Modeling the flexibility offered by coupling the heating sector and the power sector: an assessment at the EU level

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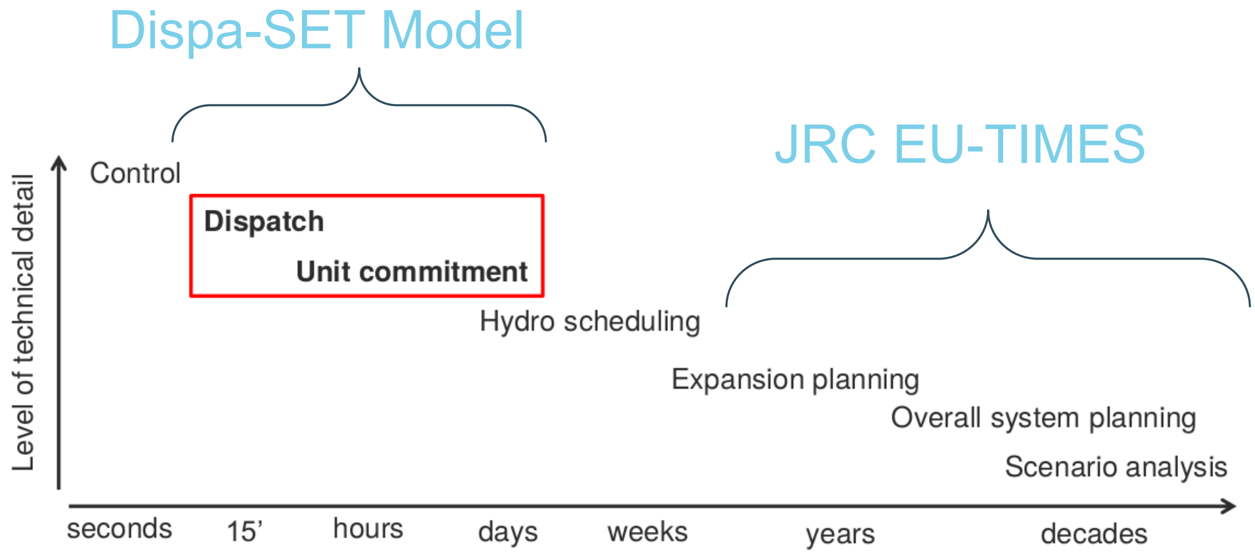
Introduction

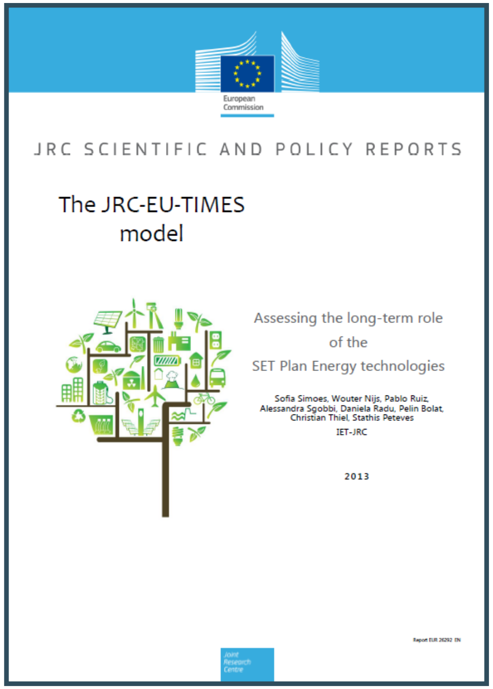
- ***Main questions***:
  - How much flexibility can we obtain from district heating, CHPs and thermal storage in the EU power system?
  - How does that compare to other flexibility options (hydro, EVs)?
  - How can this be modeled in a long-term planning context?

JRC models:



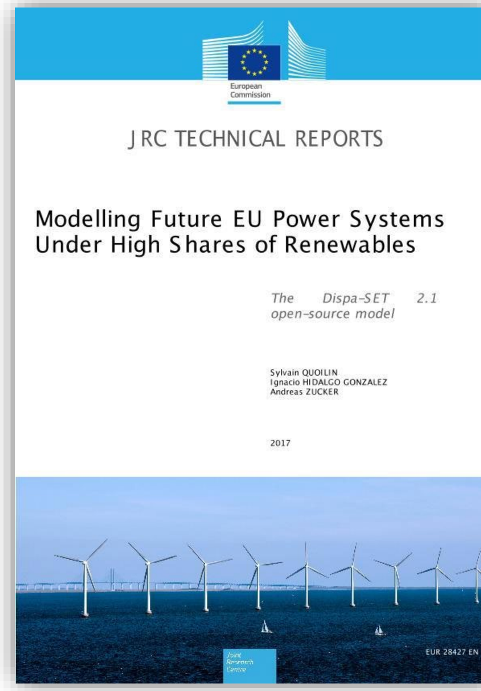
JRC-EU-TIMES in a nutshell

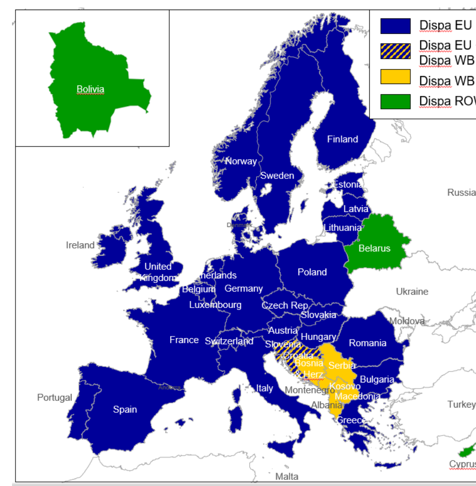
- Model horizon: 2005-2050 (2075)
- ***Technology rich*** (300+) ***bottom-up energy system optimisation*** (partial equilibrium) model based on the TIMES model generator of the IEA
- Designed for analysing the ***role of energy technologies*** and their innovation for meeting Europe's energy and ***climate related policy objectives***
- ***Electricity multi-grid model*** (high, medium and low voltage grid), tracking demand-supply via 12 time slices (4 seasons, 3 diurnal periods), and gas across 4 seasons
- ***70*** exogenous ***demands*** for energy services



