Techno-Economic Assessment of Transition Pathways to Low-Carbon Technologies

Ndaona Chokani
ETH Zürich

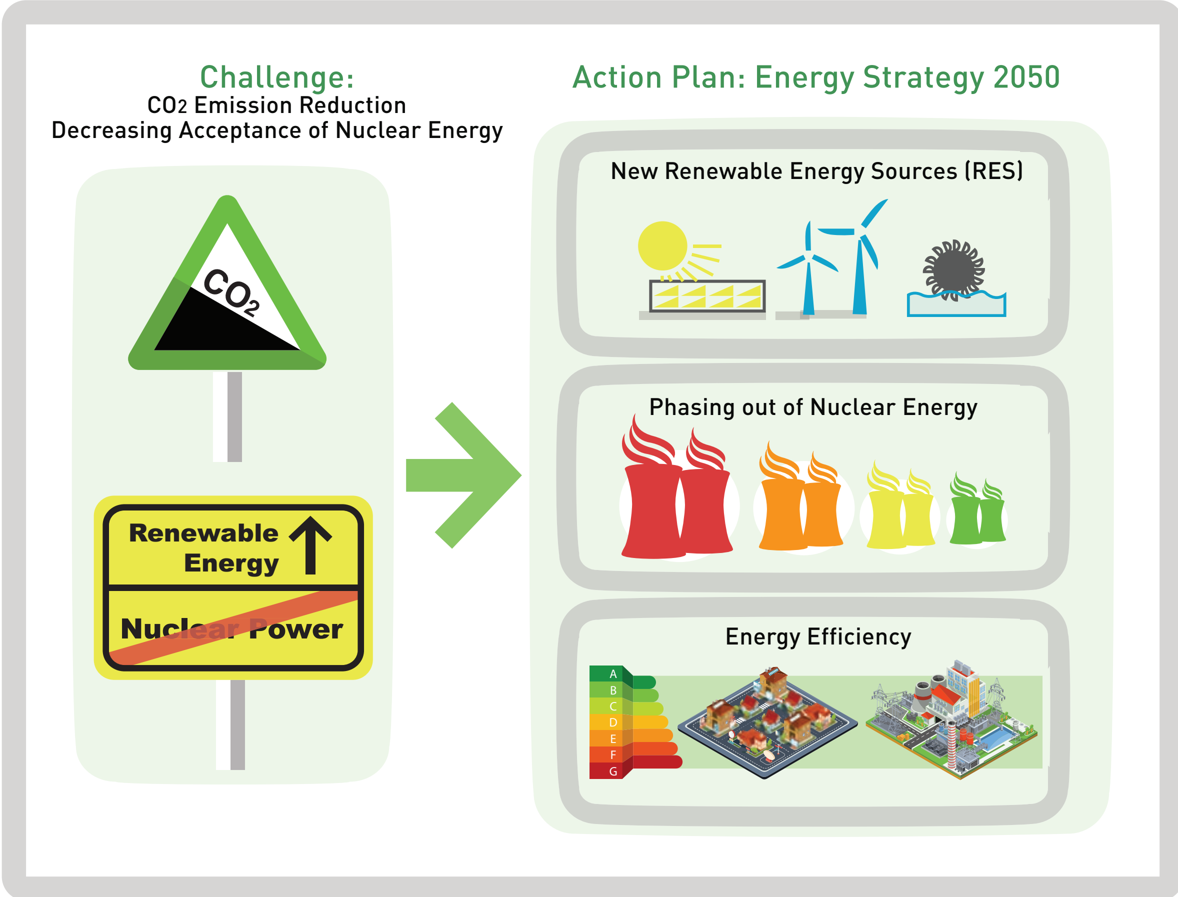
Faculty of Engineering, Stellenbosch University
15 May 2018

Outline of Presentation

- Introduction
- EnerPol – Models for Electricity
- EnerPol – Validations and Applications
- Concluding Remarks

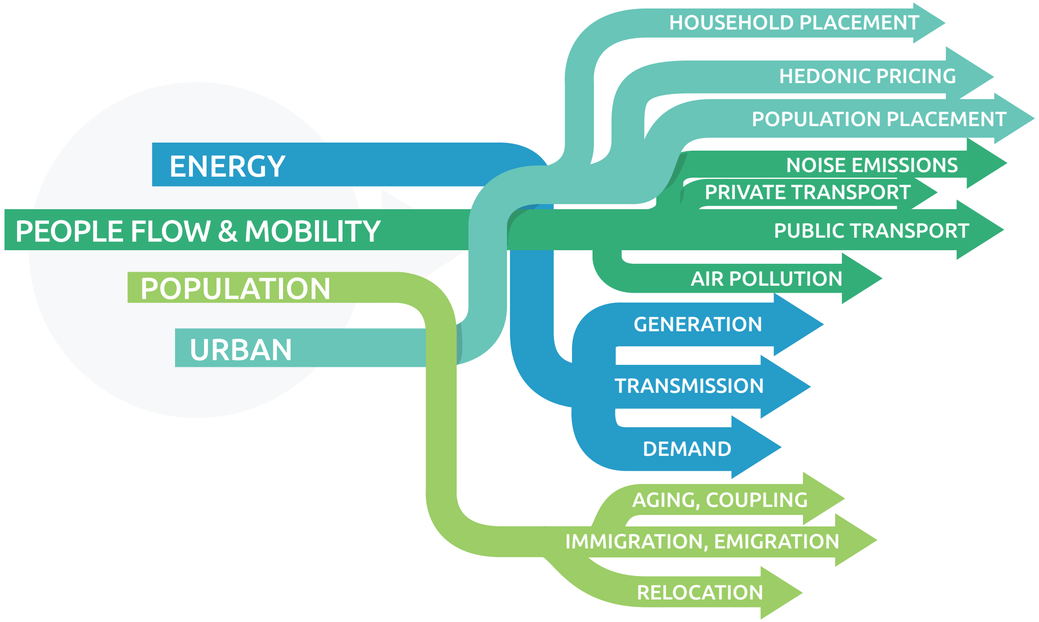
Transformation of Energy System

- Europe's energy system is undergoing transition to low carbon technologies
- Strategic plans for transformation have been developed at different scales:
  - Europe-wide: Strategic Energy Technology Plan (SET Plan)
  - National: for example, Switzerland's Energy Strategy 2050 with phaseout of nuclear
  - City: for example, city of St. Gallen, Energiekonzept 2050 with fourfold decrease/increase of non-renewables/renewables



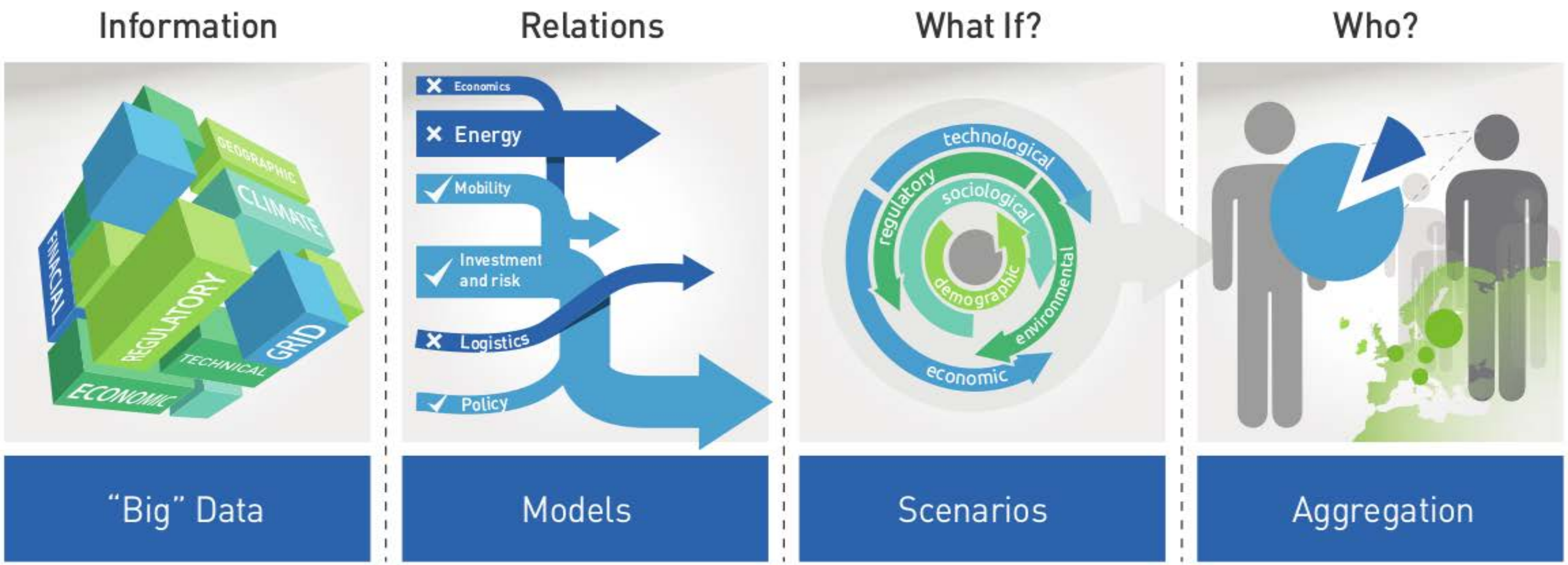
Overview of EnerPol Framework

- In development since 2009, EnerPol framework provides system-wide (on scale of continent or country) scenario-based assessments with high spatial (30m × 30m) and temporal (sub-hourly) resolutions of:
  - Energy, transportation and urban infrastructures, and population
- EnerPol's intent is strategic decision-making with bottom-up framework:
  - More than 200 anthropological, geography, climate & weather, regulatory and financial variables
  - In-house geo-referenced database



