Open Source Energy Models – Current Status and Outlook on Multi-sector Modelling

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Agenda

- Introduction
- Open Energy Data
- Open Energy Models
- Sector Coupling
- Summary and Outlook

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Energy System Modelling at FH OÖ

Project: Multidisciplinary simulation model of the European electricity industry

- **Aim:** Development of a comprehensive technical and economic simulation model of the European electricity industry
- Model generation, grid, consumption and prices
- The model allows the study of different scenarios:
  - Policy measures (e.g. addition of renewables, e-mobility)
  - Effects on Europe and Austria
  - Sector coupling
- Analysis of multiple open source frameworks, models and databases

Development of Energy System Modelling

- Global transition towards sustainable energy systems:
  - Requires development of alternative future energy scenarios
  - Leads to increasing complexity due to cross-sectoral and decentralized structures
  - Requires more scientific efforts and collaboration in energy modelling
- Open source, open access and data transparency represent a major trend in energy system modelling
- Can contribute to improve model-based analysis of future energy systems
- History of open energy modelling:
  - 2001: release of the Balmorel model
  - 2009: release of the OSeMOSYS modelling framework
  - 2010: release of the TEMOA modelling framework
  - 2014: foundation of the Open Energy Modelling Initiative by a group of modellers to better coordinate further developments of open models and data

Reasoning for Open Data and Open Code

Why data and code are mostly not open

- Property rights and security constraints, particularly in the case of data
- Unwanted exposure
- Time-consuming
- Unsuitable institutional structures

Why data and code should be open

- Improved quality of science
- More effective collaboration
- Increased productivity through burden sharing
- Profound relevance to societal debates

(Pfenninger et al., 2017)

Licensing of Open Data and Open Code

Restrictive ↑ … ↓ Open

		Open Data	Open Code	Open Access
COPYLEFT	Require derivative work to be shared under the same or a compatible licence.	ODbL	GPL AGPL	CC BY SA
PERMISSIVE	Generally allow all re-use, including integration into closed-source projects. Stipulate some limited requirements, e.g. attribution.	CC BY	ISC MIT BSC Apache	CC BY
PUBLIC DOMAIN	Allow sharing, modification, and use for any purpose and without any restrictions. Intended for use on databases or their contents.	PDDL CC0	CC0	CC0

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Open Data Categories in the Energy Sector

Demand
- Electricity demand
- Thermal demand
- Transport demand
- Industrial demand

Resources and Potentials
- Weather data and availability of renewable energy
- Wind geographical potentials
- Biomass potentials
- Hydroelectricity potentials

Networks
- Electricity transmission network datasets
- Electricity distribution network datasets
- Gas network datasets

Generation Technologies
- Power plants
- Generation technology assumptions and projections
- Storage technology assumptions and projections
- End-use technology assumptions and projections

General Data
- Demographic and socio-economic data
- Environmental data and regulations
- Historical data and profiles
- Energy scenarios
- Country-specific targets and policies

Open Data Projects for the Energy Sector

Project Name	Type of Data	Spatial Coverage	Data License
Renewables.ninja	Hourly PV and wind generation data	Worldwide	CC BY-NC 4.0
OpenGridMap	Electricity grid data	Worldwide	CC BY 3.0
Open Energy Database (oedb)	Energy system modelling data	Worldwide	Various (CC BY, CC0)
Open Power System Data (OPSD)	Power system data	Europe	Various (CC BY, CC0)
SMARD	Hourly generation, consumption, price and balancing data	Germany, Austria, Luxembourg	CC BY 4.0

