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Energy hub optimization framework based on open-source: review of frameworks and concept for districts & industrial parks

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Agenda

- Importance and aim of “Energy System Integration“
- Energy Hub
- Open Source
- Methodology
- Preliminary results (suggested framework)
- Summary & next steps

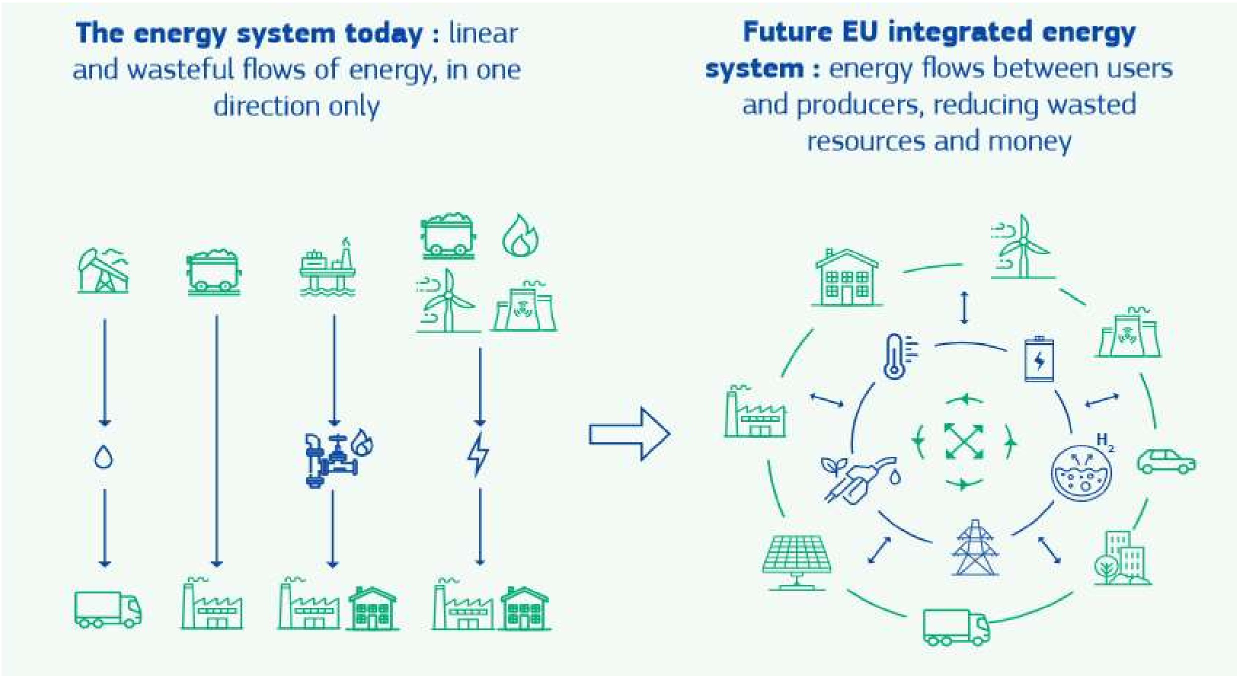
Intro (EU Energy System Integration Strategy / #EUGreenDeal)

<u>Integrated EU Energy System will have:</u>

- A more **efficient and "circular" system**, where waste energy is captured and re-used
- A **cleaner power system**, with more direct electrification of end-use sectors such as industry, heating of buildings and transport.
- A **cleaner fuel system**, for hard-to-electrify sectors like heavy industry or transport

→ **Covers all scales of energy customers**, e.g., countries, municipalities, districts, cities, and residentials.

