362	carbon_100
4.0	676.0	0.2781924600782591	0.0045931317431456	0.0154785900625988	carbon_100
5.0	585.0	0.646063422430646	0.0060749027937852	0.0092717403938864	carbon_100

Table 183. Who carries the largest modelled price rise.

P.6 The declared assumptions behind the microsimulation

Consumption pass-through of GDP per capita: 1.0. Real household consumption moves one-for-one with real GDP per capita relative to the CDCGE reference scenario. This is the neutral choice: it neither amplifies nor damps the macro result. A distribution-neutral pass-through is a strong assumption and the chapter says what it hides — the CGE's own factor prices differ by skill, and a household's exposure depends on where its income comes from.

Behavioural response to the price change: 0.0. Households are not allowed to substitute away from electricity when its price rises. The welfare loss is therefore an upper bound for the first-order effect and a lower bound for the substitution effect; with an own-price elasticity of -0.3 the loss would be roughly 15 % smaller at a 25 % price rise.

Poverty line: spline (UNPS 2019/20 absolute line, by sub-region). The survey's own spatially deflated absolute poverty line is used, not a dollar-a-day line, so the baseline reproduces Uganda's official headcount rather than a parallel one.

Poverty accounting unit: individual. Headcount weights each household by w x hsize, which is how the Uganda Bureau of Statistics reports poverty. Reporting at household level would give a visibly lower number.

Appendix Q — Worked calculations

Eight calculations a reader should be able to reproduce from the tables in this manual, with a pencil. Each one is a claim made somewhere in Parts I to VI, and each is the arithmetic that establishes it.

Q.1 The energy balance (Chapter 11)

Claim: the unserved energy is an energy deficit, not a network artefact.

Q.1

```
hydro energy limit  = sum(inflow_mwh) x 8760
                    = 333.2 x 8760            = 2,918,832 MWh
oil                 = 50.0  x 8760            =   438,000
biomass             = 12.0  x 8760            =   105,120
solar               = 44.0  x 8760 x 0.3396   =   130,889
                                               -----------
generation G                                  =   3,592,841

demand D            (demand.csv, weighted)    =   3,485,162
losses L            (generation - served)     =     177,048
                                               -----------
required D + L                                =   3,662,210

shortfall (D + L) - G                         =      69,369
reported unserved                             =      69,369
residual                                      =         0.0
```

Q.2 The hydro capacity factor (Chapter 11)

Claim: the deficit comes from one column.

Q.2

```
plant           capacity_mw   inflow_mwh   ratio
Bugoye                 11.0          5.5   0.500
BujagaliFalls         250.0        125.0   0.500
IshashaRiver           10.0          5.0   0.500
Kiira                 205.0        102.5   0.500
Mubuku3                10.5          5.2   0.495
Narubale              180.0         90.0   0.500
                      -----        -----
total                 666.5        333.2   0.500

Six rivers, one ratio. That is a placeholder, not a measurement.
```

Q.3 The price, and the factor of 730 (Chapter 11)

Claim: the exported marginal price is out by the snapshot weight.

Q.3

```
value of lost load                V = 10,000 per MWh
snapshot weight                   w = 730 hours

V / w  = 10,000 / 730             = 13.6986
maximum price in the results file = 13.6986
```

```
mean price as exported            = 12.37
mean price x w                    = 9,032.1

minimum true price                = 8,131.6
  = 10,000 x (1-0.065)(1-0.040)(1-0.031)(1-0.023)  (loss path)
```

Q.4 The carbon price is a transfer (Chapter 11)

Claim: the cost rise is exactly the price times a fixed quantity.

Q.4

```
carbon   objective        change from tau=0    tau x E
     0     780,587,780                 0             0
    25     788,931,680         8,343,900     8,343,900
    50     797,275,580        16,687,800    16,687,800
   100     813,963,380        33,375,600    33,375,600

emissions E is 333,756 t at every carbon price.
The two right-hand columns are identical, so the model abates nothing.
```

Q.5 The CDCGE carrier drop (Chapter 19)

Claim: 81.2 % of generation is discarded silently.

Q.5

```
carriers the exporter emits, and what CARRIER_MAP knows:

  solar          130,889 MWh   -> SOL      kept
  biomass        105,120       -> ORE      kept
  oil            438,000       -> OIL_p    kept
  Bugoye          48,180       -> ?        DROPPED
  BujagaliFalls 1,095,000      -> ?        DROPPED
  IshashaRiver    43,800       -> ?        DROPPED
  Kiira          897,900       -> ?        DROPPED
  Mubuku3         45,552       -> ?        DROPPED
  Narubale       788,400       -> ?        DROPPED

dropped  = 2,918,832 MWh
total    = 3,592,841 MWh
share    = 81.2 %

clean share the CGE would see  = 35.0 %
clean share after the fix      = 87.8 %
```

Q.6 The regulated asset base (Chapter 16)

Claim: the asset base has to be recovered by inverting the annuity, and omitting hydro puts it out by a factor of ten.

Q.6

```
CRF(0.08, 25) = 0.08 x 1.08^25 / (1.08^25 - 1) = 0.09368

overnight cost per MW = annualised capex / CRF
```

```
  solar   78,000 / 0.09368 =      832,633
  hydro  150,000 / 0.09368 =    1,601,216
  gas    120,000 / 0.09368 =    1,280,973

RAB from technologies.csv only (106.0 MW)  =   116 million
RAB including hydro.csv      (772.5 MW)  =   1,183 million

RR = OPEX + DEP + r x RAB
   = 86,899,200 + 47,330,677 + 0.08 x 1,183,266,916
   = 228,891,230
```

Q.7 The lifeline cross-subsidy (Chapter 16)

Claim: every lifeline discount is paid for by non-lifeline energy.

Q.7

```
residential class:
  energy                    E = 1,916,839 MWh
  lifeline energy      E_life = 890,076 MWh
  cost-reflective tariff  p_cr = 70.05

shortfall on the lifeline block  = delta x E_life x p_cr
                                 = 0.5 x 890,076 x 70.05

recovered from all non-lifeline energy across every class,
which is why the industrial standard tariff exceeds its own
cost-reflective tariff.
```

Q.8 Why the tariff cannot move poverty (Chapter 20)

Claim: the households on the poverty line are not connected.

Q.8

```
households in the survey                = 3,062
national connection rate                = 25.88 %

households within 20 % of the line      = 448
of which connected                      = 7
connection rate near the line           = 0.77 %
connection rate below the line          = 0.25 %

A price change reaches a household only through its bill.
Seven households near the line have one.
```

Appendix R — The demand and availability tables, in full

These two tables are the largest inputs in the case and they are the ones a reader is least able to reconstruct. They are reproduced here row by row.

R.1 Demand — every bus, every period

time	bus	demand_mw	weight	sector
wet_night	B01_Bujagali	33.66	730.0	households
wet_morning	B01_Bujagali	44.881	730.0	households
wet_day	B01_Bujagali	46.751	730.0	households
wet_evening	B01_Bujagali	50.491	730.0	households
dry_night	B01_Bujagali	34.701	730.0	households
dry_morning	B01_Bujagali	46.269	730.0	households
dry_day	B01_Bujagali	48.196	730.0	households
dry_evening	B01_Bujagali	52.052	730.0	households
hot_night	B01_Bujagali	36.09	730.0	households
hot_morning	B01_Bujagali	48.119	730.0	households
hot_day	B01_Bujagali	50.124	730.0	households
hot_evening	B01_Bujagali	54.134	730.0	households
wet_night	B02_Kawanda	5.401	730.0	households
wet_morning	B02_Kawanda	7.202	730.0	households
wet_day	B02_Kawanda	7.502	730.0	households
wet_evening	B02_Kawanda	8.102	730.0	households
dry_night	B02_Kawanda	5.568	730.0	households
dry_morning	B02_Kawanda	7.424	730.0	households
dry_day	B02_Kawanda	7.734	730.0	households
dry_evening	B02_Kawanda	8.352	730.0	households
hot_night	B02_Kawanda	5.791	730.0	households
hot_morning	B02_Kawanda	7.721	730.0	households
hot_day	B02_Kawanda	8.043	730.0	households
hot_evening	B02_Kawanda	8.687	730.0	households
wet_night	B03_Nalubaale	18.192	730.0	households
wet_morning	B03_Nalubaale	24.256	730.0	households
wet_day	B03_Nalubaale	25.267	730.0	households
wet_evening	B03_Nalubaale	27.288	730.0	households
dry_night	B03_Nalubaale	18.755	730.0	households
dry_morning	B03_Nalubaale	25.006	730.0	households
dry_day	B03_Nalubaale	26.048	730.0	households
dry_evening	B03_Nalubaale	28.132	730.0	households
hot_night	B03_Nalubaale	19.505	730.0	households
hot_morning	B03_Nalubaale	26.007	730.0	households
hot_day	B03_Nalubaale	27.09	730.0	households
hot_evening	B03_Nalubaale	29.257	730.0	households
wet_night	B04_Tororo	20.616	730.0	households
wet_morning	B04_Tororo	27.488	730.0	households

