

Economic Viability of Flexibility Options for Smart Energy Systems With High Share of Renewable Energy

Luka Herc¹, Antun Pfeifer¹, Neven Duić¹, Fei Wang²,

¹ University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia,

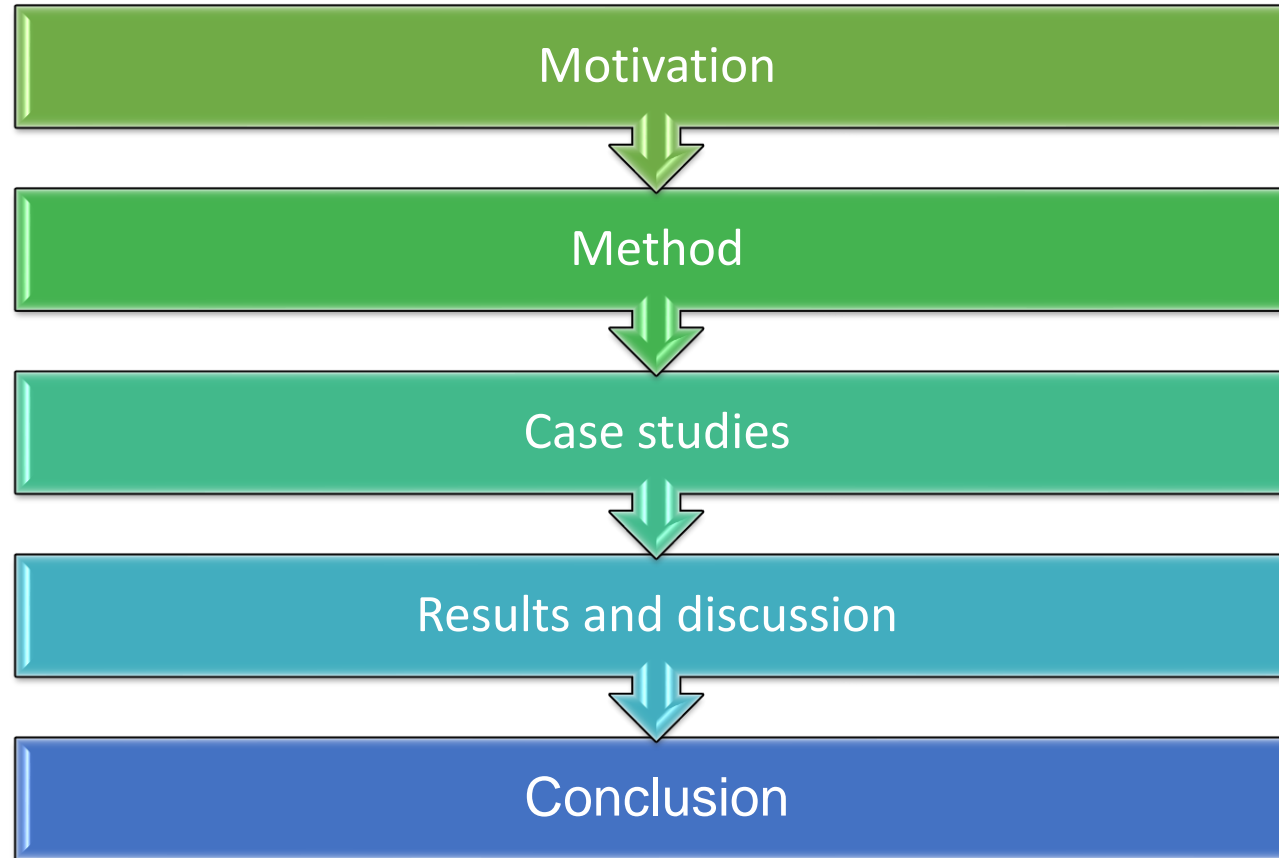
² North China Electric Power University, China



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MOTIVATION

- **Goals:**

- 1) High RES system
- 2) Low CO₂ emissions
- 3) Low CEEP (high CF)
- 4) Low annual cost to current system
- 5) Limited biomass use

- **These requirements often not aligned**

- **Example: Focus on increasing the share of renewables while CF decreases**

- **Planning can involve optimization of use of various technologies, which is required in each step towards higher share of RES**

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How to increase the share of RES?

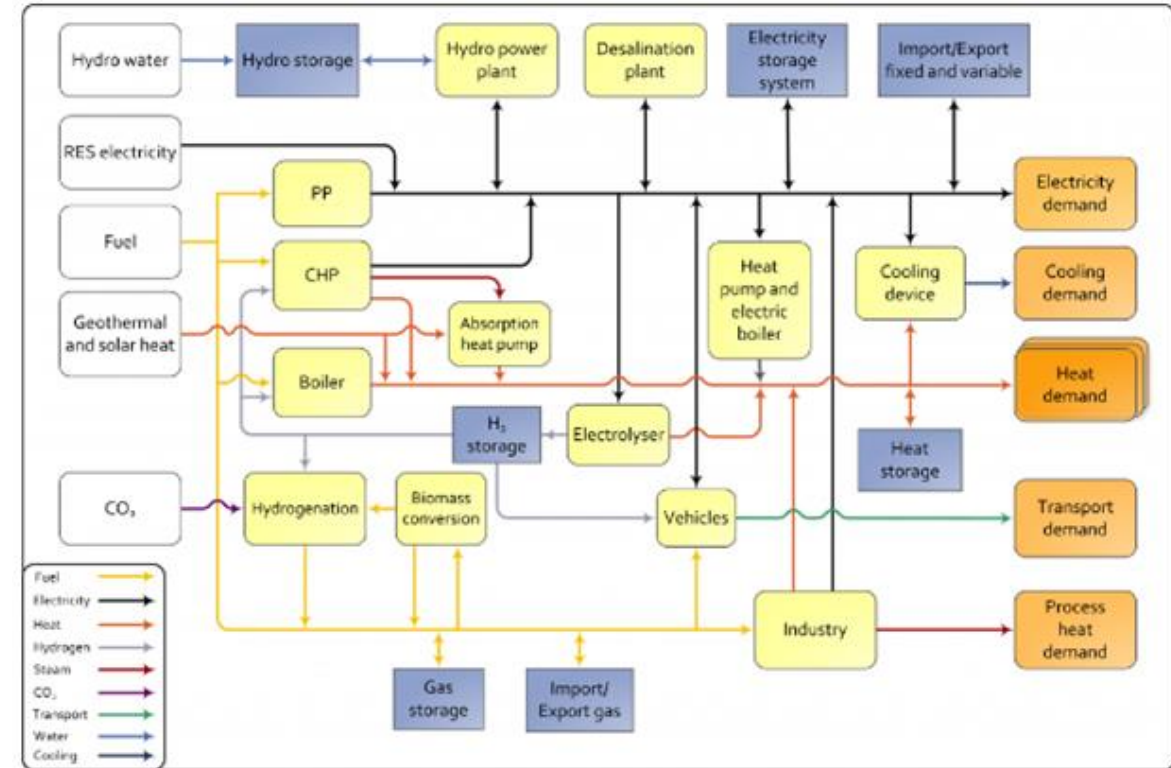
- RES generating capacity:
 - Addition of wind, PV and run of river capacity, biomass share in the fuel mix of thermal power plants, solar district heating
- Flexibility options:
 - V2G, P2H, Power plant flexibility, demand flexibility, interconnections, etc.

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Method - EnergyPLAN

- Energy system simulation and analysis software
- Required data: installed capacities, demand and distribution curves.
- Deterministic software – measurable influence of each variable variations on output values



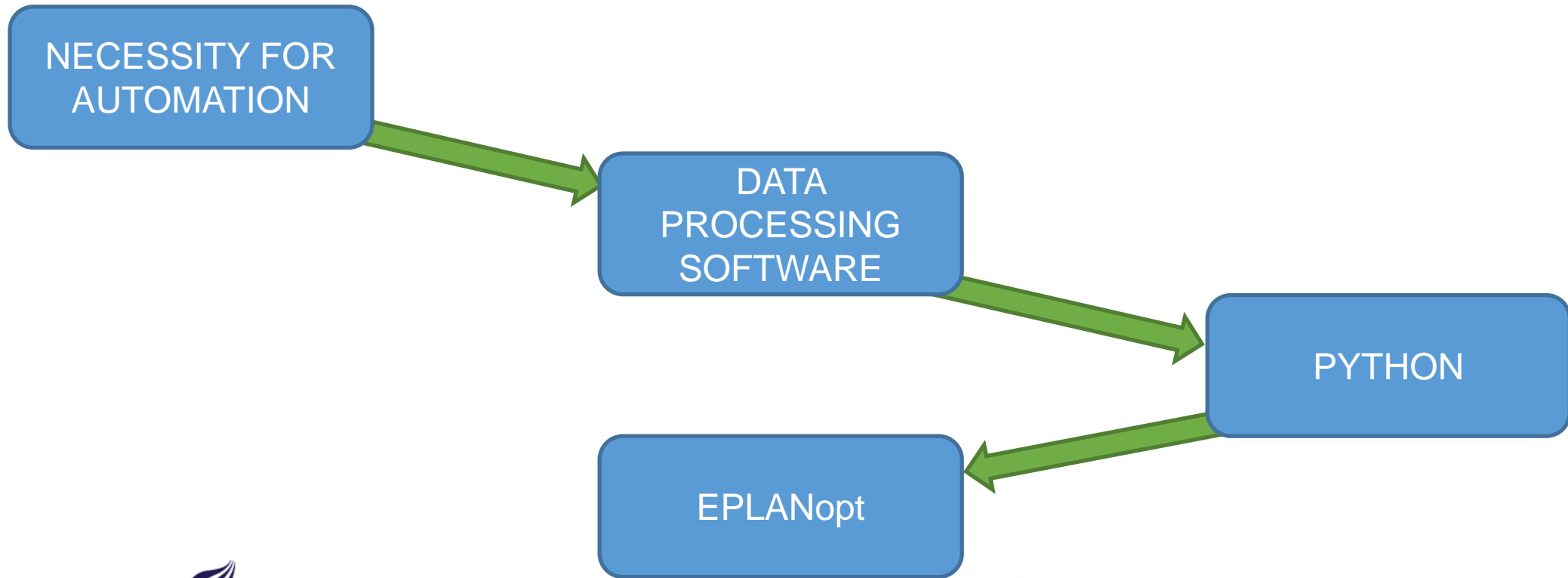
EnergyPLAN, Aalborg University,
<https://www.energyplan.eu/>