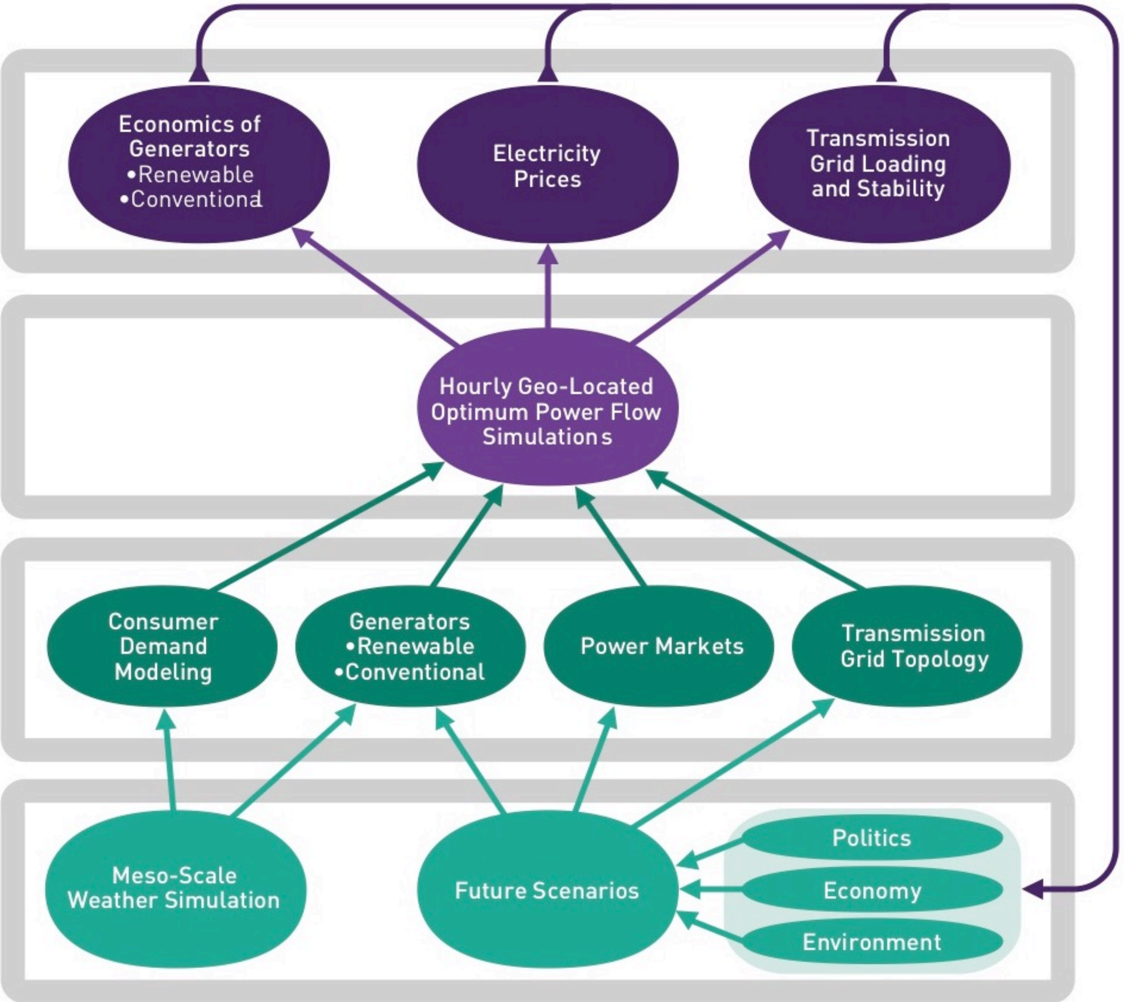
Components of EnerPol Framework

- ‘Big data’ and detailed models are linked to allow ‘what if’ scenarios to be easily run, and outcomes presented to different decision makers (OEMs, TSOs, utilities, etc.)



EnerPol Methodology

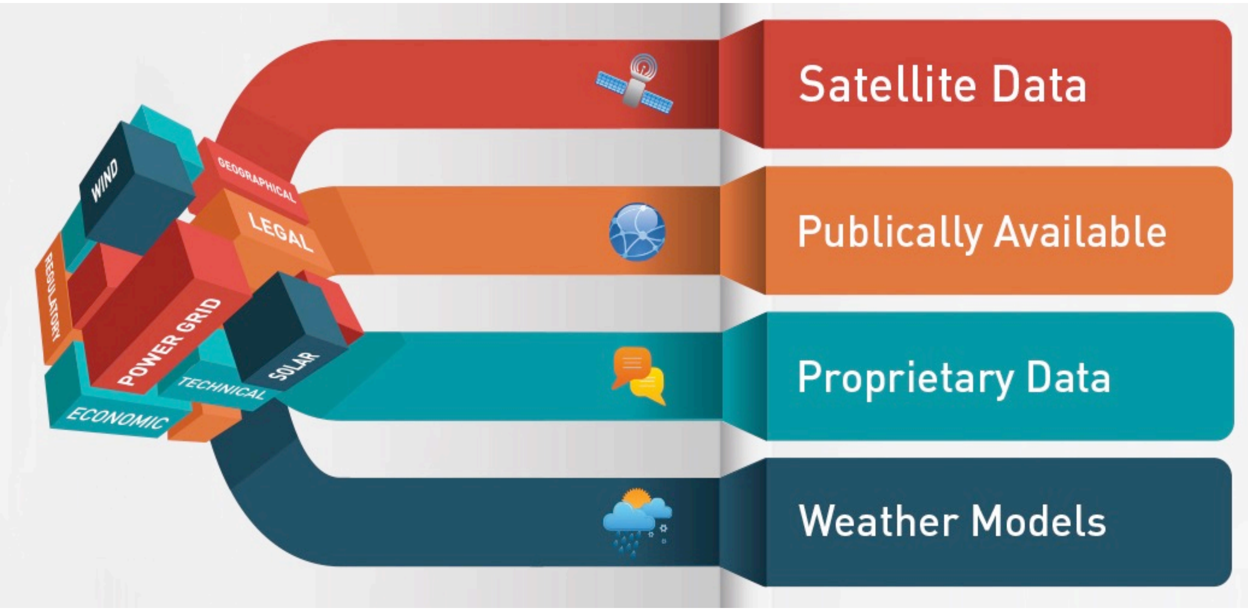
Structure of Simulations of Electricity Systems



- Core capabilities include:
  - Evaluation of techno-economic performance of conventional and renewable generators
  - Identification and analysis of opportunities for development of new power plant
  - Assessment of availability of transmission grid for connection of new power projects and security of grid

Sources of Data

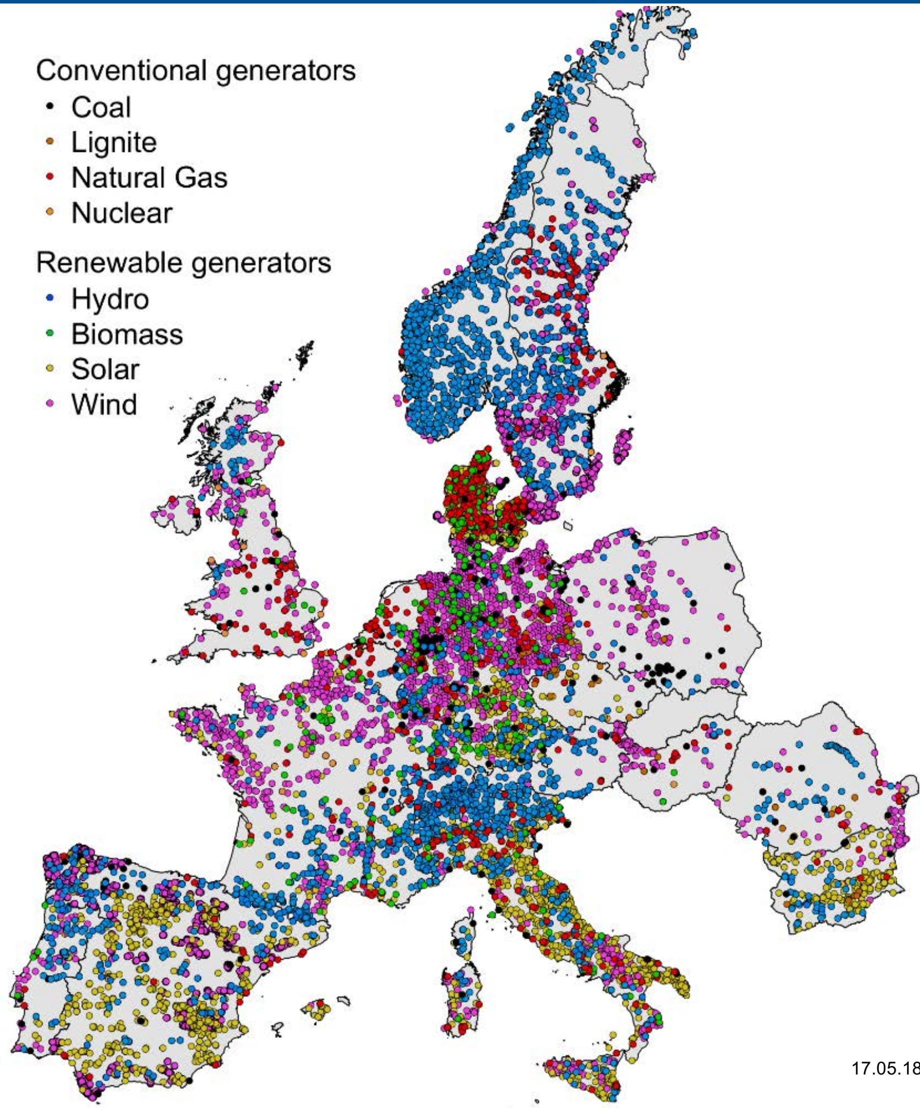
- Data are obtained from different sources, including satellites, open source, proprietary, etc., and converted into EnerPol-standardised formats



- Multi-spectral image processing to identify natural resources and built infrastructure
- For example, TSOs, DSOs
- Project partners
- Mesoscale weather predictions integrated into EnerPol framework

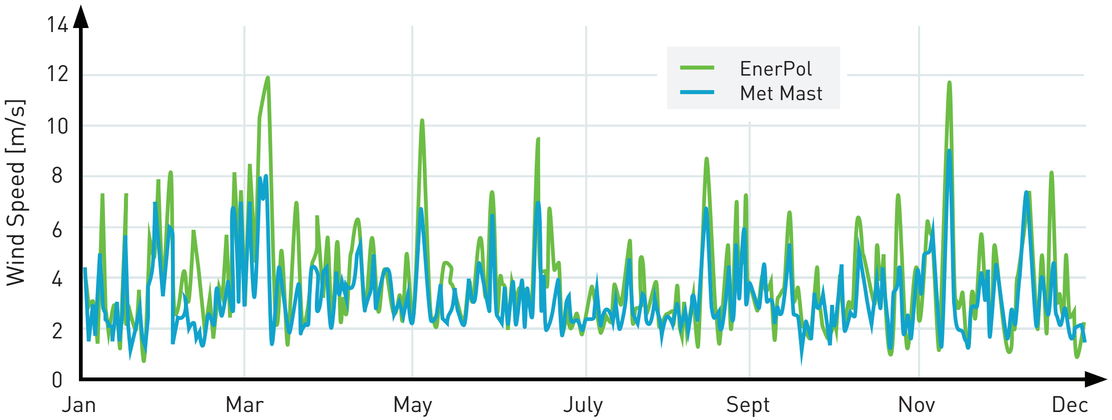
Electricity Generation Model

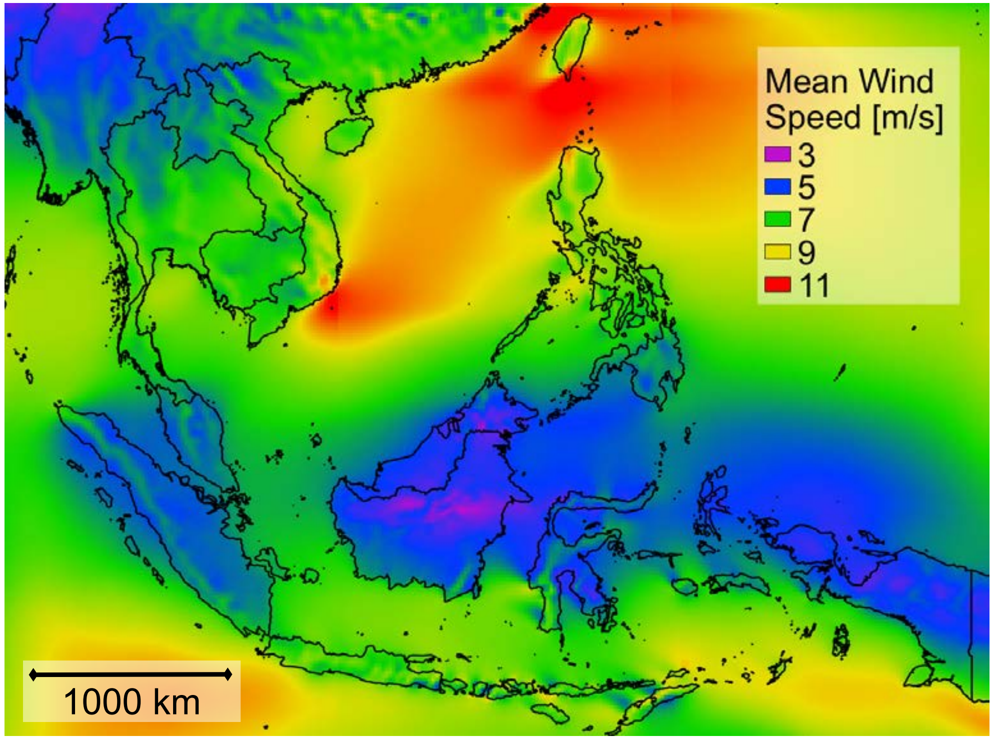
- Individual renewable and conventional power plants (33'500 in European generation model) are geo-referenced and modelled
  - Power plants are differentiated by fuel type
  - Variation of fuel prices is taken into account
  - Cycling of thermal power plants is accounted for