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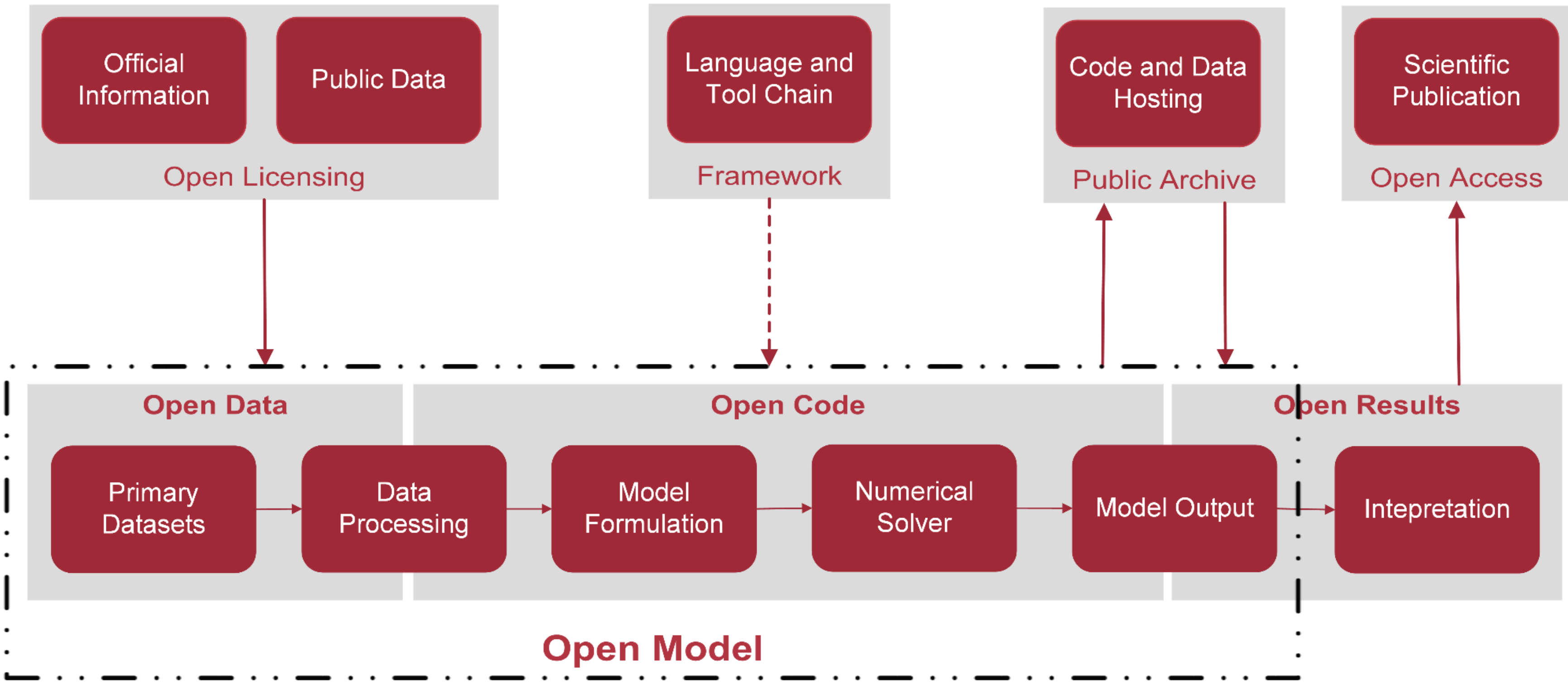
Open Modelling Pipeline



Framework: provides the structure for a model
Model: include data and assumptions

(Morrison, 2018)

Examples for Open Frameworks

Name	Description	Language	License
OSeMOSYS	Open source modelling system for long-run integrated assessment and energy planning	MathProg, GAMS, Python	Apache 2.0
PyPSA	Free software toolbox for simulating and optimising modern electrical power systems over multiple periods	Python	GPLv3
calliope	Linear programming framework for spatial–temporal energy system optimisation	Python	Apache 2.0
oemof	Modular open source framework to model energy supply systems	Python	GPLv3
MESSAGEix	Versatile, open-source, dynamic systems-optimisation modelling framework	GAMS, Python, R	Apache 2.0

Examples for Open Frameworks

OSeMOSYS
Open Source Energy Modelling System

- **Most relevant Models using OSeMOSYS:**
  - OSeMBE (The Open Source Energy Model Base for the EU)
  - SAMBA (South America Model Base)
  - GENeSYS-MOD (Global Energy System Model)

- **Class:** energy modelling system
- **Sectors:** power, gas, heat, transport
- **Technologies:** renewable and conventional generation, CHP
- **Network coverage:** transmission, distribution

- **Type:** optimisation
- **Objective:** minimisation total discounted costs of system

Examples for Open Frameworks

PyPSA: Python for Power System Analysis

- **Most relevant Models using PyPSA:**
  - PyPSA-Eur (Model of the European Transmission System)
  - PyPSA-Eur-Sec-30 (Sector-coupled Energy Model of Europe)
  - PyPSA-ZA (Model of the South African Energy System)

- **Class:** energy modelling system
- **Sectors:** power, gas, heat, transport
- **Technologies:** renewable and conventional generation, CHP
- **Network coverage:** transmission, distribution, AC and DC load flow, NTC
- **Type:** optimisation, simulation
- **Objective:** cost minimisation

Examples for Open Models

Name	Description	Framework	Regions	Language	License
GENeSYS-MOD	Uses a system of linear equations of the energy system to search for lowest-cost solutions for a secure energy supply, given externally defined constraints, mainly in terms of CO2-emissions.	OSeMOSYS	Worldwide	GAMS	Apache 2.0
PyPSA-Eur-Sec-30	Uses linear optimisation to minimise annual operational and investment costs subject to technical and physical constraints.	PyPSA	Europe	Python	GPLv3
PyPSA-Eur	An open model dataset of the European power system at the transmission network level that covers the full ENTSO-E area.	PyPSA	Europe	Python	GPLv3
Balmorel	Bottom-up partial equilibrium energy system optimisation model with a special focus on electricity and district heating sectors.	-	Nordic and Baltic countries	GAMS	ISC
Dispa-SET	Open-source unit commitment and optimal dispatch model focused on the balancing and flexibility problems in European grids	-	Europe	GAMS, Python	EUPL v1.2