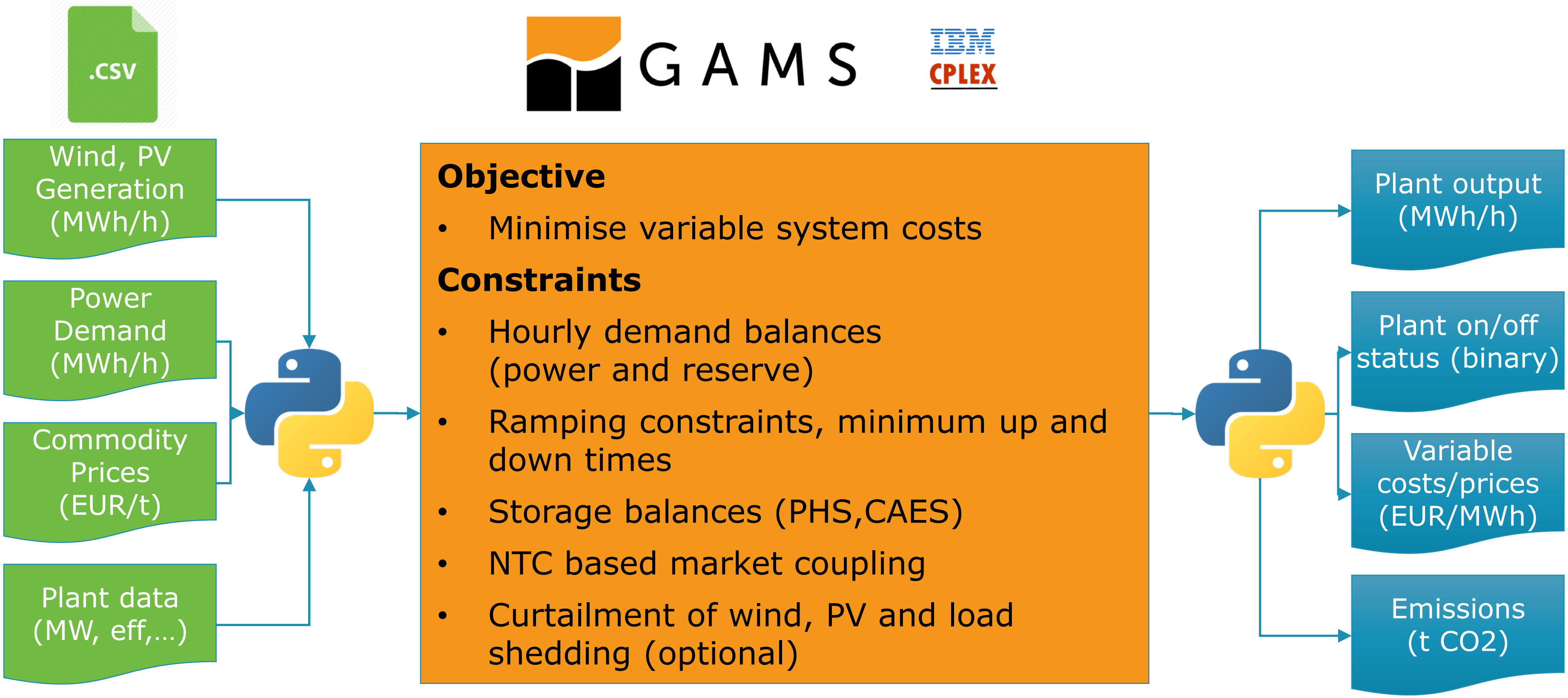
Dispa-SET in a nutshell

- ***Unit commitment and dispatch model*** of the European power system
- Optimises ***short-term scheduling*** of power stations in large-scale power systems
- Assess ***system adequacy and flexibility needs*** of power systems, with growing share of renewable energy generation
- Assess feasibility of power sector solutions generated by the JRC-EU-TIMES model
- ***Technology mix*** from ***ProRES 2050*** scenario used as ***inputs*** for Dispa-SET power plant portfolio



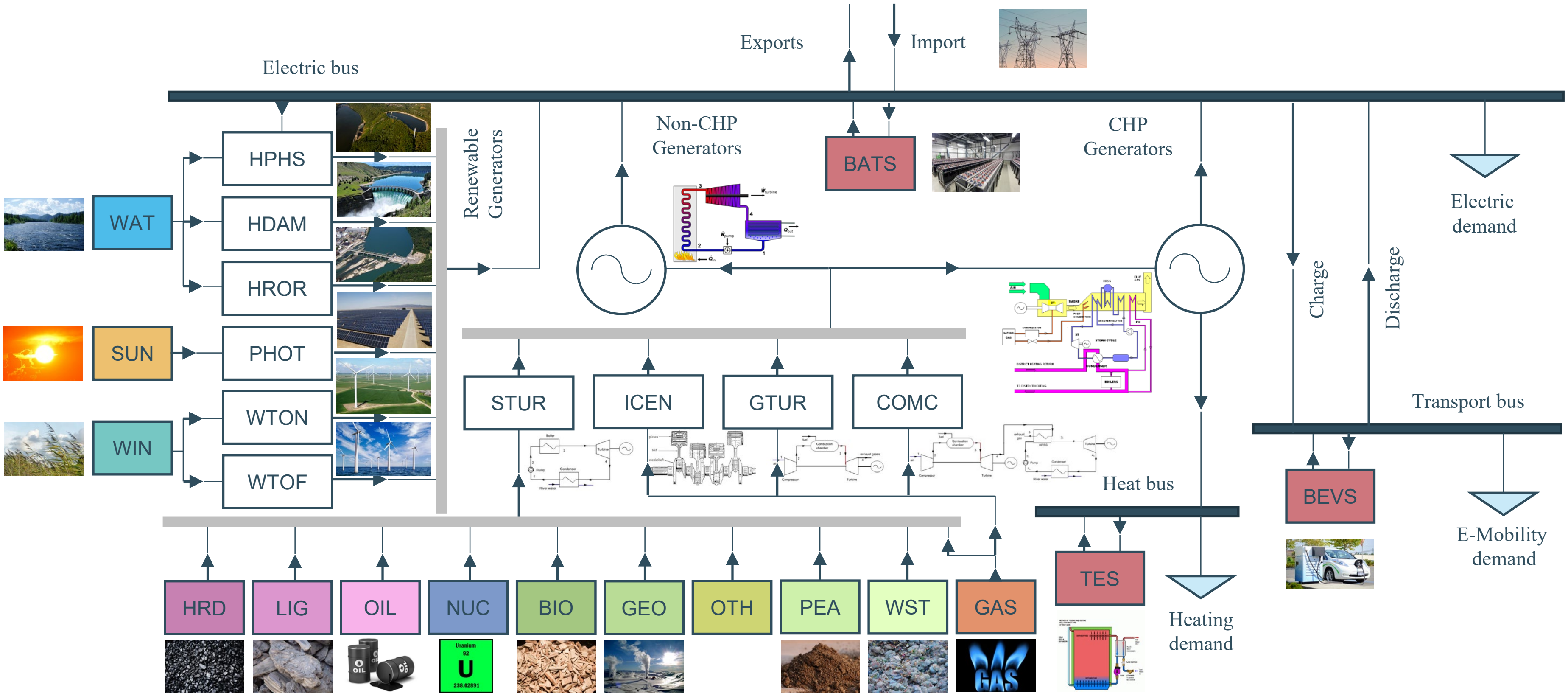


Dispa-SET 2.3: unit commitment and dispatch



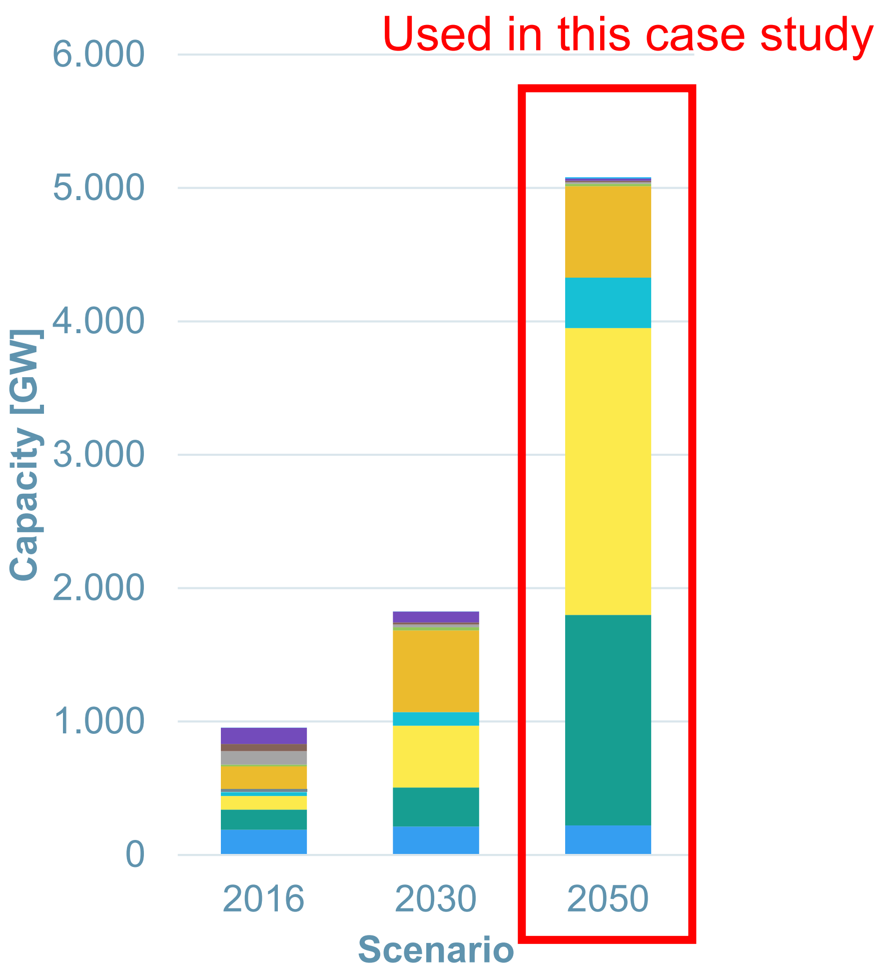
- Formulated as a tight and compact mixed integer program (MILP)
- Implemented in Python and *GAMS*, solved with *CPLEX*

