Ayudando en los estudios eléctricos para hacer la transición energética

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Disclaimer

Soy un ingeniero

que trabaja en una Escuela de Ingeniería

al que le gusta la Optimización

Principio de cualquier desarrollador

No dejes que la realidad estropee un bello modelo matemático

1. Business intelligence
2. Software implementation
3. Optimization

1

Business intelligence

Where we are and where we must go

- In the 2019 European Green Deal and 2020 Fit for 55 legislative packages, the European Union and its Member States commit to reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.
- By 2030, renewable energy sources must generate 40% of total energy consumption.
- For electricity, this minimum percentage is 74%.
- In Spain, renewable generation reached 47% in 2021 and 42% in 2022, a reduction partly due to lower hydraulicity.

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How the electricity transition to a decarbonized power system can be achieved

- Energy Storage Systems (ESS) (e.g., hydropower plants, open- and closed-loop pumped-hydro storage, battery, EV, DSM, and solar thermal) and transmission networks are pillars for achieving decarbonization and integrating renewables

Key questions to analyze (i)

- Centralized vs. distributed solar PV production

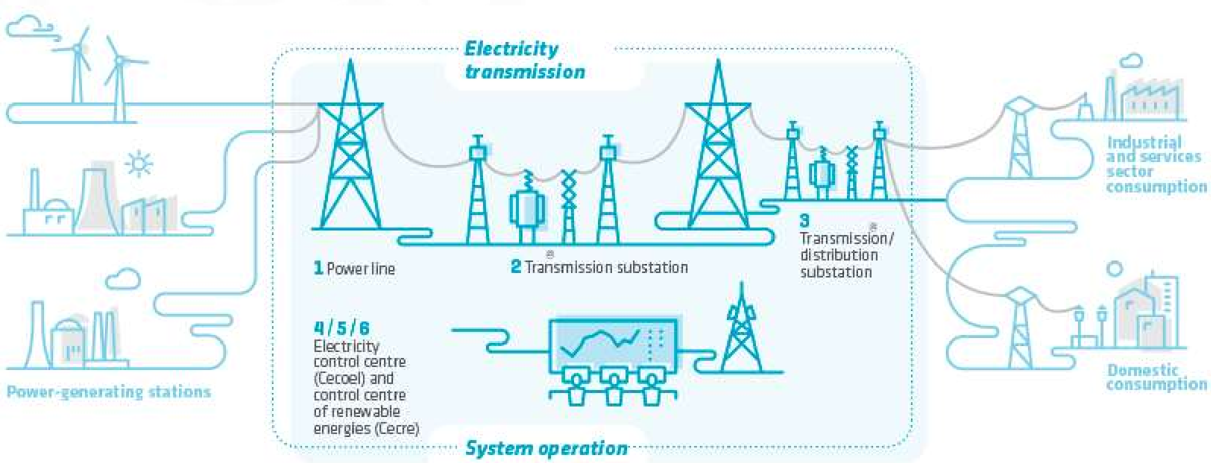
- Home vs. utility-scale batteries
- Closure of CCGTs or nuclear power plants in Spain
- Electrification of energy demand (heat pumps, electric vehicles, hydrogen production)

Key questions to analyze (ii)

- Flexibility of the electric demand. Local energy communities
- Pumped-hydro storage vs. batteries
- Uncertainty of renewables and security of supply (dunkelflaute)

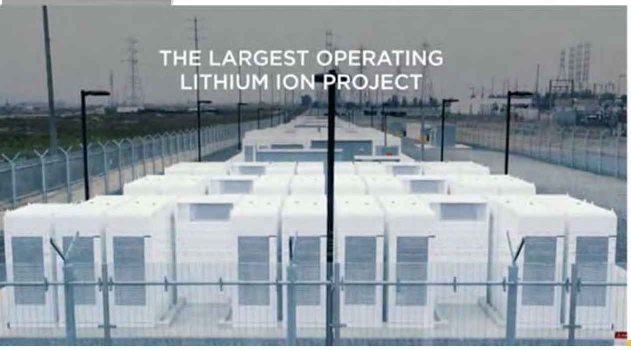
Main modeling features (i)

