# Energy System Modeling in the INTERENERGY project: H2RES model.

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# The INTERENERGY project

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InterEnergy

- INTERENERGY: Investigating energy transitions pathways – Interrelation between power-to-X, demand response and market coupling.

- Main goals of the project
  - ✓ Optimal mix between Power-to-X and demand response technologies.
  - ✓ Provide comprehensive knowledge about these technologies and their opportunities on emerging markets
  - ✓ Provide an environment well suited to the education of new generation of researchers

- To achieve these objectives we,
  - ✓ Develop a bottom-up model which allows for consideration of several types of technologies with different techno/economic characteristics.
  - ✓ Free and open sources for researchers to use.

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- The **H2RES** model, we develop and propose:
  - ✓ A linear program optimization model.
  - ✓ A Long-term energy capacity investment model with hourly dispatch resolution.
  - ✓ A model that provides the "cheapest" mix of technologies (transition) to supply the energy demand from different sectors.

- The H2RES model optimizes the mix of technologies and provides the optimal:
  - ✓ Size or capacities (investment of different technologies and power plants)
  - ✓ Dispatch of such technologies
  - ✓ Transformation of energy carriers
  - ✓ Storage levels
  - ✓ Critical Excess of Electricity Production (CEEP)
  - ✓ Other

- The optimization is done to comply with different policy options, including limits on CEEP, penetration of RES, limits on $CO_2$ emissions from different sectors, others.

# Methods: The H2RES model

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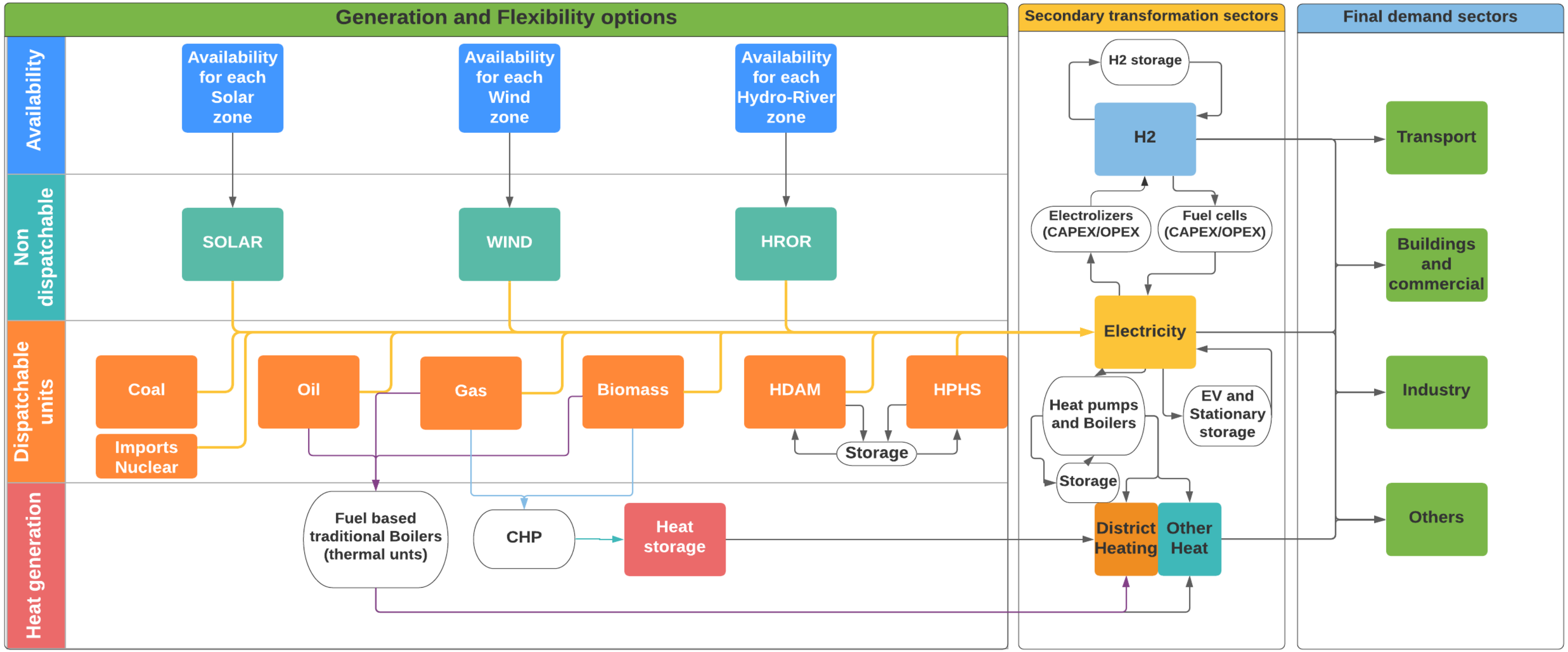


A long-term Optimization Energy Planning Model

Yearly decisions: Optimize sizing problem (size or capacities of existing and new technologies)

Hourly decisions: Given the optimal sizes, we model the dispatch that minimizes the total operational cost

# Methods: The H2RES model

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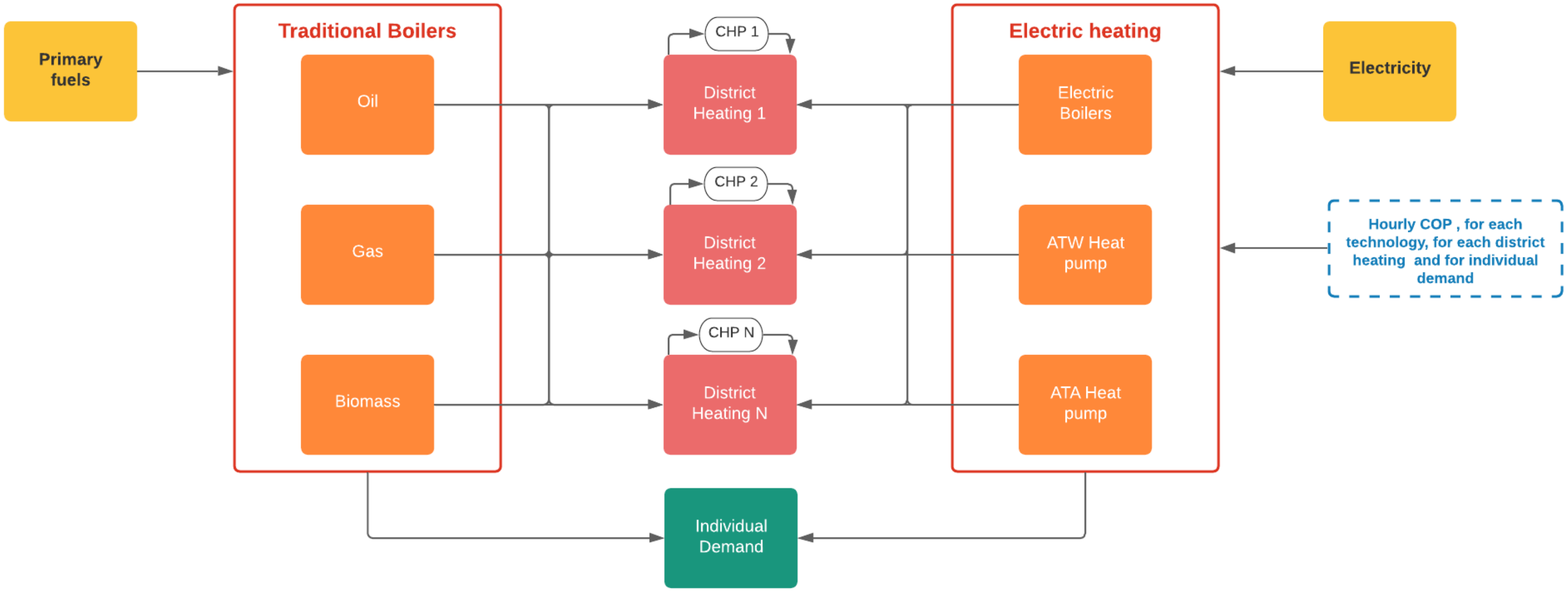
❖ The **H2RES** model: Heating sector and Power-to-Heat

