PATHFNDR Project
Calliope and Euro-Calliope
Stefan Pfenninger (TU Delft)
Calliope and Euro-Calliope

Calliope
www.callio.pe

A tool to build energy system models

Euro-Calliope
github.com/calliope-project/euro-calliope

Data and workflows to build models of the European energy system using Calliope
An example application: Continental or regional scale supply?

Regional supply: Regions self-supply on average over the year

Continental supply: Wind and PV at best locations

Continental supply requires 2.5x the capacity of today’s electricity transmission system

What if I don’t want to build so many new transmission lines?

Tröndle et al. (2020). Joule. https://doi.org/gg8zk2
Less integrated systems are possible, but cost more

Tröndle et al. (2020). *Joule*. https://doi.org/gg8zk2
Model used

Spatial resolution
497 first-level administrative units

Technologies
- PV
- Wind
- Biofuel
- Hydro
- Short and long-term storage

Temporal resolution
4 hours, single year, 2007–2016

Sensitivity analysis
- 10 weather years
- Uncertainty in technology costs, capital cost, bioenergy availability (by sampling a surrogate model)

Open-source and reproducible
Calliope code: [www.calliope.pe](http://www.calliope.pe)
Model/data: [github.com/calliope-project/euro-calliope](https://github.com/calliope-project/euro-calliope)

Tröndle et al. (2020). *Joule*. [https://doi.org/gg8zk2](https://doi.org/gg8zk2)
Purpose of Calliope

• A tool to build energy system optimisation models at any scale (urban to continental)
• Allow high resolution in time and space in order to adequately model renewables
• Human-readable models in the form of text files; Calliope translates these into a mathematical model and solves it
• Range of built-in functionality like time series aggregation, modelling to generate alternatives (MGA) algorithms, …
• 100% free and open-source

www.callio.pe
## Process: inputs and outputs for a typical Calliope model

### Model Inputs
- Model regions/locations and possible transport/transmission connections between them
- Demand, wind, PV, hydro generation time series
- Technologies including their performance parameters and costs
- Technology capacity constraints
- Policy constraints like emissions caps or renewable targets

### Model Outputs
- Technology capacities
- Investment and variable costs
- Emissions
- Technology operation decisions
- Energy transport and transmission decisions
- Storage levels
- Consumed resources

### Derived Outputs
- Capacity factors
- Levelised costs
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Calliope and Euro-Calliope

- **Input data (e.g. temperature, renewable generation)**
- **Euro-Calliope workflow**
- **Question-specific model of the European energy system**
- **Model** (=set of text files and data tables)
- **Data processing code** (=set of Python scripts and assumptions)

**Modelling software** (=command-line app written in Python)
User interface of Calliope

ccgt:
  essentials:
    name: 'Combined Cycle Gas Power Plant'
    color: '#FDC97D'
    parent: 'supply'
    carrier_out: 'electricity'
  constraints:
    resource: inf
    energy_cap_max: 400000 # kW
    energy_ramping: 0.8
  costs:
    monetary:
      energy_cap: 750 # USD per kW
      om_con: 0.02 # USD per kWh

NREL built an open-source web UI:
https://engage.nrel.gov/
We want to go beyond just electricity!

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Euro-Calliope v2.0 workflow

Research focus: trade-offs in building 100% renewable all-sector European energy system

- Electricity
- Household and commercial heat
- Passenger and freight transport
- Industry process heat and feedstocks (e.g. for chemicals)

Possible spatial configurations:
- 98 nodes based on transmission system
- All European countries
- Single country

Temporal resolution: 1 hour

The SENTINEL project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 837089.
Current models built with the Euro-Calliope 2.0 workflow

Euro-SPORES

Bryn Pickering

Based on Lombardi et al. (2020). Joule. https://doi.org/gg8z6v

ABBIE

Role of bioenergy

STAGES

UNIQUE ROLES

Supply

Enhancing energy security/diversity

Balancing intermittency

Decarbonizing aviation

Consumption

Post-treatment

Negative emissions

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie (MSC) grant agreement No. 847585.
Euro-Calliope and Calliope

**Euro-Calliope v2.0**

Full energy system (will be used in PATHFNDR)

**Euro-Calliope v1.0**

Electricity sector only

**Calliope**

A tool to build energy system models

www.callio.pe
Future development under the PATHFNDR project

- A model to assess pathways for Switzerland within the context of decisions taken Europe-wide

**Research & Development**

WP1: Pathways on a national and international scale

WP2: Pathways on a district and city scale

WP3: Technology and model development

WP4: Test market designs for existing technologies

WP5: Test new technologies for flexibility utilization

**Pilot & Demonstration**

WP10: Integration and Synthesis

**Management**

WP8: Management and Coordination

WP9: Knowledge and Technology Transfer

WP7: Policies for sector coupling and enhanced flexibility

WP6: Business opportunities and innovation strategies

WP5: Test new technologies for flexibility utilization

WP4: Test market designs for existing technologies

WP3: Technology and model development

WP2: Pathways on a district and city scale

WP1: Pathways on a national and international scale
Linkage to other tools of the PATHFNDR project

• Provide boundary conditions for the detailed modelling of the Swiss energy system with nexus-e

• Explore integration of operational constraints from the more detailed models, e.g. Ehub and ReMaP
Validation / calibration

- Input data is validated or checked, e.g. renewable generation data, cost data, ...

Renewables.ninja

- Calliope has extensive automated tests to ensure that the code does what we think it does

Azure DevOps

Validated renewable generation data

https://dev.azure.com/calliope-project/calliope/_build/results?buildId=242&view=results
Limitations - there are many!

- It is a (usually cost-minimising) linear/mixed-integer optimisation model, fed with a range of assumptions which may or may not be “correct”.

- It requires some technical flair to operate both Calliope and Euro-Calliope.

- It requires a high-performance computing cluster for its full capabilities.

- User must be aware of what it can and cannot do.

- Third-party graphical user interface (NREL) and we are working on accessibility for both Calliope and Euro-Calliope.

- We are working on model formulation and algorithm improvements to reduce computational needs.
Users

Current users:
• A range of academic and industrial users
• e.g. Imperial College London, University of Cambridge, University of Reading, University of Strathclyde, FZ Jülich, Politecnico di Milano, NREL, PBL, IASS Potsdam, ITA Brazil, University of Lisboa, …
• Major energy companies and engineering consulting firms

Potential users:
• Quite a few
Licenses: everything is free and open-source

Input data (e.g. temperature, renewable generation) with a few exceptions, open data

Euro-Calliope workflow

Question-specific model of the European energy system

Calliope software

Apache 2.0 license:

github.com/calliope-project/calliope

e.g. Tröndle et al. 2020, Creative Commons CC-BY license:

doi.org/10.5281/zenodo.3949552

MIT license:

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