- Generation, storage, and transmission operation and expansion planning (GEP+SEP+TEP)
- Network-constrained unit commitment (NCUC)
- DC power flow (DCPF) with ohmic losses
  - [ACPF also available]



Main modeling features (ii)

- Energy Storage Systems (ESS) (e.g., hydropower plants, open- and closed-loop pumped-hydro storage, battery, EV, DSM, and solar thermal)
- Pumped-hydro storage (PHS), batteries, or DSM operate shifting energy between different timeframes and represent a small modification of the operation variable cost
    - Unit-based modeling of ESS



Generation, Storage, and Transmission Expansion (GEP+SEP+TEP)

- Determines the investment or retirement plans of new assets for supplying the forecasted demand at minimum cost.
- Minimum adequacy reserve margin [p.u.]
- The user pre-defined candidate generator, ESS, and lines.
  - Candidate lines can be HVDC or HVAC circuits.
  - [Candidate discovery allows to propose automatically new transmission candidates].
- Provides an investment plan while considering system operation. It incorporates a Unit Commitment and schedules the operation of medium- and short-term storage (i.e., pumped-hydro storage, batteries).

Dealing with uncertainty

- Several stochastic parameters that can influence the optimal expansion decisions are considered.
- The operation scenarios are associated with renewable energy sources, electricity demand, and natural hydro inflows

Demand and operating reserves

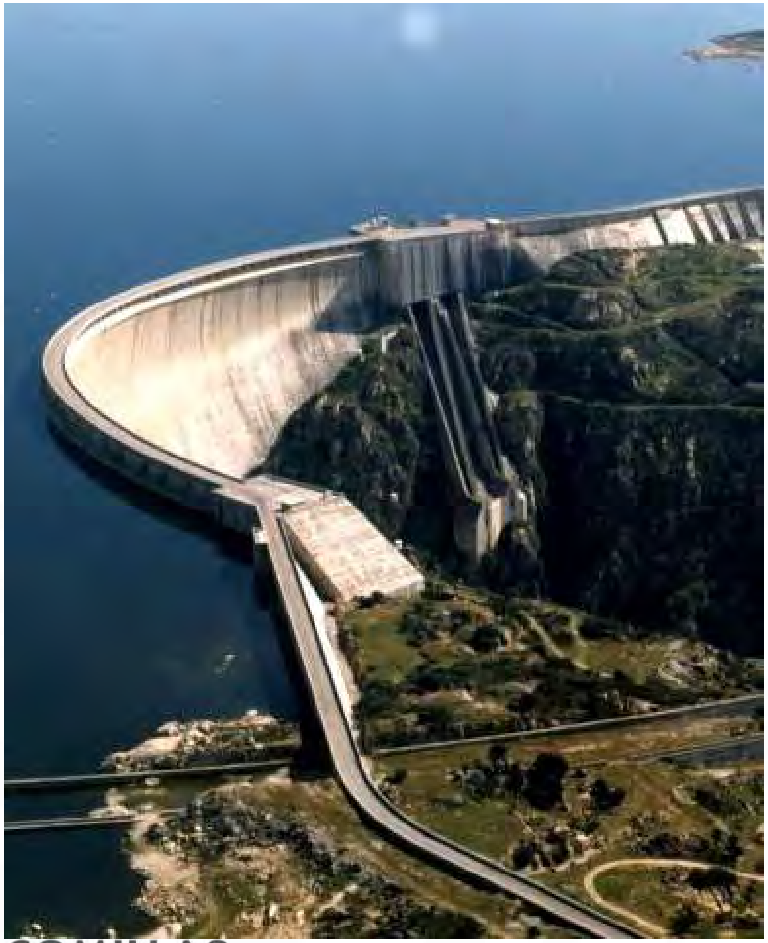
- Balance of generation and demand [GW]
- Upward and downward operating reserves (aFRR, mFRR, RR) [GW] provided by controllable generators (CCGT, storage hydro) and ESS (pumped-hydro storage, batteries), including reserve activation [GWh]
- Reserve activation parameter: a proportion (e.g., 25-30 %) of the power provided as operating reserves which is asked to be deployed as energy