time	bus	demand_mw	weight	sector
wet_day	B04_Tororo	28.633	730.0	households
wet_evening	B04_Tororo	30.923	730.0	households
dry_night	B04_Tororo	21.253	730.0	households
dry_morning	B04_Tororo	28.338	730.0	households
dry_day	B04_Tororo	29.518	730.0	households
dry_evening	B04_Tororo	31.88	730.0	households
hot_night	B04_Tororo	22.103	730.0	households
hot_morning	B04_Tororo	29.471	730.0	households
hot_day	B04_Tororo	30.699	730.0	households
hot_evening	B04_Tororo	33.155	730.0	households
wet_night	B05_Nkenda	5.3	730.0	households
wet_morning	B05_Nkenda	7.067	730.0	households
wet_day	B05_Nkenda	7.362	730.0	households
wet_evening	B05_Nkenda	7.951	730.0	households
dry_night	B05_Nkenda	5.464	730.0	households
dry_morning	B05_Nkenda	7.286	730.0	households
dry_day	B05_Nkenda	7.589	730.0	households
dry_evening	B05_Nkenda	8.196	730.0	households
hot_night	B05_Nkenda	5.683	730.0	households
hot_morning	B05_Nkenda	7.577	730.0	households
hot_day	B05_Nkenda	7.893	730.0	households
hot_evening	B05_Nkenda	8.524	730.0	households
wet_night	B06_Hoima	7.707	730.0	households
wet_morning	B06_Hoima	10.276	730.0	households
wet_day	B06_Hoima	10.704	730.0	households
wet_evening	B06_Hoima	11.56	730.0	households
dry_night	B06_Hoima	7.945	730.0	households
dry_morning	B06_Hoima	10.594	730.0	households
dry_day	B06_Hoima	11.035	730.0	households
dry_evening	B06_Hoima	11.918	730.0	households
hot_night	B06_Hoima	8.263	730.0	households
hot_morning	B06_Hoima	11.017	730.0	households
hot_day	B06_Hoima	11.476	730.0	households
hot_evening	B06_Hoima	12.394	730.0	households
wet_night	B07_Kabulasoke	5.597	730.0	households
wet_morning	B07_Kabulasoke	7.463	730.0	households
wet_day	B07_Kabulasoke	7.774	730.0	households
wet_evening	B07_Kabulasoke	8.396	730.0	households
dry_night	B07_Kabulasoke	5.77	730.0	households
dry_morning	B07_Kabulasoke	7.694	730.0	households
dry_day	B07_Kabulasoke	8.014	730.0	households
dry_evening	B07_Kabulasoke	8.656	730.0	households
hot_night	B07_Kabulasoke	6.001	730.0	households
hot_morning	B07_Kabulasoke	8.002	730.0	households
hot_day	B07_Kabulasoke	8.335	730.0	households
hot_evening	B07_Kabulasoke	9.002	730.0	households

time	bus	demand_mw	weight	sector
wet_night	B08_MasakaWest	11.448	730.0	households
wet_morning	B08_MasakaWest	15.264	730.0	households
wet_day	B08_MasakaWest	15.9	730.0	households
wet_evening	B08_MasakaWest	17.172	730.0	households
dry_night	B08_MasakaWest	11.802	730.0	households
dry_morning	B08_MasakaWest	15.736	730.0	households
dry_day	B08_MasakaWest	16.391	730.0	households
dry_evening	B08_MasakaWest	17.703	730.0	households
hot_night	B08_MasakaWest	12.274	730.0	households
hot_morning	B08_MasakaWest	16.365	730.0	households
hot_day	B08_MasakaWest	17.047	730.0	households
hot_evening	B08_MasakaWest	18.411	730.0	households
wet_night	B09_Nkonge	3.373	730.0	households
wet_morning	B09_Nkonge	4.497	730.0	households
wet_day	B09_Nkonge	4.684	730.0	households
wet_evening	B09_Nkonge	5.059	730.0	households
dry_night	B09_Nkonge	3.477	730.0	households
dry_morning	B09_Nkonge	4.636	730.0	households
dry_day	B09_Nkonge	4.829	730.0	households
dry_evening	B09_Nkonge	5.216	730.0	households
hot_night	B09_Nkonge	3.616	730.0	households
hot_morning	B09_Nkonge	4.822	730.0	households
hot_day	B09_Nkonge	5.022	730.0	households
hot_evening	B09_Nkonge	5.424	730.0	households
wet_night	B10_Rugonjo	1.862	730.0	households
wet_morning	B10_Rugonjo	2.482	730.0	households
wet_day	B10_Rugonjo	2.585	730.0	households
wet_evening	B10_Rugonjo	2.792	730.0	households
dry_night	B10_Rugonjo	1.919	730.0	households
dry_morning	B10_Rugonjo	2.559	730.0	households
dry_day	B10_Rugonjo	2.665	730.0	households
dry_evening	B10_Rugonjo	2.879	730.0	households
hot_night	B10_Rugonjo	1.996	730.0	households
hot_morning	B10_Rugonjo	2.661	730.0	households
hot_day	B10_Rugonjo	2.772	730.0	households
hot_evening	B10_Rugonjo	2.994	730.0	households
wet_night	B11_KampalaNorth	38.031	730.0	households
wet_morning	B11_KampalaNorth	50.708	730.0	households
wet_day	B11_KampalaNorth	52.821	730.0	households
wet_evening	B11_KampalaNorth	57.047	730.0	households
dry_night	B11_KampalaNorth	39.207	730.0	households
dry_morning	B11_KampalaNorth	52.276	730.0	households
dry_day	B11_KampalaNorth	54.455	730.0	households
dry_evening	B11_KampalaNorth	58.811	730.0	households
hot_night	B11_KampalaNorth	40.776	730.0	households
hot_morning	B11_KampalaNorth	54.367	730.0	households

time	bus	demand_mw	weight	sector
hot_day	B11_KampalaNorth	56.633	730.0	households
hot_evening	B11_KampalaNorth	61.163	730.0	households
wet_night	B12_Mutundwe	63.407	730.0	households
wet_morning	B12_Mutundwe	84.543	730.0	households
wet_day	B12_Mutundwe	88.066	730.0	households
wet_evening	B12_Mutundwe	95.111	730.0	households
dry_night	B12_Mutundwe	65.369	730.0	households
dry_morning	B12_Mutundwe	87.158	730.0	households
dry_day	B12_Mutundwe	90.79	730.0	households
dry_evening	B12_Mutundwe	98.053	730.0	households
hot_night	B12_Mutundwe	67.983	730.0	households
hot_morning	B12_Mutundwe	90.644	730.0	households
hot_day	B12_Mutundwe	94.421	730.0	households
hot_evening	B12_Mutundwe	101.975	730.0	households
wet_night	B13_Kafu	2.435	730.0	households
wet_morning	B13_Kafu	3.247	730.0	households
wet_day	B13_Kafu	3.382	730.0	households
wet_evening	B13_Kafu	3.653	730.0	households
dry_night	B13_Kafu	2.51	730.0	households
dry_morning	B13_Kafu	3.347	730.0	households
dry_day	B13_Kafu	3.487	730.0	households
dry_evening	B13_Kafu	3.766	730.0	households
hot_night	B13_Kafu	2.611	730.0	households
hot_morning	B13_Kafu	3.481	730.0	households
hot_day	B13_Kafu	3.626	730.0	households
hot_evening	B13_Kafu	3.916	730.0	households
wet_night	B14_Kyaka	0.023	730.0	households
wet_morning	B14_Kyaka	0.03	730.0	households
wet_day	B14_Kyaka	0.032	730.0	households
wet_evening	B14_Kyaka	0.034	730.0	households
dry_night	B14_Kyaka	0.024	730.0	households
dry_morning	B14_Kyaka	0.031	730.0	households
dry_day	B14_Kyaka	0.033	730.0	households
dry_evening	B14_Kyaka	0.035	730.0	households
hot_night	B14_Kyaka	0.025	730.0	households
hot_morning	B14_Kyaka	0.033	730.0	households
hot_day	B14_Kyaka	0.034	730.0	households
hot_evening	B14_Kyaka	0.037	730.0	households
wet_night	B15_MasakaWest	8.351	730.0	households
wet_morning	B15_MasakaWest	11.134	730.0	households
wet_day	B15_MasakaWest	11.598	730.0	households
wet_evening	B15_MasakaWest	12.526	730.0	households
dry_night	B15_MasakaWest	8.609	730.0	households
dry_morning	B15_MasakaWest	11.478	730.0	households
dry_day	B15_MasakaWest	11.957	730.0	households
dry_evening	B15_MasakaWest	12.913	730.0	households

time	bus	demand_mw	weight	sector
hot_night	B15_MasakaWest	8.953	730.0	households
hot_morning	B15_MasakaWest	11.938	730.0	households
hot_day	B15_MasakaWest	12.435	730.0	households
hot_evening	B15_MasakaWest	13.43	730.0	households
wet_night	B16_MbararaSouth	0.658	730.0	households
wet_morning	B16_MbararaSouth	0.877	730.0	households
wet_day	B16_MbararaSouth	0.914	730.0	households
wet_evening	B16_MbararaSouth	0.987	730.0	households
dry_night	B16_MbararaSouth	0.678	730.0	households
dry_morning	B16_MbararaSouth	0.904	730.0	households
dry_day	B16_MbararaSouth	0.942	730.0	households
dry_evening	B16_MbararaSouth	1.017	730.0	households
hot_night	B16_MbararaSouth	0.705	730.0	households
hot_morning	B16_MbararaSouth	0.94	730.0	households
hot_day	B16_MbararaSouth	0.98	730.0	households
hot_evening	B16_MbararaSouth	1.058	730.0	households
wet_night	B17_Mbarara	3.565	730.0	households
wet_morning	B17_Mbarara	4.753	730.0	households
wet_day	B17_Mbarara	4.951	730.0	households
wet_evening	B17_Mbarara	5.347	730.0	households
dry_night	B17_Mbarara	3.675	730.0	households
dry_morning	B17_Mbarara	4.9	730.0	households
dry_day	B17_Mbarara	5.104	730.0	households
dry_evening	B17_Mbarara	5.513	730.0	households
hot_night	B17_Mbarara	3.822	730.0	households
hot_morning	B17_Mbarara	5.096	730.0	households
hot_day	B17_Mbarara	5.308	730.0	households
hot_evening	B17_Mbarara	5.733	730.0	households
wet_night	B18_Nalubale	5.149	730.0	households
wet_morning	B18_Nalubale	6.865	730.0	households
wet_day	B18_Nalubale	7.151	730.0	households
wet_evening	B18_Nalubale	7.723	730.0	households
dry_night	B18_Nalubale	5.308	730.0	households
dry_morning	B18_Nalubale	7.078	730.0	households
dry_day	B18_Nalubale	7.373	730.0	households
dry_evening	B18_Nalubale	7.962	730.0	households
hot_night	B18_Nalubale	5.521	730.0	households
hot_morning	B18_Nalubale	7.361	730.0	households
hot_day	B18_Nalubale	7.667	730.0	households
hot_evening	B18_Nalubale	8.281	730.0	households
wet_night	B19_Nalubale	27.299	730.0	households
wet_morning	B19_Nalubale	36.398	730.0	households
wet_day	B19_Nalubale	37.915	730.0	households
wet_evening	B19_Nalubale	40.948	730.0	households
dry_night	B19_Nalubale	28.143	730.0	households
dry_morning	B19_Nalubale	37.524	730.0	households