- ✓ The heating sector considers District Heating (DH) demand sectors (no limit) and individual space heating demand.
- ✓ DH demand sectors may (or not) have a CHP (different fuels) plant and heat storage.
- ✓ Both DH sectors and individual heat demand ban be supplied by traditional boilers and electric heating (different heat-pump technologies and boilers).



# Methods: The H2RES model

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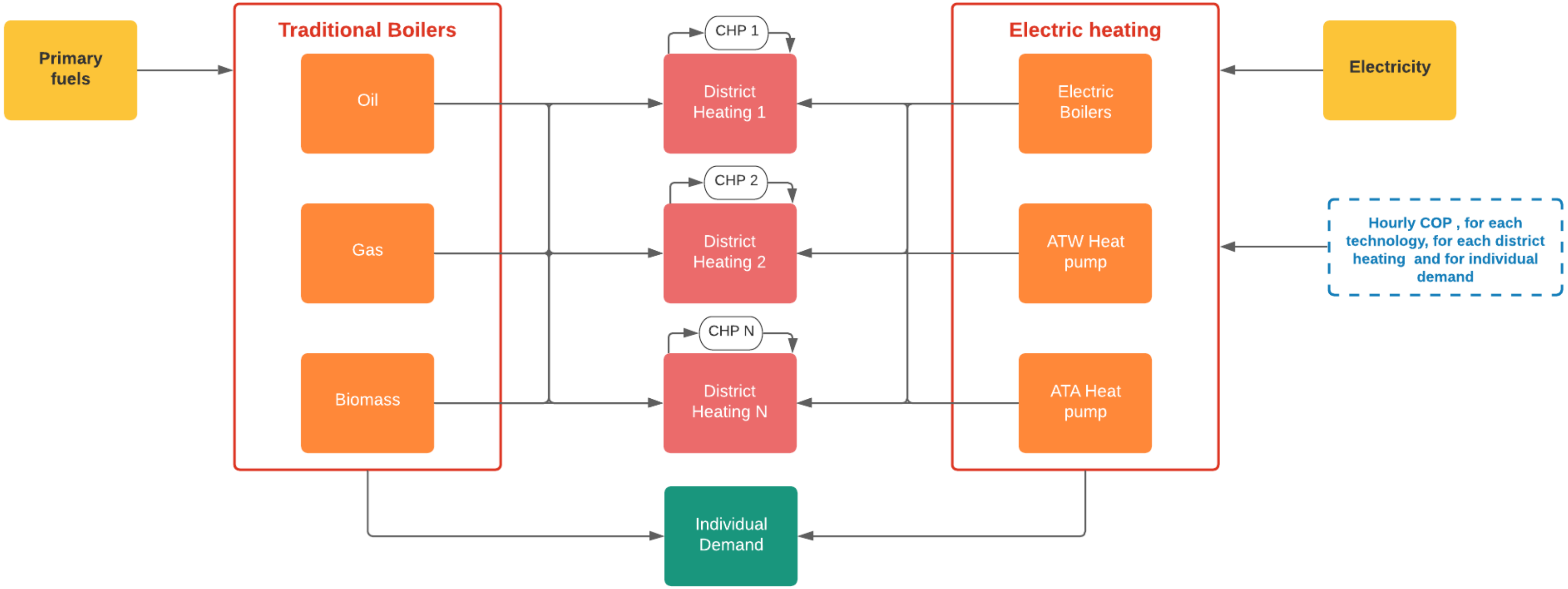
- The **H2RES** model: Heating sector and Power-to-Heat




- Constraints include:
  - Heat network storage size, supply = demand, heat storage for individual heating (electric heating), fuel prices for traditional boilers, investments in capacity for each DH area and individual heating, among others

# Methods: The H2RES model

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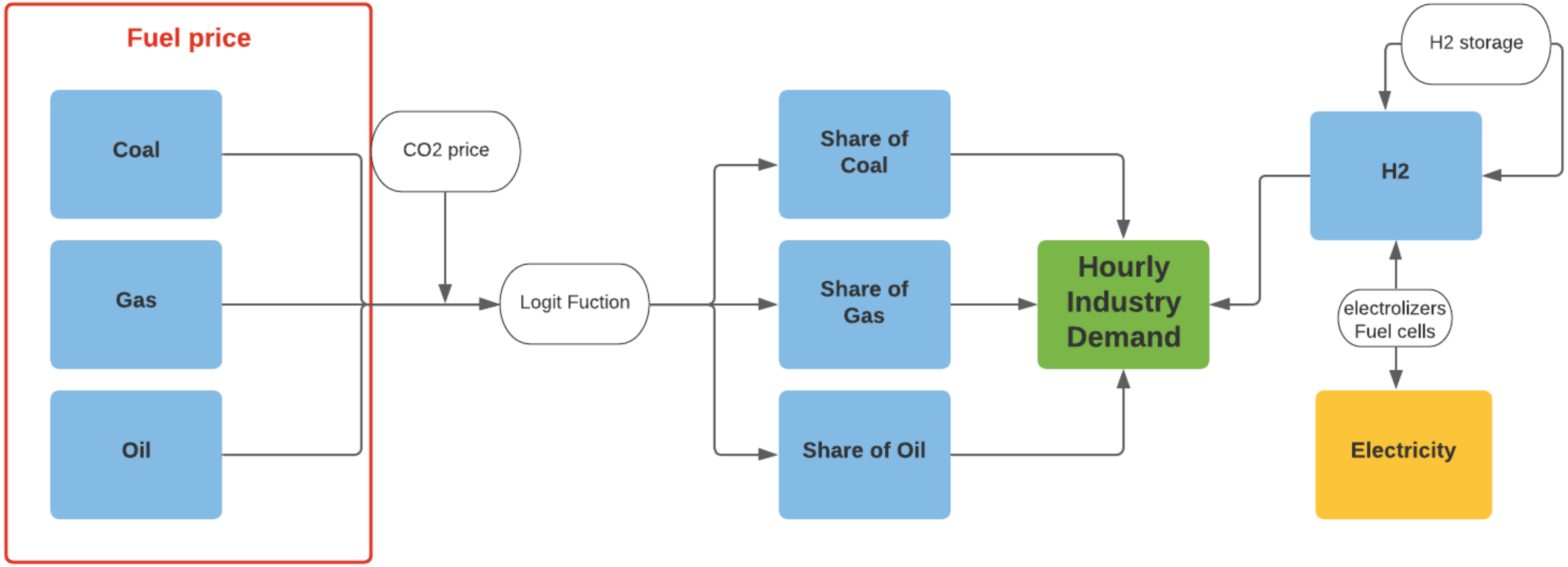
## ❖ The **H2RES** model: Industry sector