GENeSYS-MOD

Main Characteristics

- Methodology: Linear optimisation
- Approach: Bottom-up
- Objective: Minimising the total costs of supply
- Constraints: Environmental
- Geographical resolution: Worldwide (10 regions)
- Temporal resolution: 6 slices (3 seasons, day/night)
- Baseline: 2015
- Sectors: Power, heat, transport
- Network representation: NTC
- Scenario: CO_2-budget of 650 Gt for 2015 to 2050

PyPSA-Eur-Sec-30

Main Characteristics

- Methodology: Linear optimisation
- Approach: Bottom-up
- Objective: Minimising annual operation and investment costs
- Constraints: Technical, physical
- Geographical resolution: Europe (30 countries)
- Temporal resolution: Hourly
- Baseline: 2011
- Sectors: Power, heat, gas, transport
- Network representation: NTC
- Scenario: 95% reduction in CO_2 emissions compared to 1990

Balmorel – Base model

Main Characteristics

- Methodology: Linear optimisation
- Approach: Bottom-up
- Objective: Maximising social welfare
- Constraints: Technical, physical, regulatory
- Geographical resolution: Nordic and Baltic countries
- Temporal resolution: Hourly/Aggregate
- Sectors: Power, heat
- Network representation: NTC
- Scenario: User-defined

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Sector Coupling and Energy Modelling

- Fluctuating generation from wind and PV can lead to supply surplus during certain time periods
- Surplus needs to be stored for later consumption
- Increasing share of RES-E requires more storage capacity to absorb surplus in generation
- Storage capacity in electrical power systems might not be sufficient
- Conversion of power-to-X (Sector Coupling) can be a potential solution, bringing flexibility
- Multi-sector Energy System Models can be used to analysis different Sector Coupling approaches and strategies

Overview frameworks and models for Sector Coupling

- All frameworks analysed are capable of modelling all energy sectors and interactions between them
- But current models
  - Do not cover all sectors (mostly because of lack of data)
  - Cover sectors just at high level (aggregation, e.g. one node per country)

Model	Power	Heat	Gas	Transport	Sector Coupling
Balmorel	x	x			x
GENeSYS-MOD	x	x		x	x
PyPSA-Eur	x				
PyPSA-Eur-Sec-30	x	x	x	x	x
Dispa-SET	x				

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Open Data for Sector Coupling
Gas

Source	Type of data	Temporal resolution	Regions	Year	Data license
ENTSO-G	Demand history, outlook	Yearly	EU27	2007-2020	Not explicitly specified
Eurostat	supply, import, export	Monthly	EU28	2014-2018	Various but most often CC BY
ENTSO-G	Technical and commercial	Hourly, daily	EU	2007-2019	Not explicitly specified
AGSI+	Storage data	Hourly	EU	2011-2019	Not explicitly specified
GIE	Storage database	-	Incl. Europe	2016, 2018	Not explicitly specified
ENTSO-G	Transmission capacity	-	EU	2010-2017	Not explicitly specified

Open Data for Sector Coupling Thermal Demand

Source	Type of data	Temporal resolution	Regions	Year	Sector	Data license
Austrian Heat Map	Space heating and cooling	Yearly	Austria LAU2	2012	-	Not explicitly specified
Hotmaps	Heating	Hourly*	EU28 NUTS2	2010	Residential Tertiary	CC BY
Hotmaps	Heating	Hourly*	EU28 NUTS2	2018	Industry	CC BY
Hotmaps	Space heating and hot water	Hourly*	EU28 NUTS2	2010	Residential	CC BY
Hotmaps	Hot water	Hourly*	EU28 NUTS2	2010	Tertiary	CC BY
Hotmaps	Cooling	Hourly*	EU28 NUTS2	2010	Residential Tertiary	CC BY

* Generated out of a generic data

Open Data for Sector Coupling
District Heating Network

Project name	Type of data	Spatial coverage	Year	Data license
Austrian Heat Map	Location, connected buildings, connected living quarters	Austria	2001	Not explicitly specified
Austrian Heat Map	Location, Operator, Fuel, rated power (thermal + electrical)	Austria	2018	Not explicitly specified

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Summary and Outlook

- Open energy system modelling comes with many benefits:
  - Increases the quality of research
  - Reduces duplication of work
  - Increases credibility and legitimacy
  - Provides transparency
- Analysed sector coupling studies have either focused on just a few demand sectors, or sacrificed spatial or temporal resolution
- Despite significant contributions to date, there remains a number of key challenges:
  - Awareness of data and code licensing
  - More detailed modelling of multi-sector coupling
  - Comparable data for all sectors (time and geographical resolution, quality)

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