Dispa-SET 2.3: System structure & technology overview for a single node



- Sector coupling options: P2H, P2V, V2G…

JRC-EU-TIMES ProRES Scenario

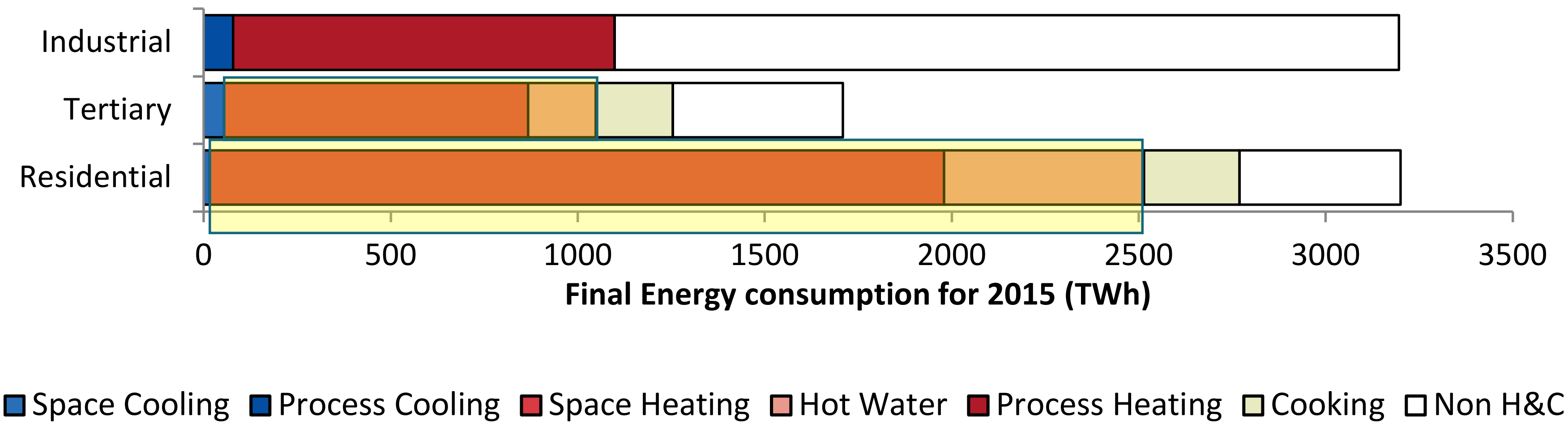


- Ambitious scenario in terms of additions of RES-E technologies
- Significant reduction of fossil fuel use, in parallel with nuclear phase out
- CCS doesn't become commercial
- Deep emission reduction is achieved with high deployment of RES, electrification of transport and heat and high efficiency gains
- Primary energy is about 430 Ej, renewables supply 93% of electricity demand in 2050

Evaluating the “suitable” heating demand

Heating and cooling needs are responsible for half of the EU28's energy consumption

In this analysis, we consider only space heating and DHW for the residential and tertiary sectors:

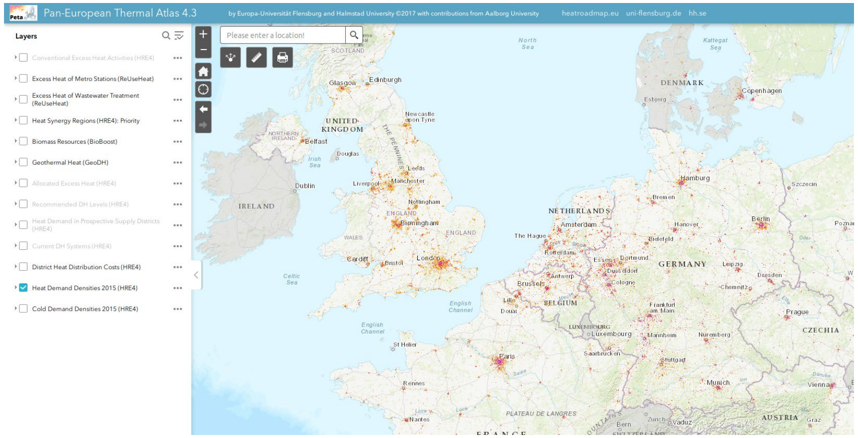


Data source: JRC IDEES Database

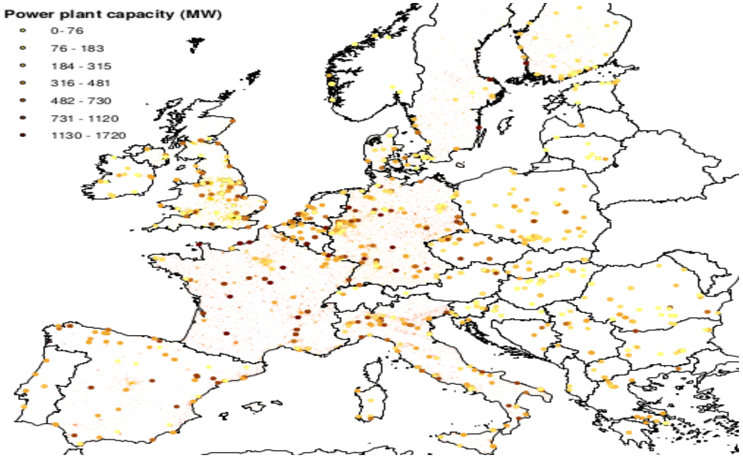
Evaluating the "suitable" heating demand

- We consider only the heating demand that fulfills the following conditions:
  - Medium heat demand density areas: > 120 TJ/km²
  - Maximum distance from a Power plant: 100 km

Pan-European Thermal Atlas Peta v4.3:



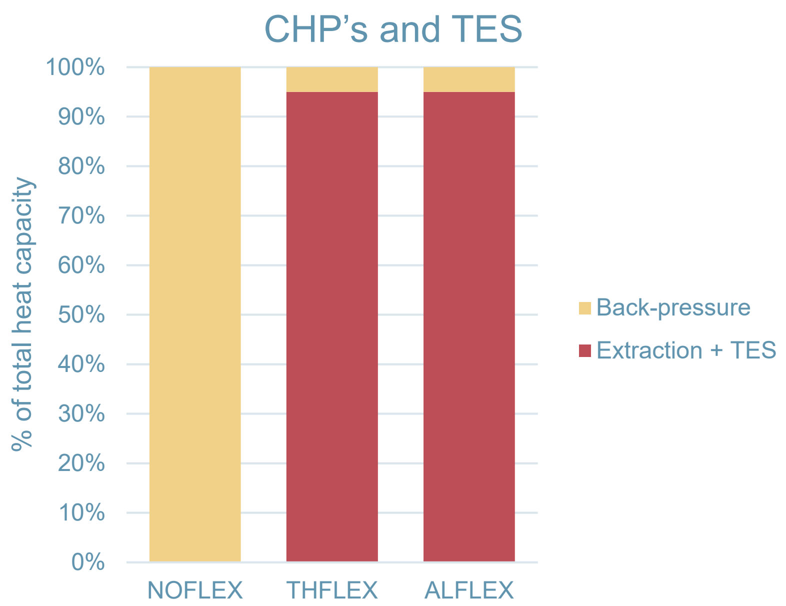
JRC Power plant database:

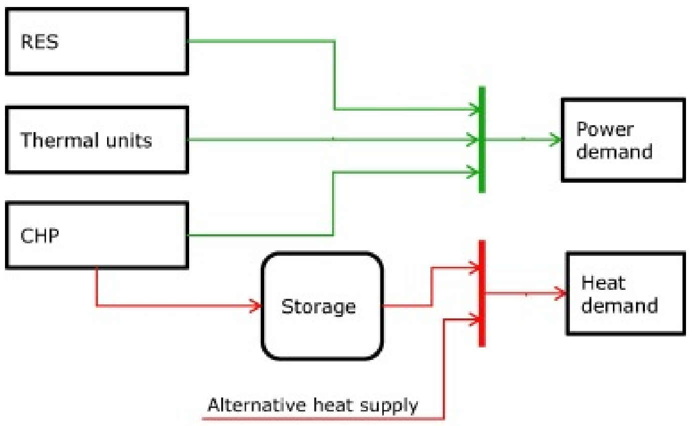


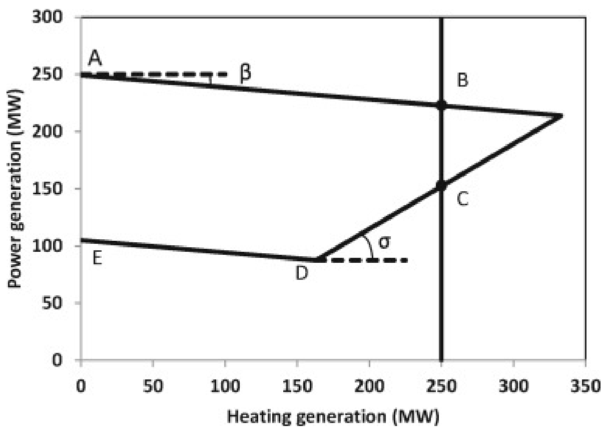
Considered heat demand: ~~[illegible]0~~ TWh → **690 TWh** (630 TWh in 2050)