Modeling Individual Renewable Plants

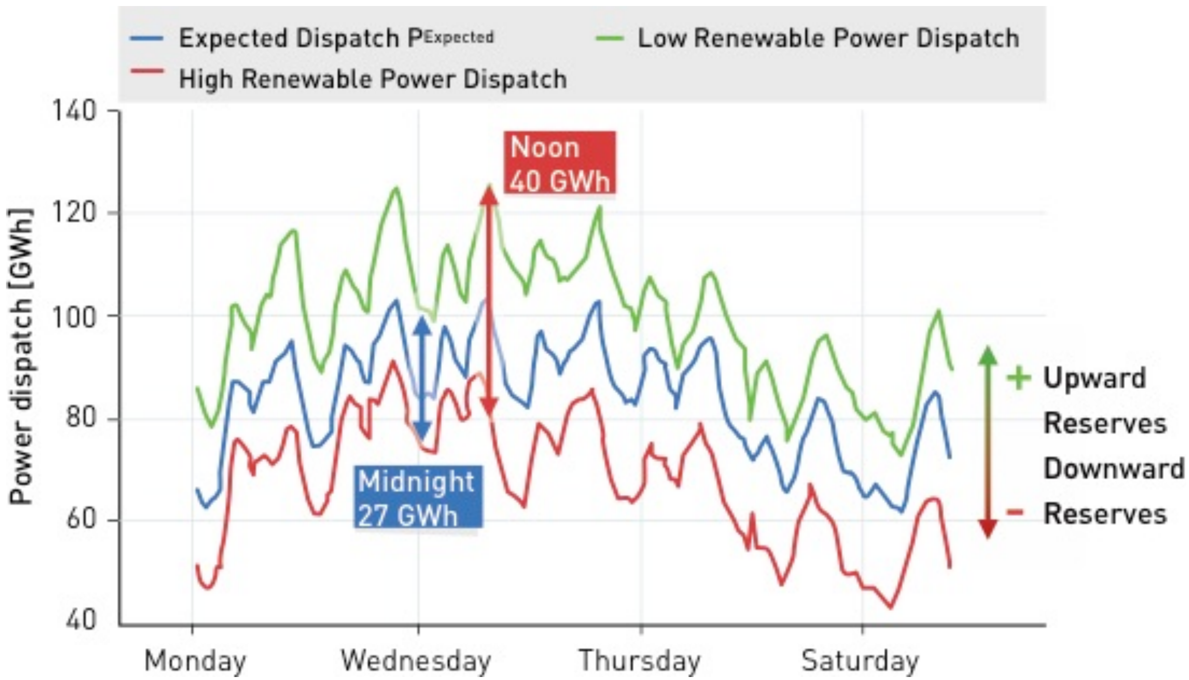
- Mesoscale simulation of wind speed and solar irradiation integrated in EnerPol framework
- Simulation period: multiple years
- Temporal resolution: 10-min or hourly
- Spatial resolution: 10km × 10km or 20km × 20km





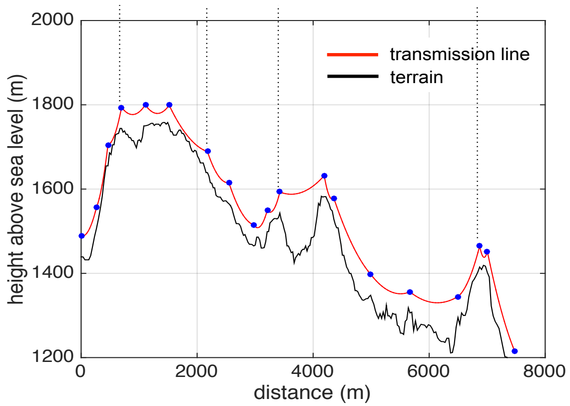
Modeling Weather-Derived Power System Uncertainty

- Intrinsic uncertainty and variability of weather resources is accounted for
- Time-varying reserve requirements are identified based on mesoscale weather simulations
- Operation of power plants designed for ancillary services markets (for example SC GTs) is driven by reserve requirements

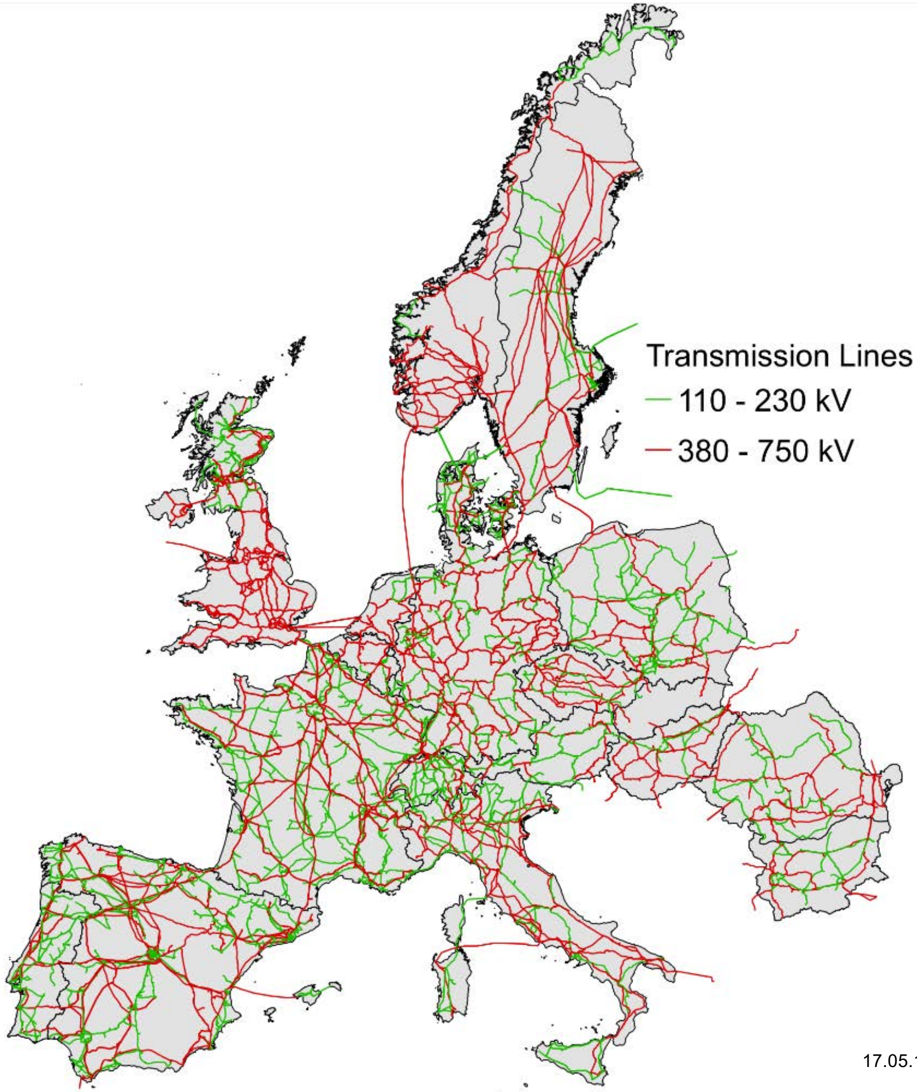


Electricity Transmission Model

- Individual transmission lines (275'000 km) and substations (4'300) are geo-referenced and modelled



- Impact of weather, derived from mesoscale weather simulations, on operation of lines is accounted for

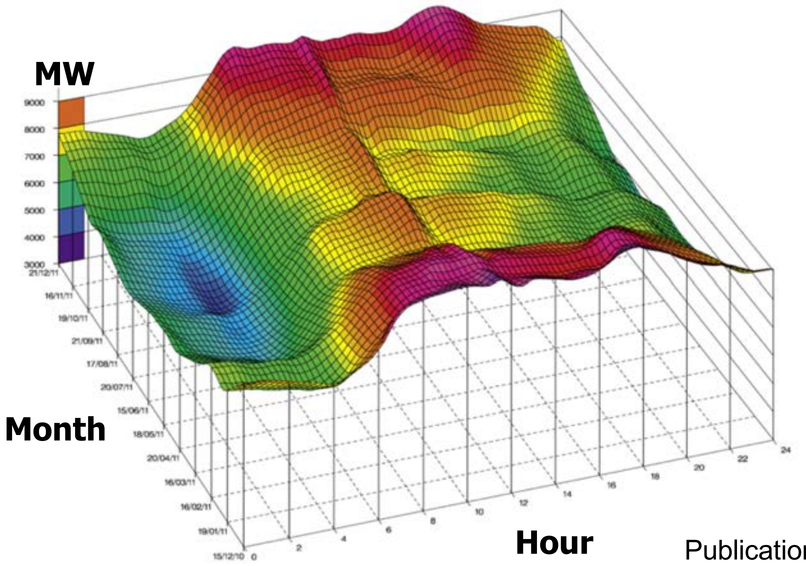


Modelling Electricity Demand

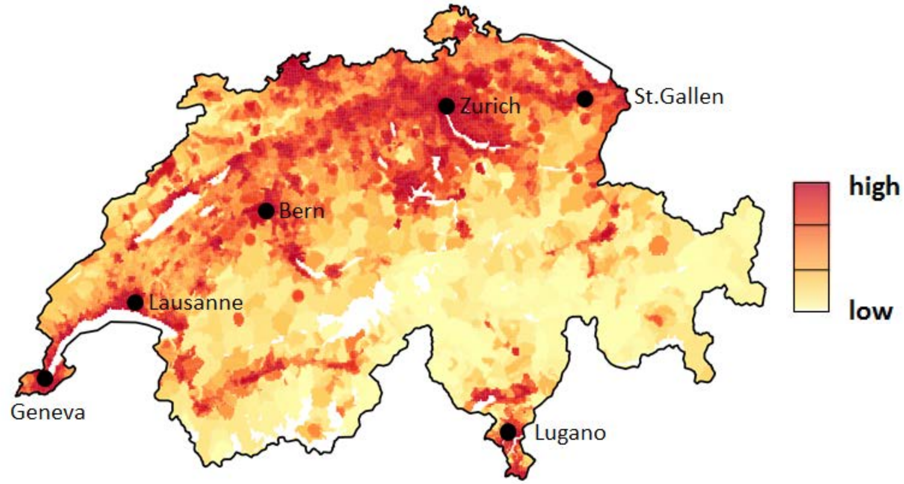
- Hourly electricity demands of spatially-resolved, household, commercial, industrial and transportation sectors are modelled

$$Power\ Demand_{[i]} = f\left(time, pop.density_{[i]}, commerce_{[i]}, industry_{[i]}, transport_{[i]}\right)$$