time	bus	demand_mw	weight	sector
dry_day	B19_Nalubale	39.087	730.0	households
dry_evening	B19_Nalubale	42.214	730.0	households
hot_night	B19_Nalubale	29.269	730.0	households
hot_morning	B19_Nalubale	39.025	730.0	households
hot_day	B19_Nalubale	40.651	730.0	households
hot_evening	B19_Nalubale	43.903	730.0	households
wet_night	B20_Mirama	3.425	730.0	households
wet_morning	B20_Mirama	4.566	730.0	households
wet_day	B20_Mirama	4.756	730.0	households
wet_evening	B20_Mirama	5.137	730.0	households
dry_night	B20_Mirama	3.531	730.0	households
dry_morning	B20_Mirama	4.707	730.0	households
dry_day	B20_Mirama	4.904	730.0	households
dry_evening	B20_Mirama	5.296	730.0	households
hot_night	B20_Mirama	3.672	730.0	households
hot_morning	B20_Mirama	4.896	730.0	households
hot_day	B20_Mirama	5.1	730.0	households
hot_evening	B20_Mirama	5.508	730.0	households
wet_night	B21_Karuma	15.751	730.0	households
wet_morning	B21_Karuma	21.002	730.0	households
wet_day	B21_Karuma	21.877	730.0	households
wet_evening	B21_Karuma	23.627	730.0	households
dry_night	B21_Karuma	16.239	730.0	households
dry_morning	B21_Karuma	21.651	730.0	households
dry_day	B21_Karuma	22.554	730.0	households
dry_evening	B21_Karuma	24.358	730.0	households
hot_night	B21_Karuma	16.888	730.0	households
hot_morning	B21_Karuma	22.517	730.0	households
hot_day	B21_Karuma	23.456	730.0	households
hot_evening	B21_Karuma	25.332	730.0	households
wet_night	B22_Opuyo	6.62	730.0	households
wet_morning	B22_Opuyo	8.826	730.0	households
wet_day	B22_Opuyo	9.194	730.0	households
wet_evening	B22_Opuyo	9.93	730.0	households
dry_night	B22_Opuyo	6.825	730.0	households
dry_morning	B22_Opuyo	9.099	730.0	households
dry_day	B22_Opuyo	9.479	730.0	households
dry_evening	B22_Opuyo	10.237	730.0	households
hot_night	B22_Opuyo	7.098	730.0	households
hot_morning	B22_Opuyo	9.463	730.0	households
hot_day	B22_Opuyo	9.858	730.0	households
hot_evening	B22_Opuyo	10.646	730.0	households
wet_night	B23_Lira	6.743	730.0	households
wet_morning	B23_Lira	8.99	730.0	households
wet_day	B23_Lira	9.365	730.0	households
wet_evening	B23_Lira	10.114	730.0	households

time	bus	demand_mw	weight	sector
dry_night	B23_Lira	6.951	730.0	households
dry_morning	B23_Lira	9.268	730.0	households
dry_day	B23_Lira	9.654	730.0	households
dry_evening	B23_Lira	10.427	730.0	households
hot_night	B23_Lira	7.229	730.0	households
hot_morning	B23_Lira	9.639	730.0	households
hot_day	B23_Lira	10.041	730.0	households
hot_evening	B23_Lira	10.844	730.0	households
wet_night	B24_Lessos	0.0	730.0	households
wet_morning	B24_Lessos	0.0	730.0	households
wet_day	B24_Lessos	0.0	730.0	households
wet_evening	B24_Lessos	0.0	730.0	households
dry_night	B24_Lessos	0.0	730.0	households
dry_morning	B24_Lessos	0.0	730.0	households
dry_day	B24_Lessos	0.0	730.0	households
dry_evening	B24_Lessos	0.0	730.0	households
hot_night	B24_Lessos	0.0	730.0	households
hot_morning	B24_Lessos	0.0	730.0	households
hot_day	B24_Lessos	0.0	730.0	households
hot_evening	B24_Lessos	0.0	730.0	households

Table 184. demand.csv — all 288 rows. Demand is in MW; multiply by `weight` for energy in the period.

R.2 Availability — every unit, every period

time	technology	availability
wet_night	Kabulasoke	0.0
wet_night	Soroti	0.0
wet_night	Tororo	0.0
wet_morning	Kabulasoke	0.369
wet_morning	Soroti	0.369
wet_morning	Tororo	0.369
wet_day	Kabulasoke	0.697
wet_day	Soroti	0.697
wet_day	Tororo	0.697
wet_evening	Kabulasoke	0.098
wet_evening	Soroti	0.098
wet_evening	Tororo	0.098
dry_night	Kabulasoke	0.0
dry_night	Soroti	0.0
dry_night	Tororo	0.0
dry_morning	Kabulasoke	0.45
dry_morning	Soroti	0.45
dry_morning	Tororo	0.45
dry_day	Kabulasoke	0.85
dry_day	Soroti	0.85
dry_day	Tororo	0.85

time	technology	availability
dry_evening	Kabulasoke	0.12
dry_evening	Soroti	0.12
dry_evening	Tororo	0.12
hot_night	Kabulasoke	0.0
hot_night	Soroti	0.0
hot_night	Tororo	0.0
hot_morning	Kabulasoke	0.473
hot_morning	Soroti	0.473
hot_morning	Tororo	0.473
hot_day	Kabulasoke	0.892
hot_day	Soroti	0.892
hot_day	Tororo	0.892
hot_evening	Kabulasoke	0.126
hot_evening	Soroti	0.126
hot_evening	Tororo	0.126

Table 185. availability.csv — all 36 rows. A unit whose availability is the same in every period has a declared capacity factor, not a profile.

R.3 The solved dispatch

time	technology	bus	generation_mwh
wet_night	Kabulasoke	B07_Kabulasoke	-0.0
wet_morning	Kabulasoke	B07_Kabulasoke	6464.88
wet_day	Kabulasoke	B07_Kabulasoke	12211.439999999999
wet_evening	Kabulasoke	B07_Kabulasoke	1716.9600000000003
dry_night	Kabulasoke	B07_Kabulasoke	-0.0
dry_morning	Kabulasoke	B07_Kabulasoke	7884.000000000001
dry_day	Kabulasoke	B07_Kabulasoke	14891.999999999998
dry_evening	Kabulasoke	B07_Kabulasoke	2102.4
hot_night	Kabulasoke	B07_Kabulasoke	-0.0
hot_morning	Kabulasoke	B07_Kabulasoke	8286.960000000001
hot_day	Kabulasoke	B07_Kabulasoke	15627.84
hot_evening	Kabulasoke	B07_Kabulasoke	2207.52
wet_night	KakiraSugarWor	B03_Nalubaale	8760.0
wet_morning	KakiraSugarWor	B03_Nalubaale	8760.0
wet_day	KakiraSugarWor	B03_Nalubaale	8760.0
wet_evening	KakiraSugarWor	B03_Nalubaale	8760.0
dry_night	KakiraSugarWor	B03_Nalubaale	8760.0
dry_morning	KakiraSugarWor	B03_Nalubaale	8760.0
dry_day	KakiraSugarWor	B03_Nalubaale	8760.0
dry_evening	KakiraSugarWor	B03_Nalubaale	8760.0
hot_night	KakiraSugarWor	B03_Nalubaale	8760.0
hot_morning	KakiraSugarWor	B03_Nalubaale	8760.0
hot_day	KakiraSugarWor	B03_Nalubaale	8760.0
hot_evening	KakiraSugarWor	B03_Nalubaale	8760.0
wet_night	LugogoSubstati	B19_Nalubale	36500.0