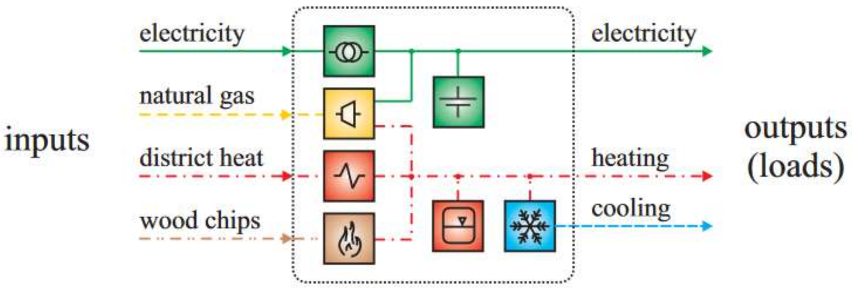
→ **Focus:** districts & industrial parks

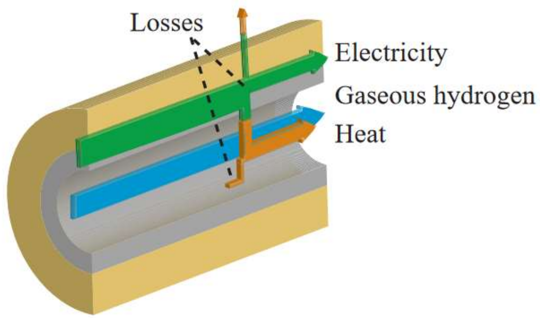


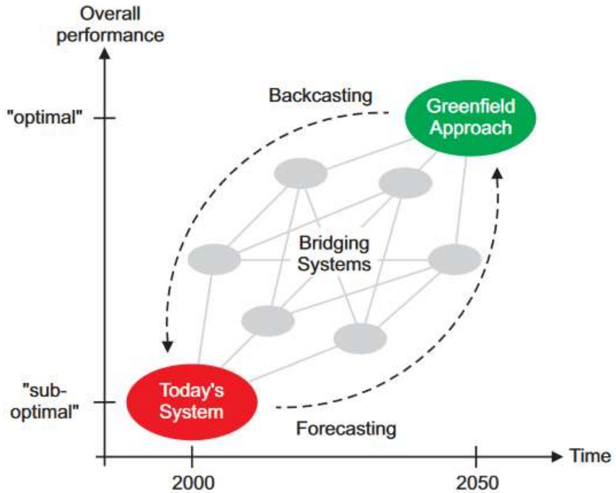
Source: EC (2020) EU strategy on energy system integration [online], European Commission. Available from: https://ec.europa.eu/energy/topics/energy-system-integration/eu-strategy-energy-system-integration_en

Energy Hub

- Definition: “**unit where multiple energy carriers can be converted, conditioned, and stored**"
- **Energy interconnector** able to transport/exchange multiple energy carriers
- Research question defines **energy hubs coverage**:
  - house, district, city, region, country
  - greenfield, brownfield retrofit
  - with or without transmission and/or distribution constraints







Source: Geidl et al. (2007) The energy hub - a powerful concept for future energy systems [online], Third annual Carnegie Mellon Conference on the Electricity Industry. Pittsburgh. Available from: https://research.ece.cmu.edu/~electricityconference/2007/2007%20Conf%20Papers/Andersson%20Paper%20final.pdf

Open Source - From Closed/Proprietary Source

Why they are (mostly) not open?

- **Concerns** (ethical, security, and/or commercial)
- **Unwanted exposure** (e.g., flawed code, data, or analysis)
- **Time-consuming** (write code, verifying code, documentation, manage feature requests)
- **Competitive advantage**
- Institutional and **personal** and **institutional inertia**

Why they should be open?