Annual electricity demand in Switzerland



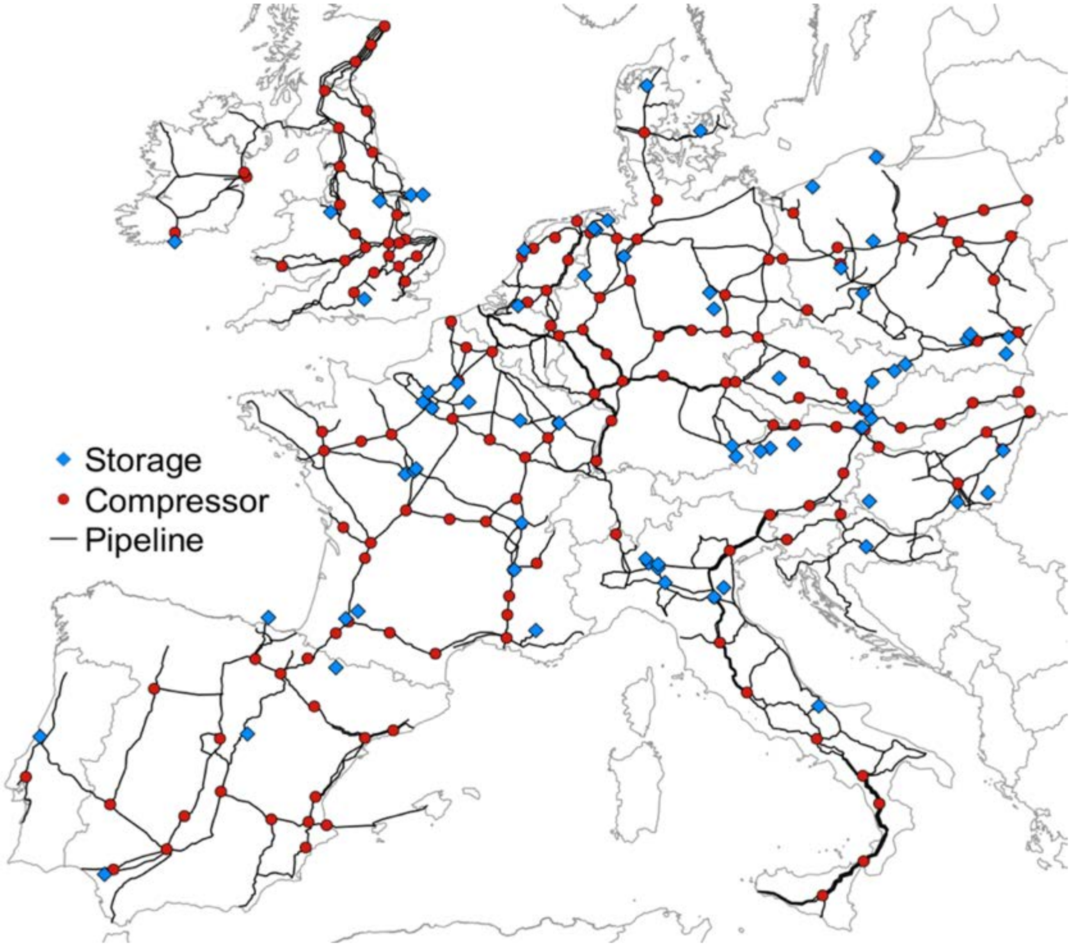
Snapshot of electricity demand



Publication
Singh, Eser, Chokani, Abhari: "*Improved modelling of demand and generation in high resolution simulations of interconnected power systems*", EEM 2015.

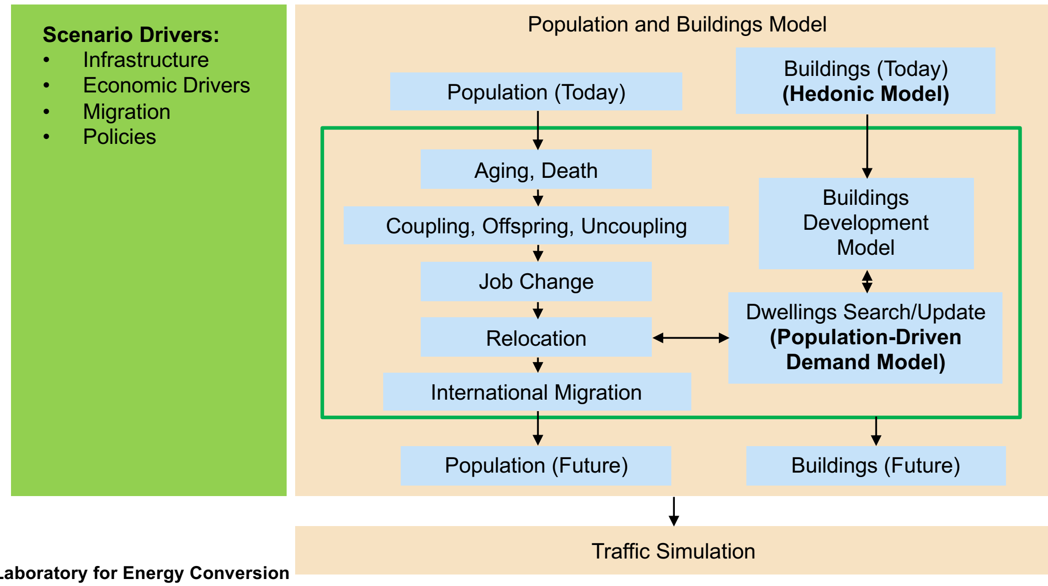
Electricity and Gas Networks Co-Optimized

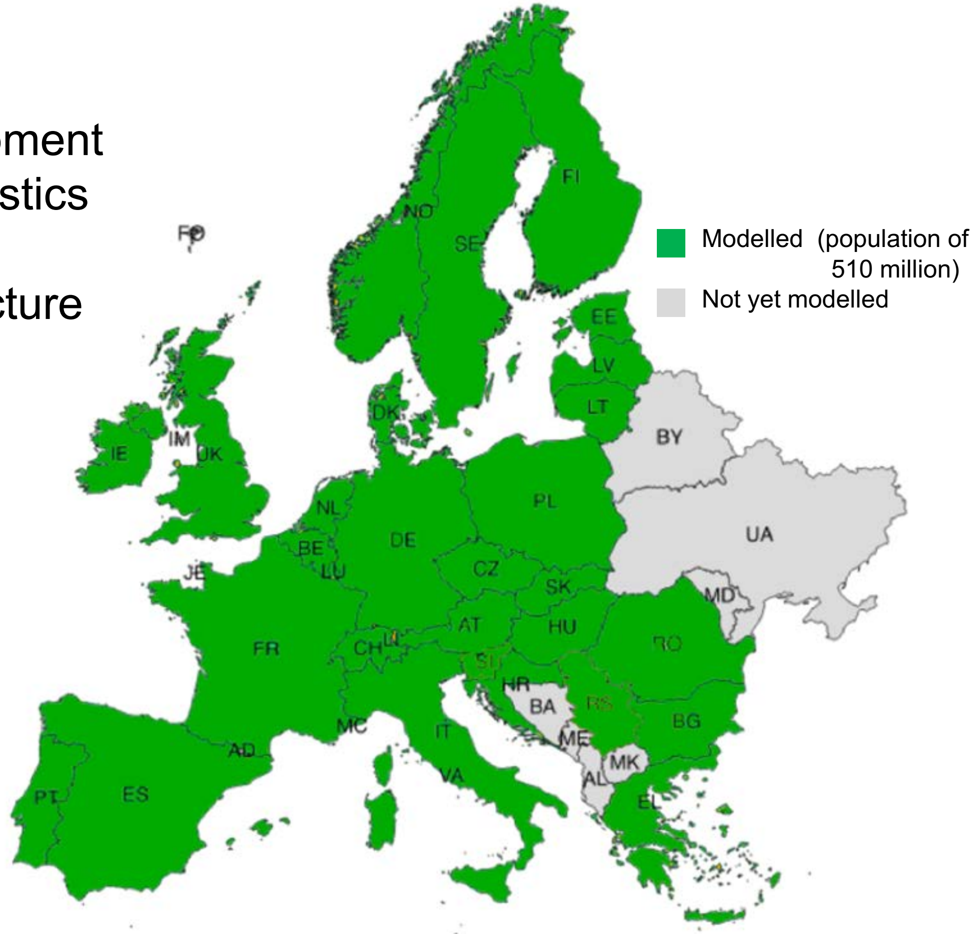
- EnerPol includes gas model to co-optimize electricity and gas networks
- Gas pipelines are modelled individually with pumps, flow limits and storage capacities
- Co-optimization enables sufficiency of gas grid to support operation of natural gas power plants to be assessed



Agent-Based Population, Building, and Traffic Models

- Agent-based population model predicts future population based on different drivers
- Infrastructure and building models predict development of new buildings, including location and characteristics
- Traffic simulation used to simulate mobility and to assess accessibility and quality of urban infrastructure

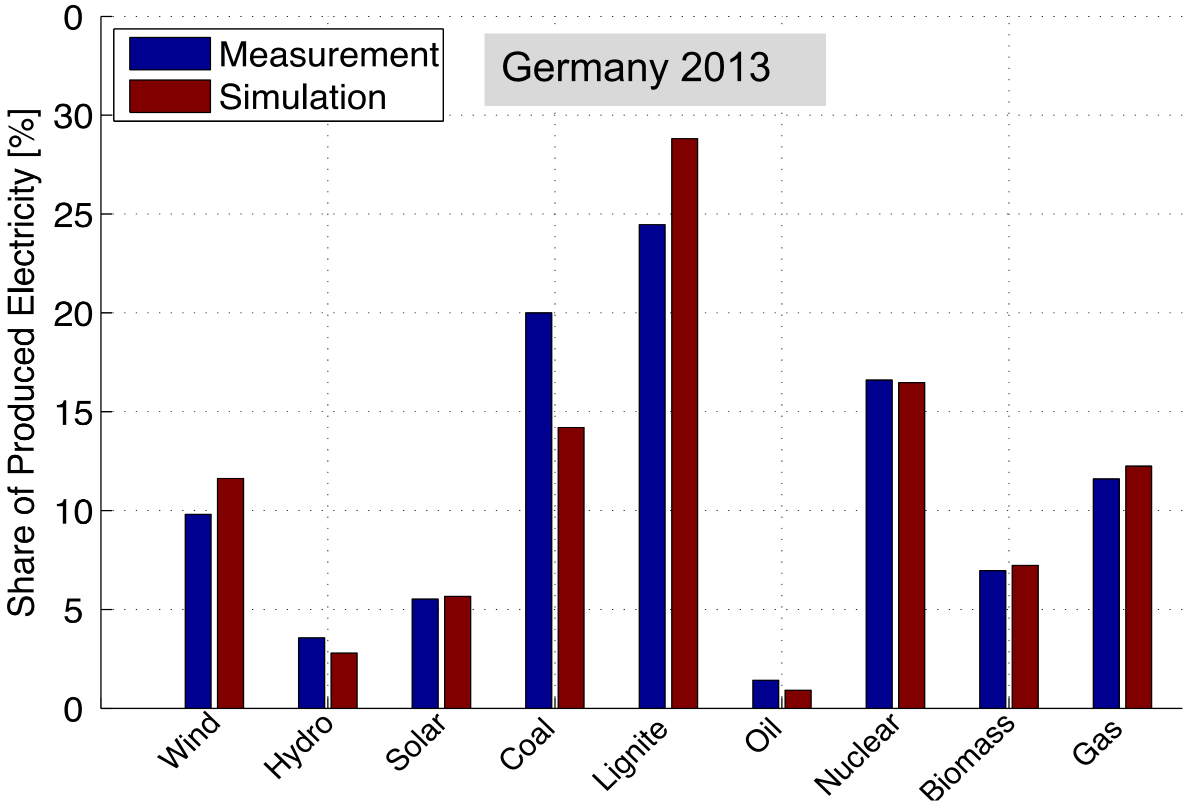




EnerPol Model Validation

Accurate Simulation of Electricity Dispatch

- EnerPol accurately predicts market shares for all technologies due to physical modelling of production costs for each fuel type
- Average difference between predicted and actual market shares for 2013 German market is 12%
- As purely wholesale market is modelled, lower priced lignite is favoured over coal