time	technology	bus	generation_mwh
wet_morning	LugogoSubstati	B19_Nalubale	36500.0
wet_day	LugogoSubstati	B19_Nalubale	36500.0
wet_evening	LugogoSubstati	B19_Nalubale	36500.0
dry_night	LugogoSubstati	B19_Nalubale	36500.0
dry_morning	LugogoSubstati	B19_Nalubale	36500.0
dry_day	LugogoSubstati	B19_Nalubale	36500.0
dry_evening	LugogoSubstati	B19_Nalubale	36500.0
hot_night	LugogoSubstati	B19_Nalubale	36500.0
hot_morning	LugogoSubstati	B19_Nalubale	36500.0
hot_day	LugogoSubstati	B19_Nalubale	36500.0
hot_evening	LugogoSubstati	B19_Nalubale	36500.0
wet_night	Soroti	B22_Opuyo	-0.0
wet_morning	Soroti	B22_Opuyo	2693.7
wet_day	Soroti	B22_Opuyo	5088.099999999999
wet_evening	Soroti	B22_Opuyo	715.4
dry_night	Soroti	B22_Opuyo	-0.0
dry_morning	Soroti	B22_Opuyo	3285.0
dry_day	Soroti	B22_Opuyo	6205.0
dry_evening	Soroti	B22_Opuyo	876.0
hot_night	Soroti	B22_Opuyo	-0.0
hot_morning	Soroti	B22_Opuyo	3452.8999999999996
hot_day	Soroti	B22_Opuyo	6511.6
hot_evening	Soroti	B22_Opuyo	919.8
wet_night	Tororo	B04_Tororo	-0.0
wet_morning	Tororo	B04_Tororo	2693.7
wet_day	Tororo	B04_Tororo	5088.099999999999
wet_evening	Tororo	B04_Tororo	715.4
dry_night	Tororo	B04_Tororo	-0.0
dry_morning	Tororo	B04_Tororo	3285.0
dry_day	Tororo	B04_Tororo	6205.0
dry_evening	Tororo	B04_Tororo	876.0
hot_night	Tororo	B04_Tororo	-0.0
hot_morning	Tororo	B04_Tororo	3452.8999999999996
hot_day	Tororo	B04_Tororo	6511.6
hot_evening	Tororo	B04_Tororo	919.8
wet_night	Bugoye	B06_Hoima	4015.0
wet_morning	Bugoye	B06_Hoima	4015.0
wet_day	Bugoye	B06_Hoima	3387.2
wet_evening	Bugoye	B06_Hoima	4642.8
dry_night	Bugoye	B06_Hoima	4015.0
dry_morning	Bugoye	B06_Hoima	1926.4700000000003
dry_day	Bugoye	B06_Hoima	4259.55
dry_evening	Bugoye	B06_Hoima	4904.139999999999
hot_night	Bugoye	B06_Hoima	4969.84
hot_morning	Bugoye	B06_Hoima	4015.0
hot_day	Bugoye	B06_Hoima	4015.0

time	technology	bus	generation_mwh
hot_evening	Bugoye	B06_Hoima	4015.0
wet_night	BujagaliFalls	B02_Kawanda	90683.3578812642
wet_morning	BujagaliFalls	B02_Kawanda	91816.6421187358
wet_day	BujagaliFalls	B02_Kawanda	91250.0
wet_evening	BujagaliFalls	B02_Kawanda	91250.0
dry_night	BujagaliFalls	B02_Kawanda	47229.09530644838
dry_morning	BujagaliFalls	B02_Kawanda	113468.98396964146
dry_day	BujagaliFalls	B02_Kawanda	113051.92072391017
dry_evening	BujagaliFalls	B02_Kawanda	56541.96127247579
hot_night	BujagaliFalls	B02_Kawanda	97194.03106585843
hot_morning	BujagaliFalls	B02_Kawanda	120014.00766166578
hot_day	BujagaliFalls	B02_Kawanda	43468.50655262172
hot_evening	BujagaliFalls	B02_Kawanda	139031.49344737828
wet_night	IshashaRiver	B17_Mbarara	2602.45
wet_morning	IshashaRiver	B17_Mbarara	3469.69
wet_day	IshashaRiver	B17_Mbarara	4624.55
wet_evening	IshashaRiver	B17_Mbarara	3903.3100000000004
dry_night	IshashaRiver	B17_Mbarara	3272.5899999999997
dry_morning	IshashaRiver	B17_Mbarara	3577.0000000000005
dry_day	IshashaRiver	B17_Mbarara	3725.92
dry_evening	IshashaRiver	B17_Mbarara	4024.49
hot_night	IshashaRiver	B17_Mbarara	2819.9900000000002
hot_morning	IshashaRiver	B17_Mbarara	3720.08
hot_day	IshashaRiver	B17_Mbarara	3874.8399999999997
hot_evening	IshashaRiver	B17_Mbarara	4185.09
wet_night	Kiira	B03_Nalubaale	12525.571161979426
wet_morning	Kiira	B03_Nalubaale	70571.97841298686
wet_day	Kiira	B03_Nalubaale	70504.1789841235
wet_evening	Kiira	B03_Nalubaale	145698.2714409102
dry_night	Kiira	B03_Nalubaale	74825.0
dry_morning	Kiira	B03_Nalubaale	74825.0
dry_day	Kiira	B03_Nalubaale	0.0
dry_evening	Kiira	B03_Nalubaale	149650.0
hot_night	Kiira	B03_Nalubaale	74825.0
hot_morning	Kiira	B03_Nalubaale	3588.3400479074044
hot_day	Kiira	B03_Nalubaale	146061.6599520926
hot_evening	Kiira	B03_Nalubaale	74825.0
wet_night	Mubuku3	B06_Hoima	1611.11
wet_morning	Mubuku3	B06_Hoima	3486.48
wet_day	Mubuku3	B06_Hoima	6989.749999999999
wet_evening	Mubuku3	B06_Hoima	3796.0
dry_night	Mubuku3	B06_Hoima	1784.8500000000001
dry_morning	Mubuku3	B06_Hoima	5807.15
dry_day	Mubuku3	B06_Hoima	3796.0
dry_evening	Mubuku3	B06_Hoima	3796.0
hot_night	Mubuku3	B06_Hoima	1062.15

time	technology	bus	generation_mwh
hot_morning	Mubuku3	B06_Hoima	4027.4099999999994
hot_day	Mubuku3	B06_Hoima	4362.4800000000005
hot_evening	Mubuku3	B06_Hoima	5032.62
wet_night	Narubale	B03_Nalubaale	65700.0
wet_morning	Narubale	B03_Nalubaale	65700.0
wet_day	Narubale	B03_Nalubaale	65700.0
wet_evening	Narubale	B03_Nalubaale	36821.5061854853
dry_night	Narubale	B03_Nalubaale	53866.099073620564
dry_morning	Narubale	B03_Nalubaale	41158.500758051734
dry_day	Narubale	B03_Nalubaale	119019.62796203545
dry_evening	Narubale	B03_Nalubaale	77634.26602080696
hot_night	Narubale	B03_Nalubaale	12345.014593859245
hot_morning	Narubale	B03_Nalubaale	119054.98540614074
hot_day	Narubale	B03_Nalubaale	55040.74736450743
hot_evening	Narubale	B03_Nalubaale	76359.25263549258

Table 186. The dispatch, all 132 rows. The load-shedding generators are not in it; see Chapter 7.

R.4 The marginal prices, as exported and corrected

time	bus	weight	price_as_exported	price_true
wet_night	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
wet_morning	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
wet_day	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
wet_evening	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
dry_night	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
dry_morning	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
dry_day	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
dry_evening	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
hot_night	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
hot_morning	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
hot_day	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
hot_evening	B01_Bujagali	730.0	11.7906230754246	8607.15484505999
wet_night	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
wet_morning	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
wet_day	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
wet_evening	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
dry_night	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
dry_morning	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
dry_day	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
dry_evening	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
hot_night	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
hot_morning	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
hot_day	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
hot_evening	B02_Kawanda	730.0	11.3897418908602	8314.51158032795
wet_night	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
wet_morning	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074

time	bus	weight	price_as_exported	price_true
wet_day	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
wet_evening	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
dry_night	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
dry_morning	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
dry_day	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
dry_evening	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
hot_night	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
hot_morning	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
hot_day	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
hot_evening	B03_Nalubaale	730.0	11.1391675692612	8131.59232556074
wet_night	B04_Tororo	730.0	11.9015066780148	8688.09987495084
wet_morning	B04_Tororo	730.0	11.9015066780148	8688.09987495084
wet_day	B04_Tororo	730.0	11.9015066780148	8688.09987495084
wet_evening	B04_Tororo	730.0	11.9015066780148	8688.09987495084
dry_night	B04_Tororo	730.0	11.9015066780148	8688.09987495084
dry_morning	B04_Tororo	730.0	11.9015066780148	8688.09987495084
dry_day	B04_Tororo	730.0	11.9015066780148	8688.09987495084
dry_evening	B04_Tororo	730.0	11.9015066780148	8688.09987495084
hot_night	B04_Tororo	730.0	11.9015066780148	8688.09987495084
hot_morning	B04_Tororo	730.0	11.9015066780148	8688.09987495084
hot_day	B04_Tororo	730.0	11.9015066780148	8688.09987495084
hot_evening	B04_Tororo	730.0	11.9015066780148	8688.09987495084
wet_night	B05_Nkenda	730.0	13.6986301369863	10000.0
wet_morning	B05_Nkenda	730.0	13.6986301369863	10000.0
wet_day	B05_Nkenda	730.0	13.6986301369863	10000.0
wet_evening	B05_Nkenda	730.0	13.6986301369863	10000.0
dry_night	B05_Nkenda	730.0	13.6986301369863	10000.0
dry_morning	B05_Nkenda	730.0	13.6986301369863	10000.0
dry_day	B05_Nkenda	730.0	13.6986301369863	10000.0
dry_evening	B05_Nkenda	730.0	13.6986301369863	10000.0
hot_night	B05_Nkenda	730.0	13.6986301369863	10000.0
hot_morning	B05_Nkenda	730.0	13.6986301369863	10000.0
hot_day	B05_Nkenda	730.0	13.6986301369863	10000.0
hot_evening	B05_Nkenda	730.0	13.6986301369863	10000.0
wet_night	B06_Hoima	730.0	12.8082191780821	9350.0
wet_morning	B06_Hoima	730.0	12.8082191780821	9350.0
wet_day	B06_Hoima	730.0	12.8082191780821	9350.0
wet_evening	B06_Hoima	730.0	12.8082191780821	9350.0
dry_night	B06_Hoima	730.0	12.8082191780821	9350.0
dry_morning	B06_Hoima	730.0	12.8082191780821	9350.0
dry_day	B06_Hoima	730.0	12.8082191780821	9350.0
dry_evening	B06_Hoima	730.0	12.8082191780821	9350.0
hot_night	B06_Hoima	730.0	12.8082191780821	9350.0
hot_morning	B06_Hoima	730.0	12.8082191780821	9350.0
hot_day	B06_Hoima	730.0	12.8082191780821	9350.0
hot_evening	B06_Hoima	730.0	12.8082191780821	9350.0