- **Improved quality** (e.g., transparency, peer review)
- More effective **collaboration**
- **Governments model for numbers** (not insight)
- **Collaboratively developed datasets and models** able to be shared across academia, governments
- Increased **productivity** through burden sharing [coding, data collecting, assessing, verifying]
- **Research** only matters if it is **seen and used**
- Balanced societal and political debate requires **transparent arguments**
- **Ethical argument**: research funded by public money should be available to the public

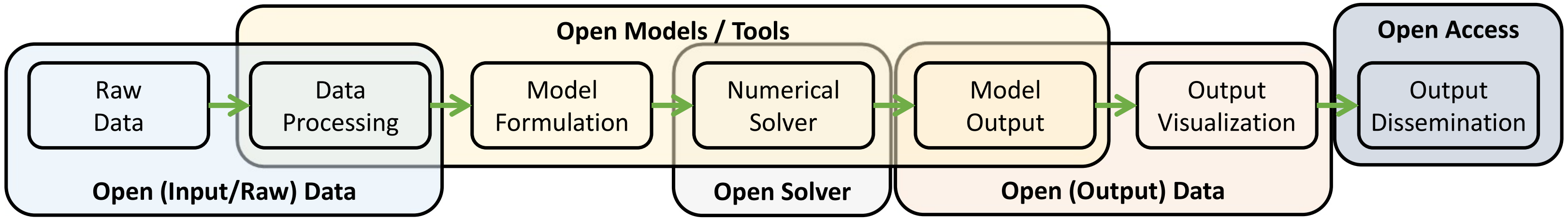
What needs to be done?

- **Incentivize open and transparent research**
- **Reducing parallel efforts and duplication of work** (e.g., common code bases, common datasets, community standards, coordinated verification)
- **Increase transparency, reproducibility**
- **Bring aboard different stakeholders**

→ EU Open Data Directive (EU) *2019/1024* enforced Jul. '19 (implemented until Jul. '21)

Source: EU (2016) SETIS Magazine November 2016 - Energy Systems Modelling [online], European Commission. Available from https://setis.ec.europa.eu/
EU (2019) Directive (EU) 2019/1024 on open data and the re-use of public sector information [online]. Available from http://data.europa.eu/eli/dir/2019/1024/oj
Wikipedia (2020) Open Source [online]. Available from https://de.wikipedia.org/wiki/Open_Source

Open Source - some initiatives



Examples	Raw Data	Data Processing	Model Formulation	Numerical Solver	Model Output	Output Visualization	Output Dissemination
Open Energy Modelling Initiative openmod-initiative.org/							
Energy Modelling Platform Europe www.energymodellingplatform.eu							
Open Power System Data open-power-system-data.org/							
Open Source for the OR Community www.coin-or.org/							
Open Street Map www.openstreet.org	streets, buildings, power lines, pipelines						
This work – link existing work framework to be shared via zenodo.org	FTP, API	python	pyomo-based models www.pyomo.org	NEOS neos-server.org			OA journals, arXiv, figshare, dryad, zenodo