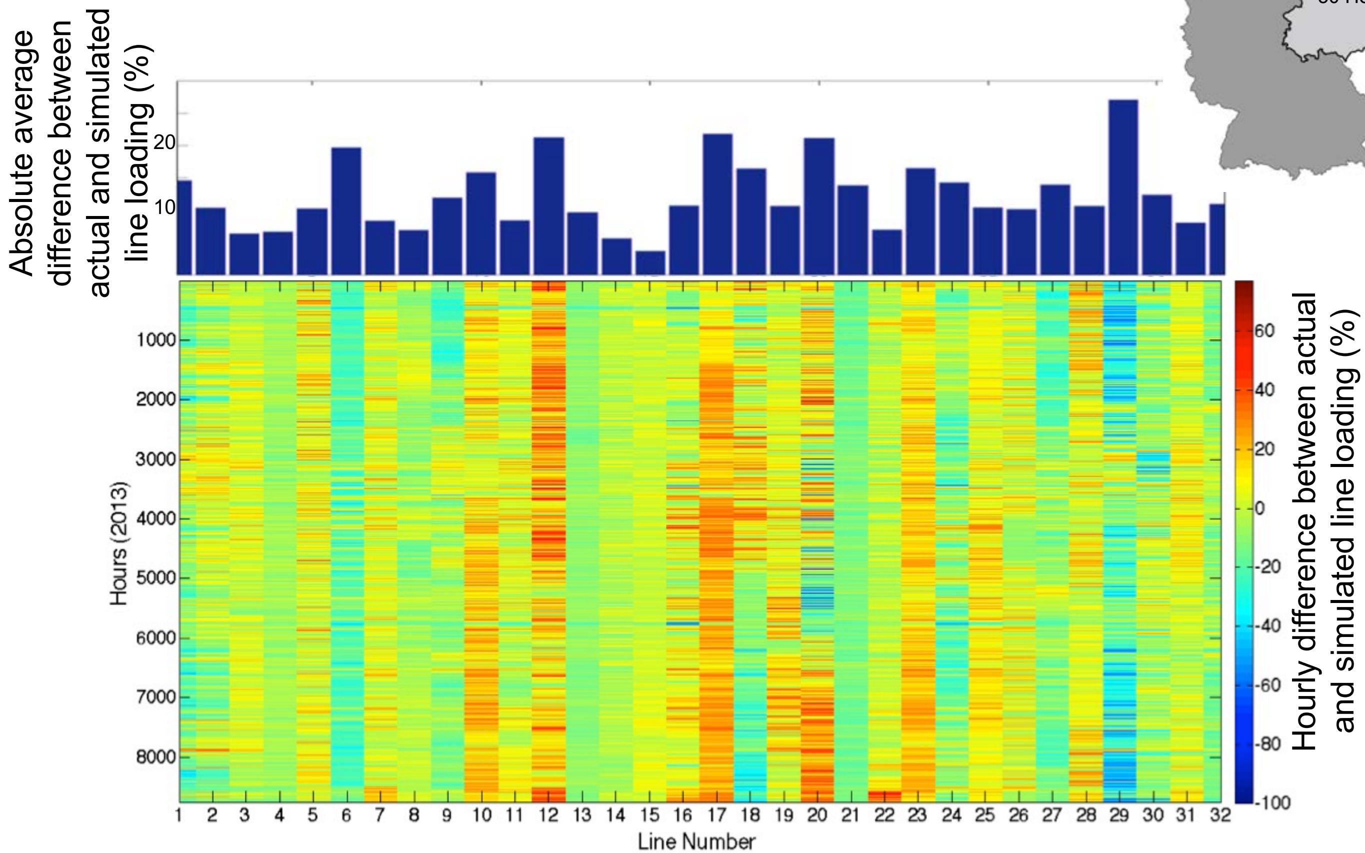


Publication
Eser, Singh, Chokani, Abhari: "*Effects of increased renewables generation on operation of thermal power plants*", Applied Energy, 2016.

Accurate Prediction of Transmission Line Flows

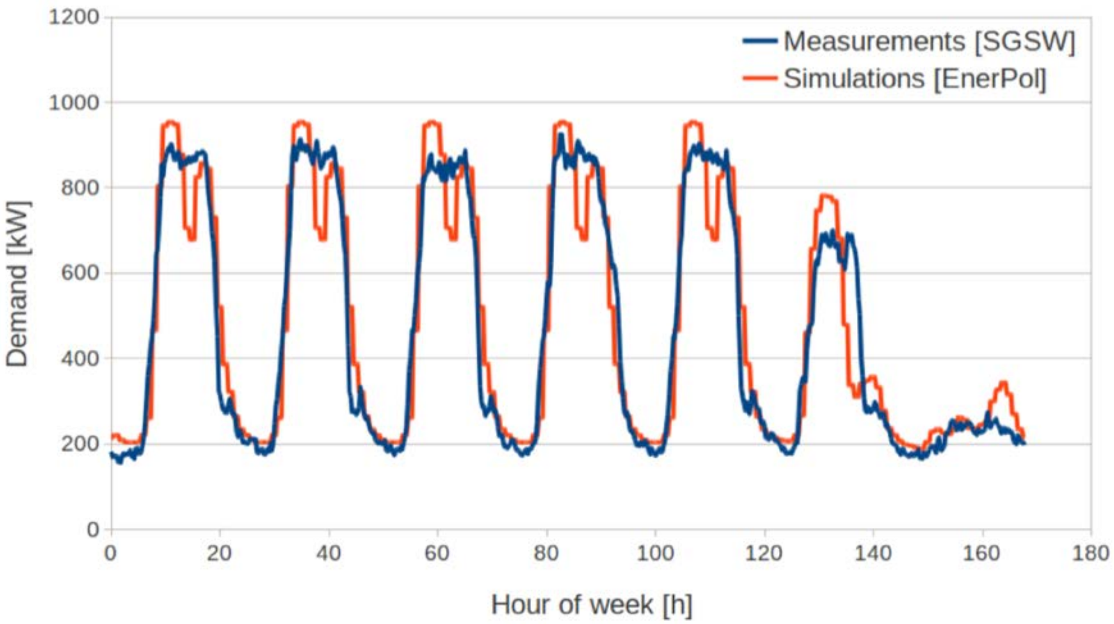
- EnerPol's hourly prediction of transmission line flows in 50Hertz TSO region have, for 2013, overall difference of 12% compared to data

- Accurate predictions of power flows are necessary to assess sufficiency of transmission grid in high-renewable scenarios



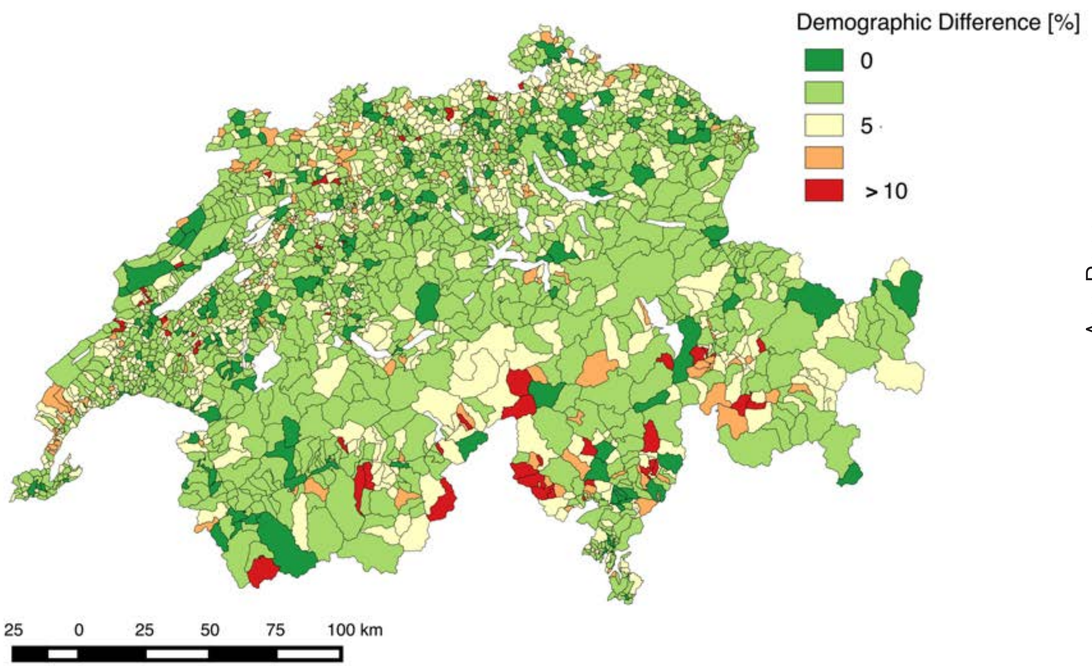
Accurate Prediction of Demand

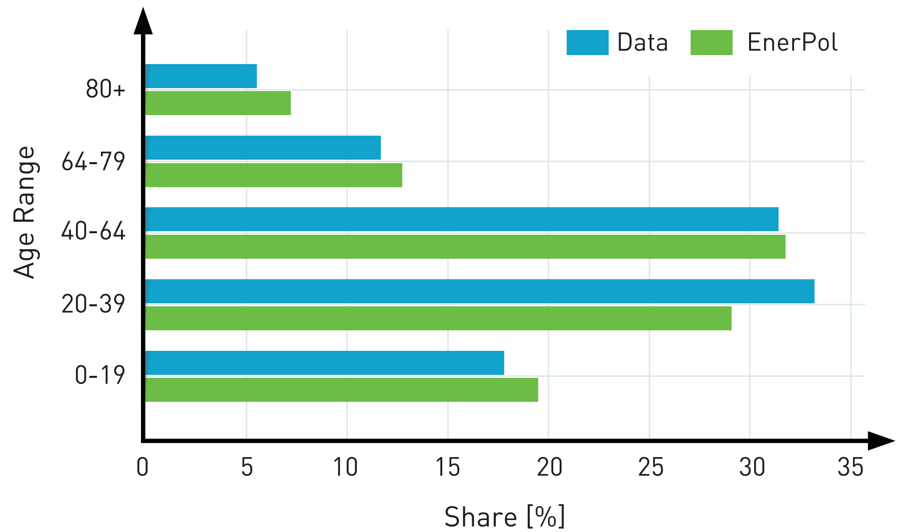
- EnerPol's hourly prediction of demand in city of St. Gallen have overall difference of 2% compared to smart meter data



Accurate Prediction of Population

- Modelling of Switzerland's population from 2000 to 2014 has 1.6% difference between predicted population (8'243'340) and actual population (8'111'741), and accurate prediction by municipality, for example St. Gallen