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Method

- Necessity to run large number of simulations with slight variations in a short time span – automation



Method - EPLANopt

- Python and EnergyPLAN integration software
- Based on DEAP genetic algorithm
- Create set of inputs
- Set optimization targets for each of the variables (maximize or minimize)

The screenshot shows a Python IDE with the following code in the editor:

```
1 # -*- coding: utf-8 -*-
2 """
3 Created on Mon Jul 20 16:30:37 2015
4
5 @author: MPrina
6 Genetic Algorithm implemented with deap algorithm
7
8 version 1.1 to install from master branch of github repository
9 pip install -U git+https://github.com/DEAP/deap
10 """
11
12 from GA import GA
13 from libeplan import Node
14 from termcolor import colored
15 import time
16
17 global VARIABLES, START, X, MOLT_FACTORS, INPUTFILE
18 global ENERGYPLAN, OUT_FOLDER, FUNCTION_2_EVAL
19 global CONSTRAIN
20
21 #----- INPUT DATA -----
22 data = {"EnergyPLAN folder": r"E:\ZIPEnergyPLAN1211\ZIPEnergyPLAN121",
23        "Input file": r"E:\ZIPEnergyPLAN1211\ZIPEnergyPLAN121\energyPlan_Data\data\b07510.txt",
24        "Output folder": r"E:\ZIPEnergyPLAN1211\ZIPEnergyPLAN121\energyPlan_Data\data3",
25        "Number of process": 4,
26        "Genetic algorithm": ("Size of population": 40,
27                             "Number of generations": 40),
28
29        "Variables": [{"EnergyPLAN Name": "input_RES1_capacity", "Range": [7000, 20000], "Multiplication factor":
30                      {"EnergyPLAN Name": "input_RES2_capacity", "Range": [1046, 30000], "Multiplication factor":
31                      {"EnergyPLAN Name": "input_RES3_capacity", "Range": [613, 1200], "Multiplication factor": 1}
32                      {"EnergyPLAN Name": "input_cap_hp3_el", "Range": [0, 6000], "Multiplication factor": 1}, #0
33                      {"EnergyPLAN Name": "input_storage_gr3_cap", "Range": [0, 72], "Multiplication factor": 1},
34                      {"EnergyPLAN Name": "input_fuel_chp3[1]", "Range": [5, 10], "Multiplication factor": 0.1}, #
35                      {"EnergyPLAN Name": "input_fuel_chp3[3]", "Range": [0, 11], "Multiplication factor": 1}, #0,
36                      {"EnergyPLAN Name": "input_fuel_chp3[4]", "Range": [0, 5], "Multiplication factor": 0.1}, #1
37                      {"EnergyPLAN Name": "input_fuel_pp1[1]", "Range": [5, 10], "Multiplication factor": 0.1}, #0
38                      {"EnergyPLAN Name": "input_fuel_pp1[3]", "Range": [0, 1], "Multiplication factor": 1}, #0, 5
39                      {"EnergyPLAN Name": "input_fuel_pp1[4]", "Range": [0, 5], "Multiplication factor": 0.1}, #0,
40                      {"EnergyPLAN Name": "input_nuclear_cap", "Range": [0, 2000], "Multiplication factor": 1}, #1, #1
```

The console output shows the results of a simulation:

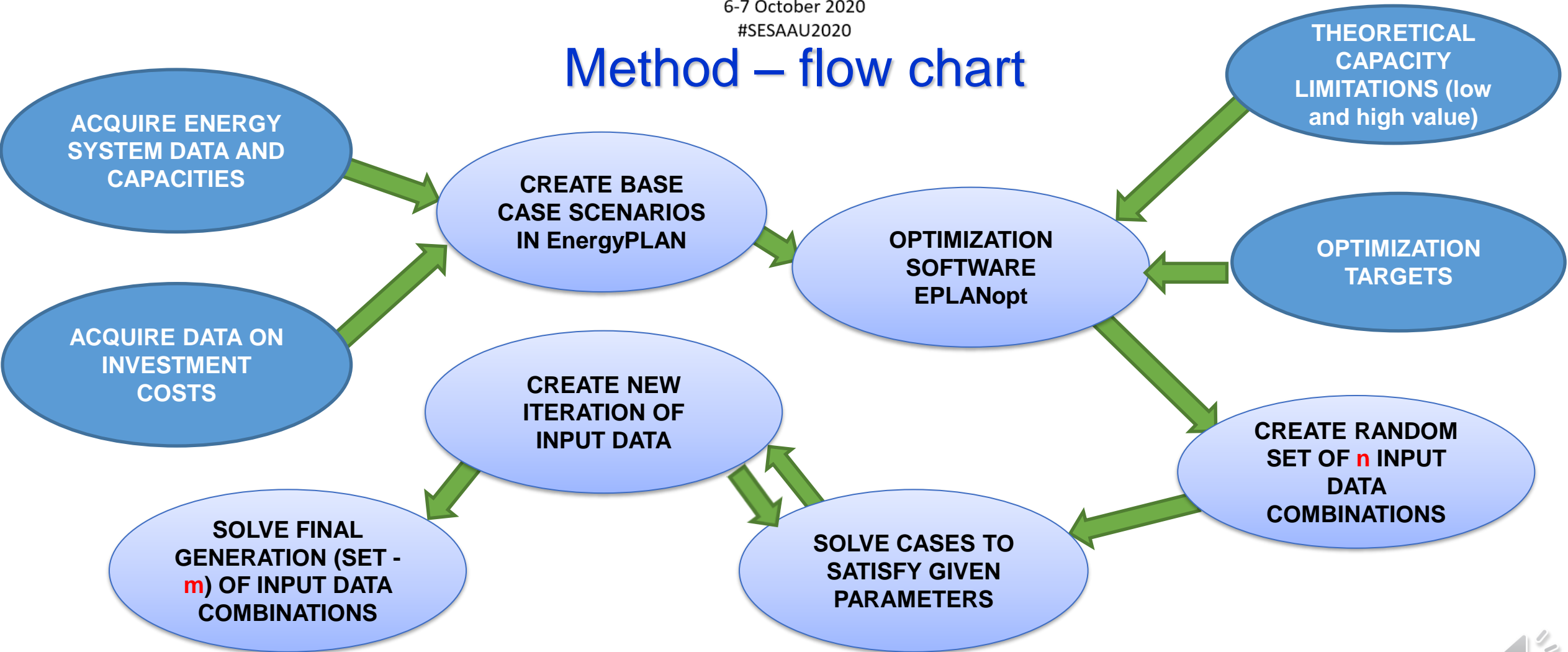
```
simulation executed, n = 255
Costs: [1000000] [€]
RES: [100000] [%]
CEEP: [100000] [TWh]
dem: [100000] [TWh]
flex: [100000] [TWh]
HP: [100000] [TWh]
Pump: [100000] [TWh]
V2Gch: [100000] [TWh]
CEEP: [100000] [TWh]
Biomass_con: [100000] [%]
CO2: [100000] [Mt]
```

EPLANopt, EURAC,
<https://gitlab.inf.unibz.it/URS/EPLANopt>

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Method – flow chart



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Case study

- Case of Bulgarian energy system model
- Proof of concept
- Available data for detail energy model in EnergyPLAN
- 2030 NECP

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Considered technologies

- Electricity generating technologies
- Industry electrification
- Heat generating technologies
- Flexibility options



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Modeling other variables

- No single value defining variable
- Combination of manually predefined cases and EPLANopt
- V2G, demand flexibility, industry electrification

TWh/year	Fossil	Biofuel	Waste*	Synthetic Fuel	Total	Distribution
JP (Jet Fuel)	0.2	0		0	0.20	
Diesel	20.1	1	0.00	0	21.10	
Petrol	7	2		0	9.00	
Ngas* (Grid Gas)	0				0.00	Gas const.txt
LPG	5				5.00	
H2 (Produced by Electrolysers)					0	H2 EV demand_smart.txt
Electricity (Dump Charge)					1	Dump EV demand.txt
Electricity (Smart Charge)					0	Smart EV demand_smart.txt