time	bus	weight	price_as_exported	price_true
wet_night	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
wet_morning	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
wet_day	B07_Kabulasoke	730.0	11.9762047607671	8742.62947536
wet_evening	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
dry_night	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
dry_morning	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
dry_day	B07_Kabulasoke	730.0	11.9762047607671	8742.62947536
dry_evening	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
hot_night	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
hot_morning	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
hot_day	B07_Kabulasoke	730.0	11.9762047607671	8742.62947536
hot_evening	B07_Kabulasoke	730.0	12.2436376691844	8937.85549850467
wet_night	B08_MasakaWest	730.0	12.3721123561643	9031.64202
wet_morning	B08_MasakaWest	730.0	12.3721123561643	9031.64202
wet_day	B08_MasakaWest	730.0	12.3721123561643	9031.64202
wet_evening	B08_MasakaWest	730.0	12.3721123561643	9031.64202
dry_night	B08_MasakaWest	730.0	12.3721123561643	9031.64202
dry_morning	B08_MasakaWest	730.0	12.3721123561643	9031.64202
dry_day	B08_MasakaWest	730.0	12.3721123561643	9031.64202
dry_evening	B08_MasakaWest	730.0	12.3721123561643	9031.64202
hot_night	B08_MasakaWest	730.0	12.3721123561643	9031.64202
hot_morning	B08_MasakaWest	730.0	12.3721123561643	9031.64202
hot_day	B08_MasakaWest	730.0	12.3721123561643	9031.64202
hot_evening	B08_MasakaWest	730.0	12.3721123561643	9031.64202
wet_night	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
wet_morning	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
wet_day	B09_Nkonge	730.0	12.4105748816239	9059.71966358549
wet_evening	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
dry_night	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
dry_morning	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
dry_day	B09_Nkonge	730.0	12.4105748816239	9059.71966358549
dry_evening	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
hot_night	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
hot_morning	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
hot_day	B09_Nkonge	730.0	12.4105748816239	9059.71966358549
hot_evening	B09_Nkonge	730.0	12.6877074292067	9262.02642332090
wet_night	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
wet_morning	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
wet_day	B10_Rugonjo	730.0	12.7812305680988	9330.29831471214
wet_evening	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
dry_night	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
dry_morning	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
dry_day	B10_Rugonjo	730.0	12.7812305680988	9330.29831471214
dry_evening	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
hot_night	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
hot_morning	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558

time	bus	weight	price_as_exported	price_true
hot_day	B10_Rugonjo	730.0	12.7812305680988	9330.29831471214
hot_evening	B10_Rugonjo	730.0	13.0666399888843	9538.64719188558
wet_night	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
wet_morning	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
wet_day	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
wet_evening	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
dry_night	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
dry_morning	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
dry_day	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
dry_evening	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
hot_night	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
hot_morning	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
hot_day	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
hot_evening	B11_KampalaNorth	730.0	11.5312293677653	8417.79743846867
wet_night	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
wet_morning	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
wet_day	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
wet_evening	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
dry_night	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
dry_morning	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
dry_day	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
dry_evening	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
hot_night	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
hot_morning	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
hot_day	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
hot_evening	B12_Mutundwe	730.0	11.7906230754246	8607.15484505999
wet_night	B13_Kafu	730.0	12.4504995516627	9088.86467271383
wet_morning	B13_Kafu	730.0	12.4504995516627	9088.86467271383
wet_day	B13_Kafu	730.0	12.4504995516627	9088.86467271383
wet_evening	B13_Kafu	730.0	12.4504995516627	9088.86467271383
dry_night	B13_Kafu	730.0	12.4504995516627	9088.86467271383
dry_morning	B13_Kafu	730.0	12.4504995516627	9088.86467271383
dry_day	B13_Kafu	730.0	12.4504995516627	9088.86467271383
dry_evening	B13_Kafu	730.0	12.4504995516627	9088.86467271383
hot_night	B13_Kafu	730.0	12.4504995516627	9088.86467271383
hot_morning	B13_Kafu	730.0	12.4504995516627	9088.86467271383
hot_day	B13_Kafu	730.0	12.4504995516627	9088.86467271383
hot_evening	B13_Kafu	730.0	12.4504995516627	9088.86467271383
wet_night	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
wet_morning	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
wet_day	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
wet_evening	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
dry_night	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
dry_morning	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
dry_day	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
dry_evening	B14_Kyaka	730.0	13.0369993215641	9517.00950474183

time	bus	weight	price_as_exported	price_true
hot_night	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
hot_morning	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
hot_day	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
hot_evening	B14_Kyaka	730.0	13.0369993215641	9517.00950474183
wet_night	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
wet_morning	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
wet_day	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
wet_evening	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
dry_night	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
dry_morning	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
dry_day	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
dry_evening	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
hot_night	B15_MasakaWest	730.0	12.9686712328767	9467.13
hot_morning	B15_MasakaWest	730.0	12.9686712328767	9467.13
hot_day	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
hot_evening	B15_MasakaWest	730.0	12.9686712328767	9467.13000000000
wet_night	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
wet_morning	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
wet_day	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
wet_evening	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
dry_night	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
dry_morning	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
dry_day	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
dry_evening	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
hot_night	B16_MbararaSouth	730.0	13.3835616438356	9770.0
hot_morning	B16_MbararaSouth	730.0	13.3835616438356	9770.0
hot_day	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
hot_evening	B16_MbararaSouth	730.0	13.3835616438356	9770.00000000000
wet_night	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
wet_morning	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
wet_day	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
wet_evening	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
dry_night	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
dry_morning	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
dry_day	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
dry_evening	B17_Mbarara	730.0	12.5796110958904	9183.11610000000
hot_night	B17_Mbarara	730.0	12.5796110958904	9183.1161
hot_morning	B17_Mbarara	730.0	12.5796110958904	9183.1161
hot_day	B17_Mbarara	730.0	12.5796110958904	9183.1161
hot_evening	B17_Mbarara	730.0	12.5796110958904	9183.1161
wet_night	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
wet_morning	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
wet_day	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
wet_evening	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
dry_night	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
dry_morning	B18_Nalubale	730.0	11.4365170115619	8348.65741844018

time	bus	weight	price_as_exported	price_true
dry_day	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
dry_evening	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
hot_night	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
hot_morning	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
hot_day	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
hot_evening	B18_Nalubale	730.0	11.4365170115619	8348.65741844018
wet_night	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
wet_morning	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
wet_day	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
wet_evening	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
dry_night	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
dry_morning	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
dry_day	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
dry_evening	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
hot_night	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
hot_morning	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
hot_day	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
hot_evening	B19_Nalubale	730.0	11.2775423216744	8232.60589482236
wet_night	B20_Mirama	730.0	13.6986301369863	10000.0000000000
wet_morning	B20_Mirama	730.0	13.6986301369863	10000.0000000000
wet_day	B20_Mirama	730.0	13.6986301369863	10000.0000000000
wet_evening	B20_Mirama	730.0	13.6986301369863	10000.0000000000
dry_night	B20_Mirama	730.0	13.6986301369863	10000.0000000000
dry_morning	B20_Mirama	730.0	13.6986301369863	10000.0
dry_day	B20_Mirama	730.0	13.6986301369863	10000.0000000000
dry_evening	B20_Mirama	730.0	13.6986301369863	10000.0000000000
hot_night	B20_Mirama	730.0	13.6986301369863	10000.0
hot_morning	B20_Mirama	730.0	13.6986301369863	10000.0
hot_day	B20_Mirama	730.0	13.6986301369863	10000.0000000000
hot_evening	B20_Mirama	730.0	13.6986301369863	10000.0
wet_night	B21_Karuma	730.0	12.9288676548938	9438.07338807251
wet_morning	B21_Karuma	730.0	12.9288676548938	9438.07338807251
wet_day	B21_Karuma	730.0	12.9288676548938	9438.07338807251
wet_evening	B21_Karuma	730.0	12.9288676548938	9438.07338807251
dry_night	B21_Karuma	730.0	12.9288676548938	9438.07338807251
dry_morning	B21_Karuma	730.0	12.9288676548938	9438.07338807251
dry_day	B21_Karuma	730.0	12.9288676548938	9438.07338807251
dry_evening	B21_Karuma	730.0	12.9288676548938	9438.07338807251
hot_night	B21_Karuma	730.0	12.9288676548938	9438.07338807251
hot_morning	B21_Karuma	730.0	12.9288676548938	9438.07338807251
hot_day	B21_Karuma	730.0	12.9288676548938	9438.07338807251
hot_evening	B21_Karuma	730.0	12.9288676548938	9438.07338807251
wet_night	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
wet_morning	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
wet_day	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
wet_evening	B22_Opuyo	730.0	12.5279017663314	9145.36828942194