- ✓ The model considers a profile for energy demand in industry. Different industries are grouped as a single demand; however, it is possible to desegregate.
- ✓ Fuel utilization to satisfy the demand level follows a "logit function" approach rather than a purely cost approach.
- ✓ H2 is used to decarbonize the industry sector (we can include electricity, WIP)



# Methods: The H2RES model

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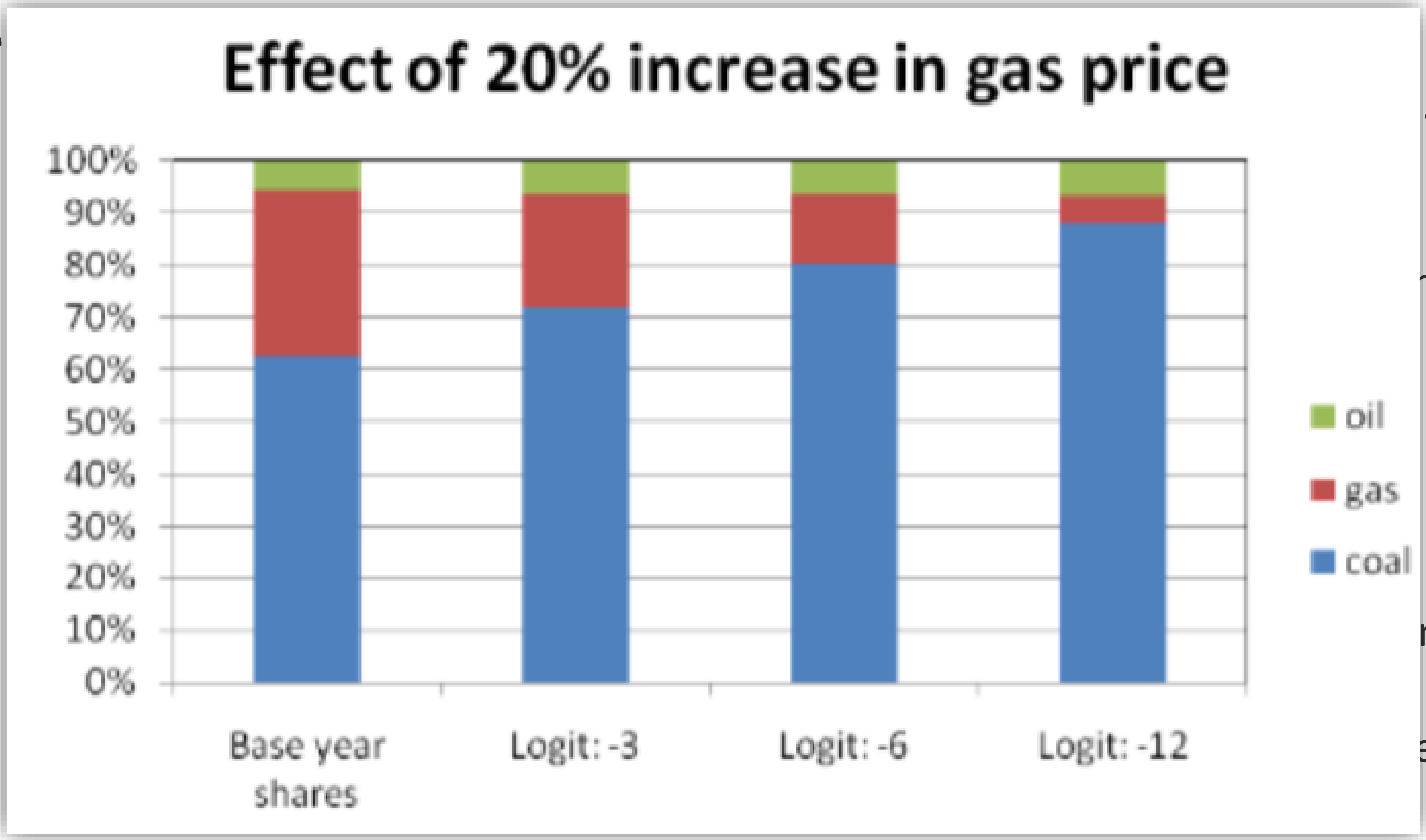