DEPENDENT VARIABLES

Electric Vehicle Specifications

Smart Charge Vehicles:

- Max. share of cars during peak demand: 0.2
- Capacity of grid to battery connection: 513 MW
- Share of parked cars grid connected: 0.7
- Efficiency (grid to battery): 0.9
- Battery storage capacity: 0 GWh

Additional Specifications for Vehicle-to-Grid (V2G):

- Capacity of battery to grid connection: 0 MW
- Efficiency (battery to grid): 0.9

```

graph LR
    Oil --> CC1[Combustion cars] --> TD1[Transport demand]
    Ngas --> CC2[Combustion cars] --> TD2[Transport demand]
    Biomass --> CC3[Combustion cars] --> TD3[Transport demand]
    H2storage[H2 storage] --> FC[FC] --> TD4[Transport demand]
    Electricity --> EV[Electric vehicle] --> TD5[Transport demand]
  
```

Industry and Other Fuel Consumption

TWh/year	Industry	Various*	Fuel Losses*	Distribution
Coal	1.163	1	0	
Oil	1.865	1.35	0	
Ngas	5.4	0.1	0	<input type="button" value="Ngas"/> const.txt
Biomass	1.5875	0	0	

Electricity Demand and Fixed Import/Export

Electricity demand:	25.542	TWh/year	<input type="button" value="Change distribution"/>	Doris_Electricity_Load_Ho
Electric heating (IF included)	- 0	TWh/year	Subtract electric heating using distribution from 'ir	
Electric cooling (IF included)	- 0	TWh/year	Subtract electric cooling using distribution from 'c	
Elec. for Biomass Conversion	0.06	TWh/year	(Transferred from Biomass Conversion TabSheet)	
Elec. for Transportation	1.00	TWh/year	(Transferred from Transport TabSheet)	
Sum (excluding electric heating and cooling)	26.60	TWh/year		
Electric heating (individual)	0.00	TWh/year		
Electricity for heat pumps (individual)	0.00	TWh/year		
Electric cooling	0.00	TWh/year		
Flexible demand (1 day)	6.6	TWh/year	Max-effect	1210 MW
Flexible demand (1 week)	6.75	TWh/year	Max-effect	1238 MW
Flexible demand (4 weeks)	12.4655	TWh/year	Max-effect	1142 MW
Fixed Import/Export	0	TWh/year	<input type="button" value="Change distribution"/>	Hour_Tysklandsexport.txt
Total electricity demand*	52.41	TWh/year		

Dependent variables

-Demand flexibility

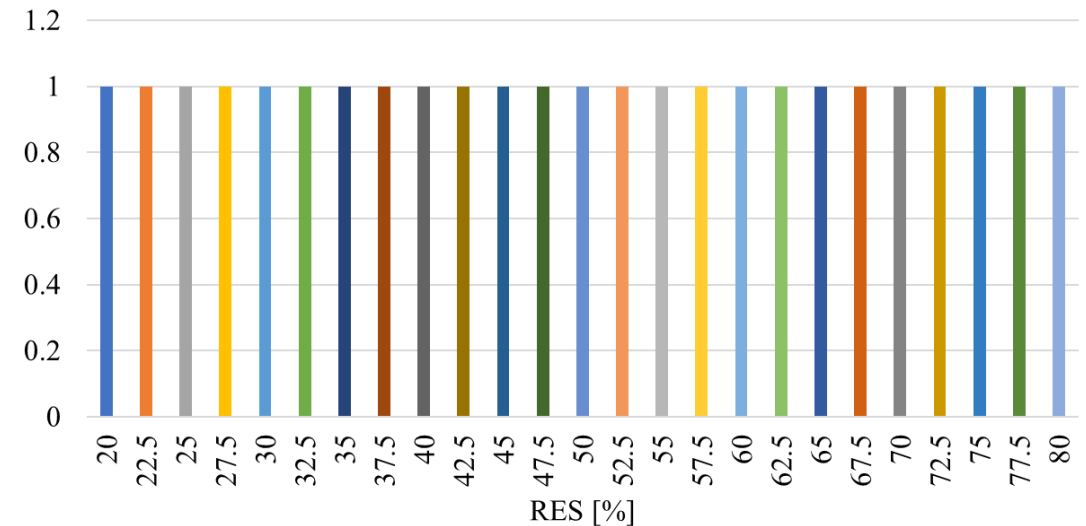
-Industry electrification

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How to determine applicable technology at each RES segment?

- All results in the range from 20 to 80 % RES
- Area divided to 24 segments at 2,5 % range
- Average value for each technology for all segments
- Plot charts



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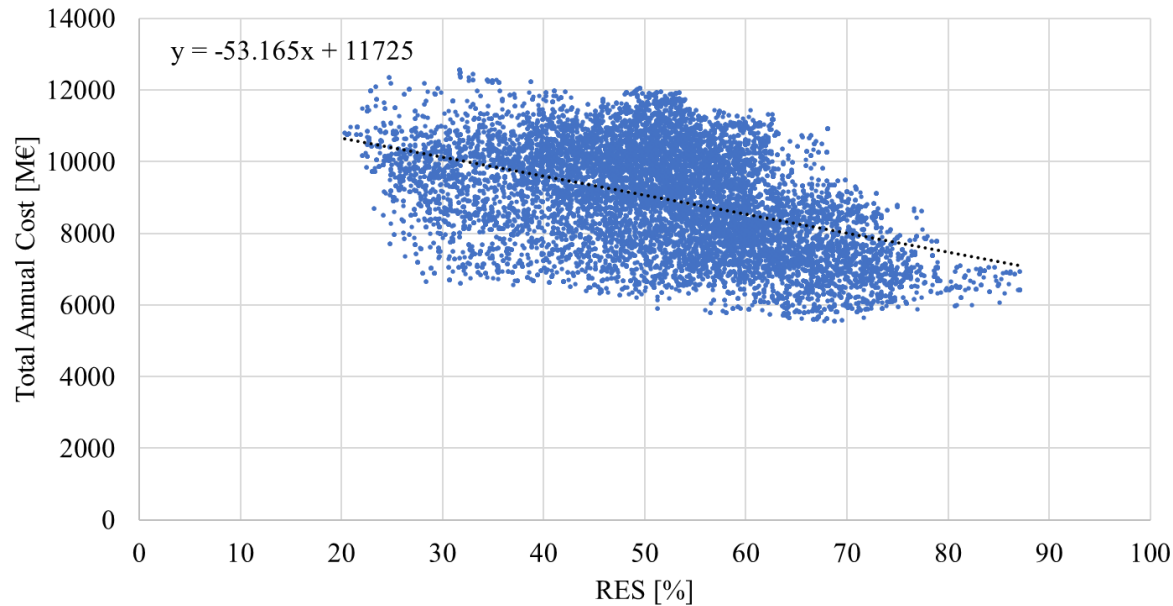
System limitations - EPLANopt

Name	Lower limit value	Higher limit value	Unit
Wind capacity	7000	20000	MW
PV capacity	1046	30000	MW
River capacity	613	1200	MW
P2H generating capacity	0	6000	MW
P2H storage capacity	0	72	GWh
Thermal power plant minimum operating power	0	800	MW
Coal in CHP	0.5	1	-
Natural gas in CHP	0	1	-
Biomass in CHP	0	0.5	-
Coal in PP	0.5	1	-
Natural gas in PP	0	1	-
Biomass in PP	0	0.5	-
Import/export capacity	3000	10000	MW
Industrial excess heat in DH	0	5	TWh
Solar energy in DH	0	5	TWh
Solar energy in individual heating	0	5	TWh