S. Huclin et al. "*Exploring the roles of storage technologies in the Spanish electric system with high share of renewable energy*" Energy Reports 8:4041-4057, November 2022. 10.1016/j.egyr.2022.03.032

Thermal subsystem

- Maximum and minimum output of the second block of a committed unit (all except the VRES units) [p.u.]
- Total output of a committed unit [GW]
- Logical relation between commitment, startup, and shutdown status of a committed unit [p.u.]
- Maximum ramp up and down for the second block of a thermal unit [p.u.]
- Minimum up time and down time of a thermal unit [h]

Hydro and storage subsystems



- Power plants: hydro, open-loop pumped-hydro storage (PHS) aggregated in management units, closed-loop PHS treated individually, and system battery storage
- ESS energy inventory (only for load levels multiple of 24 or 168 h depending on the ESS type) [GWh]
- Energy outflows to represent H2 production or km for EV
- Total charge of an ESS unit [GW]
- Maximum and minimum charge of an ESS [p.u.]
- Incompatibility between charge and discharge of an ESS [p.u.]

Variable renewable energy (VRE)

- Power plants: solar PV, onshore wind, biomass, cogeneration, run-of-the-river hydro
- Maximum and minimum hourly variable generation

Research projects

- Open Modelling Toolbox for development of long-term pathways for the energy system in Africa (OpenMod4Africa), developed for the **European Union**.
- Analysis of the technical and economic benefits of solar thermal generation in the Spanish peninsular system, developed for **ProTermosolar**. March 2023. A. Ramos, L. Sigrist
- Hydro generation advanced systems: modeling, control, and optimized integration to the system (AVANHID), developed for the **Ministry of Science and Innovation/State Research Agency** (10.13039/501100011033) under the program **Public-Private Partnerships** with **NextGenerationEU/PRTR** funds (CPP2021-009114). December 2022 - November 2025. A. Ramos, J.M. Latorre, L. Rouco, L. Sigrist, I. Egido, J.D. Gómez
- Local markets for energy communities: designing efficient markets and assessing the integration from the electricity system perspective (OptiREC), developed for the **Ministry of Science and Innovation/State Research Agency** (10.13039/501100011033) under the program **Strategic projects oriented to the ecological transition and digital transition** with **NextGenerationEU/PRTR** funds (TED2021-131365B-C43). December 2022 - November 2024. A. Ramos, J.P. Chaves, J.M. Latorre, M. Troncia, S.A. Mansouri, O.M. Valarezo
- Delivering the next generation of open Integrated Assessment MOdels for Net-zero, sustainable Development (DIAMOND), developed for the **European Union**. October 2022 - August 2025. S. Lumbreras, L. Olmos, A. Ramos
- Application of the ENTSO-e cost-benefit analysis method to Aguayo II pumped-hydro storage, developed for **Repsol**. June 2022. A. Ramos, L. Olmos, L. Sigrist
- Application of the ENTSO-e cost-benefit analysis method to Los Guájares pumped-hydro storage, developed for **VM Energía**. May 2022 - June 2022. A. Ramos, L. Olmos, L. Sigrist
- Impact of the electric vehicle in the electricity markets in 2030, developed for **Repsol**. November 2021 - February 2022. A. Ramos, P. Frías, J.P. Chaves, P. Linares, J.J. Valentín
- European Climate and Energy Modelling Forum (ECEMF), developed for the **European Union**. May 2021 - December 2024. S. Lumbreras, A. Ramos, L. Olmos, C. Mateo, D. Santos Oliveira
- Assessment of the storage needs for the Spanish electric system in a horizon 2020-2050 with large share of renewables, developed for the **Instituto para la Diversificación y Ahorro de la Energía (IDAE)**. January 2021 - June 2022. A. Ramos, P. Linares, J.P. Chaves, J. García, S. Wogrin, J.J. Valentín
- FlexEner. New 100% renewable, flexible and robust energy system for the integration of new technologies in generation, networks and demand - Scenarios, developed for **Iberdrola** under **Misiones CDTI 2019** program (MIG-20201002). October 2020 - December 2023. M. Rivier, T. Gómez, A. Sánchez, F. Martín, T. Freire, J.P. Chaves, A. Ramos
- Improving energy system modelling tools and capacity, developed for the **European Commission**. October 2020 - June 2022. S. Lumbreras, A. Ramos, P. Linares, D. Santos, M. Pérez-Bravo, A.F. Rodríguez Matas, J.C. Romero
- MODESC – Platform of innovative models for speeding the energy transition towards a decarbonized economy, developed for the **Ministry of Science and Innovation** under **Retos Colaboración 2019** program (RTC2019-007315-3). September 2020 - December 2023. T. Gómez, M. Rivier, J.P. Chaves, A. Ramos, P. Linares, F. Martín, L. Herding
- Open ENergy TRansition ANalyses for a low-carbon Economy (openENTRANCE), developed for the **European Union**. May 2019 - June 2023. L. Olmos, S. Lumbreras, A. Ramos, E. Alvarez
- Analysis of the expansion and operation of the Spanish electricity system for a 2030-2050 time horizon, developed for **Iberdrola**. January 2019 - December 2021. M. Rivier, T. Gómez, A. Sánchez, F. Martín, T. Freire, J.P. Chaves, T. Gerres, S. Huclin, A. Ramos