$$\frac{S_i}{S_j} = \frac{\alpha_i}{\alpha_j}\ e^{[\beta(p_i - p_j)]}$$

# Methods: The H2RES model

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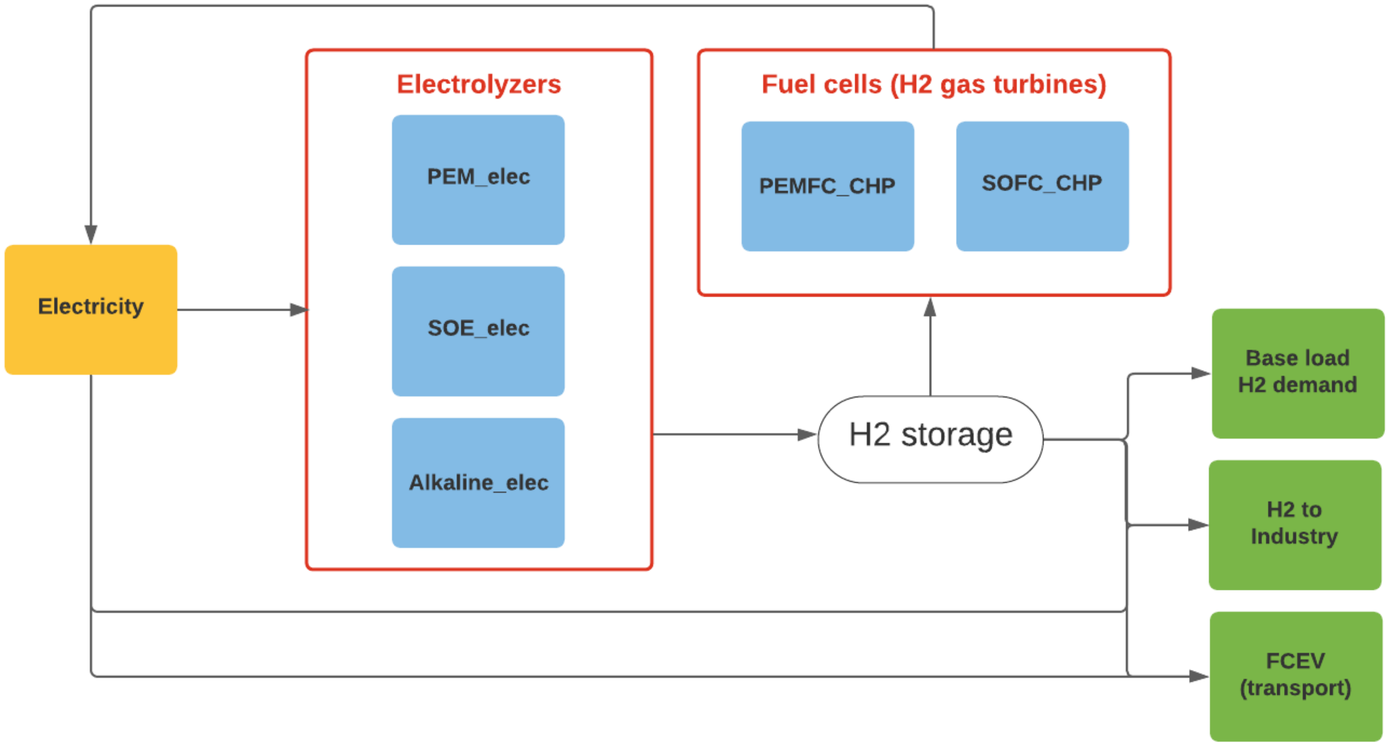
❖ The **H2RES** model: Power to Hydrogen and Power (H2) to Power

- ✓ H2 can be produced from different electrolyzer technologies.
- ✓ H2RES considers a single H2 storage (optimized) which serves different demands
- ✓ Feedback loop (power to power) with fuel cell technologies
- ✓ H2 base load and transformation of Industry and transport (WIP) sectors



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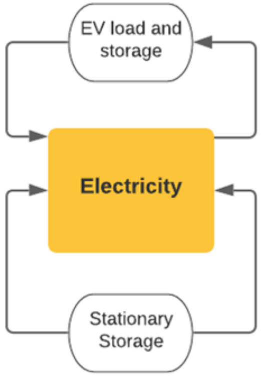
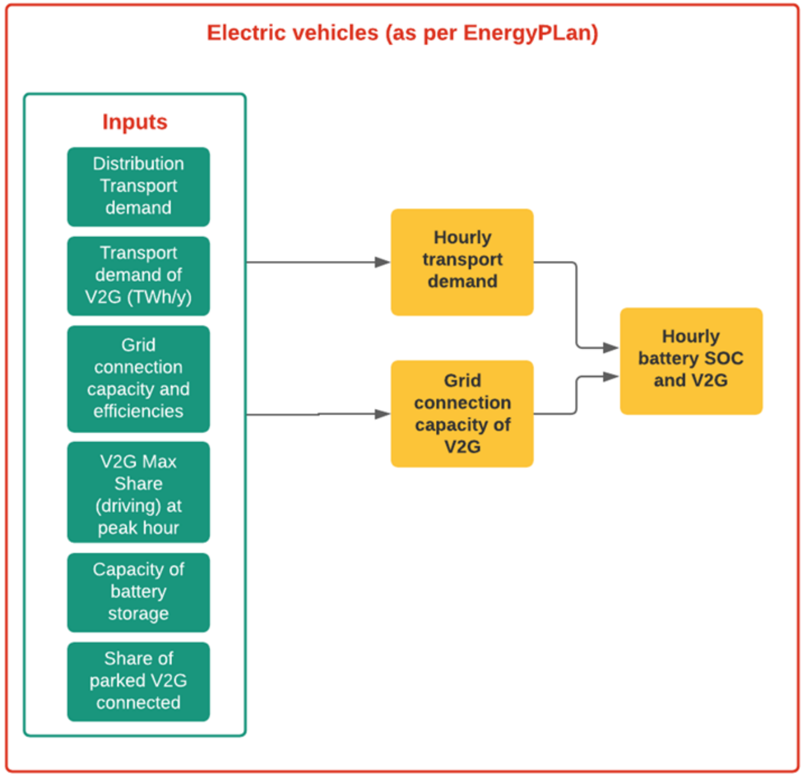
- The **H2RES** model: Electricity storage and Power to EV (transport)
  - ✓ The model allows for endogenous investments in stationary storage (electricity and H2)
  - ✓ The transport sector, via EV, provides variable storages depending on profiles of EV availability and their energy consumption.
  - ✓ We follow similar assumptions than the EnergyPlan model.



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# Methods: The H2RES model

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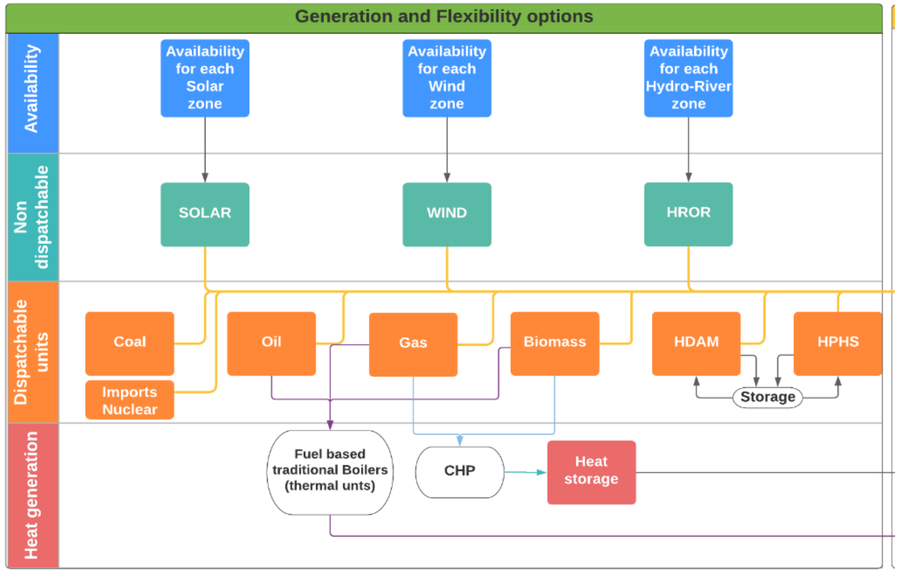
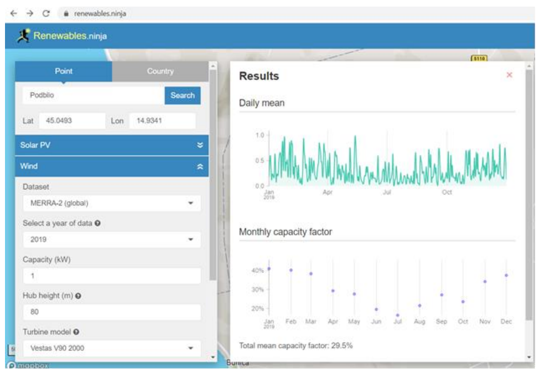
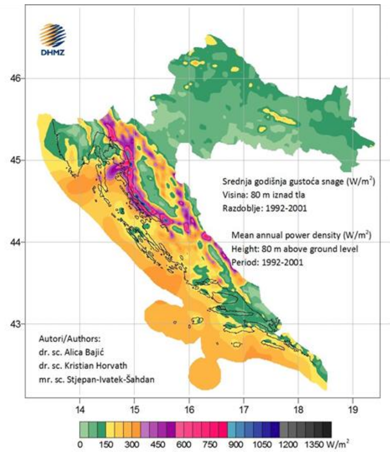
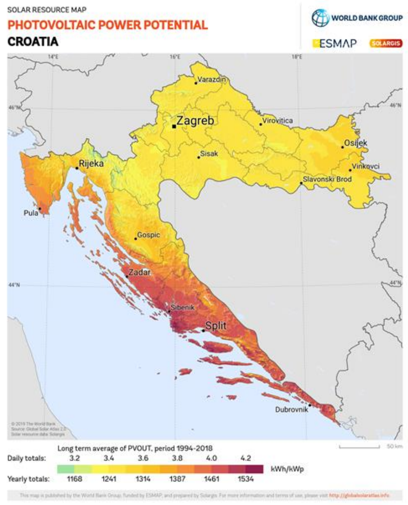
## ❖ The **H2RES** model: Power Sector