Modeling the flexibility resources linked to DH

- Flexibility of CHP + thermal storage:
  - Back-pressure
    - no flexibility, based on P2H ratio, installed heat capacity = 100% of maximum hourly heat demand
  - Extraction + TES
    - dispatch flexibility, based on P2H ratio and Power Loss Factor
    - additional flexibility, provided by thermal storage unit (24H)

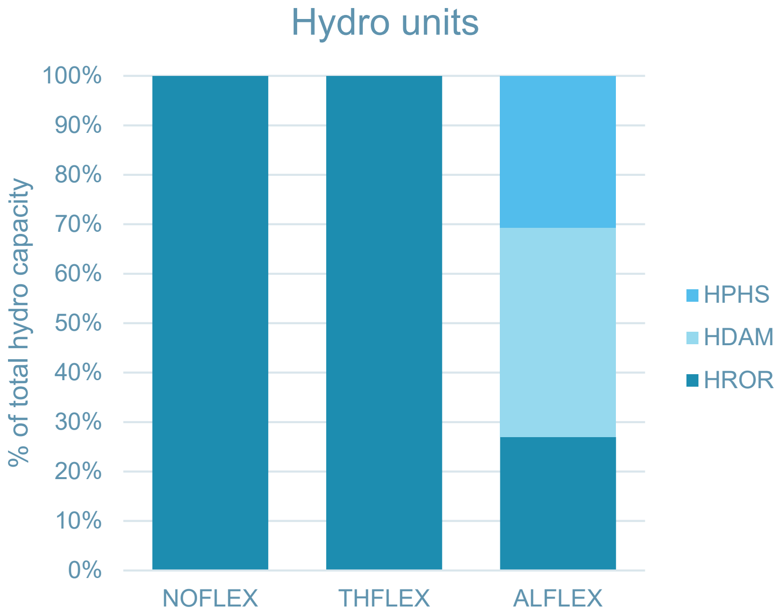






Alternative flexibility options: Hydro

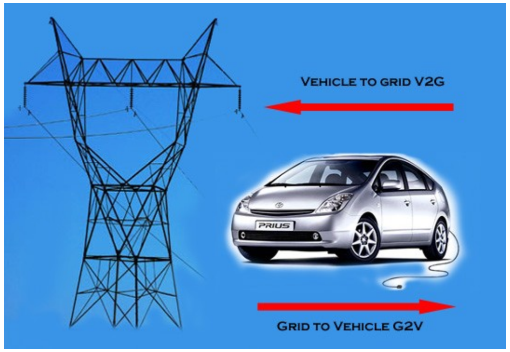
- Flexibility of hydro units:
  - HROR units
    - no flexibility, based on availability factors
  - HDAM units
    - dispatch flexibility, based on inflows and accumulation capacity
  - HPHS units
    - load shifting flexibility, pumped storage units based on inflows from upper and lower streams and accumulation capacity

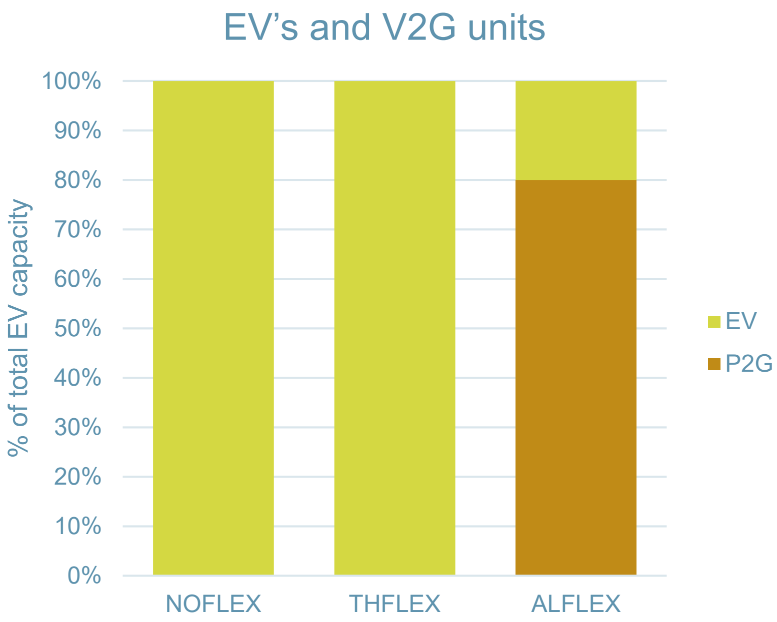


Alternative flexibility options: electric vehicles

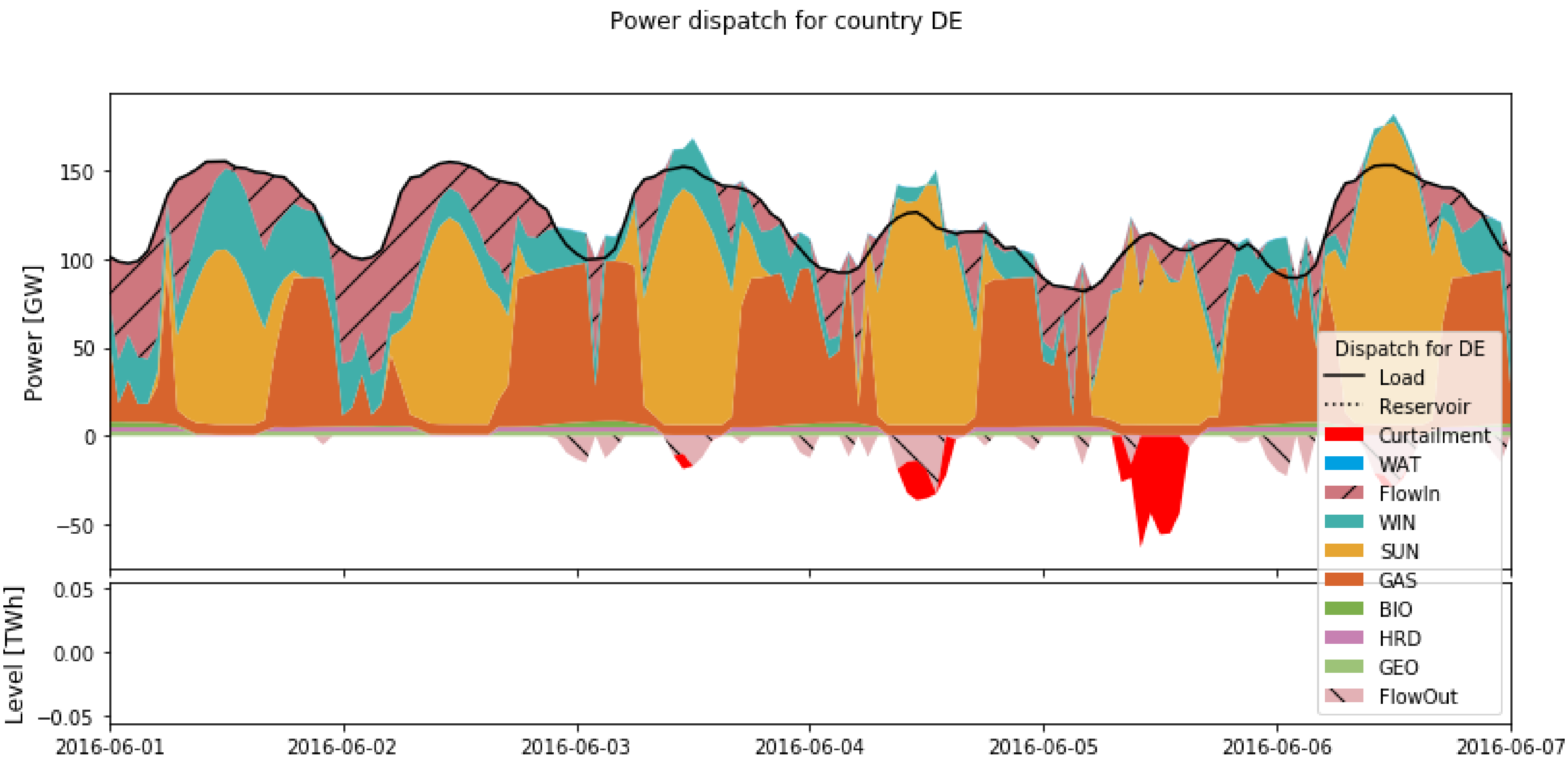
- We assume that EVs constitute 75% of the whole vehicle fleet by 2050