EUROPEAN CLIMATE+ENERGY MODELLING FORUM

open ENTRANCE

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DIAMOND. Scope of the analysis

- Interoperable interface of the openTEPES model will be developed for GCAM-Europe, OMNIA, and OPEN-PROM, allowing to assess the network needs in IAM scenarios and identifying no-regret investments common among scenarios toward constituting the basic architecture of a European expansion plan

ECEMF. Scope of the analysis

- Research question: What is the tradeoff between hydrogen and electricity for heat production?
- Scenario: DIAG-C400-lin, Target Year = 2050
- Target technologies (deployment and use to be optimized):
  - Hydrogen production (electrolyzers)
  - RES generation for heat
  - Transmission network
- Use of TYNDP 2022 Distributed Energy 2050 for data disaggregation

openENTRANCE. Scope of the analysis

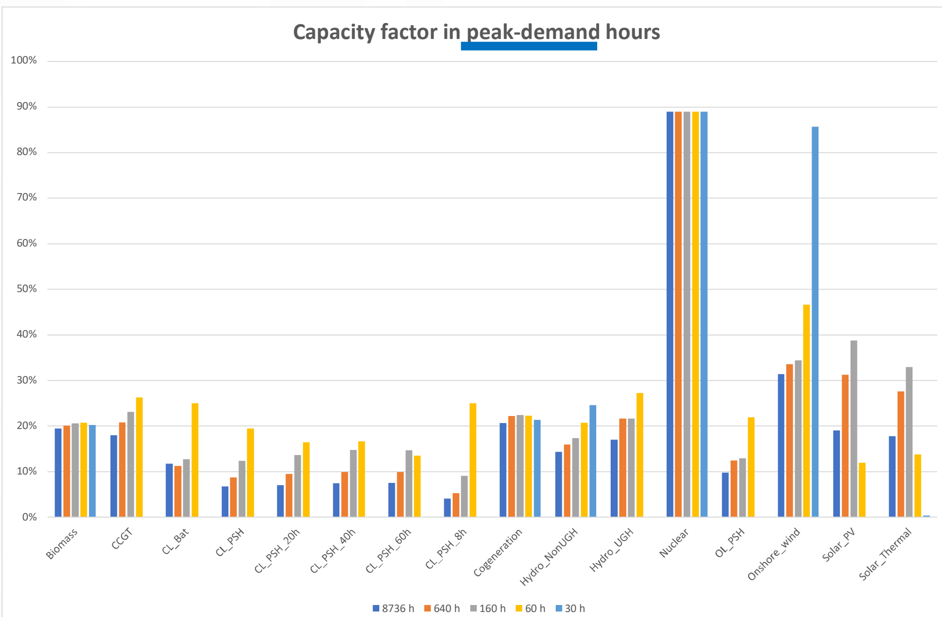
- Analysis of the impact on the system operation, the transmission network development, the level of use of the several flexibility sources, and wholesale electricity prices of local energy communities (LECs)
- Assessing to what extent the flexibility provided by LECs is a substitute for that to be supplied by centralized storage (batteries, pumped hydro) and the grid
- The introduction of LECs is only considered within the Spanish and the Norwegian systems, which are represented with a higher level of detail (several areas per country and more detailed modeling of storage management)
- The rest of the European system is only represented at an aggregate level (single node per country and more simplified management of storage)
- Only the development of the transmission grid is affected by an increase in the penetration of LECs
- Techno-friendly Scenario considered: high environmental awareness, bottom-up societal revolution, and top-down technology revolution
- Static planning: 1 year (2030 horizon) with hourly resolution