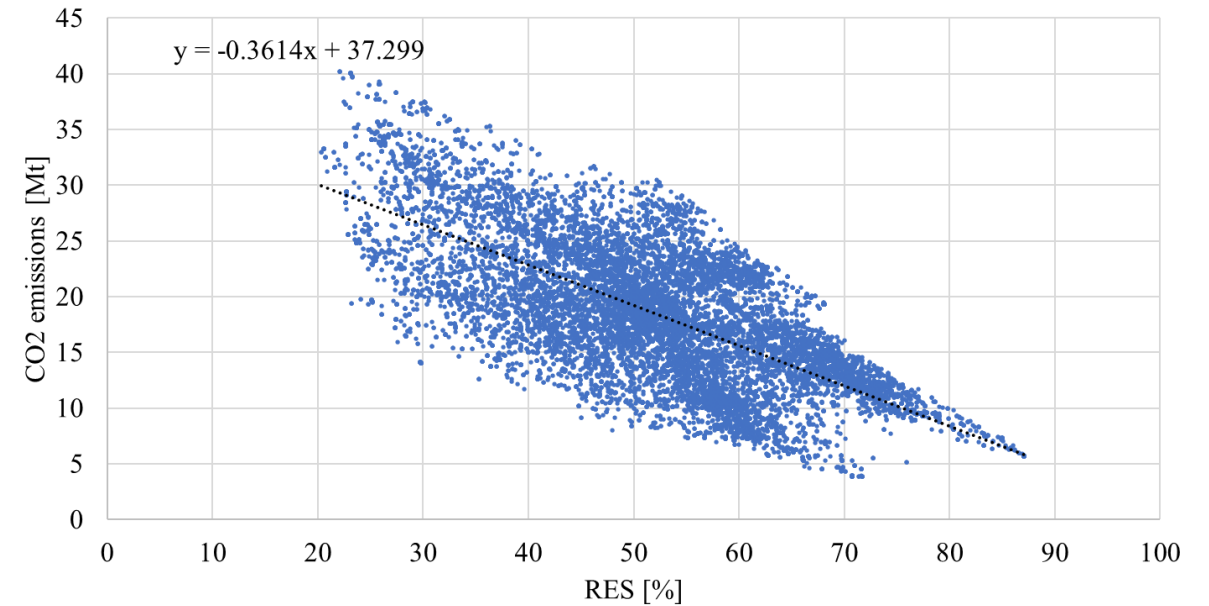


Results

Total Annual Cost



CO2 Emissions



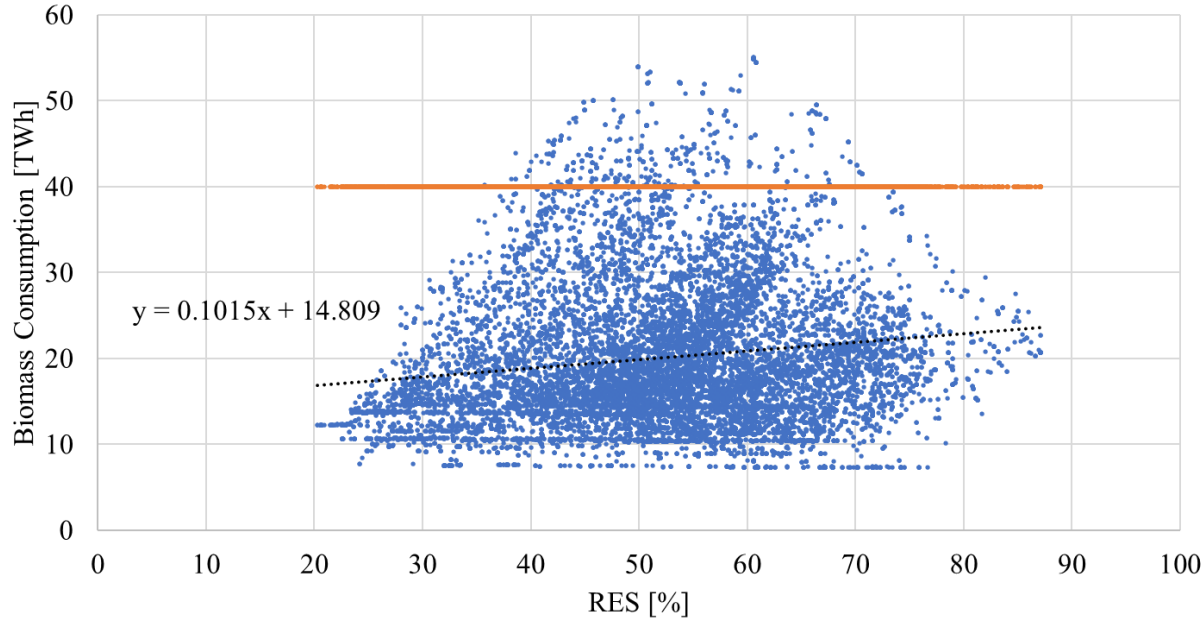
Decrease from 11 B€ to 7 B€
Bulgaria 2019 - 10,2 B€

Decrease from 30 Mt to 5 Mt
Bulgaria 2018 – 58,6 Mt CO2

Powered by (eurostat)

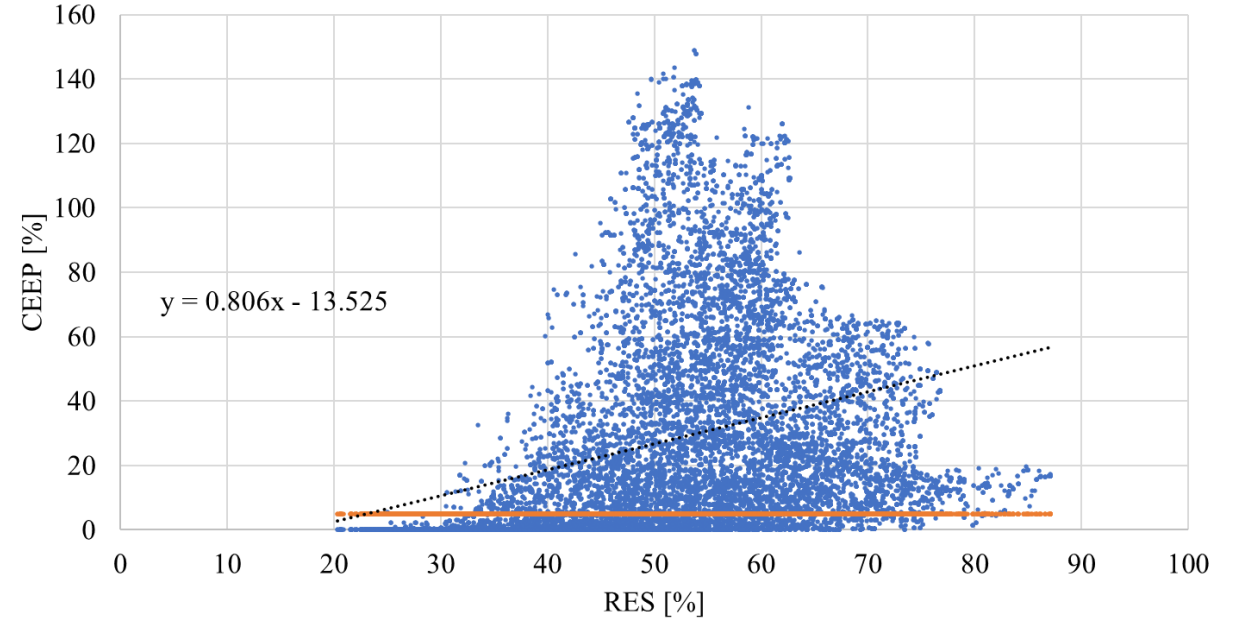


Biomass Consumption



Limit biomass consumption < 40 TWh
7445 out of 8191 cases

CEEP



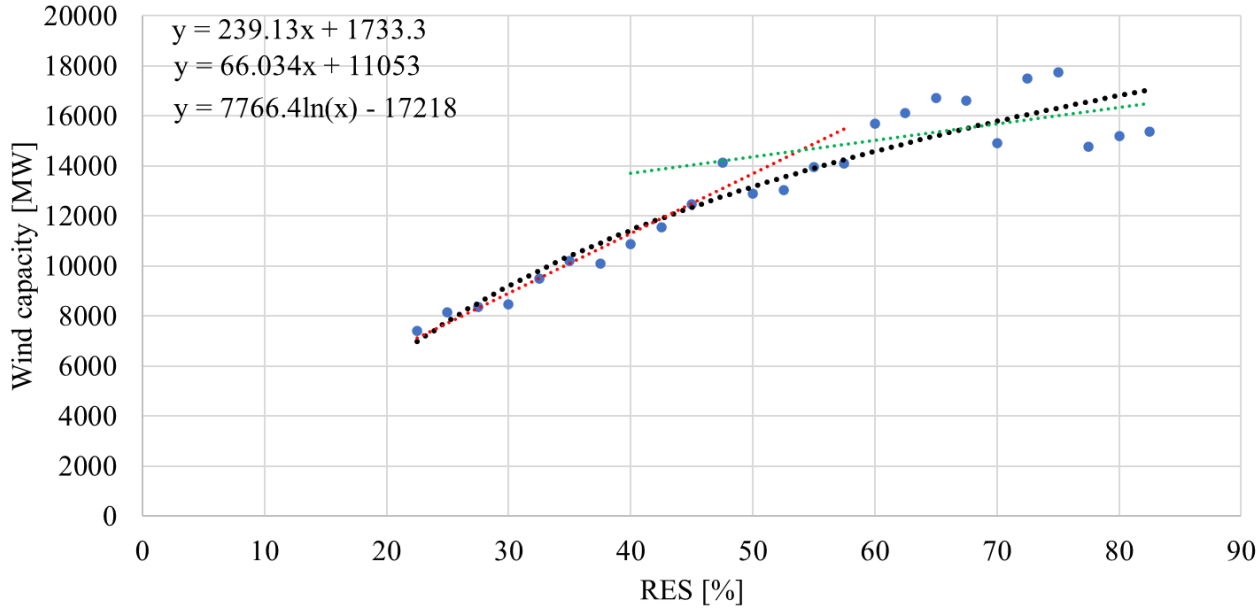
Consider cases with CEEP < 5 %
8191 out of 24000 cases (34%)