- ✓ Dispatchable and non-dispatchable units.
- ✓ Users define the level of aggregation.
- ✓ Multiple zones for non-dispatchable units, particularly important for wind and solar.
- ✓ Capacity investment for existing and new units, considering the potential for different technologies.
- ✓ Decommission and obsolesce rates are considered for all power plants.



# Methods: The H2RES model

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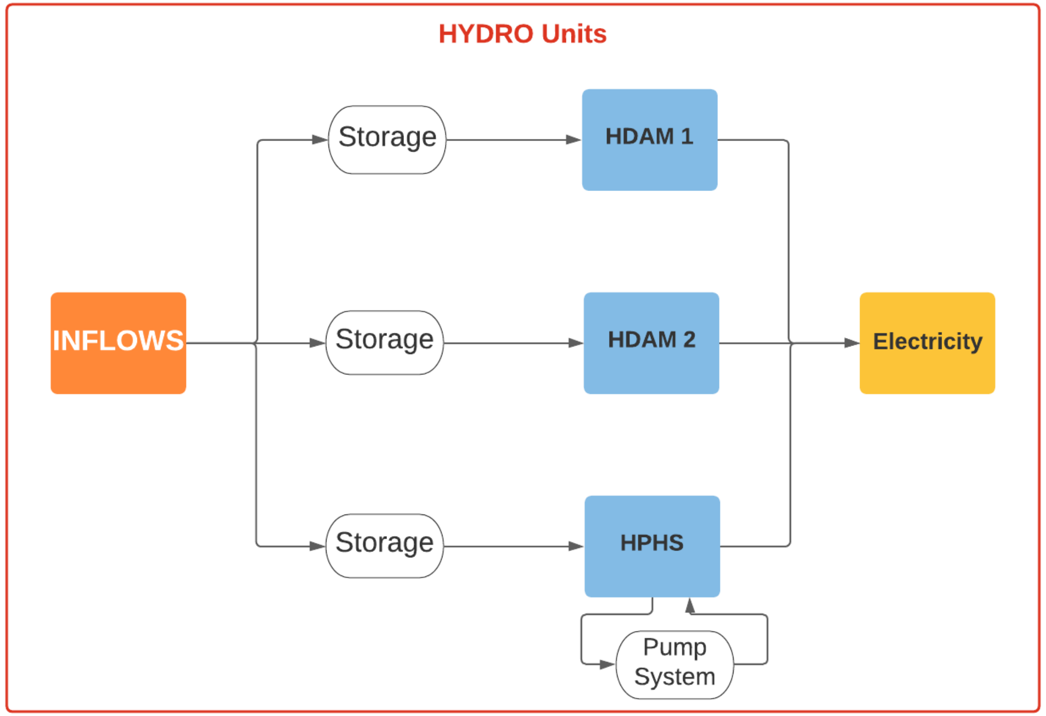
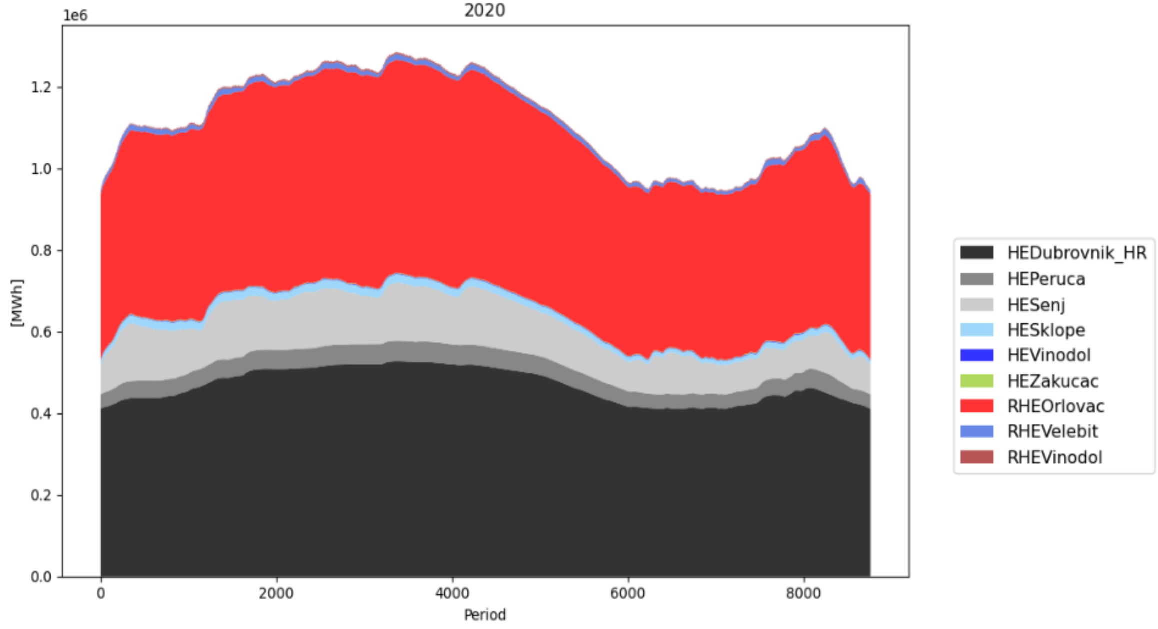
## ❖ The **H2RES** model: Power Sector - Hydro sources