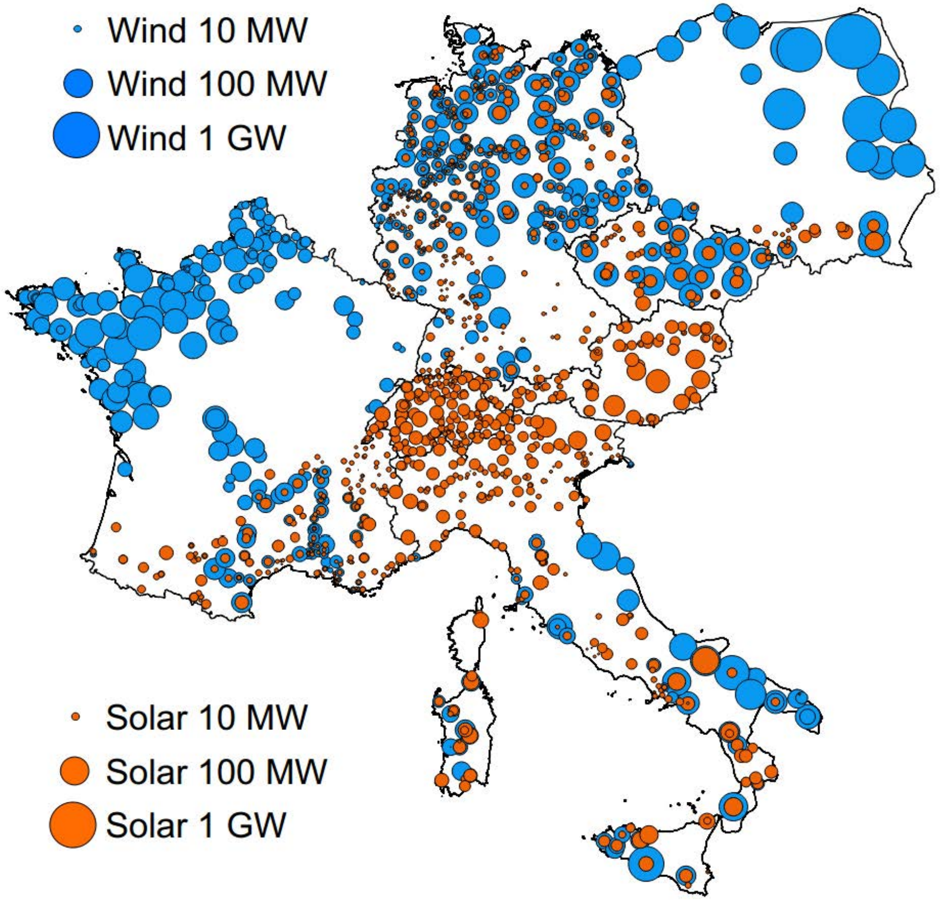


Example Case Studies

How can EU achieve 45% renewable electricity by 2030?

- To achieve 45% RES target, 221 GW of wind and 82 GW of solar need to be installed across central Europe

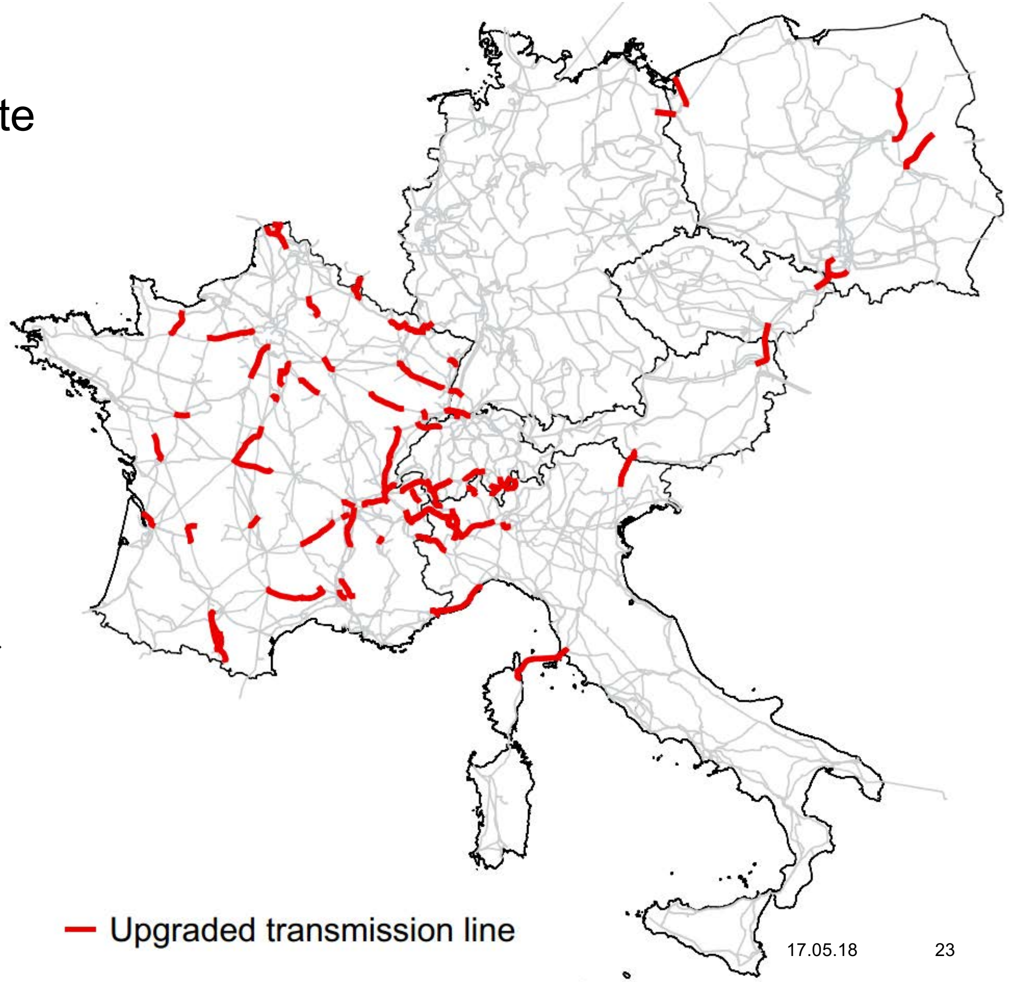
	New Wind [GW]	New Solar [GW]
Austria	2	12
Czech	14	6
Germany	60	15
France	72	9
Italy	33	26
Poland	37	2
Switzerland	3	12
Total	**221**	**82**



Publication
Eser, Chokani, Abhari: "*Optimal RES portfolio to achieve 45% renewable electricity in central Europe by 2030*", IEEE PES GM 2017.

Main bottlenecks on 45%-RES pathway found in Italy and France

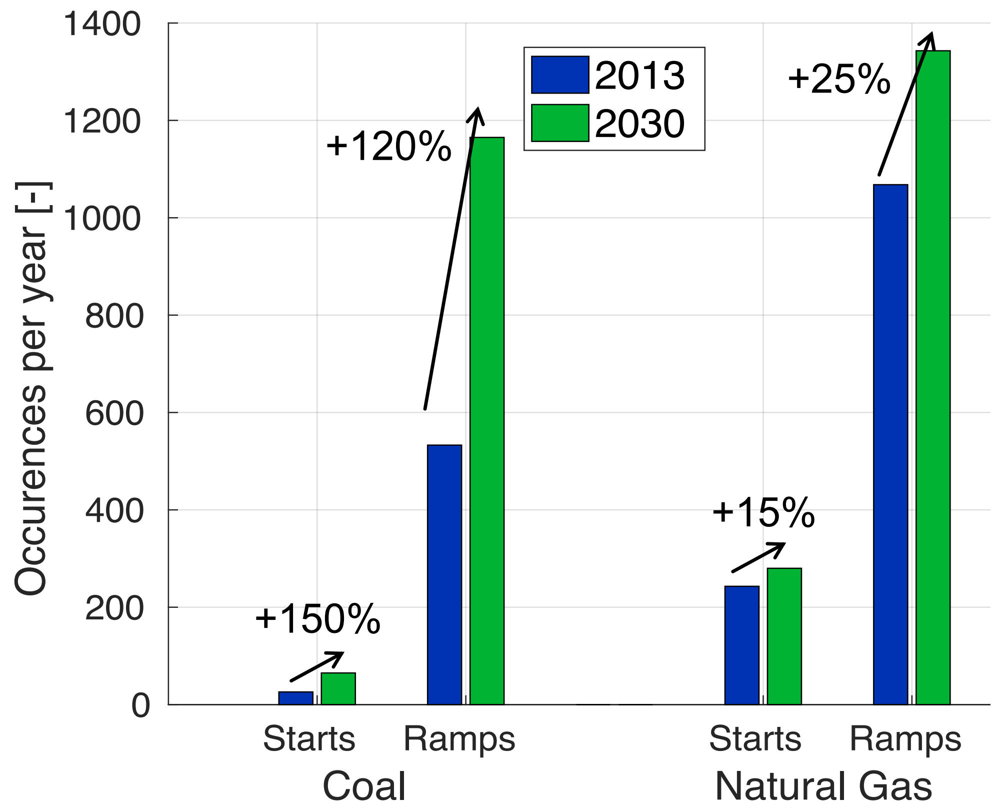
- Transmission grid is co-optimized to accommodate additional capacities of solar and wind
- Main bottlenecks in 45%-RES power system of EU 2030:
  - Connections between Italy, France and Switzerland
  - Crossborder connections Germany → Poland → Czech → Austria → Italy
  - Lines across central France



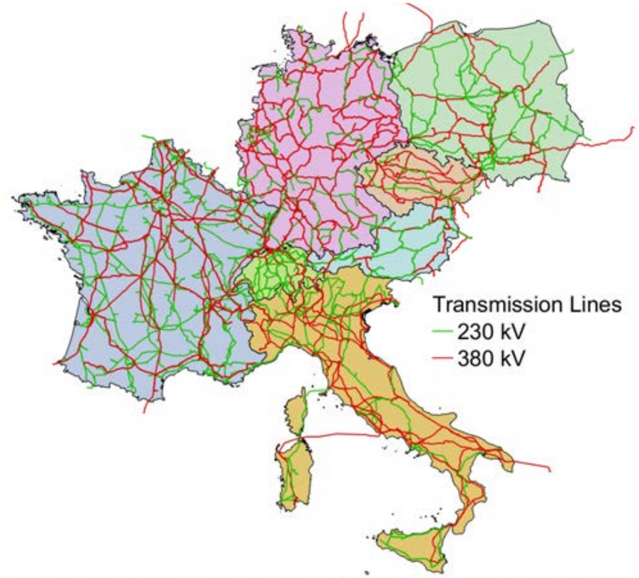
Impact of Increased RES on Cycling of Conventional Power Plants

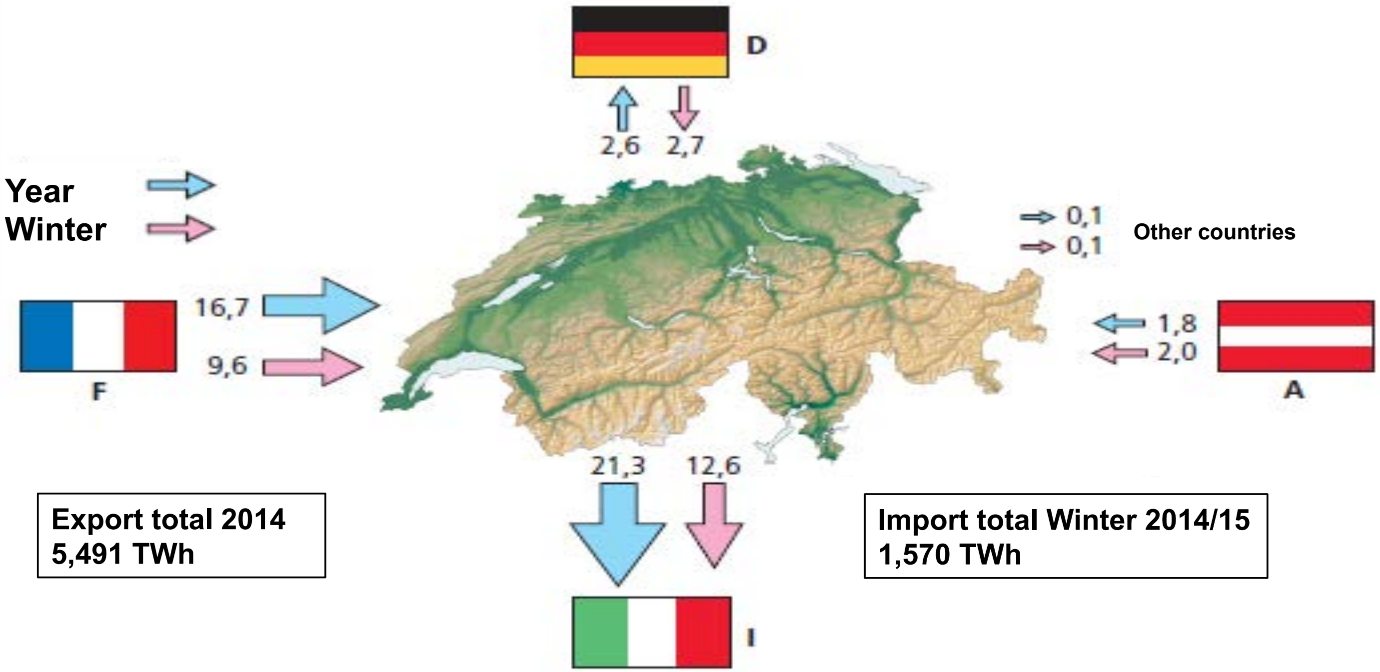
- EnerPol simulations show that for Europe with increased penetration of RES electricity in 2030 coal and natural gas power plants face significant increase in cycling operation