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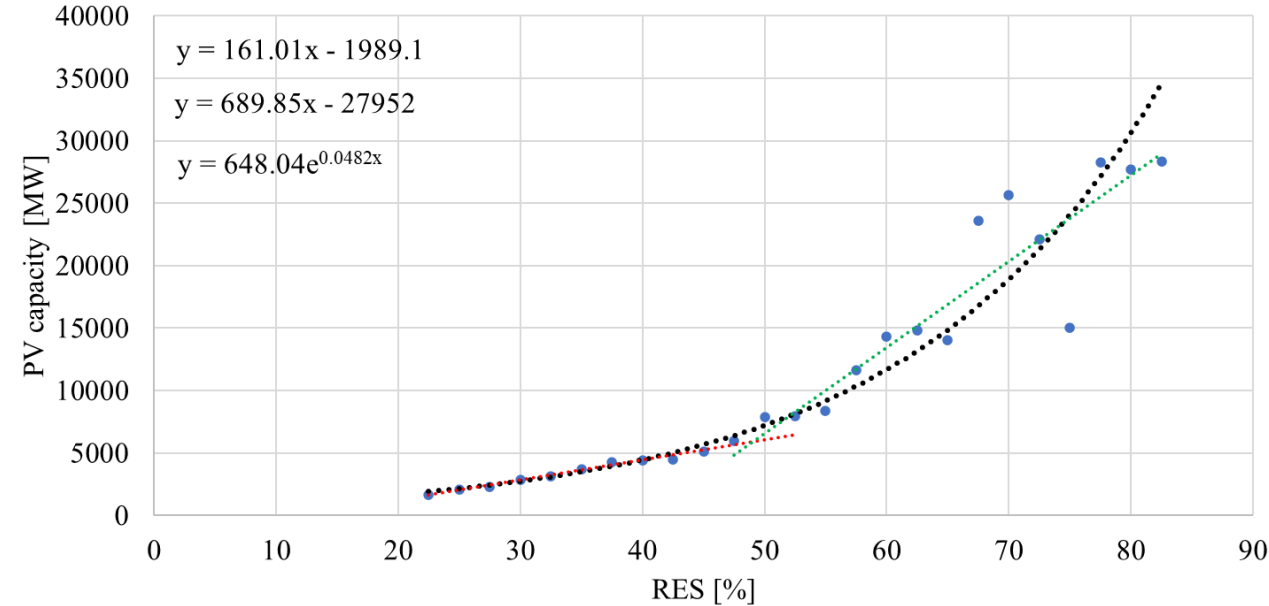


Power generating technologies

Wind Capacity



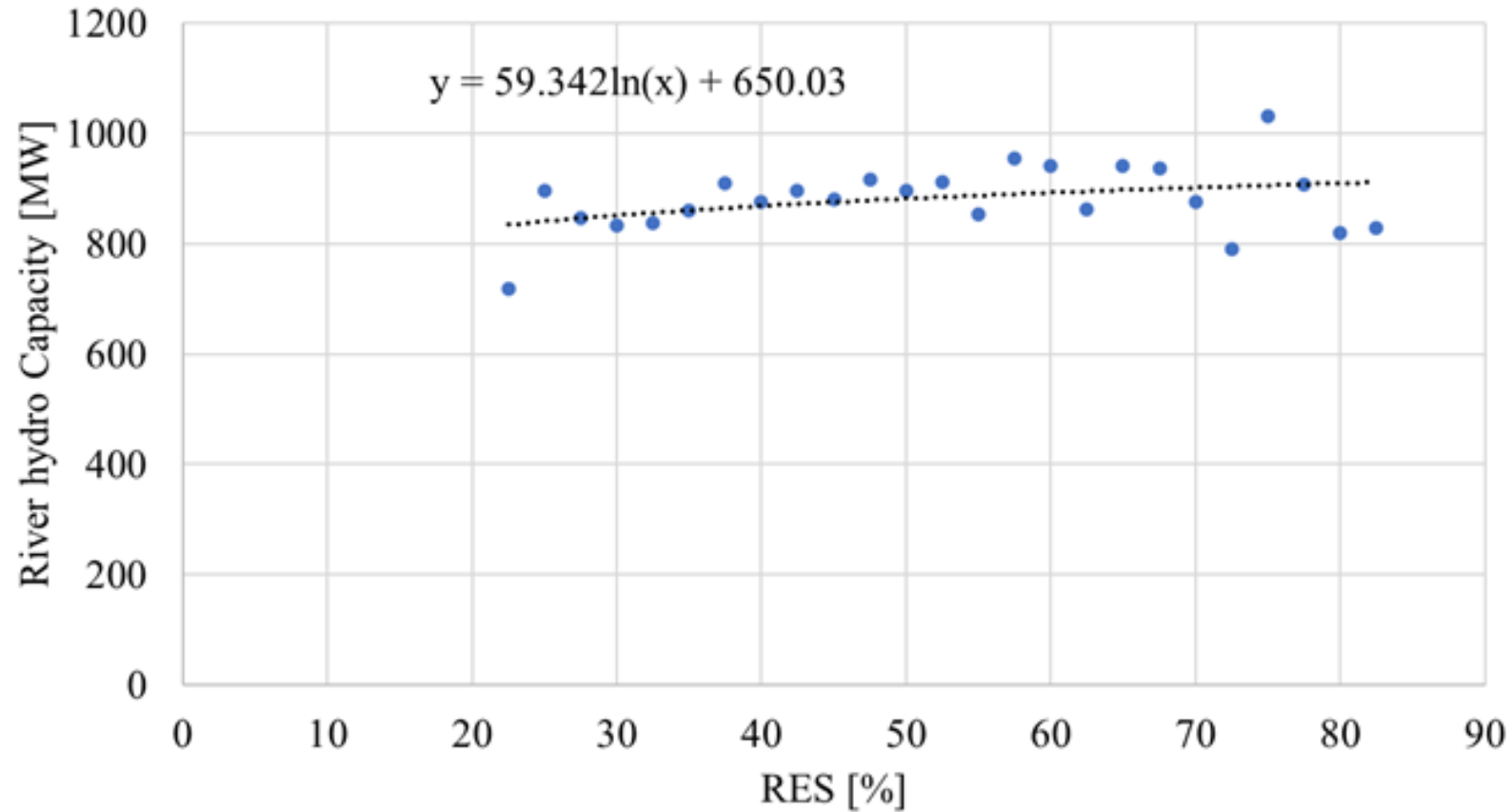
PV Capacity



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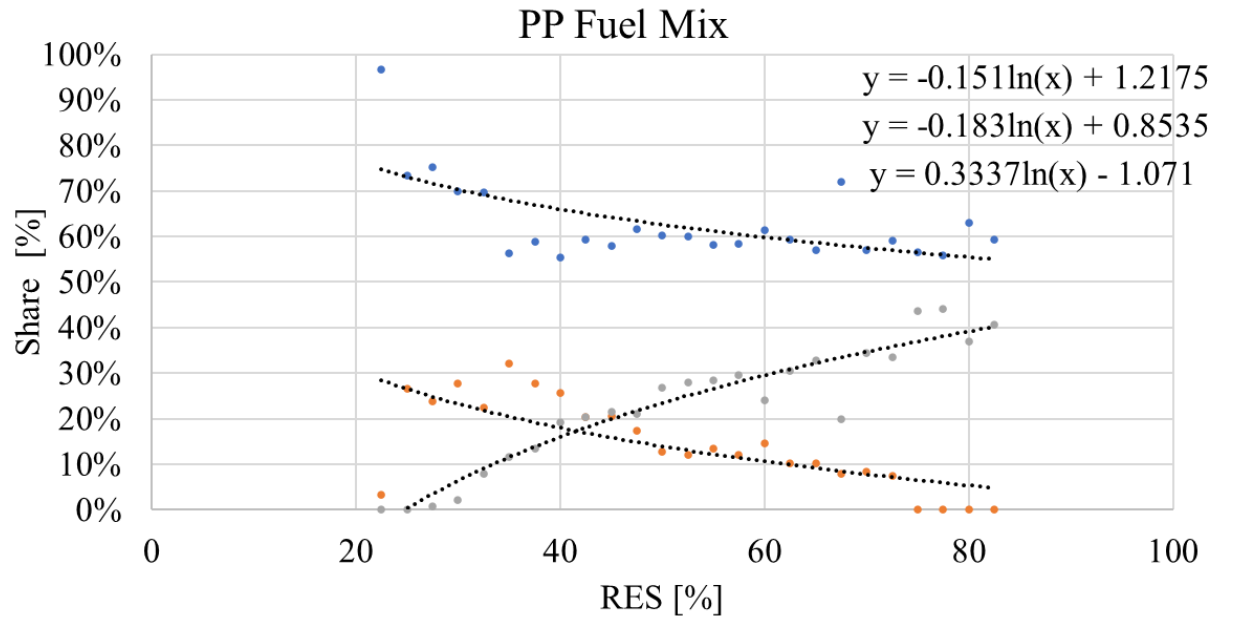
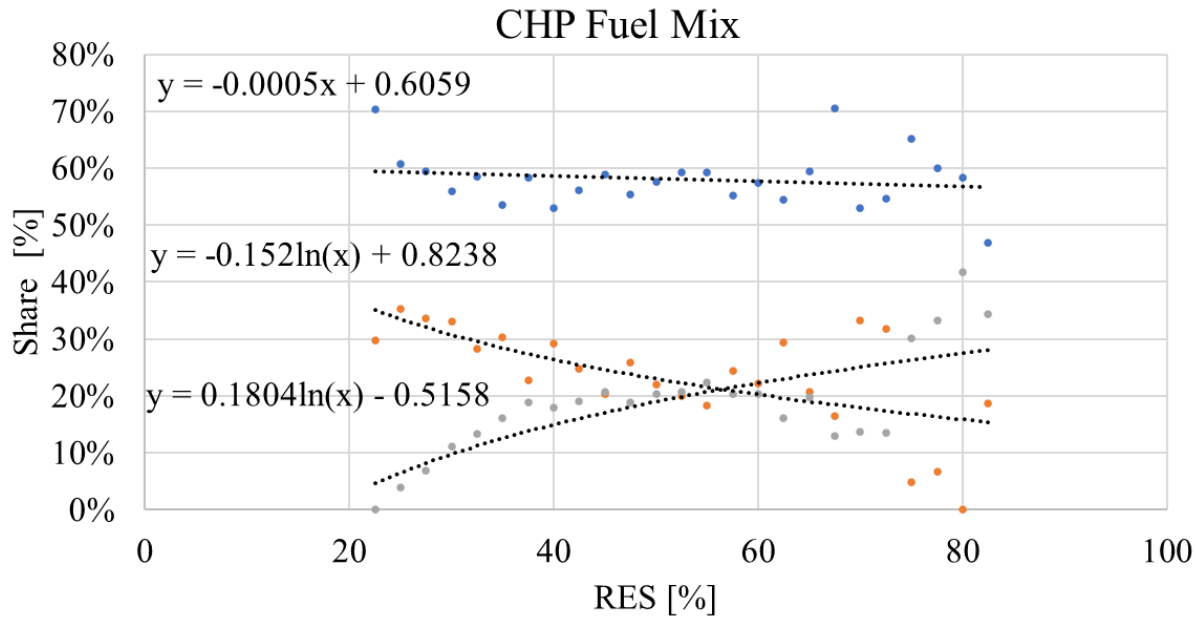
Run of the River Capacity