- ✓ H2RES considers HDAM and HPHS
- ✓ Hydro plants are optimized as a dispatchable unit
- ✓ H2RES considers investments in the generator turbines only (not storage)
- ✓ Natural inflows




Hydro storage level



# Methods: The H2RES model

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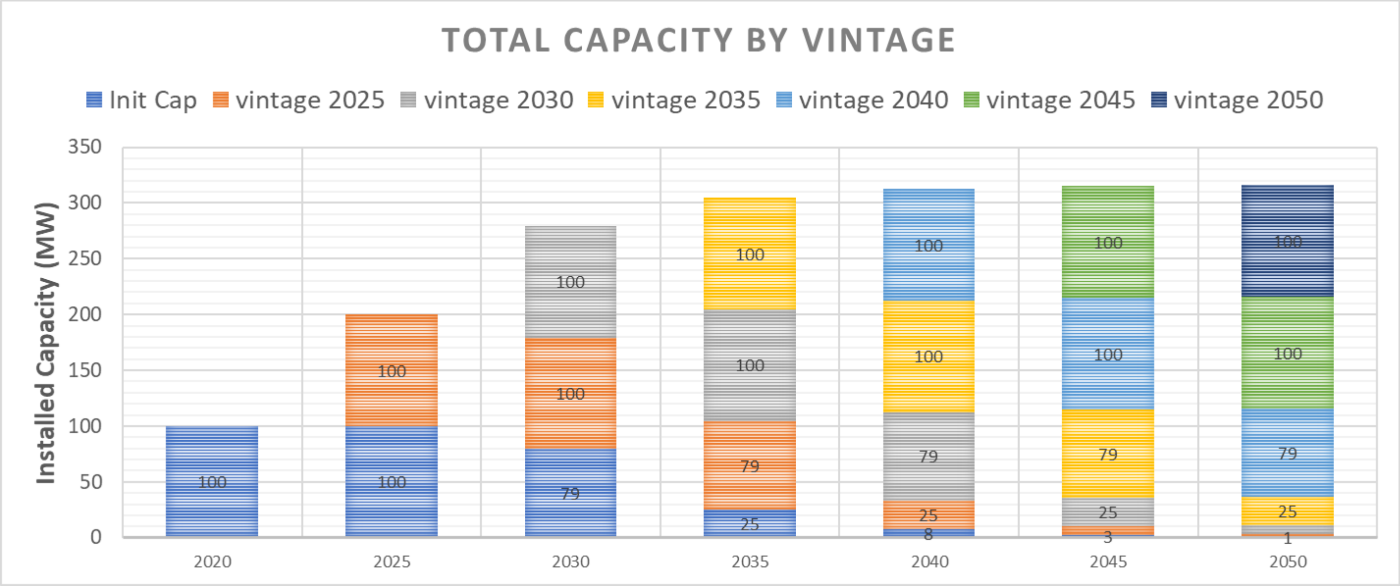
## ❖ The **H2RES** model: Decommission of technologies

✓ H2RES models the decommission for all technologies and power plants. We follow an exponential decay left-over to account for share of technologies that will remain.

$$\text{Decay Rate} = 1 - 10^{[\log(\text{Left Over})/(\text{lifetime} - \text{Year decommission start})]}$$

$$Gen_{i,year} <= Gen_{i,0} + \sum_{vintage <= year} CapInv_{i,vintage}\,(1 - \text{Decay } Rate)^{[max(Decommission\ year, year\ -\ vintage)\ -Decommission\ year]}$$

- ❖ Assume 100 MW installed at the beginning of horizon
- ❖ 100 additional MW each model year
- ❖ Lifetime of 20 years but technology starts failing after 10 years
- ❖ Remaining capacity of 10%



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# H2RES: Interface and structure

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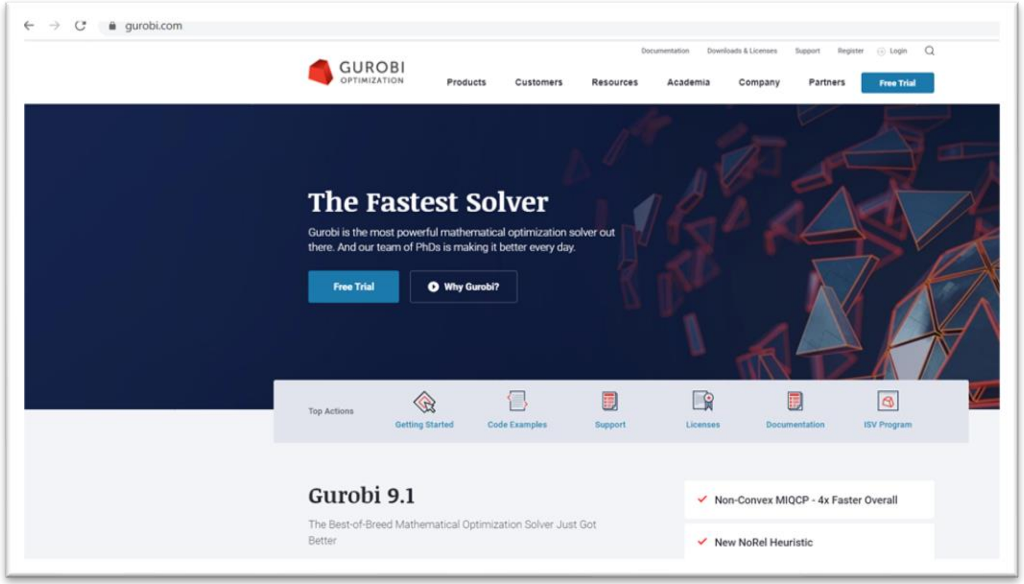
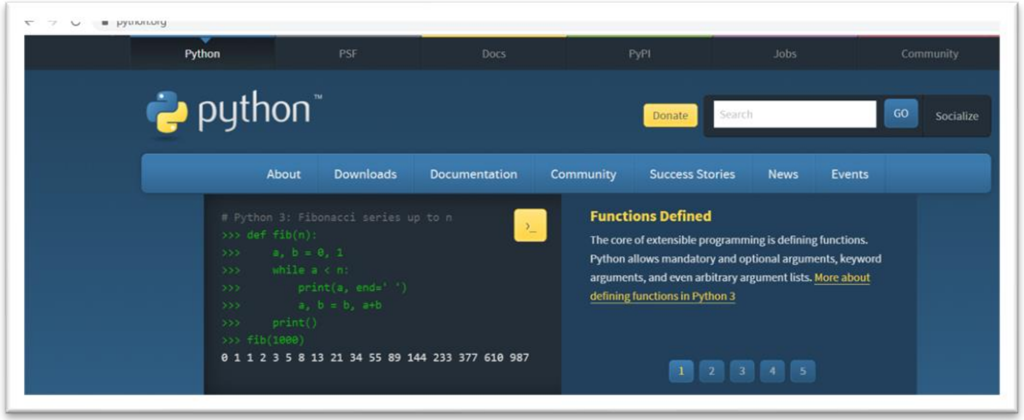
- ✓ H2RES is written in Python. **Basic** knowledge of Python is needed to use H2RES
- ✓ H2RES is solved using the **GUROBI** solver. Both Python and GUROBI are free, making H2RES freely available to the community.
- ✓ Computational time depends on the size of the scenario.
- ✓ Test runs, considering hourly dispatch choices, from 2020 to 2050 (5 years time intervals), are solved in 45-90 min (scenario based). Single year simulations are solved in approximately 5 minutes.