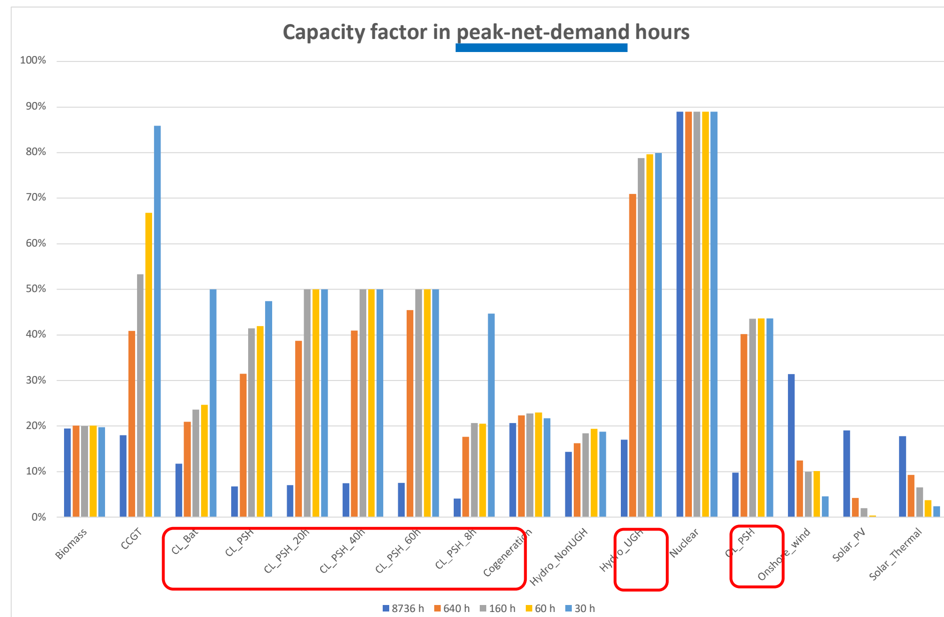
TIMES-SINERGIA. Scope of the analysis

- Development of additional features of TIMES-SINERGIA to improve the Spanish energy system
- Top-down connection with power sector model openTEPES
- Both models are the core for the update of the Spain NECP

Firmness/Electric Load Carrying Capability (ELCC)

Capacity factors of the different technologies at peak hours of demand and net demand