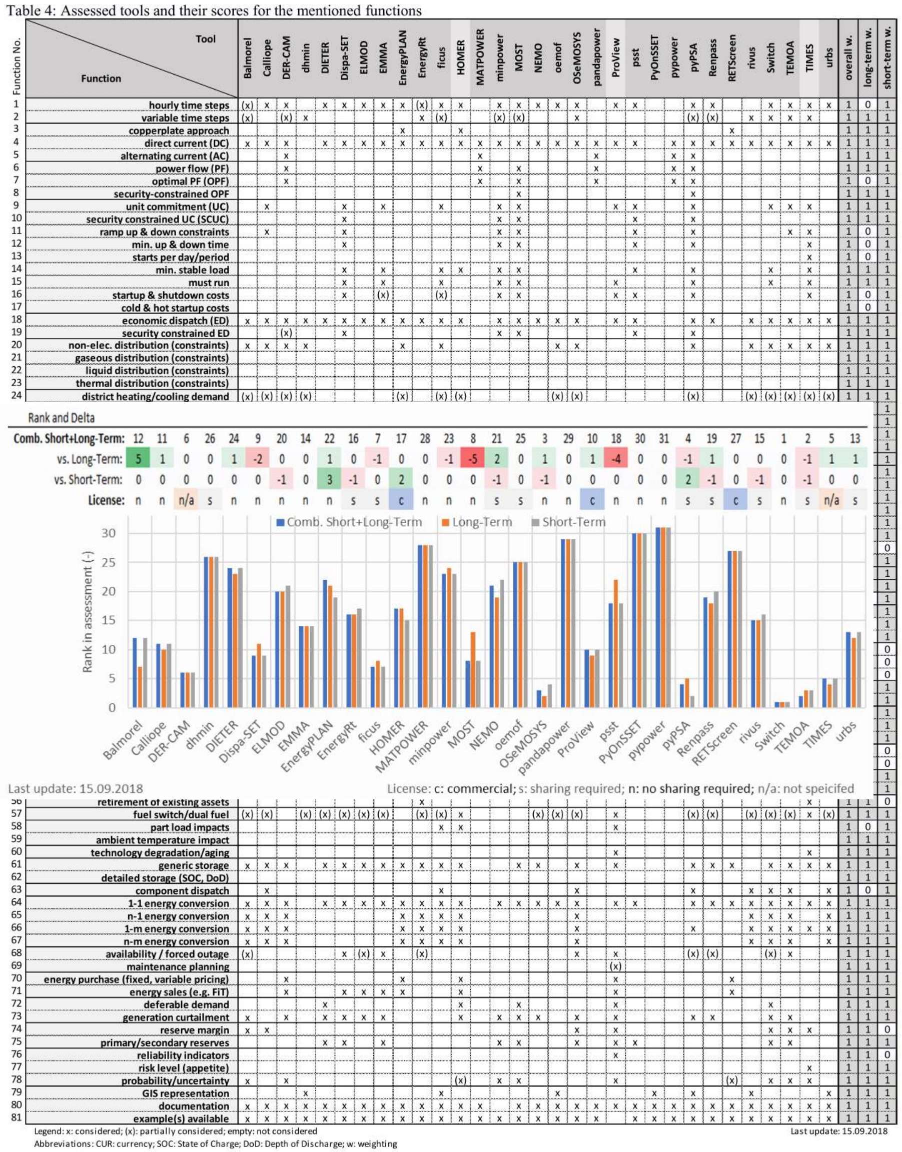
Sources: BMWI (2018) Open Data for Electricity Modeling - An assessment of input data for modeling the European electricity system regarding legal and technical usability [online]. Available from https://www.bmwi.de/Redaktion/EN/Publikationen/Studien/open-Data-for-electricity-modeling.html
nature (2020) Recommended Data Repositories [online]. Available from: https://www.nature.com/sdata/policies/repositories#physics