- Flexibility by EVs:
  - Base case:
    - no flexibility, based on charging patterns, charging demand integrated into the electricity demand
  - V2G
    - Possibility for the system to use the connected batteries. Restricted by the charging paterns and the share of the fleet that is connected to the grid and available for providing flexibility

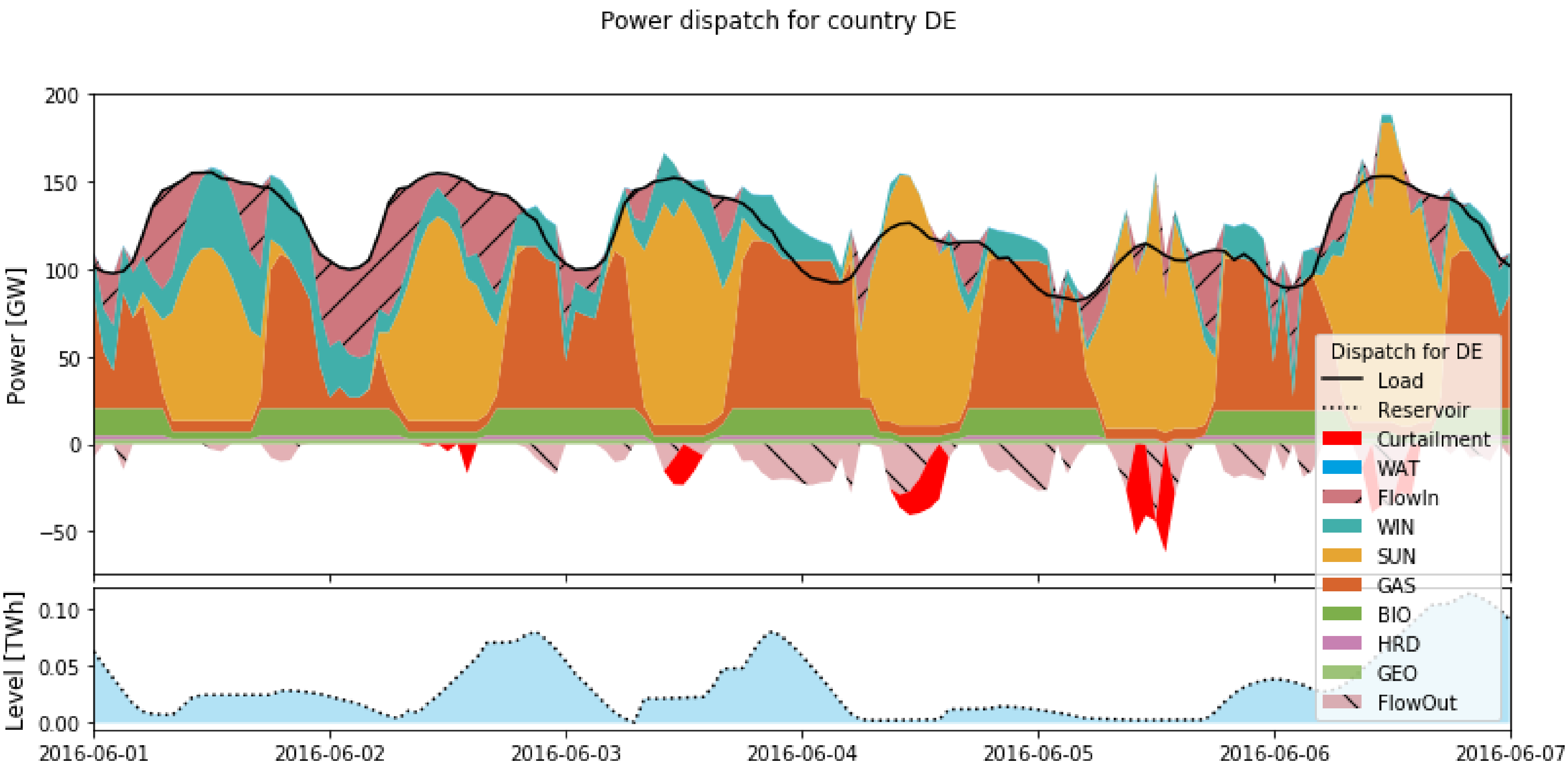




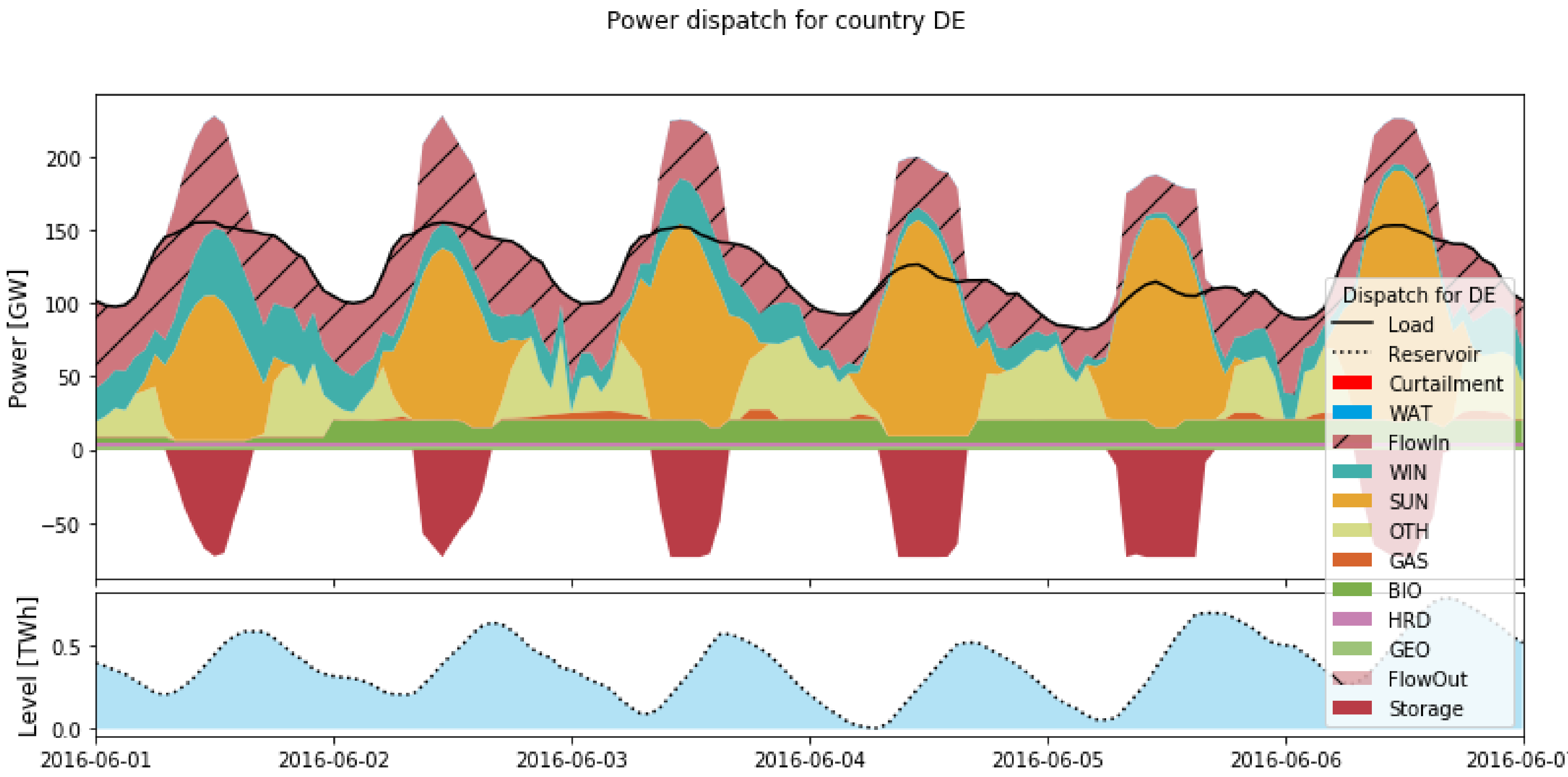
Example simulation results (Summer) – NOFLEX