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Thermal power plant fuel mix



• Coal • Natural gas • Biomass
 Linear (Coal) Log. (Natural gas) Log. (Biomass)

• Coal • Natural gas • Biomass
 Log. (Coal) Log. (Natural gas) Log. (Biomass)

Coal
Natural gas



Biomass

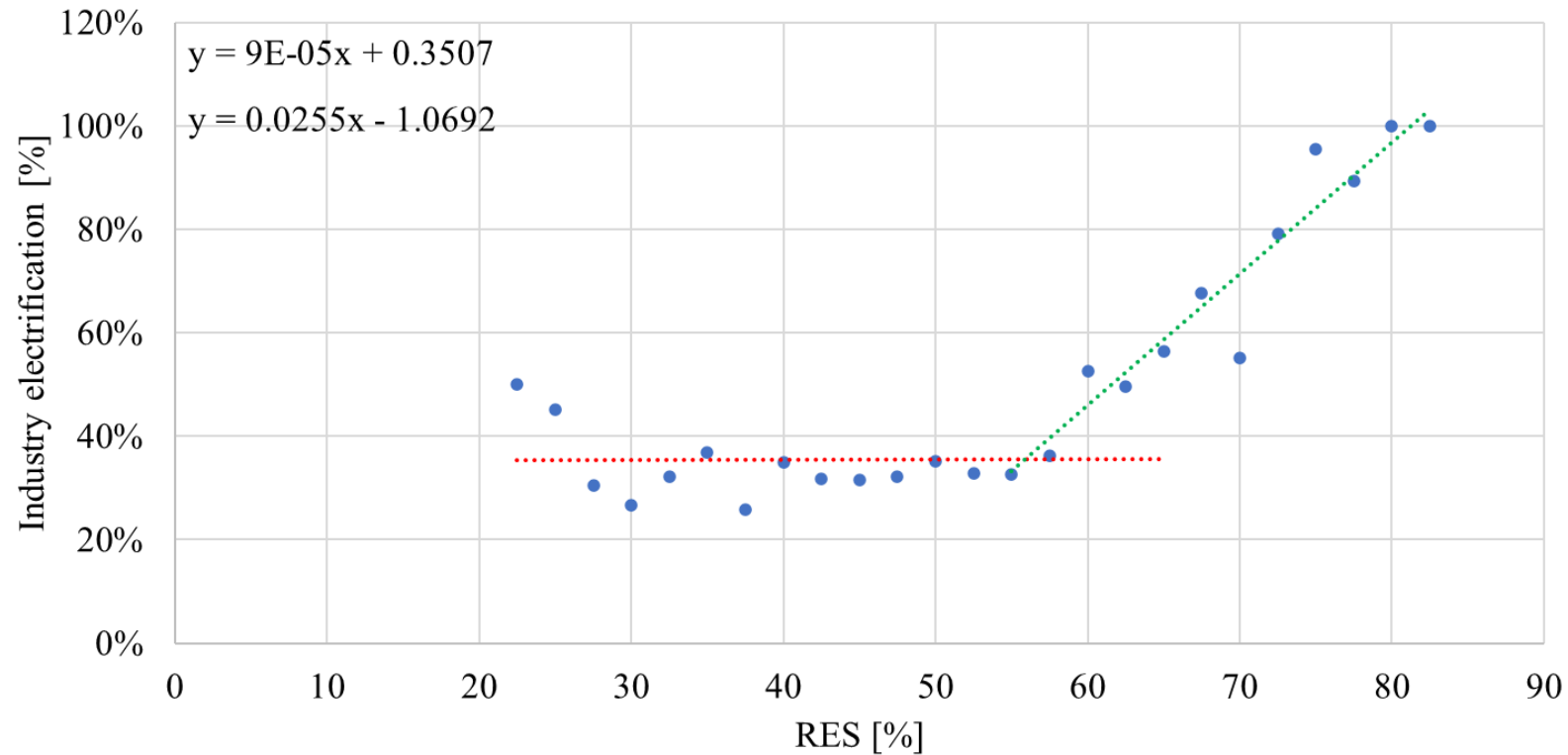


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Industry electrification

Industry electrification

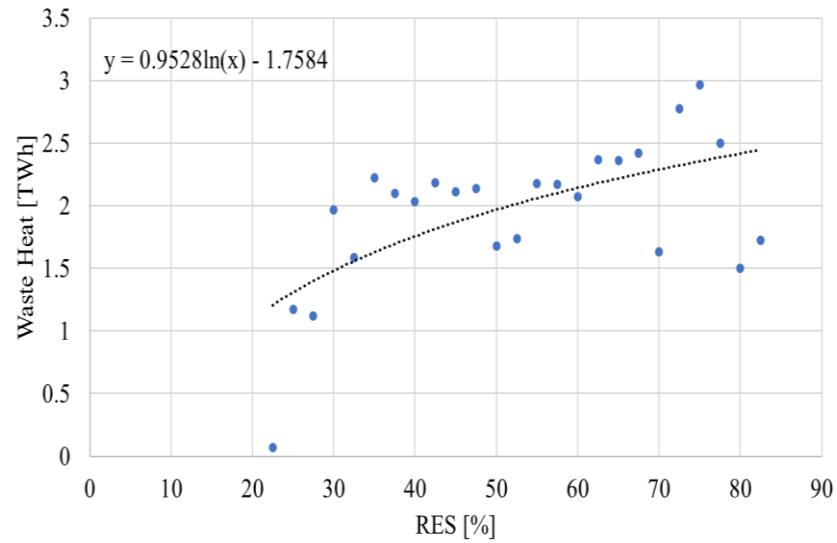


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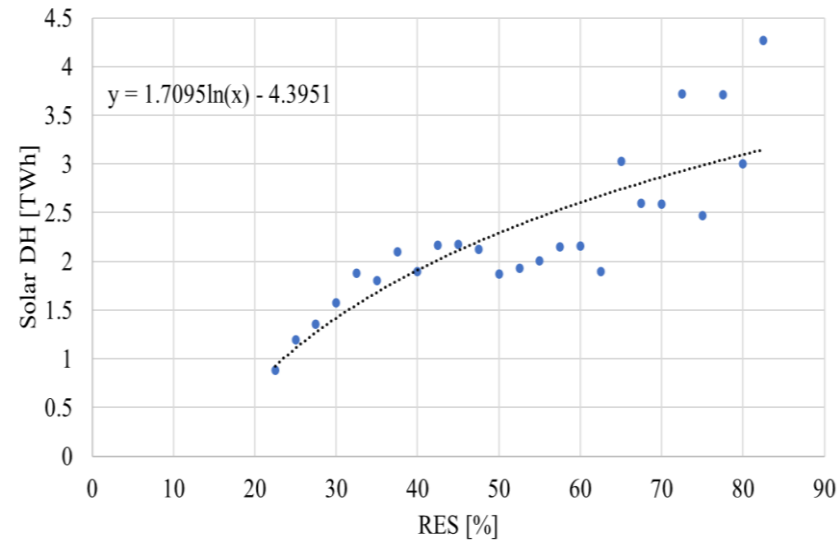