Color codes:
Focus of initiative
Link existing work

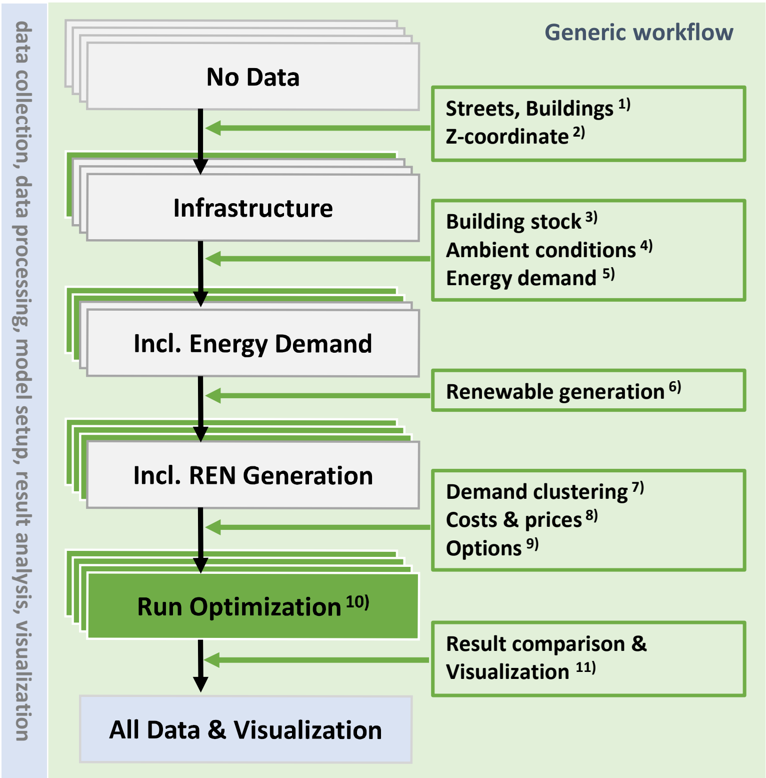
Methodology

- **Detailed assessment of 31** (>90% open-source) **tools**:
  ~1/2 Python, ~1/4 GAMS, Executable, R, Matlab/Octave
- Oldest tools are >20 years (by age: RETscreen, EnergyPlan, Balmorel)
- **Majority is ≤ 5 years** (alphabetical order: DIETER, EnergyRT, ficus, MOST, oemof, pandapower, psst, PyONSSET, pyPSA, Renpass,, Switch)
- **Assessed** 12 **'applications**' (e.g., geographical scope, consider energy carriers, open source, optimization or simulation)
- **Assessed** 81 **'functions**' differentiated in required for long-term and/or short-term functions (e.g., variable time steps, copperplate, DC, AC, SCOPF, SCUC, SCED, perfect foresight/rolling horizon, multi-area, multi-year, VOM, FOM, SOC, DSM, examples)
- **Top open source tools**: Switch, TEMOA, OSeMOSYS, pyPSA
- **Still missing**: e.g., additional functionality such as impact of ambient air conditions, part-load behavior, redundancy considerations

Source: Groissböck (2019) Are open source energy system optimization tools mature enough for serious use?, *Renewable and Sustainable Energy Reviews*, 102, pp. 234-248, DOI:10.1016/j.rser.2018.11.020.



Methodology



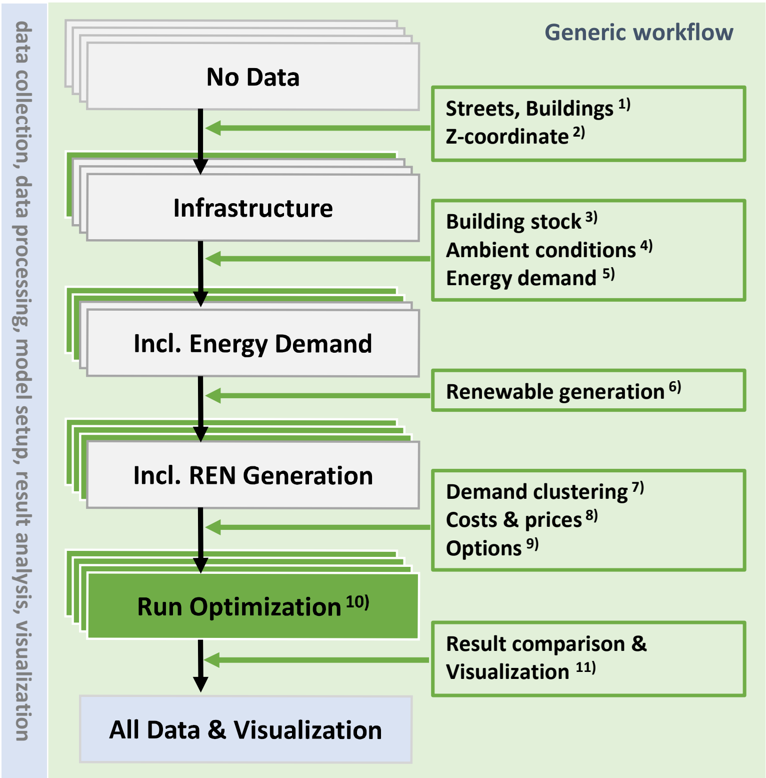
Comments and possible open source data and tools