➢ EnerPol helps OEMs identify utilities' flexibility needs for large range of possible scenarios



Switzerland: international import and export of electricity





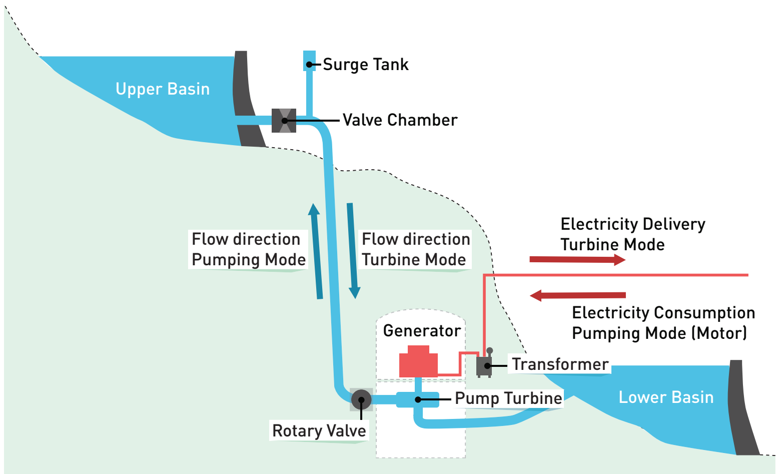
Export total 2014
5,491 TWh

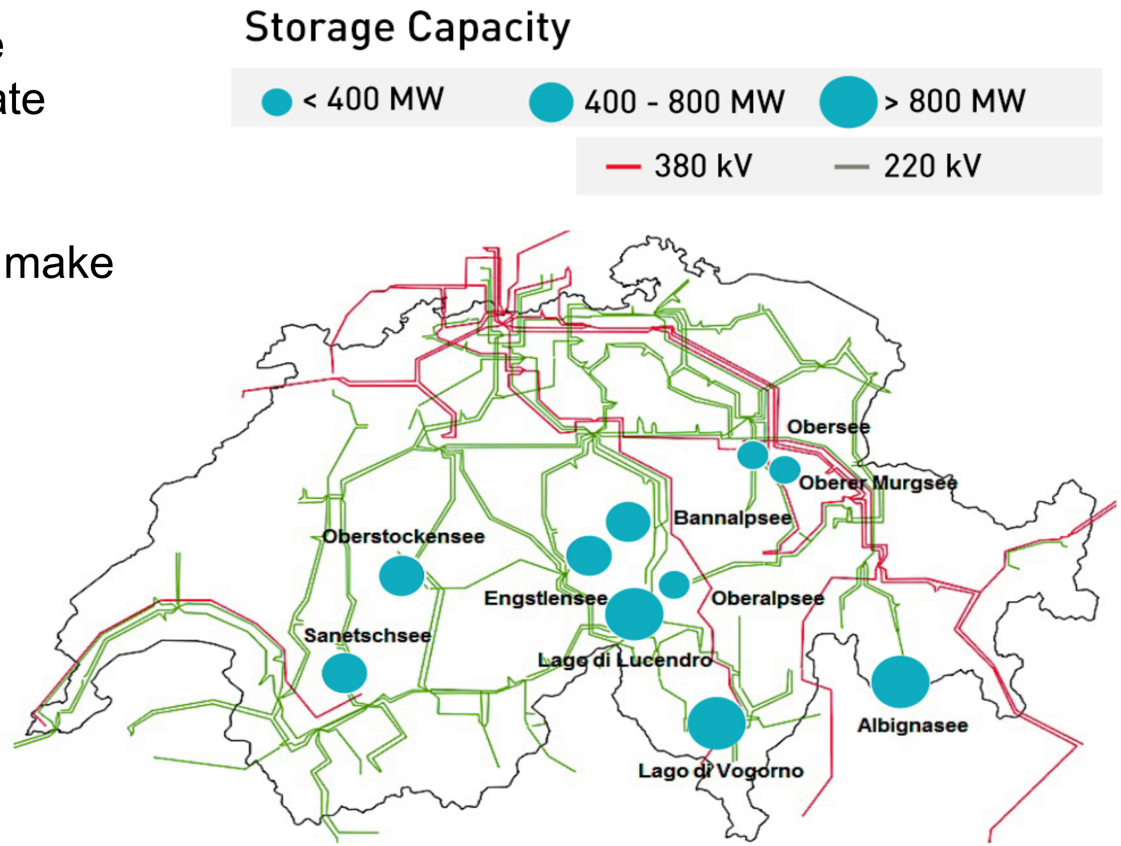
Import total Winter 2014/15
1,570 TWh

Identification of Possible Swiss Pumped Hydro To Facilitate Europe's Energy Transition

- 5.8GW of possible pumped hydro storage projects in Switzerland identified to facilitate Europe's energy transition

- Favourable political decisions required to make projects financially viable

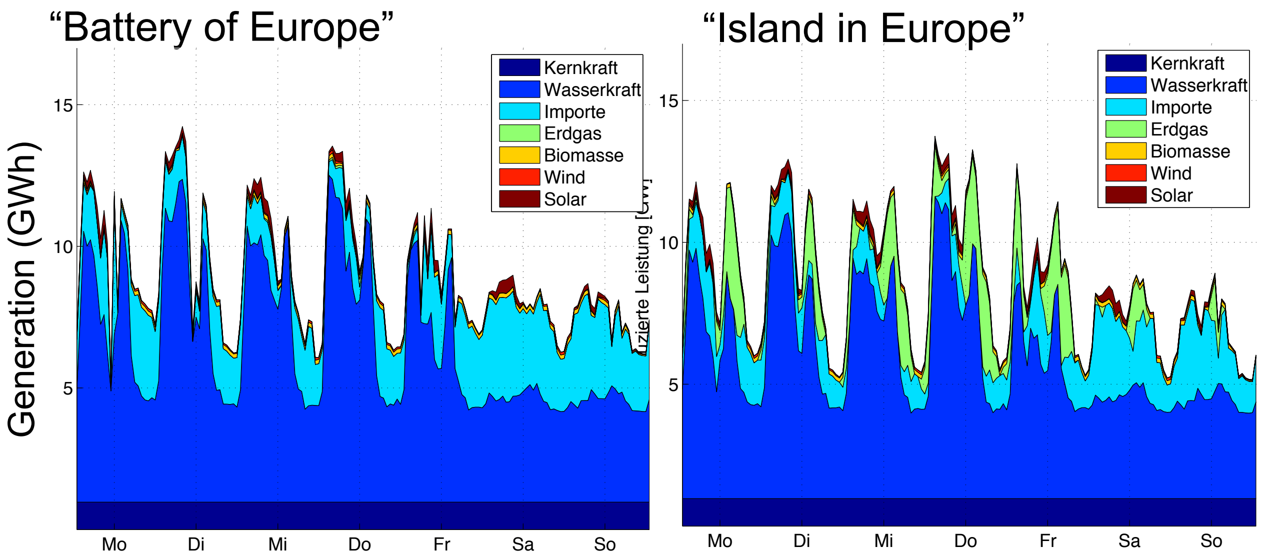




Switzerland “Battery” versus “Island”

“Battery of Europe” scenario
- additional 4.4 GW of pumped hydro
- transmission capacity upgraded by 60% (Germany, Austria) and 40% (Italy)

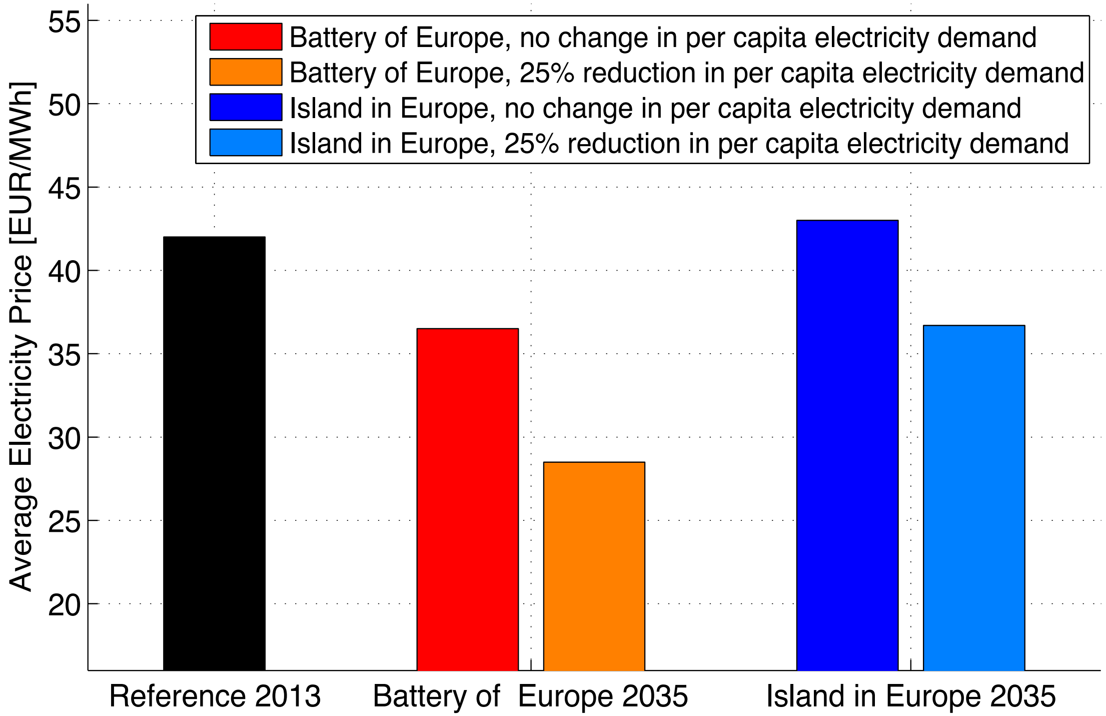
“Island in Europe” scenario
- 3.5 GW combined cycle gas plants at location of mothballed nuclear power plants



- EnerPol simulations show that, for a summer week in 2035, in Switzerland’s “Battery of Europe” scenario additional hydro in Switzerland can meet peak demand instead of gas power plants in Switzerland’s “Island of Europe” scenario