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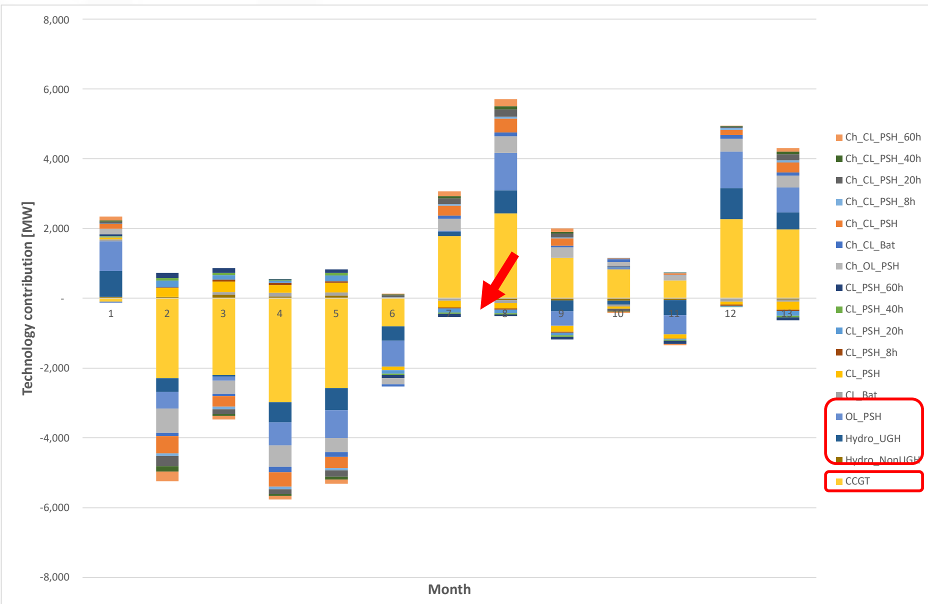
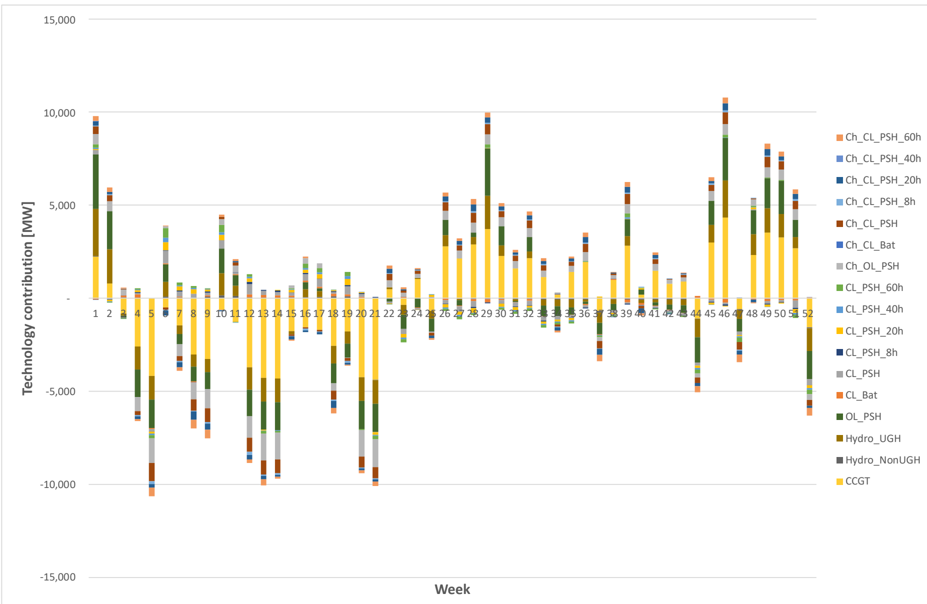
Flexibility

Technology contribution to the monthly/weekly variation of the net demand (difference between the value and its mean)





A. Ramos “*Assessing the operational flexibility provided by energy storage systems. The Spanish system in 2030*” IEA Wind Task 25 Spring 2021 meeting. April 2021

2

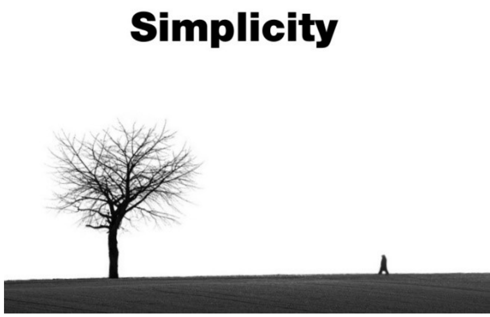
Software implementation

The EU's open science policy

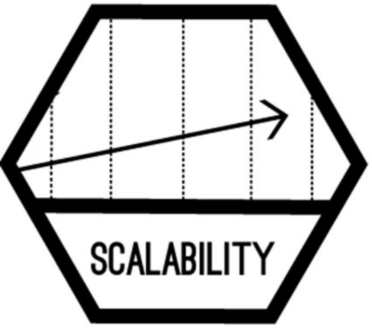
- Open data. FAIR (Findable, Accessible, Interoperable, and Re-usable data)