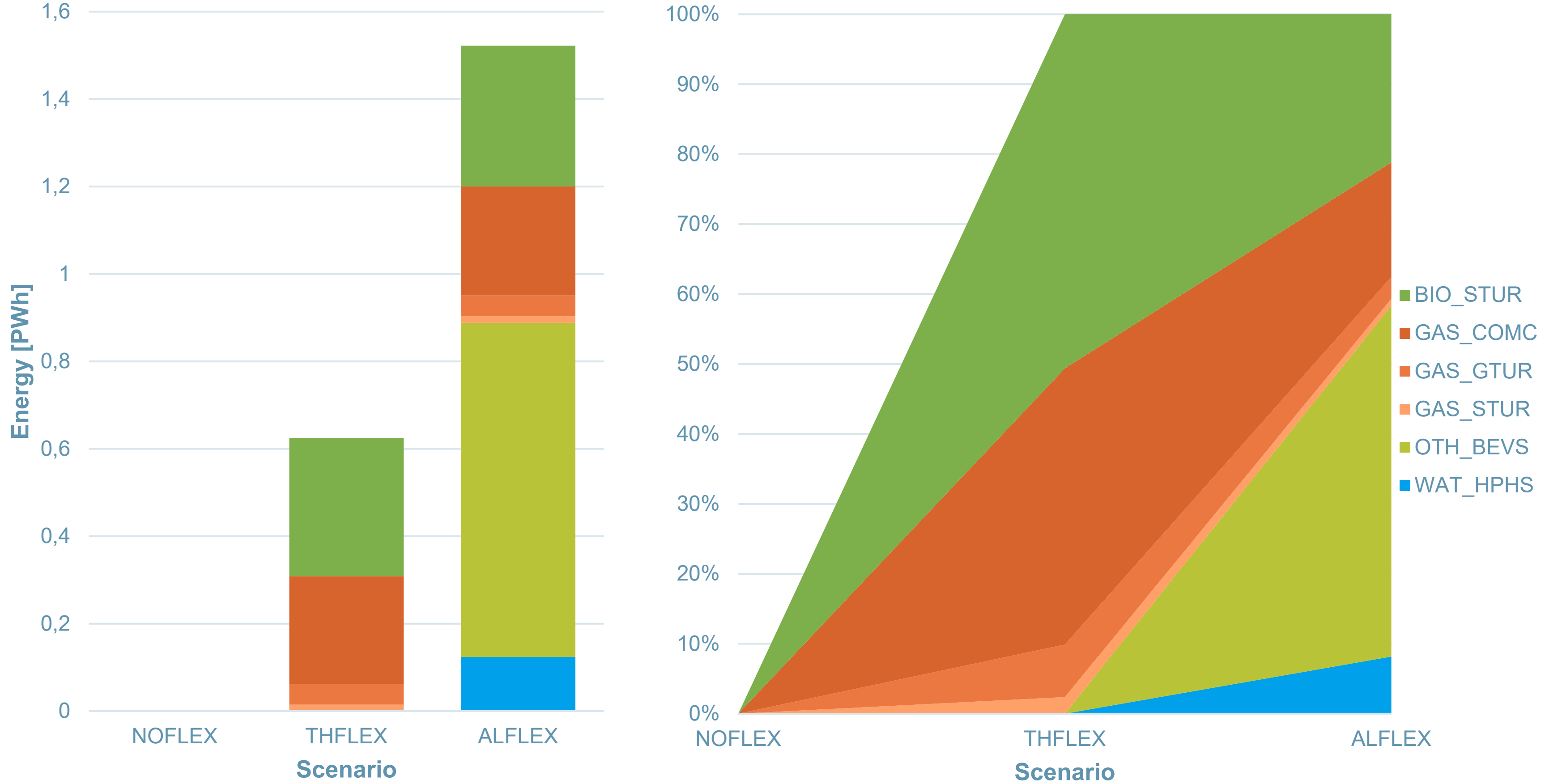
Example simulation results (Summer) – THFLEX



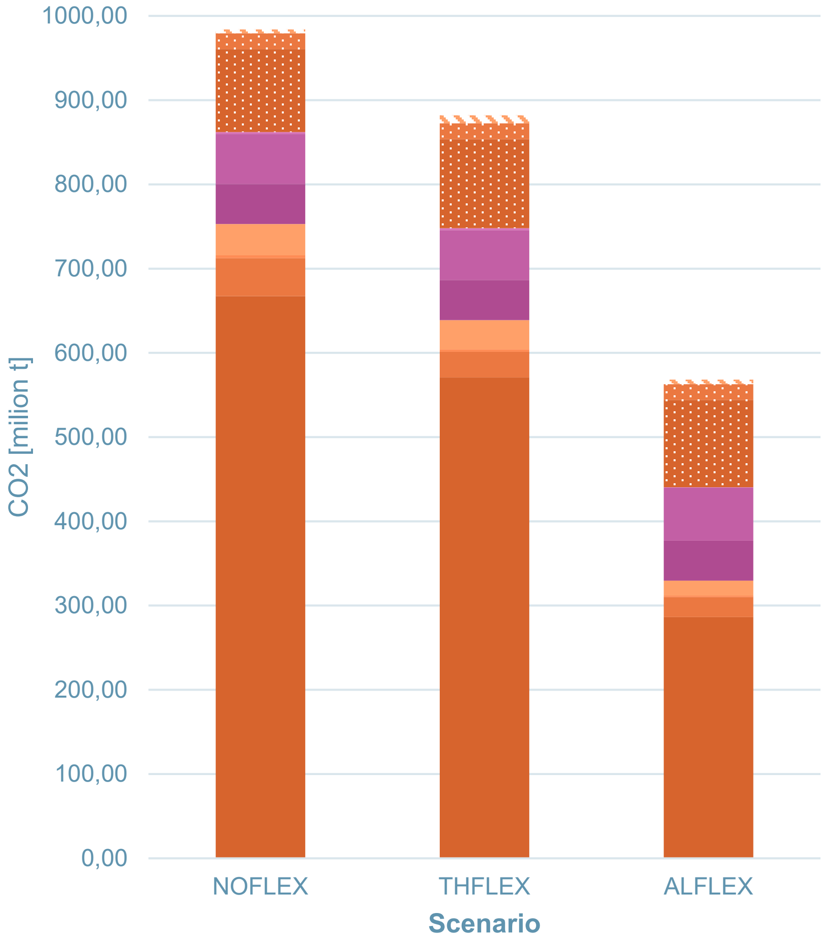
Example simulation results (Summer) – ALFLEX

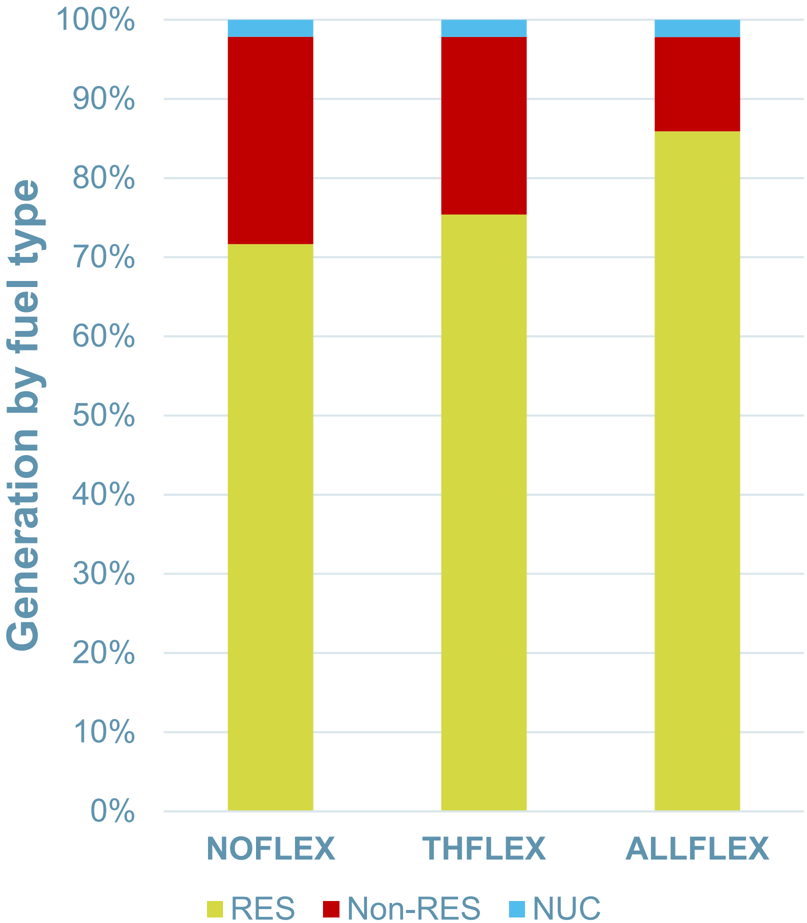


Flexibility - load shifting (Fuel / Technology)

