The Journal of Open Source Software

Calliope: a multi-scale energy systems modelling framework

Stefan Pfenninger[1] **and Bryn Pickering**[2]

1 Department of Environmental Systems Science, ETH Zürich **2** Department of Engineering, University of Cambridge

DOI: 10.21105/joss.00712

Software

- Review
- Repository
- Archive

Submitted: 30 April 2018
Published: 02 May 2018

Summary

Energy system models create coherent quantitative descriptions of how energy is converted, transported, and consumed, at scales ranging from urban districts to entire continents. Formulating such models as optimisation problems allows a modeller to asses the effect of constraints, such as limited land availability for wind power deployment, the cost of battery electricity storage, or the elimination of fossil fuels from a country or a city, on the feasibility or cost of the modelled system. These models are particularly important in planning and policy-making for the transformation of the global energy system to address climate change.

Calliope is a framework to build energy system models, designed to analyse systems with arbitrarily high spatial and temporal resolution, with a scale-agnostic mathematical formulation permitting analyses ranging from single urban districts to countries and continents. Its formulation of energy system components was influenced by the power nodes modelling framework by Heussen et al. (Heussen et al. 2010), but generalised to consider energy carriers other than electricity. Calliope's key features include the ability to handle high spatial and temporal resolution and to easily run on high-performance computing systems. Its design cleanly separates the general framework (code) from the problem-specific model (data). It provides both a command-line interface and an API for programmatic use, to be useful both for users experienced with Python and those with no Python knowledge.

A Calliope model consists of a collection of `YAML` and `CSV` files that define technologies, locations, links between locations, resource potentials, and other constraints. Calliope takes these files, constructs an optimisation problem, solves it, and reports results in the form of `xarray` (xarray 2018) Datasets, which can easily be saved to NetCDF files for further processing. It uses Pyomo (Pyomo 2018) as a backend to interface with both open and commercial solvers, currently handling linear and mixed-integer problems, although nonlinear components could be implemented if necessary for new kinds of problems. Calliope's built-in tools allow interactive exploration of results using Plotly (Plotly 2018), as shown in the Figure below.

Calliope has been used in various studies, for example, analyses of the national-scale power systems in Britain (Pfenninger and Keirstead 2015) and South Africa (Pfenninger and Keirstead 2015), and in methodological development for piecewise linearisation of characteristic technology performance curves for district-scale energy system analysis (Pickering and Choudhary 2017). Ongoing research projects using Calliope include the effect of increased resilience to uncertain future demand and the interaction between local and national actors in the clean energy transition.

Calliope is developed in the open on GitHub (Pfenninger and Pickering 2018) and each release is archived on Zenodo (Pfenninger and Pickering, n.d.).

The Journal of Open Source Software

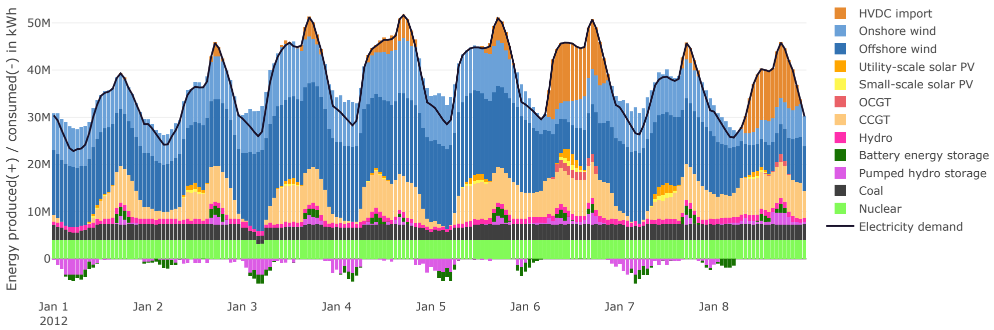

Figure 1: Example time series visualisation of aggregated generation decisions at hourly time scale from a national-scale model of the UK power system, created with the Plotly-based visualisation tools in Calliope.

Acknowledgements

The authors acknowledge funding via the European Research Council (grant StG 2012-313553), the Grantham Institute for Climate Change at Imperial College London, and the Engineering and Physical Sciences Research Council (ref EP/L016095/1).

References

Heussen, Kai, Stephan Koch, Andreas Ulbig, and Göran Andersson. 2010. "Energy Storage in Power System Operation: The Power Nodes Modeling Framework." In *Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES*, 1–8. https://doi.org/10.1109/ISGTEUROPE.2010.5638865.

Pfenninger, Stefan, and James Keirstead. 2015. "Renewables, Nuclear, or Fossil Fuels? Scenarios for Great Britain's Power System Considering Costs, Emissions and Import Dependency." *Applied Energy* 152:83–93. https://doi.org/10.1016/j.apenergy.2015.04.102.

Pfenninger, Stefan, and Bryn Pickering. 2018. "Calliope." 2018. https://github.com/calliope-project/calliope.

———. n.d. "Calliope." https://doi.org/10.5281/zenodo.593292. https://doi.org/10.5281/zenodo.593292.

Pickering, Bryn, and Ruchi Choudhary. 2017. "Applying Piecewise Linear Characteristic Curves in District Energy Optimisation." In *Proceedings of the 30th Ecos Conference, San Diego, ca, 2-6 July 2017*. https://www.researchgate.net/publication/319334427_Applying_Piecewise_Linear_Characteristic_Curves_in_District_Energy_Optimisation.

Plotly. 2018. "Plotly - Modern Visualization for the Data Era." 2018. https://plot.ly/.

Pyomo. 2018. "Pyomo - Flexible Modeling of Optimization Problems in Python." 2018. https://www.pyomo.org/.

xarray. 2018. "Xarray: N-d Labeled Arrays and Datasets in Python." 2018. https://xarray.pydata.org/en/stable/.