- Open-source software

Software Development Goals



- Simplicity and transparency
- Code written to be read by humans
- Scalability: from small- to large-scale cases
- Chronological model with a flexible duration of the time step (e.g., bi-hour, 3-hour, 4-hour time step), but also representative periods



Simplicity and Transparency

- Replicating the GAMS structure and elegance in Python/Pyomo
- Separation between
  - Dictionaries of sets
  - Parameters
  - Variables
  - Equations
  - Solve
  - Output results
- Input data and output results in text format (csv)

open TEPES

openTEPES

version 4.11.4

Navigation

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Open Generation, Storage, and **T**ransmission Operation and **E**xpansion **P**lanning Model with RES and **ES**S (**openTEPES**)

iiT

"Simplicity and Transparency in Power Systems Planning"

The **openTEPES** model has been developed at the Instituto de Investigación Tecnológica (IIT) of the Universidad Pontificia Comillas.

It is integrated in the open energy system modelling platform helping modelling Europe's energy system.

Reference: A. Ramos, E. Quispe, S. Lumbreras "OpenTEPES: Open-source Transmission and Generation Expansion Planning" SoftwareX 18: June 2022 10.1016/j.softx.2022.101070

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Read the Docs

https://opentepes.readthedocs.io/en/latest/index.html

A. Ramos, E. Quispe, S. Lumbreras "OpenTEPES: Open-source Transmission and Generation Expansion Planning" SoftwareX 18: June 2022 10.1016/j.softx.2022.101070

DOI: https://doi.org/10.24433/CO.8709849.v1

GitHub - IIT-EnergySystemModels/openTEPES: Open Generation, Storage, and Transmission Operation and Expansion Planning Model with RES and ESS (openTEPES)

GNU AFFERO GENERAL PUBLIC LICENSE. Version 3 (AGPLv3)

- The code can't become part of a closed-source commercial software product
- Any future changes and improvements to the code remain free and open

- Guarantee end users the freedom to run, study, share, and modify the software
- Any derivative work must be distributed under the same or equivalent license terms
- The licensee is allowed to charge a fee for this service or do this free of charge.
- Software under the GPL may be run for all purposes, including commercial purposes and even as a tool for creating proprietary software
- Demands the distribution of the source code if the program is used over a computer network

AGPL 3 Free Software
Free as in Freedom

Modeling Overview

- Built according to a bottom-up paradigm.
- It applies optimization to find the optimal generation, storage, and transmission expansion plan (GEP+SEP+TEP).
- Uses Mixed-Integer Linear Programming (runs on GUROBI, GLPK, or CBC) to solve the problem.
    - [Benders decomposition available for solving large-scale problems]

GUROBI OPTIMIZATION

3

Optimization

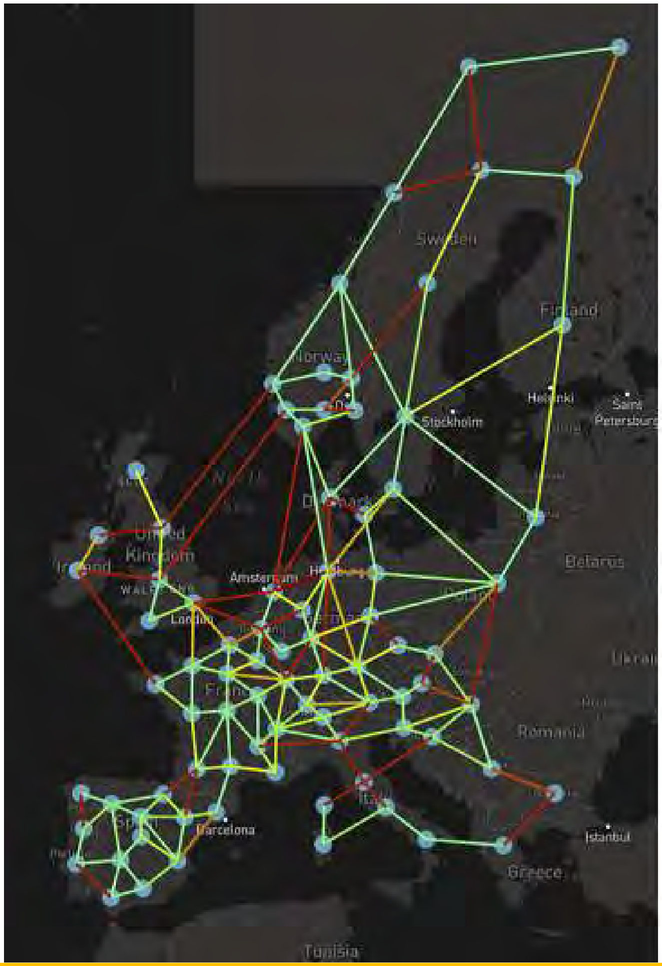
Optimization modeling (i)