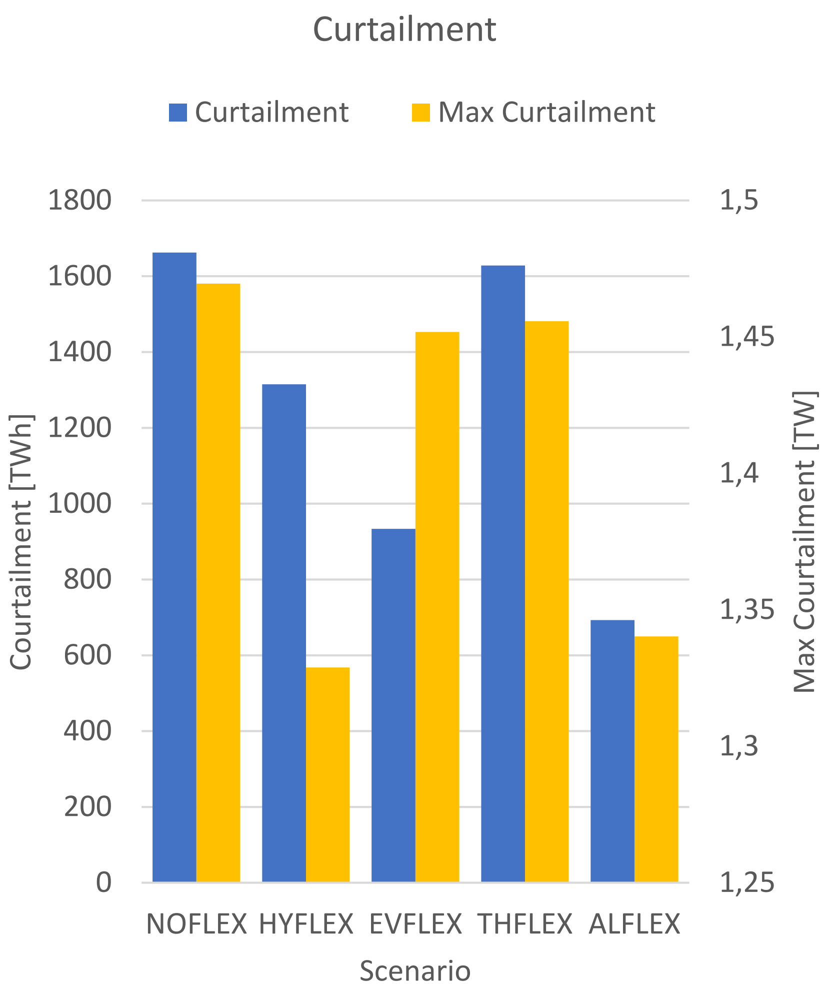


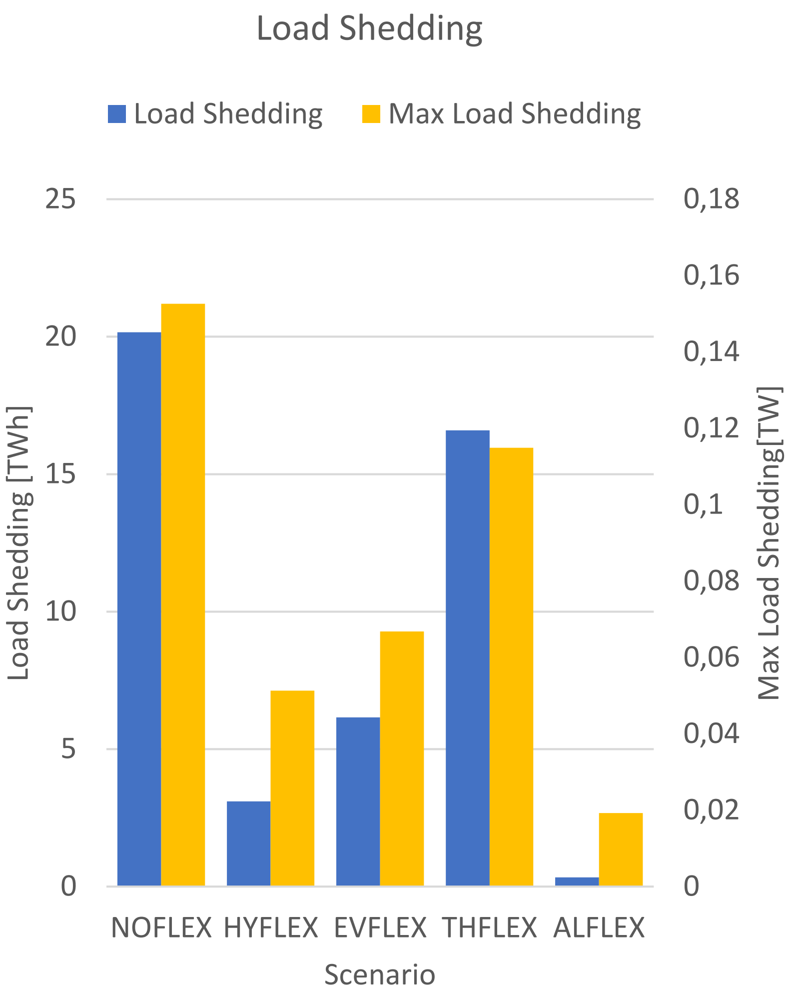
CO_2 Emissions and share of renewables





Effect of flexible technologies on curtailment and load shedding





Conclusions

- Soft-linking long-term planning models and power dispatch models allows to evaluate the adequacy and flexibility of the system, even over long time horizons.
- District heating with thermal storage does provide flexibility, but less than those provided by EVs or hydro power plants
- This is partly explained by the low share of the thermal demand covered by DH in our simulations. Considering heat pump with thermal storage would increase the benefits of heat-power sector coupling.
- All methods and models are released as **open-source** (Dispa-SET side):

https://github.com/energy-modelling-toolkit/Dispa-SET

GitHub

http://www.dispaset.eu

Thank You!

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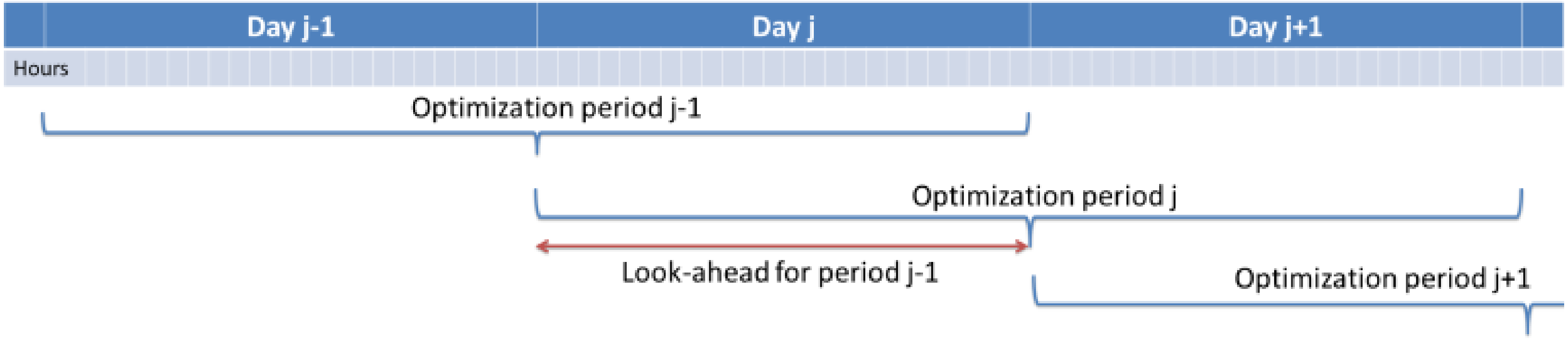
Time horizon