1. openstreetmap.org/export | github.com/RWTH-EBC/uesgraphs | github.com/gboeing/osmnx
2. **elevation/sea level detail*** | github.com/aatishnn/srtm-python | dwtkns.com/srtm30m/ | srtm.csi.cgiar.org/srtmdata/ | ec.europa.eu/jrc/en/pvgis
3. episcope.eu | entranze.enerdata.eu
4. historical weather | gmao.gsfc.nasa.gov/reanalysis/MERRA-2/ | open-power-system-data.org | ec.europa.eu/jrc/en/pvgis
5. historical demand or weather from 4. | github.com/RWTH-EBC/TEASER | github.com/oemof/demandlib | github.com/RWTH-EBC/richardsonpy | energyplus.net | openmodelica.org
   shading through other objects* (e.g., mountains) | github.com/bwinkel/pycraf | land.copernicus.eu/imagery-in-situ/eu-dem/
6. building shelf from 5., weather from 4.
   shading through other objects* (e.g., mountains) | open-power-system-data.org | github.com/pvlib/pvlib-python | github.com/wind-python/windpowerlib
7. **w/ daily profiles***
8. technology costs | pypsa-eur.readthedocs.io/en/latest/costs.html
9. w/o and w/ **elevation***
   w/o and w/ **impact of elevation on ambient***
   demand clustering
   technology options* (e.g., PV, STE, PVT; biomass for PtX/synfuels)
   building details* (e.g., U/g/A/%window/wall height, roof angle)
   regional or per building shading*
10. github.com/PyPSA | github.com/tum-ens/urbs | github.com/oemof
11. github.com/oemof | github.com/architecture-building-systems

* own contribution/development

Abbreviations: PV – Photovoltaic; STE - Solar Thermal Energy; PVT - hybrid PV-STE; LoD - Levels-of-Detail;