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# H2RES: Interface and structure

Main run file:

- ✓ Main.py: Main script used to set the scenario characteristics and run H2RES.
- ✓ “scen” defines the scenario name
- ✓ Set of Boolean indicators for different policy options
- ✓ RES targets, CO2 limits, carbon prices, CEEP limits, import prices, Net present values, technology change (learning), etc.
- ✓ Directories to the input files

main.py | read_process_data.py | Build_model_ev.py | export_plot_ev.py | combine_plot.py | combine_plot2.py

```
@author: felipe feijoo
"""
#%%
#MAIN
############################################################################
#####################SENARIO NAME and single parameters######
############################################################################
scen = 'Scenario_Name'
rps_inv         = True     # Options: True / False
carbonLimit     = True     # Options: True / False
hydro_storage   = True     # Options: True / False
exports_dat     = False    # Options: True / False
save_csv        = True     # Options: True / False
ceep_limit      = True     # Options: True / False
NoResToHeatInv  = False    # Options: True / False

#General Paramenters
resolution       = 'hour'  # Options -> 'hour', 'daily'.
rps              = list([0.5, 0.7, 0.8])
NPV              = list([1, 0.621, 0.386])
TechChangeSolar  = list([1, 0.95, 0.9])
TechChangeWind   = list([1, 0.95, 0.9])
CO2_limit        = list([3660497*0.5,3660497*0.4,3660497*0.3])
reserve          = 1        # Reserve capacity  = reserve * dema
carbon_price     = 0        # Carbon price in $/tCO2
ceep_parameter   = 0.05     # % of demand used as an upper bound
Import_Price     = 45       # $/MWh
ev_heat_cost     = 25       # Vehicle to grid cost
```

```
############################################################################
### GENCO/Demand data (enter genco data file name with extension)#############
############################################################################
genco_dat              = './data/genco_data_HR_sdewes.csv'
demand_dat             = './data/demand_2020_2050_sdewes.csv'
fuel_price_dat         = './data/fuel_cost_2020_2050_sdewes.csv'
avl_factor_plant_dat   = './data/ncre_aval_factor_HR_2020_2050_sdewes.csv'
inflows_dat            = './data/scaled_inflows_HR_2020_2050_sdewes.csv'
import_export          = './data/import_export_HR_2020_2050_sdewes.csv'
heat_demand_dat        = './data/heat_demand_HR_2020_2050_sdewes.csv'
cooling_demand_dat     = './data/cooling_demand_HR_2020_2050_sdewes.csv'
ev_transpload_dat      = './data/ev_transp_load.csv'
h2_demand_dat          = './data/demand_H2_2020_2050_sdewes.csv'
flex_tech_dat          = './data/flex_tech_HR_2020_2050_sdewes.xlsx'
```

# New H2RES Interface

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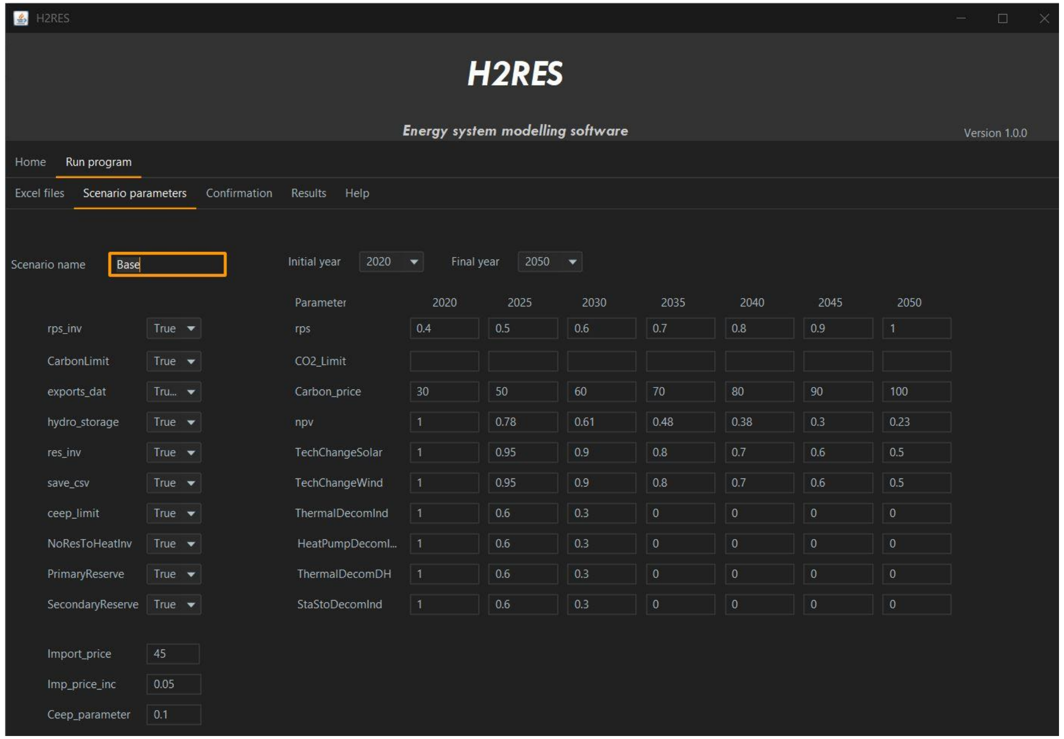
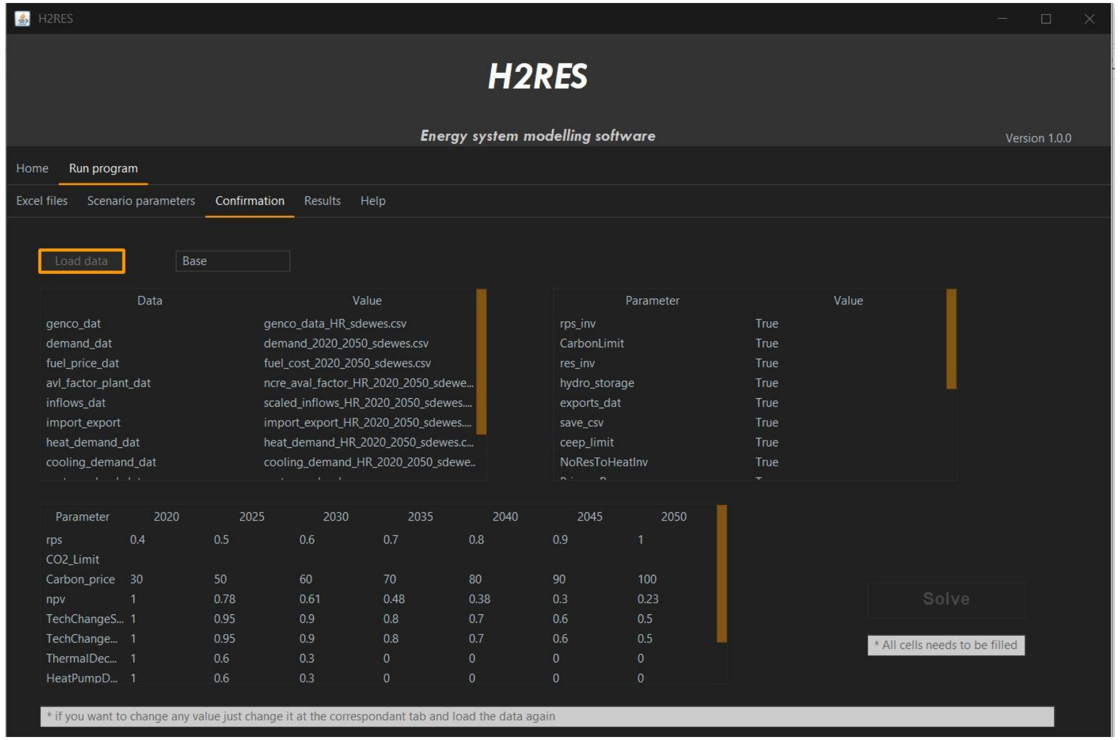
## New interface