- Simulation is performed for a **whole year** with a **time step of one hour**,
- Problem dimensions (not computationally tractable for the whole time-horizon)
- Problem is **split into smaller optimization problems** that are run recursively throughout the year.
- Optimization **horizon is three days**, with a **look-ahead period of one day**.
- The initial values of the optimization for day j are the final values of the optimization of the previous day.
- Avoid issues linked to the end of the optimization period (emptying the hydro)



Dispa-SET 2.3 Inputs

Dispa-SET Configuration File

This is the standard configuration file for Dispa-SET. It defines the data sources for all the parameters and provides some indications regarding the structure of the data. This excel file must be provided when running the main dispa-set running script

Description	Standard simulation for 6 countries, with the MILP formulation				
Simulation director	Relative Path	Simulations/simulation_test			This section defines the output of the pre-processing (which is the input of the DispaSet solver)
Write excel	True/False	FALSE			The simulation environment is defined as a directory that contains all thre reuquired data and GAMS files
Write GDX	True/False	TRUE			It is recommended to write the data in the 3 different formats (excel, gdx, pickle), but if one is not needed,
Write Pickle	True/False	TRUE			it can be skipped.
GAMS path	Path				
Start date	Date	1/1/2015			Date and time parameters of the simulation
Stop date	Date	12/31/2015			Start and stop dates need to be within the provided data
Horizon length	Number of days	3			Hour 0 of the day is defined as midnight in timezone UTC+1
Look ahead	Number of days	1			
Clustering	True/False	TRUE			This sections defines parameters that influence the formulation of the problem
Simulation type	List	MILP			These parameters influence both the pre-processing (e.g. in LP clustering, all units are aggregated by type)
Reserve calculatio	List	Generic			and the solver (some constraints are removed when solving in LP)
Allow Curtailment	True/False	TRUE			
Demand	Relative Path	Database/Load_RealTime/##			
Outages	Relative Path				This section provides the paths to the raw data used to generate the Dispa-SET simulation template.
Power plant data	Relative Path	Database/PowerPlants/##/2(			The path is a relative path, the current directory being the one where DispaSET.py is executed.
Renewables AF	Relative Path	Database/AvailabilityFactors			
Load Shedding	Relative Path		Default value	0.05	For datasets which have one file per country, replace the country code (2 characters) in the path by ##.
NTC	Relative Path	Database/DayAheadNTC/1h/			for example:
Historical flows	Relative Path	Database/CrossBorderFlows			../data/Demand/##/2014/load.csv
Scaled inflows	Relative Path	Database/HydroData/Scaled			will fetch one load.csv file per country, by replacing ## with FR, DE, NL, etc.
Price of Nuclear	Relative Path		Default value	3	
Price of Black coa	Relative Path	Database/FuelPrices/Coal/2(	Default value	11	
Price of Gas	Relative Path	Database/FuelPrices/Gas/20	Default value	20	All fuel prices are in EUR/MWh of primary energy (lower heating value)
Price of Fuel-Oil	Relative Path	Database/FuelPrices/Oil/2015	Default value	35	
Price of Biomass	Relative Path	Database/FuelPrices/Biomas	Default value	37	
Price of CO2	Relative Path		Default value	7	
Reservoir Levels	Relative Path	Database/HydroData/Reserv			

Countries to consider

NUTS1 codes (ISO 3166-1 standard) of the simulated countries. NB: all the selected countries must be

AT	TRUE	IE	FALSE
BE	TRUE	IT	FALSE
BG	FALSE	LT	FALSE
CH	TRUE	LU	FALSE
CY	FALSE	LV	FALSE
CZ	FALSE	MT	FALSE
DE	TRUE	NL	TRUE
DK	FALSE	NO	FALSE
EE	FALSE	PL	FALSE
FI	FALSE	PT	FALSE

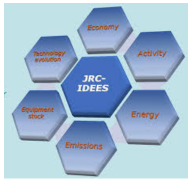
Input database:

- RES generation profiles
- Power plants
- Demand curves
- Outages
- Fuel prices
- Lines capacities
- Minimum reservoir levels

From the same database different levels of model complexity are available:

- *MILP*
- *LP with all power plants*
- *LP one cluster per technology*
- *LP presolve + MILP*

Dispa-SET validation for 2016



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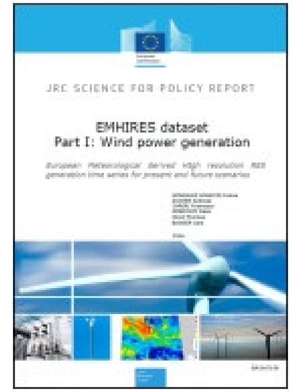

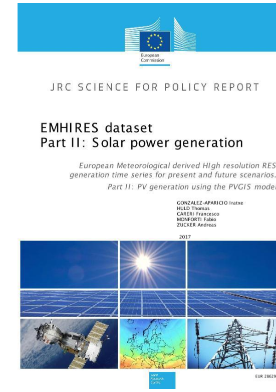

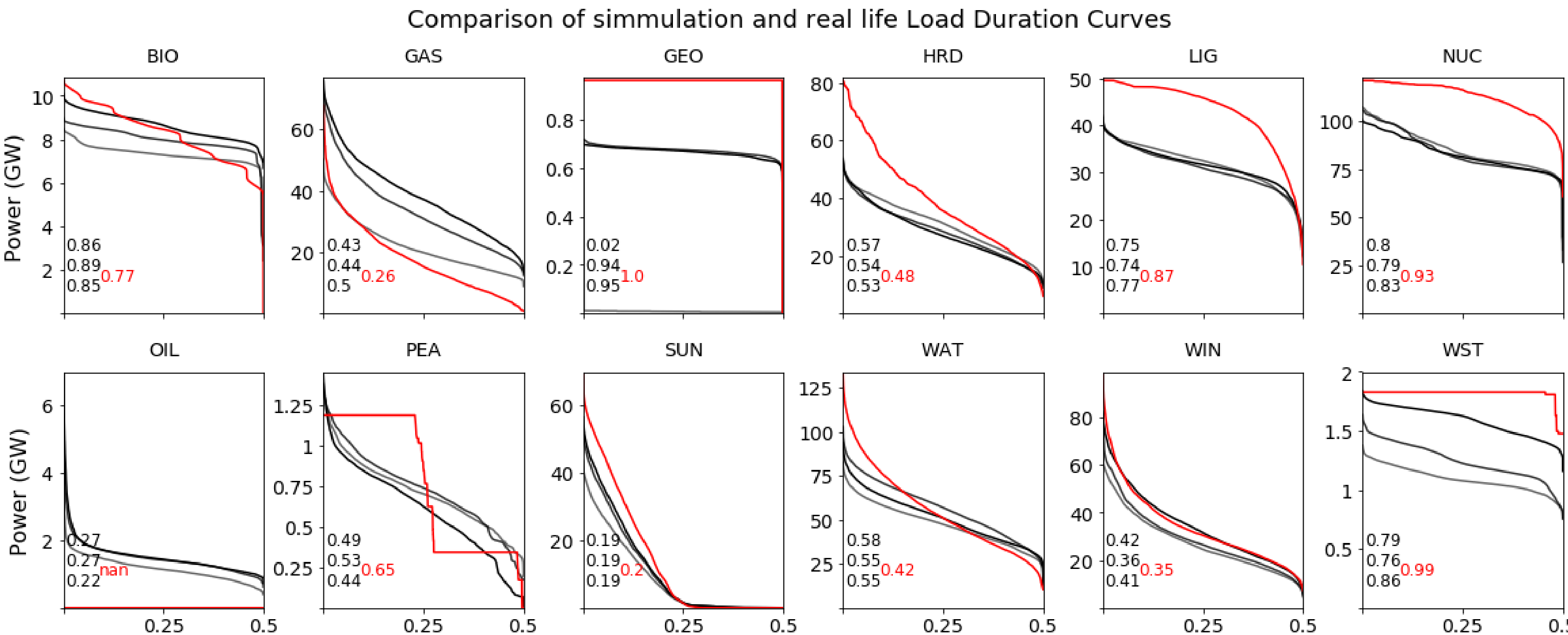

Validation of the Dispa-SET model (red lines) on the ENTSOE dataset (black/grey lines). The annotated factors correspond to the capacity factor of each technology/year.

Total system costs (Fuel / Technology)