Preliminary results

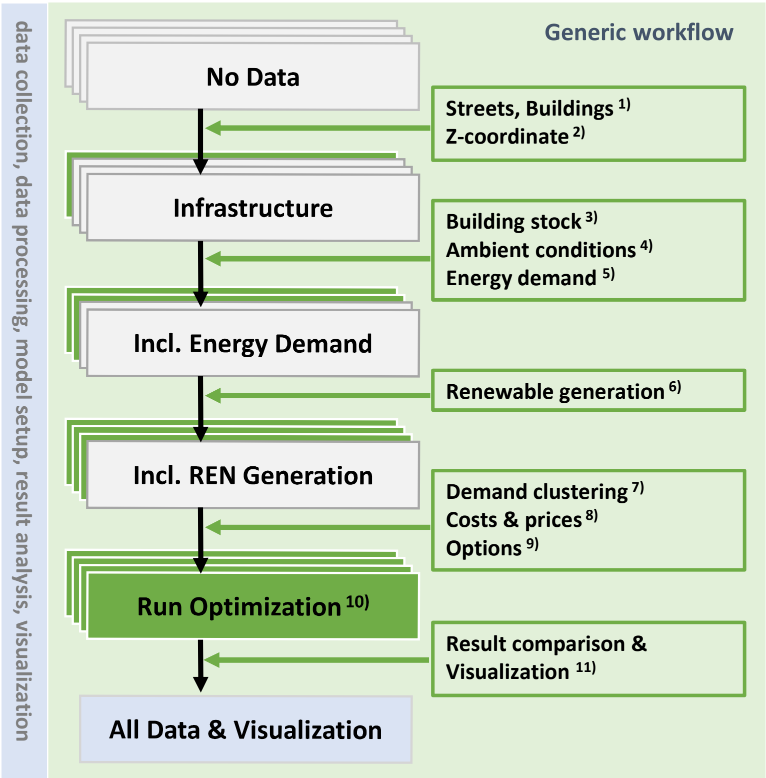


	* Spatial focus:	≥ State	≤ City	≥ State	≥ State	≤ City	≤ City
		github.com/ FZJ-IEK3-VSA	github.com/ RWTH-EBC	gitub.com/ oemof	gitub.com/ pyPSA	gitub.com/ tum-ens	github.com/ architecture-building-systems
1	Streets, buildings, Land use, District heating, Power, Gas, oil, biomass	n/a n/a n/a n/a n/a	n/a n/a n/a n/a n/a	n/a n/a n/a n/a n/a	n/a n/a n/a bdw/GridKit (!) n/a	n/a pyGRETA n/a n/a n/a	CEA CEA CEA CEA n/a
2	Z-coordinate	n/a	n/a	n/a	n/a	n/a	CEA
3	Building stock	tsib (for EU)	TEASER (for EU)	tabular (for EU)	n/a	n/a	CEA (for CH)
4	Historical ambient conditions	tsib (TRY, TMY, ISO 12831)	pyCity (TRY, TMY)	feedinlib.era5	n/a	n/a	E+ weather files (epw)
5	Energy demand	tsib, tsorb:occupation	pyCity:occupancy, TEASER, AixLib, IBPSA	demandlib	n/a	n/a	CEA
6	Renewable profile	RESKit, windtools	pyCity	feedinlib	Atlite	pyGRETA	CEA
7	Demand Clustering	tsam	pyCity	solph	pyPSA	pyCLARA	n/a
8	Cost & prices, …	n/a	n/a	n/a	Collection (e.g., DEA, DIW, IEA)	n/a	CEA
10	Optimization	FINE	pyCity	solph	pyPSA	pyPRIMA	CEA
	Solvers abstraction	any local (pyomo)	tbd	any local (pyomo)	any local (pyomo)	any local (pyomo)	Gurobi, GA
11	Visualization	n/a	n/a	OEDB	n/a	n/a	n/a
	Design for addition	n/a	n/a	yes	yes	n/a	n/a
	Additional features	• n/a	• n/a	• visio • oemof.db	• nomopyomo (cbc, gurobi)	• n/a	• GUI
	Contributors:	FZJ	EBC	RLI, FHF	KIT, FIAS	TUM	ETHZ

* *Spatial focus*: Households, District, City, State, Region, Country, Continent, World

Abbreviations: FZJ: Forschungszentrum Jülich, EBC: RWTH Aachen, E.ON EBC, RLI: Reiner Lemoine Institute, FHF: FH-Flensburg, KIT: Karlsruhe Institute of Technology, FIAS: Frankfurt Institute for Advanced Studies, TUM: Technical University of Munich, ETHZ: Eidgenössische Technische Hochschule Zürich