Heat generation

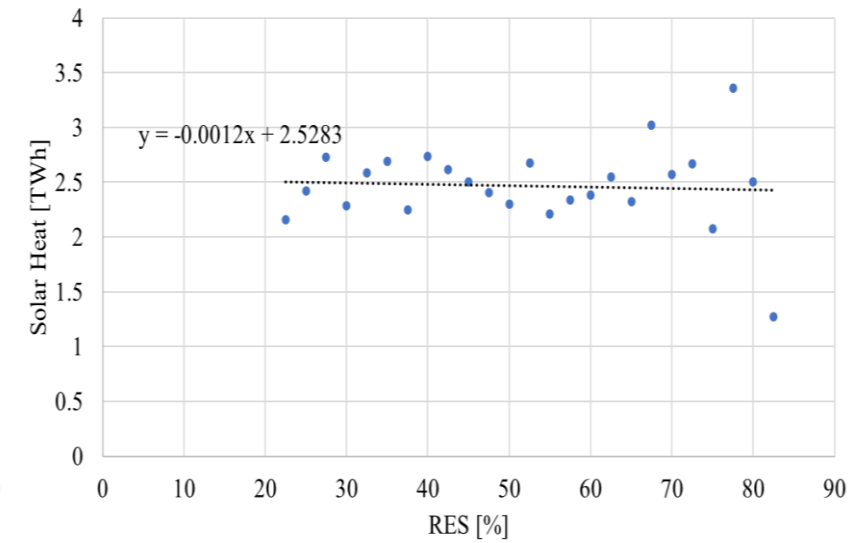
Waste Heat Utilization



Solar DH



Solar Heat in Households

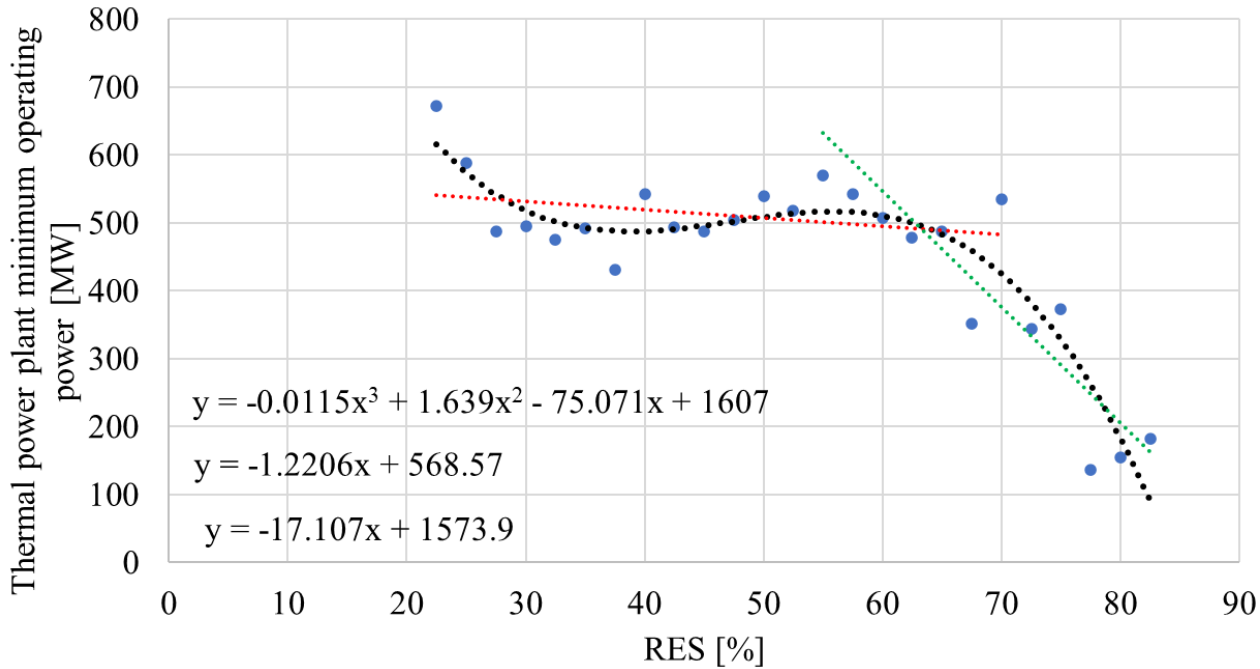


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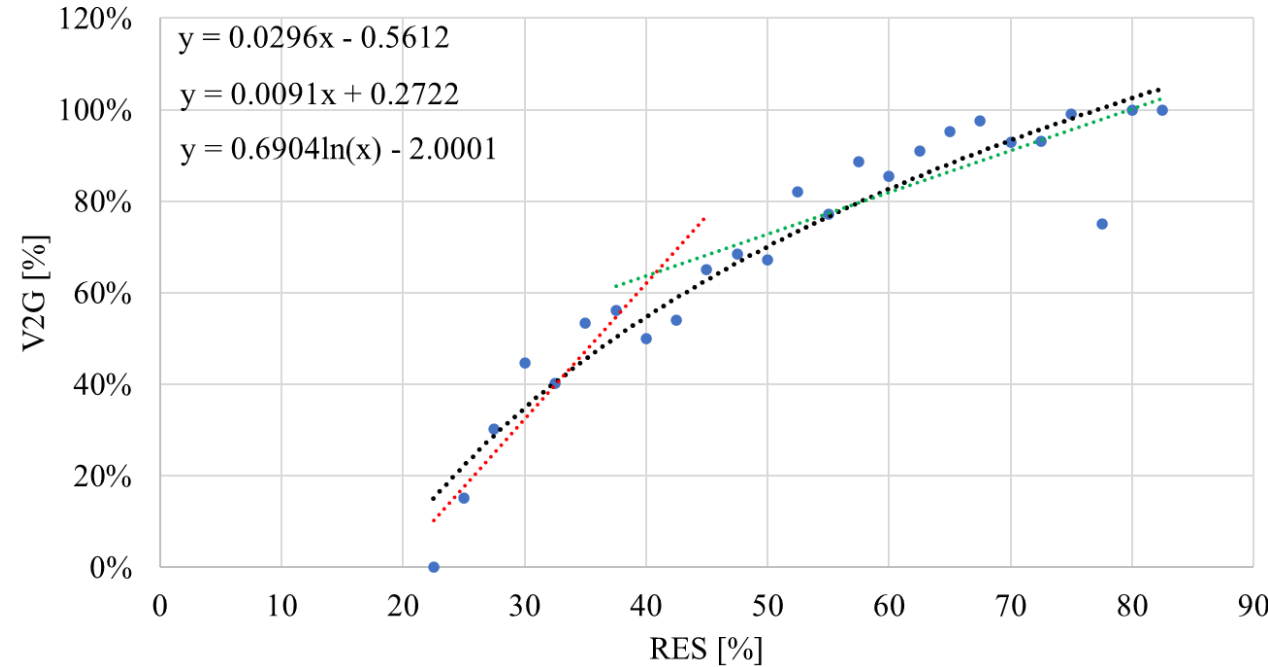