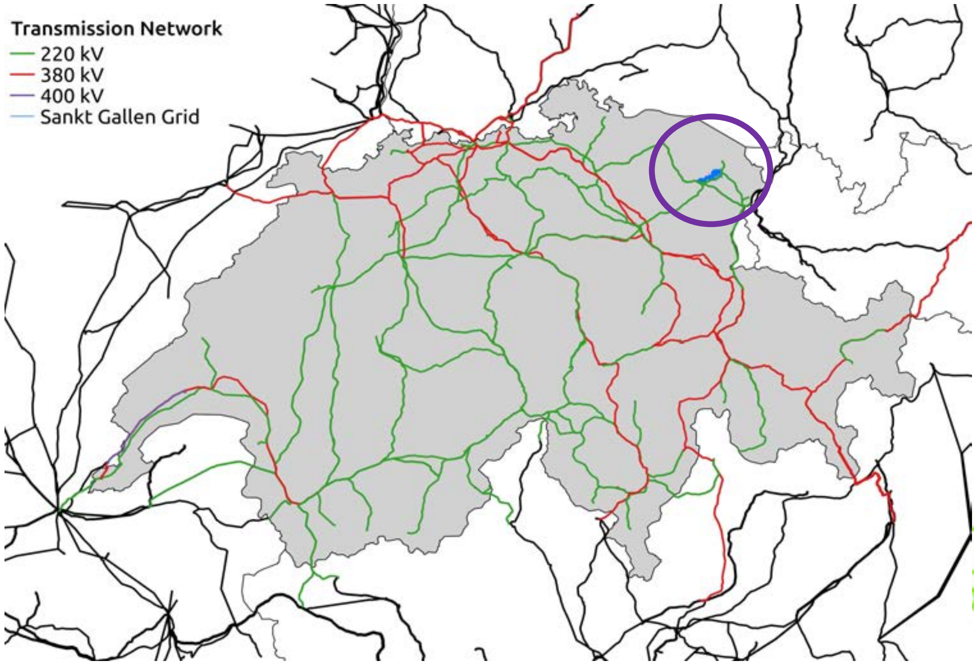
Switzerland's Integration in Europe results in lower electricity prices

- On account of relatively low-cost of RES, "Battery-of-Europe" scenario results in lower domestic electricity prices than "Island-in-Europe" scenario



City-Scale: Power Flow Simulations

- EnerPol power flow simulations with 1-min time resolution identify bottlenecks in middle- and low-voltage grid
- High temporal and spatial resolutions ensure impacts on distributed technologies are realistically simulated



Modelling Daily Activities

- Daily activities of Switzerland's population of 8,534,667 are simulated

Agent ID: 31366
Age: 21
Sex: Male
Municipality: Lausanne
Job Status: Student
Family Members: 2 Adults
Dwelling Rooms: 5
Dwelling Rent: 3220 CHF/month

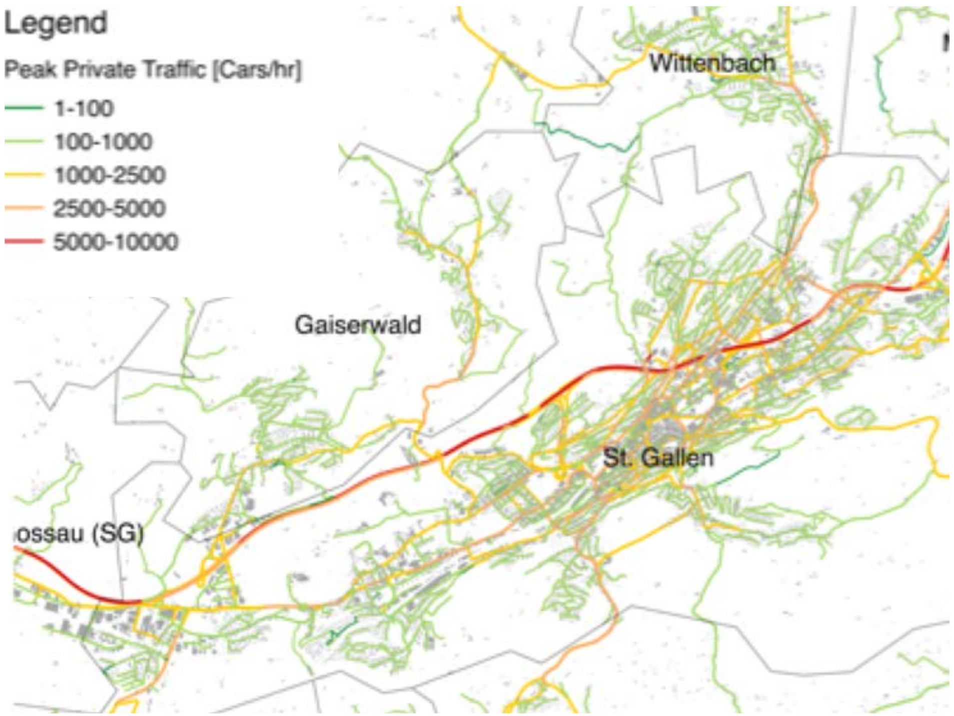
Partner: Agent ID: 31366
Age: 28
Sex: Female
Job Status: Full Time Employed
Income: 15698 CHF/month
Job: Medical Doctor
Job Sector: Tertiary
Job Municipality: Vandeouvres

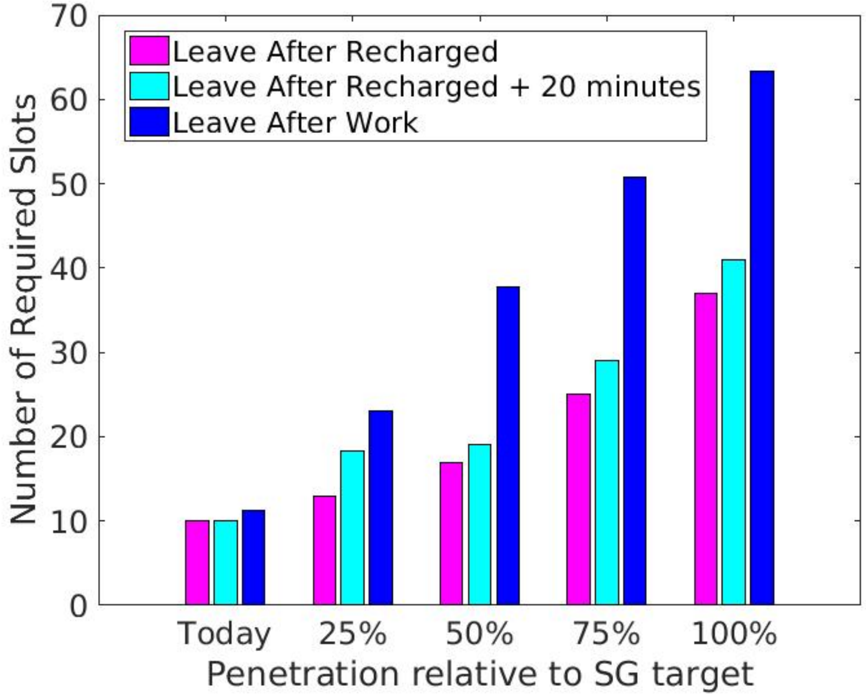
Daily Schedule

Time	Actions
08:13 – 08:20	➢ Leave home ➢ Walk to University (700 m)
08:20 – 18:29	Stay and study at University
18:29 – 19:05	➢ Walk to Montelly metro stop (550 m) ➢ Take train to Bourdonnette stop ➢ Change to bus 701 ➢ Take bus 701 to St-Sulpie stop ➢ Walk to Tennis Club St Sulpice (130 m)
19:05 – 22:00	Stay at Tennis Club St Sulpice
22:00 – 22:45	➢ Walk to St-Sulpie bus stop (800 m) ➢ Take bus 31 to Ecublens stop ➢ Exchange to metro ➢ Take train to Montelly stop ➢ Walk to home place (350 m)
22:45 –	Home

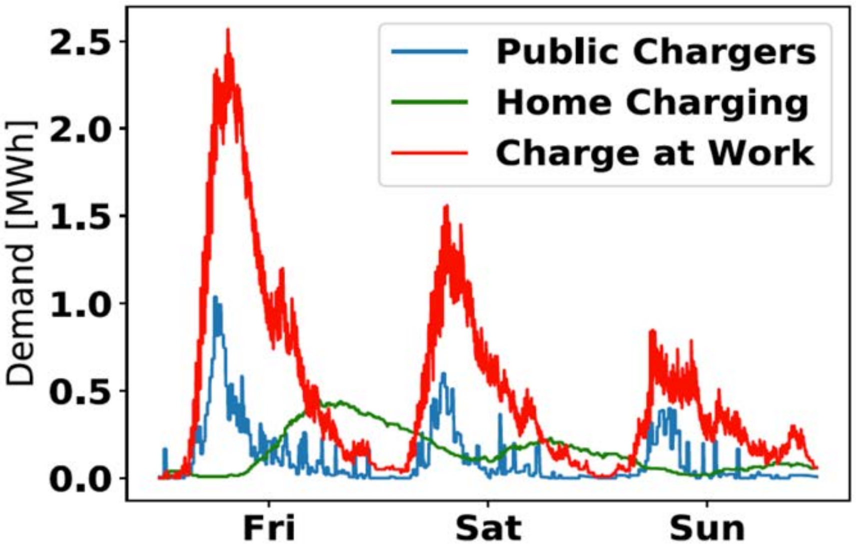
Impact of Charging Usage on Electric Vehicles Infrastructure

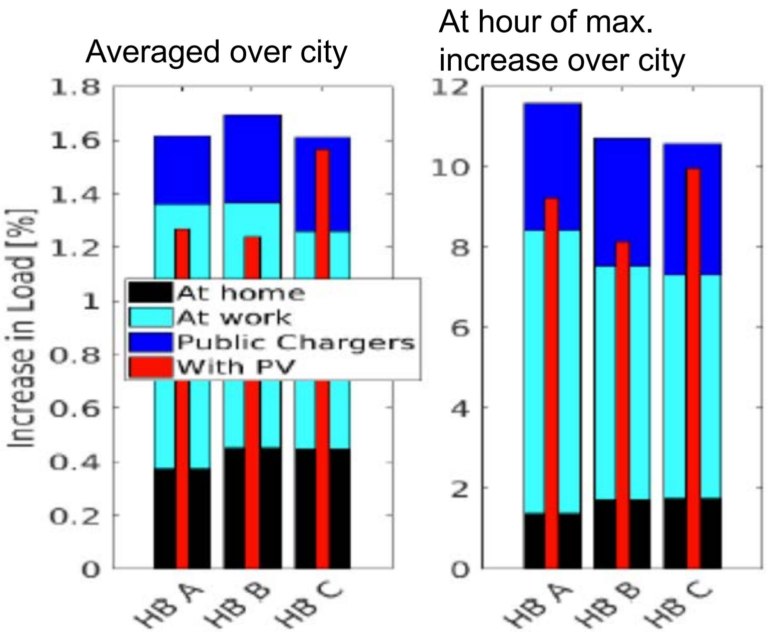
- People behaviour impacts number of EV chargers needed to meet penetration goals





Impact of People on Distribution Grid





- For year 2050 (50% penetration of electric vehicles), primary source of electric demand of electric vehicles is at workplaces

- Different human behavior (HB A: price-driven; HB B: comfort-driven; HB C: mixed price and comfort driven) have different impacts of load increase on local distribution network is assessed at transformers for three
- Deployment of rooftop PV decreases loads

Concluding Remarks

- EnerPol framework is suited to assess many different scenarios in time-efficient manner, and therefore can support transition to low carbon technologies

- Complex interactions, due to regulations, demographics, politics, and/or market drivers, that impact power system, and which sometimes are not intuitive, can be accurately assessed

- Decision-makers can be better prepared to target opportunities in specific markets