- Consistent and reduced solution time
- Get dual variables
  - Electricity locational marginal price (LMP)
- Sizes of some real cases

```
                      Case SEP2030
 2999548 rows, 3513436 columns, 11508142 nonzeros
                      Case ES2030
 5162243 rows, 6832942 columns, 21554828 nonzeros
                   Case TYNDP DE2050
22157904 rows, 26966415 columns, 73814159 nonzeros
```

Spain ES2030

Europe TF2030



Optimization modeling (ii)

- Numerical stability
  - Natural scaling variables and constraints around 1
  - Make 0 very small values
  - Condition number
  - Crossover
- Tight and compact formulation of some constraints with binary variables (minimum up/down time, startup/shutdown)
- Facilitate preprocessing
- Benders decomposition for very-large-scale cases

Mathematical formulation

https://opentepes.readthedocs.io/en/latest/MathematicalFormulation.html

Transmission system		
ict^p_{ijc}	Candidate line installed or not	{0,1}
$swt^p_{\omega nijc}, son^p_{\omega nijc}, sof^p_{\omega nijc}$	Switching state, switch-on and switch-off of a line	{0,1}
$f^p_{\omega nijc}$	Flow through a line	GW
$l^p_{\omega nijc}$	Half ohmic losses of a line	GW
$\theta^p_{\omega ni}$	Voltage angle of a node	rad

Equations

The names between parenthesis correspond to the names of the constraints in the code.

Objective function: minimization of total (investment and operation) cost for the multi-period scope of the model

Generation, storage and network investment cost plus retirement cost [M€] «`eTotalFCost`»

$$\sum^p_g DF^p CFG_g icg^p_g + \sum_{pg} DF^p CFR_g rcg^p_g + \sum_{pijc} DF^p CFT_{ijc} ict^p_{ijc} +$$

Generation operation cost [M€] «`eTotalGCost`»

$$\sum_{p\omega ng} [DF^p P^p_\omega DUR_n (CV^p_{\omega ng} gp^p_{\omega ng} + CF^p_{\omega ng} uc^p_{\omega ng}) + DF^p CSU_g su^p_{\omega ng} + DF^p CSD_g sd^p_{\omega ng}] +$$

Generation emission cost [M€] «`eTotalECost`»

$$\sum_{p\omega ng} DF^p P^p_\omega DUR_n CE_g gp^p_{\omega ng} +$$

Variable consumption operation cost [M€] «`eTotalCCost`»

$$\sum_{p\omega ne} DF^p P^p_\omega DUR_n CV_e gc^p_{\omega ne} +$$

Reliability cost [M€] «`eTotalRCost`»

$$\sum_{p\omega ni} DF^p P^p_\omega DUR_n CENSens^p_{\omega ni}$$

All the periodical (annual) costs of a period p are updated considering that the period (e.g., 2030) is replicated for a number of years defined by its weight WG^p (e.g., 5 times) and discounted to the base year T (e.g., 2020) with this discount factor $DF^p = \frac{(1+\delta)^{WG^p}-1}{\delta(1+\delta)^{WG^p-1+p-T}}$.

Constraints

v: latest

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Thank you for your attention

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