Flexibility options

Thermal power plant minimum operating power



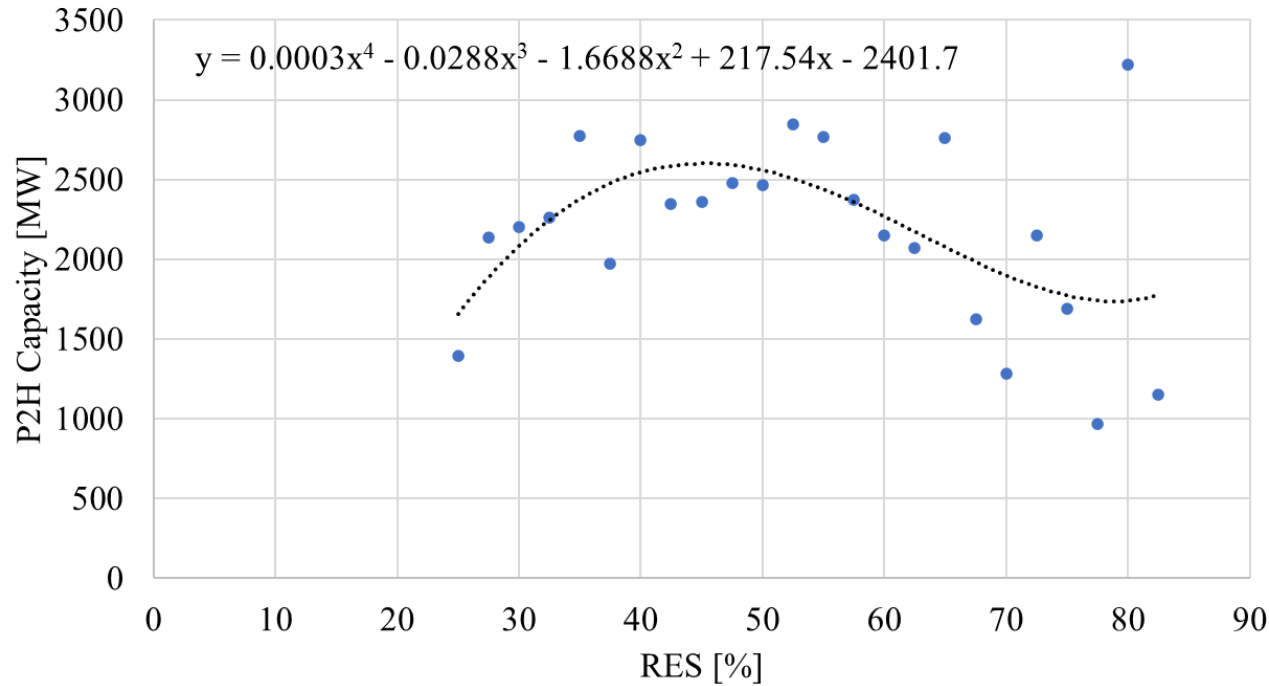
V2G



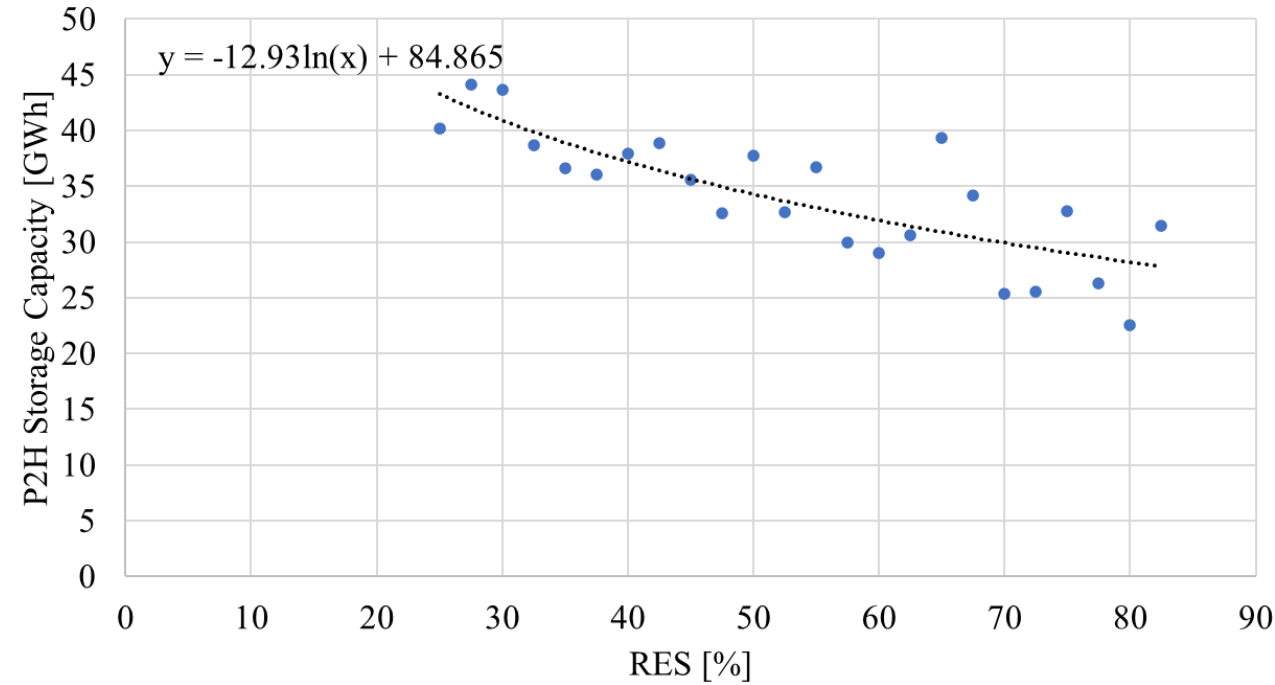
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P2H Capacity



P2H Storage Capacity

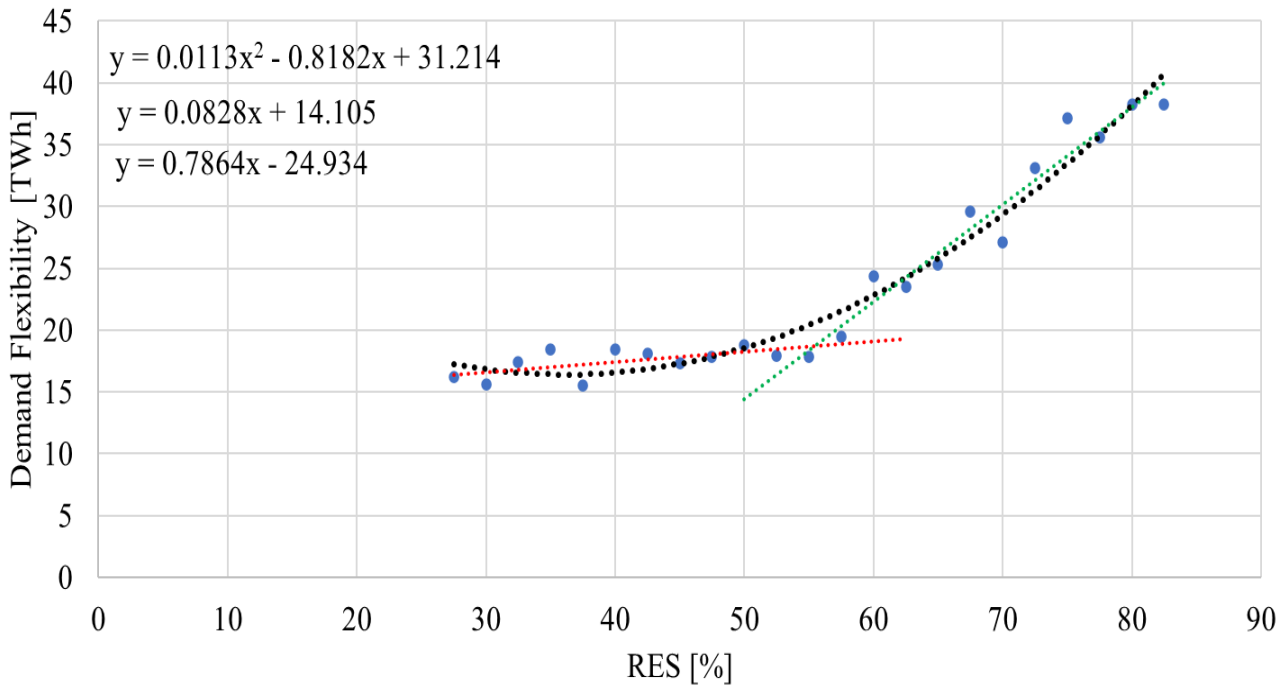


- Better at lower RES shares
- Competition with industrial excess heat and solar DH

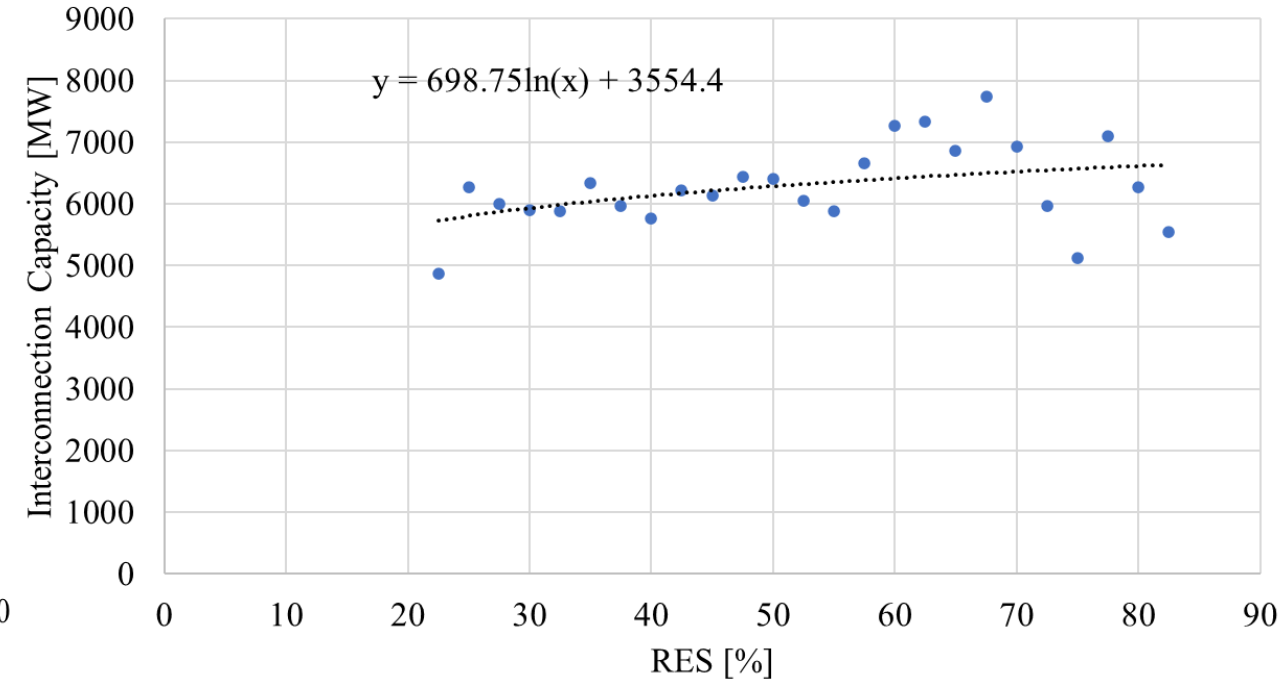
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Demand Flexibility



Interconnection Capacity



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Conclusions

- Significant reduction in Total annual cost with application of optimization
- Reduction of CO₂ emissions
- Minimization of CEEP
- Best results – V2G and PPmin for the whole RES range
- Industry electrification and demand flexibility effective at high RES share
- Further work:
 - implement linking of dependent variables
 - more detail analysis at higher RES shares
 - include other features (synthetic fuels, hydrogen)

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Low-carbon society:
An enhanced modelling tool for the transition to sustainability

Thank you very much for your attention!



Luka Herc

Luka.Herc@stud.fsb.hr



info@locomotion-h2020.eu



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