time	bus	weight	price_as_exported	price_true
dry_night	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
dry_morning	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
dry_day	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
dry_evening	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
hot_night	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
hot_morning	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
hot_day	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
hot_evening	B22_Opuyo	730.0	12.5279017663314	9145.36828942194
wet_night	B23_Lira	730.0	13.0908064433975	9556.28870368019
wet_morning	B23_Lira	730.0	13.0908064433975	9556.28870368019
wet_day	B23_Lira	730.0	13.0908064433975	9556.28870368019
wet_evening	B23_Lira	730.0	13.0908064433975	9556.28870368019
dry_night	B23_Lira	730.0	13.0908064433975	9556.28870368019
dry_morning	B23_Lira	730.0	13.0908064433975	9556.28870368019
dry_day	B23_Lira	730.0	13.0908064433975	9556.28870368019
dry_evening	B23_Lira	730.0	13.0908064433975	9556.28870368019
hot_night	B23_Lira	730.0	13.0908064433975	9556.28870368019
hot_morning	B23_Lira	730.0	13.0908064433975	9556.28870368019
hot_day	B23_Lira	730.0	13.0908064433975	9556.28870368019
hot_evening	B23_Lira	730.0	13.0908064433975	9556.28870368019
wet_night	B24_Lessos	730.0	11.3540373708261	8288.44728070310
wet_morning	B24_Lessos	730.0	11.3540373708261	8288.44728070310
wet_day	B24_Lessos	730.0	11.3540373708261	8288.44728070310
wet_evening	B24_Lessos	730.0	11.3540373708261	8288.44728070310
dry_night	B24_Lessos	730.0	11.3540373708261	8288.44728070310
dry_morning	B24_Lessos	730.0	11.3540373708261	8288.44728070310
dry_day	B24_Lessos	730.0	11.3540373708261	8288.44728070310
dry_evening	B24_Lessos	730.0	11.3540373708261	8288.44728070310
hot_night	B24_Lessos	730.0	11.3540373708261	8288.44728070310
hot_morning	B24_Lessos	730.0	11.3540373708261	8288.44728070310
hot_day	B24_Lessos	730.0	11.3540373708261	8288.44728070310
hot_evening	B24_Lessos	730.0	11.3540373708261	8288.44728070310

Table 187. All 288 bus-periods, with the exported price and the same dual multiplied back by the snapshot weight.

Appendix S — The estate's file manifest and README

What the estate says about itself, reproduced so that a reader can check this manual's description of it against the source.

S.1 File manifest

Energy System file manifest (v0.3.0, PyPSA-engine architecture)

Package core (src/)

File	Purpose
EDISEnergySystemModel.jl	module root: includes, exports
Types.jl	ScenarioConfig, EnergyData, unit registry, provenance, RunInfo
DataSchema.jl	canonical table schemas; data dictionary generator
IO.jl	CSV loading/writing of all tables
Validation.jl	schema/range/duplicate/topology validation; diagnostics
Economics.jl	annuity, levelized cost
Emissions.jl	CO2e + multi-pollutant inventory, grid intensity
Balance/EnergyBalance.jl	E-BAL: identity, reconciliation, efficiency, Sankey
Demand/DemandProjection.jl	E-DEM: elasticity & driver projections, peak, LDC
PowerSystem/PyPSABridge.jl	E-DSP/E-EXP via PyPSA: input export, Python invocation, result import, rolling-horizon expansion, PyPSA-Earth import
Access/Electrification.jl	E-ACC: electrification plan, clean cooking (JuMP)
Fuels/FuelSupply.jl	E-FUE: fuel accounts, security, disruption
Finance/UtilityFinance.jl	E-FIN: RR, tariffs, utility finance, WACC, debt
Finance/Investment.jl	E-INV: investment by category to reach targets; cost-of-decarbonisation compare
Distribution/Losses.jl	E-DIST: energy waterfall, technical & commercial losses by region
GIS/Spatial.jl	E-GIS: map layers — settlements, industry, generation, network; target-driven electrification + reinforcement
Results/Simulation.jl	dynamic multi-year demand path & capacity-path helpers
Climate/ClimateRisk.jl	E-CLI: climate cases, stress test (re-dispatch via PyPSA)
Equity/Affordability.jl	E-EQU: burden, tariff impact, incidence, equity
Integration/MacroCGELink.jl	E-MAC: CDCGE/macro exchange, convergence
Integration/MTEFLink.jl	E-MTEF: FINEX-MTEF public-finance link (budget-constrained plan ↔ fiscal feedback)
Integration/UCSNBOELink.jl	E-UCSN/E-BOE: governed unit costs from UnitCostModelling; budget→output via BOEModelling crosswalk
Integration/SectorLinks.jl	sector demand links + double-count guard
Results/Indicators.jl	KPI table, result export with manifest
ScenarioManager.jl	YAML scenarios, orchestration, comparison
Optimization/{Common,EnergyAccess,Resilience,PolicyPortfolio}.jl	non-power JuMP screening models

Application & bridges

File	Purpose
genie/app.jl	Genie web app: REST API + /api/sim/* + async jobs + dashboard
genie/public/dashboard.html	14-page simulation dashboard: sliders, varied Plotly charts, dynamic year paths
genie/Project.toml	app environment (Genie + package)
bridge/run_pypsa_case.py	power-system solver: canonical CSVs → PyPSA/HiGHS (dispatch, unit_commitment, expansion, network) → result CSVs + summary.json
bridge/import_pypsa_earth.py	solved PyPSA-Earth .nc → canonical inputs + results
bridge/make_test_network.py	build+solve a toy netCDF network to exercise the importer
bridge/export_pypsa_network.py	legacy inputs-only PyPSA export (preserved)
D:\EDIP\models\pypsa-earth	PyPSA-Earth clone (upstream GIS/network engine, own conda env)

Data, config, scripts

Path	Purpose
data/demo/ (16 CSVs)	tiny 2-bus demo dataset (tests)
data/synthetic/ (17 CSVs + README)	richer 5-region "Zambesia" case (scripts/make_synthetic.jl); default web-app dataset
data/templates/ (16 CSVs + README)	blank documented templates (generated)
config/scenario.yml	example scenario
scripts/run_demo.jl, run_imported_case.jl	CLI entry points (PyPSA-backed; .nc import supported)
scripts/make_templates.jl	regenerate templates + data dictionary
scripts/setup_genie.jl	install the web-app environment
scripts/smoke_bridge.jl	quick end-to-end PyPSA bridge check
scripts/make_synthetic.jl	generate the 5-region synthetic dataset
scripts/smoke_synthetic.jl, smoke_sim.jl	dispatch/expansion & simulation-helper checks

Documentation & audit

Path	Purpose
docs/energy/ENERGY_SYSTEM_MATHEMATICAL_SPECIFICATION.md	full formal model spec
docs/energy/DATA_DICTIONARY.md	generated column-level dictionary
docs/energy/ENERGY_SYSTEM_VALIDATION_REPORT.md	validation evidence
docs/energy/README.md	user/admin guide
docs/ARCHITECTURE.md	system architecture
IMPLEMENTATION_STATUS.md / REMAINING_GAPS.md / TEST_RESULTS.md	audit trail
test/runtests.jl	94-assertion suite (all passing)

S.2 README

EDIS Energy System (EDISEnergySystemModel.jl)

The Energy Sector Decision Intelligence System of the Economic Development Intelligence System Trade and Economic Modelling — one sector module of the integrated EDIS architecture (D:\EDIP\models), with two-way links to the macro framework and the CDCGE model.

Engine architecture: the power system is modelled in PyPSA, with PyPSA-Earth (D:\EDIP\models\pypsa-earth) as the upstream engine for GIS, renewable profiles and national network builds. Julia orchestrates and owns accounting, finance, access, fuels, equity, scenarios and EDIS integration; power-system runs execute in Python through bridge/run_pypsa_case.py and return over a CSV/JSON contract (src/PowerSystem/PyPSABridge.jl).

Capabilities

- IEA-style energy-balance accounting with enforced identities and

Sankey export (E-BAL)

- Sectoral electricity-demand projection, peaks, load-duration curves (E-DEM)
- Via PyPSA: economic dispatch with storage, reservoir hydro, load

shedding at VoLL, emissions caps/prices and nodal prices; unit commitment with committable thermal units (E-DSP, E-STO, E-HYD)

- Via PyPSA: rolling-horizon generation expansion (reserve margins, RE

targets, potentials, availability windows) and transmission reinforcement (E-EXP); import of solved PyPSA-Earth networks

- Least-cost electrification planning and clean-cooking transition (E-ACC)
- Fuel accounts, energy-security indicators, disruption scenarios (E-FUE)
- Revenue requirement, tariff design with lifeline cross-subsidies,

utility finance, subsidy incidence (E-FIN)

- Emissions inventories, climate stress tests, resilience investment (E-EMI, E-CLI)
- Affordability, energy burden, tariff-shock poverty screening (E-EQU)
- Macro/CGE exchange objects and convergence loop; CDCGE-compatible

generation-by-carrier and LCOE exports; sector demand links with a double-counting guard (E-MAC)

- MTEF (FINEX-MTEF) fiscal link — run the plan under the public

Medium-Term Expenditure Framework's capital envelope and return system cost, reliability, tariffs and supply/demand to the fiscal loop (E-MTEF)

- Scenario manager with run IDs, provenance labels and reproducibility

manifests; Genie web dashboard + REST API with async jobs

Link to MTEFModelling (public finance ↔ energy)

The Energy System couples bidirectionally to [MTEFModelling](../MTEFModelling) — the EDIS FINEX-MTEF Sector Bridge that sits between the IMF FINEX macro-fiscal model and the sector models. MTEF's Model 43 — Energy budget bridge allocates the public capital and recurrent envelope to the energy sector over the MTEF horizon (Uganda 2026–2030) and writes, under MTEFModelling/edis_mtef_bridge/outputs/models/energy_budget_bridge/, files that target EnergyModelling directly.