Preliminary results

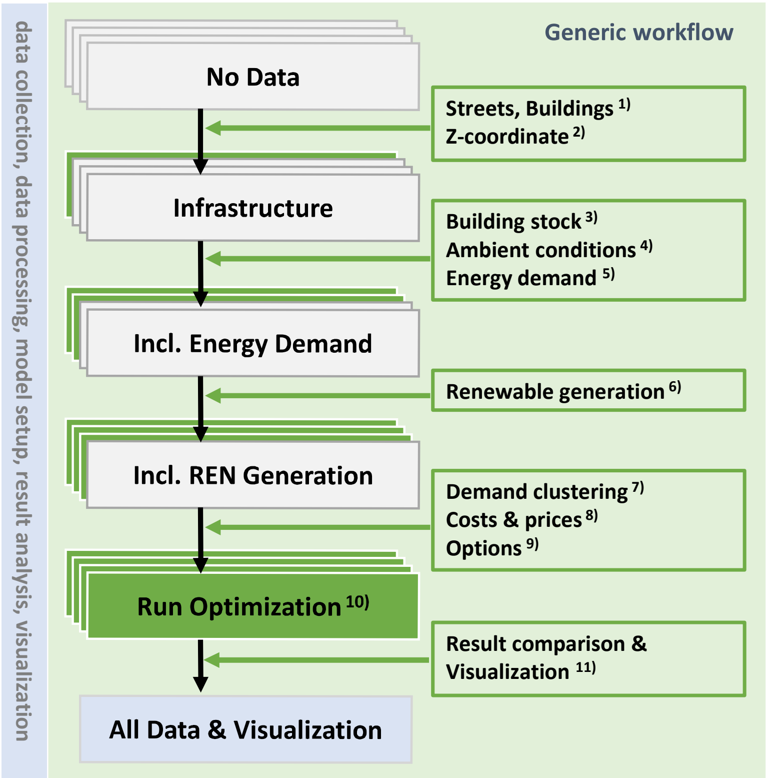


*** Spatial focus:** **≤ City & Industry**

		open data & open source	Done?
1	Streets, buildings, Land use, District heating, Power, Gas, oil, biomass	osmnx osmnx n/a - osmnx n/a - osmnx n/a - osmnx	yes yes yes yes yes
2	Z-coordinate	pycraf, **tkrajina/srtm.py**	yes
3	Building stock	tsib, TEASER, tabular	yes
4	Historical ambient conditions	OPSD/weather_data (MERRA2)	yes
5	Energy demand	pyCity.occupation, **CEA/RC_BldgSimulator**	yes
6	Renewable profile	pvlib, windlib, Solar3Dcity **(w/ horizon)**	no
7	Demand Clustering	**clustering time**, spatial (tsam)	yes
8	Cost & prices, …	technology options (**economy of scale**)	yes
10	Optimization	pyPRIMA: urbs, evrys, **solph, pyPSA**	no
	Solvers (solver abstraction)	any local (pyomo), **incl. NEOS ****	yes
11	Visualization, comparison	OpenEnergy DB (OEDB)	no
	Additional features	**pyPSA: market & reserve margin | multi-modal demand clustering** **elevation tkrajina/srtm.py** | **emissions (LCA, QELD)** | **heat/cold islands** **technology options (e.g., PV, STE, PVT; biomass for PtX/synfuels)** **building details (e.g., U/g/A/%window/wall height, roof angle)** | **regional or per building shading**	yes yes yes Yes

* *Spatial focus*: Households, District, City, State, Region, Country, Continent, World | ** NEOS: free internet-based service (neos-server.org).
Abbreviations: PV: Photovoltaic; STE: Solar Thermal Energy, PVT: hybrid PV-STE | Remark: **bold marks own contribution**

Summary & Next steps



- Review of existing based on open-source frameworks
- Outlined a complete energy hub optimization framework
- Implemented draft version of framework (shared after thorough test):
  doi.org/10.5281/4048520 or zenodo.com/record/4048520
- Framework tests/verification is ongoing
- Next: apply framework (demonstration village)
- Possible framework enhancements:
  - assess additional models/projects?
    e.g., Switch Model 2.0, FlexiGIS, IBPSA Project 1
  - use/extend 3D City DB schema?

The CityGML Database
3D City DB

Source: Alhamwi et al. (2018) FlexiGIS: an open source GIS-based platform for the optimisation of flexibility options in urban energy systems, Energy Procedia, 152, pp. 941-946, DOI: 10.1016/j.egypro.2018.09.097.
Johnston et al. (2019) Switch 2.0: A modern platform for planning high-renewable power systems, *SoftwareX*, 10, pp. 100251, DOI:10.1016/j.softx.2019.100251.
IBPSA Project 1 (2017) BIM/GIS and Modelica Framework for building and community energy system design and operation [online]. Available from: https://ibpsa.github.io/project1/

Q&A

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Presentation (and framework once available): www.doi.org/10.5281/4048520 or www.zenodo.com/record/4048520

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