- ✓ JAVA application tested on Windows machines.
- ✓ Input files-data and visualization of results.
- ✓ To be released in January on www.h2res.org.



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# H2RES: Interface and structure

https://github.com/h2res/H2RES

https://h2res.org/about-h2res/

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# THANK YOU FOR YOUR ATTENTION!

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With Antun Pfeifer, Luka Herc, and Neven Duić.

InterEnergy

HrZZ Hrvatska zaklada za znanost

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# H2RES

- The Linear Program provides the “cheapest” mix of technologies that satisfy a demand
  - Size/capacities
  - Dispatch

- Variables to optimize: New investment of technologies, dispatch, transformation of energy, storage levels, Critical Excess of Energy (CEEP).

- The model is built in PYTHON and uses GUROBI to find the optimal solution.
  - For instance: How much Solar and Wind capacity (without any power-to-x option) is required to achieve a 50% reduction of emissions?
    - And if we want to guarantee a CEEP threshold? And if we want reduce curtailed energy? On top of this, we want a cheap solution?... If we find a configuration, can we do it cheaper? (what is the cheapest!?).

  - Different policy options: % of RES and/or Reduction of Emissions, CEEP limits. These are defined in a yearly based (different targets for different years)

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# Methods: The H2RES model

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## INTERENERGY MODEL: Generation constraints

$$minGen_i * committed_{i,t,y} \leq generation_{i,t,y} \leq maxGen_i * avlFactor_{i,t,y} * committed_{i,t,y} \qquad \forall\, t, y, i \in Dispatch$$

$$RESgeneration_{i,t,y} = \left( maxGen_i + \sum_{y' \leq y} capInv_{i,y'} \right) * avlFactor_{i,t,y} \qquad \forall\, t, y, i \in ResUnits$$

$$RESgeneration_{i,t,y} = REStoPower_{i,t,y} + REStoHeat_{i,t,y} \qquad \forall t, y, i \in ResUnits$$

## INTERENERGY MODEL: Demand balance and CEEP constraints

$$\sum_i generation_{i,t,y} + import_{t,y} + evOut_{t,y} = Demand_{t,y} + CEEP_{t,y} + Exp_{t,y} + evIn_{t,y} \qquad \forall\, t, y$$

$$\sum_t CEEP_{t,y} \leq CEEPLimit * \sum_t Demand_{t,y} \qquad \forall\, y$$

$$\sum_{t,\ i \in RES} generation_{i,t,y} \geq RPS_y * \sum_t Demand_{t,y} \qquad \forall\, y$$

$$\sum_i maxGen_i * avlFactor_{i,t,y} * commited_{i,t,y} + import_{t,y} \geq Reserve * Demand_{t,y} \qquad \forall\, t, y$$

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# Methods: The H2RES model

## INTERENERGY MODEL: Power to heat

**Heat pump/Boilers**

$$\sum_{h} HeatPumpOut_{h,t,u} \leq COP * \sum_{i \in ResUnits} REStoHeat_{i,t,y} \qquad \forall t,y$$

$$HeatPumpOut_{h,t,y} \leq MaxHeatPumpCap_{h} + \sum_{y' \leq y} HeatPumpCapInv_{h,y'} \qquad \forall h,t,y$$

**Combined heat And power (CHP)**

$$HeatInput_{h,t,y} * CHPPowerToHeat_{h} \leq generation_{h,t,y} \qquad \forall h,t,y$$

$$generation_{h,t,y} \leq maxGen_{h} * avlFactor_{i,t,y} - HeatInput_{h,t,y} * CHPPowerLossFactor_{h} \qquad \forall h,t,y$$

$$HeatStorageSOC_{h,t,y} = HeatStorageSOC_{h,t-1,y} + HeatInput_{h,t,y} - HeatOut_{h,t,y} \qquad \forall h,t,y$$

$$HeatStorageSOC_{h,t,y} \leq HeatStorageMAX_{h,y} \qquad \forall h,t,y$$

$$HeatOut_{h,t,y} \leq CHPMaxHeat_{h} \qquad \forall h,t,y$$

$$HeatOut_{h,t,y} + HeatPumpOut_{h,t,y} + HeatSlack_{h,t,y} = HeatDemand_{h,t,y} \qquad \forall h,t,y$$

## INTERENERGY MODEL: Hydro constraints

$$MinHydroStorage_{i,t,y} \leq HydroStorageSOC_{i,t,y} \leq MaxHydroStorage_{i,t,y} \qquad \forall\, i,t$$

$$HydroStorageSOC_{i,t=final,y} \geq LastSOCLevel_{i} \qquad \forall\, i \in Hydro, t$$

$$HydroStorageSOC_{i,t,y} = HydroStorageSOC_{i,t-1,y} + inflows_{i,t,y} - \frac{generation_{i,t,y}}{eff_{i}} - outflows_{i,t,y} \qquad \forall\, i \in Hydro, t, y$$

$$\frac{generation_{i,t,y}}{eff_{i}} + outflows_{i,t,y} = HydroStorageSOC_{i,t,y} + inflows_{i,t,y} \qquad \forall\, i \in Hydro, t, y$$