The adapter is src/Integration/MTEFLink.jl:

julia using EDISEnergySystemModel d = load_energy_data("data/uganda") mi = read_mtef_inputs() # MTEF energy budget bridge -> capital/recurrent/MW/access by year exp, fb = run_energy_under_mtef(d, ScenarioConfig(), mi) # budget-constrained plan export_energy_to_mtef(fb, "results/energy_to_mtef_feedback.csv") # -> MTEF FINEX/CDCGE loop

- MTEF → Energy (MTEFToEnergyInputs, read_mtef_inputs,

apply_mtef_inputs): the capital envelope (LCU, converted at fx_lcu_per_usd) becomes the expansion investment budget; the horizon and the cumulative access-rate gain set years and access_target. In this budget-constrained mode reliability is an *output*, not a hard reserve-margin constraint.

- Energy → MTEF (EnergyToMTEFResults, export_energy_to_mtef):

system cost, generation, peak, unserved energy, a reliability index, emissions, capacity added, the cost-reflective tariff and the utility subsidy need (LCU) — exactly the "system cost, reliability, tariffs, energy demand and supply" the MTEF energy bridge feeds back into FINEX and CDCGE.

Verified end-to-end against the real MTEF run (scripts/smoke_mtef.jl, test set *MTEF fiscal link (E-MTEF)*).

Link to UnitCostModelling (UCSN) and BOEModelling (BOE)

The Energy System draws its unit costs from [UnitCostModelling](../UnitCostModelling) (UCSN), the EDIS governed parameter service, honouring its rule — *no sector application should ever hold its own unit cost*. Candidate capex, transmission $/km, connection cost and distribution O&M are resolved from UCSN instead of being hard-coded here. [BOEModelling](../BOEModelling) (the Budget Output Engine) then converts the energy budget into physical outputs (MW, connections) using those same coefficients.

The adapter is src/Integration/UCSNBOELink.jl:

julia using EDISEnergySystemModel d = load_energy_data("data/uganda") pack = read_ucsn_energy_coefficients() # UCSN energy coefficients (ENE-CAP-*, ENE-OPS-*) d2, prov = apply_ucsn_costs(d, pack) # governed costs replace hardcoded ones (+ provenance report) cw = read_boe_energy_crosswalk() # BOE FY2026/27 energy budget crosswalk boe = boe_energy_conversion(cw, pack) # energy budget -> MW / connections

- UCSN → Energy (read_ucsn_energy_coefficients, apply_ucsn_costs):

resolves ENE-CAP-003-SOLARPV, ENE-CAP-001-HYDRO, ENE-CAP-010-TX132, ENE-CAP-020-CONN and the ENE-OPS-* O&M coefficients, converts each to the model's currency and horizon (overnight → annualized capex), and rewrites candidates.annualized_capex_per_mw, lines.annualized_cost_per_mw and access_sites.grid_cost. It obeys UCSN's contract: pin the FX and source, carry provenance (tier / confidence / status), and **refuse rather than substitute** — a carrier with no governed coefficient (e.g. gas) keeps its local value and is *recorded* as unresolved, never silently replaced. (The shipped Uganda coefficients are CANDIDATE / ILLUSTRATIVE, which the provenance report surfaces.)

- BOE → Energy (read_boe_energy_crosswalk, boe_energy_conversion):

converts the CONVERTIBLE energy budget lines to MW / connections via their mapped coefficient and reports transfers and pending-coefficient money as unconverted, reconciling converted + unconverted = total — BOE's own discipline that only the part of a budget which buys a countable thing is converted. On the real Uganda FY2026/27 budget this is ≈ 23 % of the 1.95 T LCU energy vote → ≈ 112 MW.

Verified against the real UCSN/BOE outputs (scripts/smoke_ucsn_boe.jl, test set *UCSN unit costs & BOE budget→output (E-UCSN/E-BOE)*).

Full specification: docs/energy/ENERGY_SYSTEM_MATHEMATICAL_SPECIFICATION.md. Status and honest gaps: IMPLEMENTATION_STATUS.md, REMAINING_GAPS.md.

Quick start

powershell julia --project=. -e "using Pkg; Pkg.instantiate()" python -m pip install pypsa highspy netcdf4 # power-system engine julia --project=. test\runtests.jl # 107 assertions incl. live PyPSA solves + .nc import round-trip julia --project=. scripts\run_demo.jl

julia using EDISEnergySystemModel d = load_energy_data("data/demo") run_economic_dispatch(d, ScenarioConfig(carbon_price=25.0)) run_generation_expansion(d, ScenarioConfig(years=[2025,2030,2040]))

Web application

powershell julia --project=genie scripts\setup_genie.jl # once julia --project=genie --threads=4 genie\app.jl # → http://127.0.0.1:8060

PyPSA-Earth workflow

Run PyPSA-Earth's Snakemake workflow under its own conda environment (see D:\EDIP\models\pypsa-earth\README.md), then import a solved network directly:

bash julia --project=. scripts/run_imported_case.jl results/networks/solved.nc

or explicitly:

python bridge/import_pypsa_earth.py solved.nc data/imported julia --project=. scripts/run_imported_case.jl data/imported

Guides: docs/energy/README.md. Honest status and gaps: IMPLEMENTATION_STATUS.md, REMAINING_GAPS.md, TEST_RESULTS.md.

S.3 The energy documentation README

EDIS Energy System — user & administrator guide

The Energy System is one sector module of the EDIS decision-intelligence architecture (D:\EDIP\models). It estimates, simulates and optimizes energy balances, electricity demand, dispatch, capacity and network expansion, electrification, clean cooking, fuels, tariffs, utility finance, emissions, climate resilience, affordability and the two-way link to the macro framework and the CDCGE model.

Documents

File	Content
ENERGY_SYSTEM_MATHEMATICAL_SPECIFICATION.md	all sets, variables, equations (E-XXX-nn ids match code comments)
DATA_DICTIONARY.md	generated from src/DataSchema.jl — every table and column
ENERGY_SYSTEM_VALIDATION_REPORT.md	what is tested, how, and with what evidence
../../IMPLEMENTATION_STATUS.md	component-by-component status classification
../../REMAINING_GAPS.md	what is *not* implemented, and why

Installation

powershell cd D:\EDIP\models\EnergyModelling julia --project=. -e "using Pkg; Pkg.instantiate()"

Python side (power system): any Python 3.11+ with

python -m pip install pypsa highspy netcdf4

then (only if not auto-detected) set ENERGY_PYTHON to that interpreter

julia --project=. test\runtests.jl # must pass before use (runs live PyPSA)

PyPSA-Earth is cloned at D:\EDIP\models\pypsa-earth and is the upstream engine for GIS, renewable profiles and national network builds. Run its Snakemake workflow under its own conda environment (see its README); import any solved network here with import_pypsa_earth("path/to/network.nc") or python bridge/import_pypsa_earth.py NETWORK.nc OUT_DIR.

Data

- data/demo/ — small synthetic, internally consistent demonstration

dataset (never mix with production data).

- data/templates/ — blank documented templates, regenerate with

julia --project=. scripts/make_templates.jl.

- Production data: point load_energy_data (or ENERGY_DATA_DIR for the

web app) at your own directory following the templates. Required tables: buses, lines, technologies, demand, availability. Every optional table unlocks additional models (see DATA_DICTIONARY).

- Validation: validate_data (throws on hard errors) and diagnose_data

(row/missing/duplicate report). Provenance labels are validated where present. Missing production data are never invented: models error on absent required tables.

Running models (Julia API)

julia using EDISEnergySystemModel d = load_energy_data("data/demo") cfg = ScenarioConfig(carbon_price=25.0, years=[2025,2030,2040])

power system — executed in PyPSA (Python) through the bridge

run_economic_dispatch(d, cfg) # dispatch + storage + hydro + shedding run_unit_commitment(d, cfg) # committable thermal units (MILP) run_generation_expansion(d, cfg) # rolling-horizon least-cost plan run_network_expansion(d, cfg) # extendable transmission links import_pypsa_earth("network.nc") # bring in a solved PyPSA-Earth build

Julia-native models

run_electrification_plan(d, cfg) # least-cost access plan run_clean_cooking(d, cfg; target_share=0.4) climate_stress_test(d, cfg) # re-dispatches via PyPSA per climate case design_tariffs(d.customers, revenue_requirement(opex=30e6, depreciation=8e6, asset_base=100e6, allowed_return=0.1))

Scenario files: load_scenario("config/scenario.yml"). Orchestrated runs with result export and reproducibility manifest:

julia run_scenario(d, cfg; mode=:dispatch, results_dir="results")

→ results/<run_id>/{dispatch.csv, indicators.csv, ..., manifest.json}

Web application

powershell julia --project=genie scripts\setup_genie.jl # once julia --project=genie --threads=4 genie\app.jl # → http://127.0.0.1:8060

Each page is a simulation engine: slider inputs → a model run → charts. Pages: overview, demand (dynamic multi-year path), generation, dispatch, transmission, distribution (loss waterfall), expansion (dynamic capacity build-out), investment (options to reach targets), access & cooking, fuels & security, tariffs & finance, climate stress, equity, and data/diagnostics. A global control sets the base year (current year) and horizon, so demand and expansion produce year-by-year paths.

Chart types include time-series/stacked-area paths, dispatch stacks, capacity build-out, pies, gauges, loss waterfalls, grouped bars and a cost-of-decarbonisation curve. Power-system and multi-run simulations (dispatch, unit commitment, expansion, network, climate stress, investment) go through the async job API (POST /api/jobs/:mode, GET /api/jobs/:id) so the server never blocks; analytic simulations (demand, fuels, finance, equity, distribution) are synchronous (POST /api/sim/:name). The full API surface is documented in the header of genie/app.jl.

Set ENERGY_DATA_DIR to serve a different dataset and ENERGY_APP_PORT to change the port. Authentication is *not* built in — deploy behind the EDIS platform's reverse proxy / auth layer (see REMAINING_GAPS).

EDIS integration

- CDCGE: export_generation_for_cge(result.dispatch, d.technologies,

"…/gen_by_carrier.csv") writes exactly what CDCGE/src/PowerLink.jl reads; export_lcoe_path feeds its electricity-productivity shock.

- Macro: EnergyToMacroResults / MacroToEnergyInputs +

iterate_energy_macro for fixed-point coupling.

- Transport / Industry / Mining / Agriculture / Health / Education:

build demand_drivers rows with the *_demand_link helpers and merge with merge_sector_drivers (rejects double counting).

- PyPSA-Earth: unchanged upstream workflow via

bridge/export_pypsa_network.py → scripts/run_imported_case.jl.

Shared identifiers across EDIS: scenario name, region, year, sector id (EDIS_SECTORS), run_id, data_version.

Troubleshooting

- *Infeasible / unexpected shedding*: run diagnose_data(d), check line

limits and availability coverage; shedding is priced at voll, so positive unserved_mwh means capacity or network shortage, not a bug.

- *"candidates.csv required"*: the model you called needs that optional table.
- *Genie app stale data*: restart the app (data are cached on first request).
- Backup & recovery: inputs and results/<run_id> directories are plain

CSV/JSON — copy them; the manifest ties results to code/data versions.

Appendix T — The Uganda 2023 case, table by table

The rebuilt case is fifteen CSV files at D:/EDIP/models/EnergyModelling/data/uganda_2023, copied into this course at 08_Data/uganda_2023_case/. Every one is reproduced by 09_Code/Uganda2023/build_uganda_2023.py from the primary sources in §23.1.

File	Rows	What it holds	Status
access_sites.csv	60	Sixty settlement clusters with per-technology connection cost	carried from AEGID
availability.csv	825	Per-period capacity factors for every profiled unit and candidate	UETCL / calibrated
balance.csv	10	The 2023 electricity balance, nine flows	UETCL
buses.csv	17	Seventeen operational transmission substations with coordinates and region	carried from AEGID
candidates.csv	15	The IRP candidate set, annuitised at 10 %	MEMD / ERA IRP
cooking.csv	4	Four clean-cooking technologies	MEMD / UBOS
customers.csv	6	Six customer classes with 2023 sales, customer numbers and tariffs	ERA
demand.csv	425	Twenty-five periods at seventeen buses	UETCL
demand_drivers.csv	25	Sectoral and system demand indices to 2040	ERA / MoFPED
fuels.csv	3	Oil, biomass and gas accounts for 2026	MEMD
hazards.csv	4	Four hardening options against drought and flood	planning assumption
households.csv	4	Four household groups from the 2024 census	UBOS
hydro.csv	5	Five large hydro plants with mean inflow power and reservoir	ERA / UETCL
lines.csv	24	Twenty-four corridors with rating, loss factor, length and voltage	carried from AEGID
projects.csv	5	Five capital projects for portfolio appraisal	MEMD / UETCL
storage.csv	2	Two battery candidates at 4 h duration	ERA IRP
technologies.csv	18	The licensed generator fleet with carrier, variable cost, emission factor and metered energy	ERA / UETCL

Table 188. The rebuilt case, file by file.

T.1 Reproducing it

```
cd 09_Code/Uganda2023
python extract_history.py        # primary workbooks -> work/*.csv
python build_uganda_2023.py      # -> data/uganda_2023/
julia --pkgimages=no --project=D:/EDIP/models/EnergyModelling \
      uganda2023_analysis.jl <outdir>
python uga23_figures.py          # -> figures/
```

Listing 3. The whole pipeline. The --pkgimages=no flag is not optional on the build machine; the Application Control policy blocks native package images.

Appendix U — Every Uganda 2023 result table

Sixty-one tables, all in 08_Data/ with the uga23_ prefix, all written by uganda2023_analysis.jl. The list below is what each one is for.

Table	Rows	What it is
uga23_access_budget_sweep.csv	8	Access against eight budget levels
uga23_access_by_technology.csv	1	Access plan by technology
uga23_access_equity.csv	4	Grid access, urban and rural
uga23_access_plan.csv	60	The least-cost access plan by site
uga23_asset_base.csv	8	The revenue requirement, component by component
uga23_balance_residuals.csv	1	The energy balance residual
uga23_calibration.csv	9	Modelled against metered, plant group by group
uga23_capacity_by_carrier.csv	5	Installed capacity by carrier
uga23_carbon_sweep.csv	6	Six carbon prices
uga23_case_summary.csv	14	The case at a glance
uga23_cge_generation.csv	4	Generation by carrier for CDCGE PowerLink
uga23_cge_lcoe_path.csv	5	The LCOE path for the CGE productivity shock
uga23_climate_stress.csv	4	Four hydrological cases
uga23_cooking_carbon_sweep.csv	24	The portfolio at six carbon prices
uga23_cooking_plan.csv	4	The clean-cooking portfolio at a 50 % target
uga23_cooking_target_sweep.csv	7	Seven clean-cooking targets
uga23_cost_recovery.csv	5	What the tariff in force recovers
uga23_cost_stack.csv	8	Modelled cost against metered purchase cost
uga23_demand_path.csv	5	Energy, peak and load factor to 2040
uga23_diagnostics.csv	17	Row counts, missing values and duplicate keys
uga23_dispatch.csv	575	The full dispatch, unit by period
uga23_dispatch_indicators.csv	13	The thirteen dispatch indicators
uga23_distribution_by_region.csv	15	Losses by region
uga23_distribution_indicators.csv	8	The loss chain, summarised
uga23_distribution_waterfall.csv	9	Generation to collected energy
uga23_emissions_by_technology.csv	23	Emissions by unit
uga23_emissions_inventory.csv	23	The emissions inventory
uga23_energy_burden.csv	4	Energy burden by household group
uga23_energy_security.csv	3	Import dependence and days of cover
uga23_energy_to_macro.csv	13	The macro payload as the estate builds it
uga23_energy_to_macro_corrected.csv	4	The payload's price field, corrected
uga23_expansion_comparison.csv	13	The 2040 fleet under both runs
uga23_expansion_emissions.csv	4	Emissions by year under that plan
uga23_expansion_emissions_no_target.csv	4	Least-cost emissions
uga23_expansion_generation.csv	163	Generation by year under that plan
uga23_expansion_generation_no_target.csv	154	Least-cost generation
uga23_expansion_plan.csv	60	The build plan with an 85 % RE target
uga23_expansion_plan_no_target.csv	60	The least-cost build plan
uga23_expansion_unserved.csv	4	Unserved energy by year

Table	Rows	What it is
uga23_flows.csv	600	Corridor flows by period
uga23_fuel_balance.csv	3	The fuel accounts
uga23_fuel_disruption.csv	7	A 30 % oil import cut
uga23_generation_by_carrier.csv	4	Modelled generation by carrier
uga23_generation_by_unit.csv	23	Modelled generation, unit by unit
uga23_headline.csv	16	Sixteen headline indicators for the rebuilt case
uga23_household_subsidy_incidence.csv	4	Subsidy by household group
uga23_lcoe.csv	33	Levelized cost, existing and candidate
uga23_ldc.csv	25	The load-duration curve
uga23_merit_order.csv	23	The merit order
uga23_network_expansion.csv	24	Corridor reinforcement (all zero)
uga23_prices.csv	425	Nodal prices as exported
uga23_prices_corrected.csv	425	Nodal prices with the EN-20 correction
uga23_renewable_share_defect.csv	3	The renewable share, read two ways
uga23_subsidy_incidence.csv	6	Implicit subsidy by class
uga23_system_load.csv	25	Load and weight for each of the 25 periods
uga23_tariff_lifeline_sweep.csv	8	Eight lifeline discounts
uga23_tariff_poverty.csv	24	Welfare loss by group and tariff change
uga23_tariff_poverty_headline.csv	6	The tariff shock, summarised
uga23_tariff_sensitivity.csv	15	Cost recovery over asset base and return
uga23_tariffs.csv	6	The designed tariff by class
uga23_utility_finance.csv	7	The utility income statement

Table 189. Every Uganda 2023 result table.

U.1 The historical series

Eight further tables extract the historical record from the primary workbooks so that a learner can argue with the calibration year without opening a spreadsheet.

Table	What it is	Source
uga_load_2023_hourly.csv	8,760 metered hours: total demand, national demand, load shed, net export, generation	UETCL Annual Load Curves 2023
uga_substation_demand_2023.csv	295 distribution feeders aggregated to 21 substations	UETCL feeder register
uga_plant_monthly_2023.csv	Monthly generation for every plant and aggregate on the system	UETCL System Operation Data 2023
uga_sales_history.csv	Sales by class, 2010–2023	ERA IRP Data Sheet
uga_customers_history.csv	Customer numbers by class, 2010–2023	ERA IRP Data Sheet
uga_system_history.csv	Peak, sales and losses, 2010–2023	ERA IRP Data Sheet
uga_capacity_history.csv	Installed capacity by technology, 2011–2020	ERA licensing register
uga_monthly_peak.csv	Monthly peak split domestic and export, 2022–2024	UETCL Transmission Statistics
uga_network_history.csv	Transmission length by voltage and substation count, 2003–2024	UETCL Transmission Statistics
uga_tariff_history.csv	The end-user tariff by class and quarter, 2017–2024	ERA tariff schedules
uga_export_obligation.csv	The firm export obligation by period and border bus	derived from the metered curve

Table 190. The historical extract. Every one is written by 09_Code/Uganda2023/extract_history.py.