A Mixed-Integer Linear Optimization Approach for Power-to-X-Technologies in a District Heating System

Lukas Gnam, Thomas Nacht, Markus Puchegger,
Patricia Jasek, Markus Schindler, Christian Pfeiffer

Overview

- **Introduction**
- **Energy Hub**
- **Optimization Model**
- **Results**
- **Conclusions**

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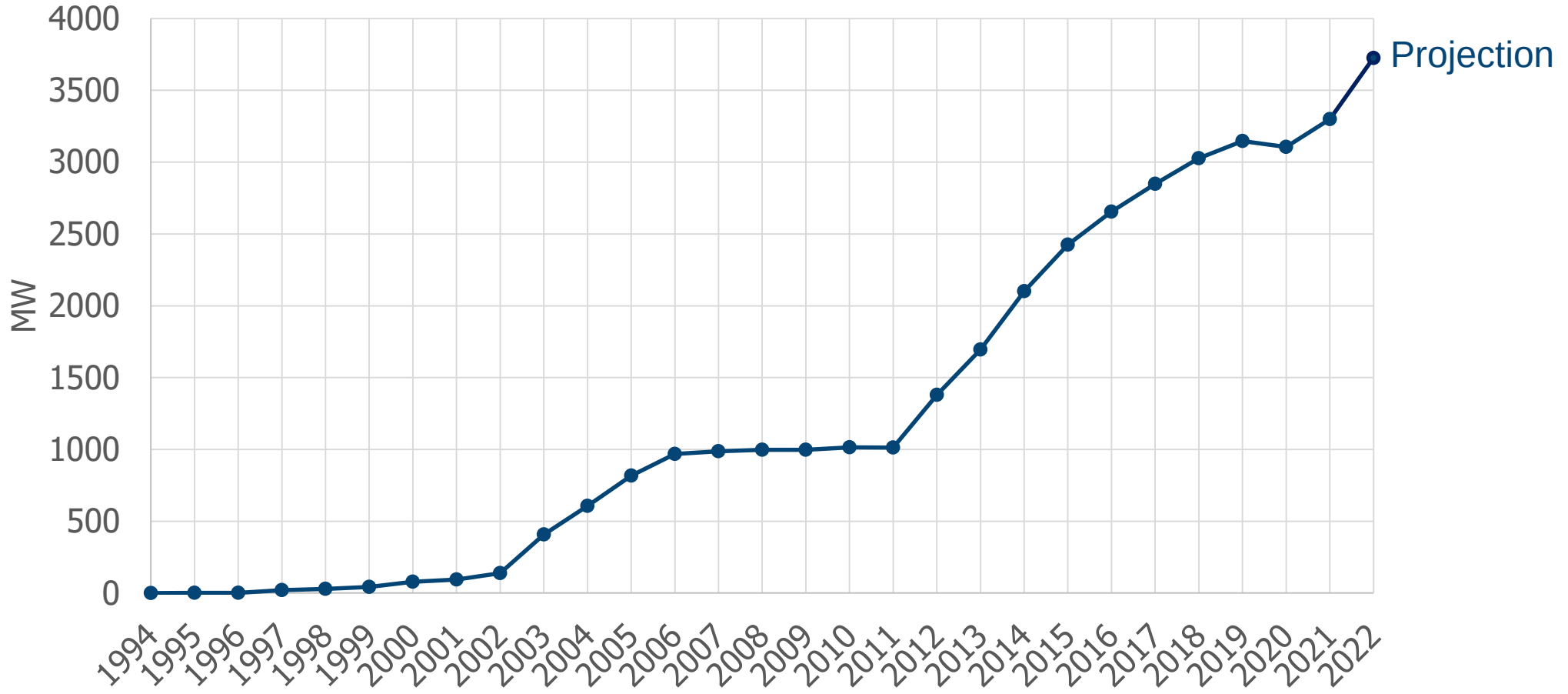
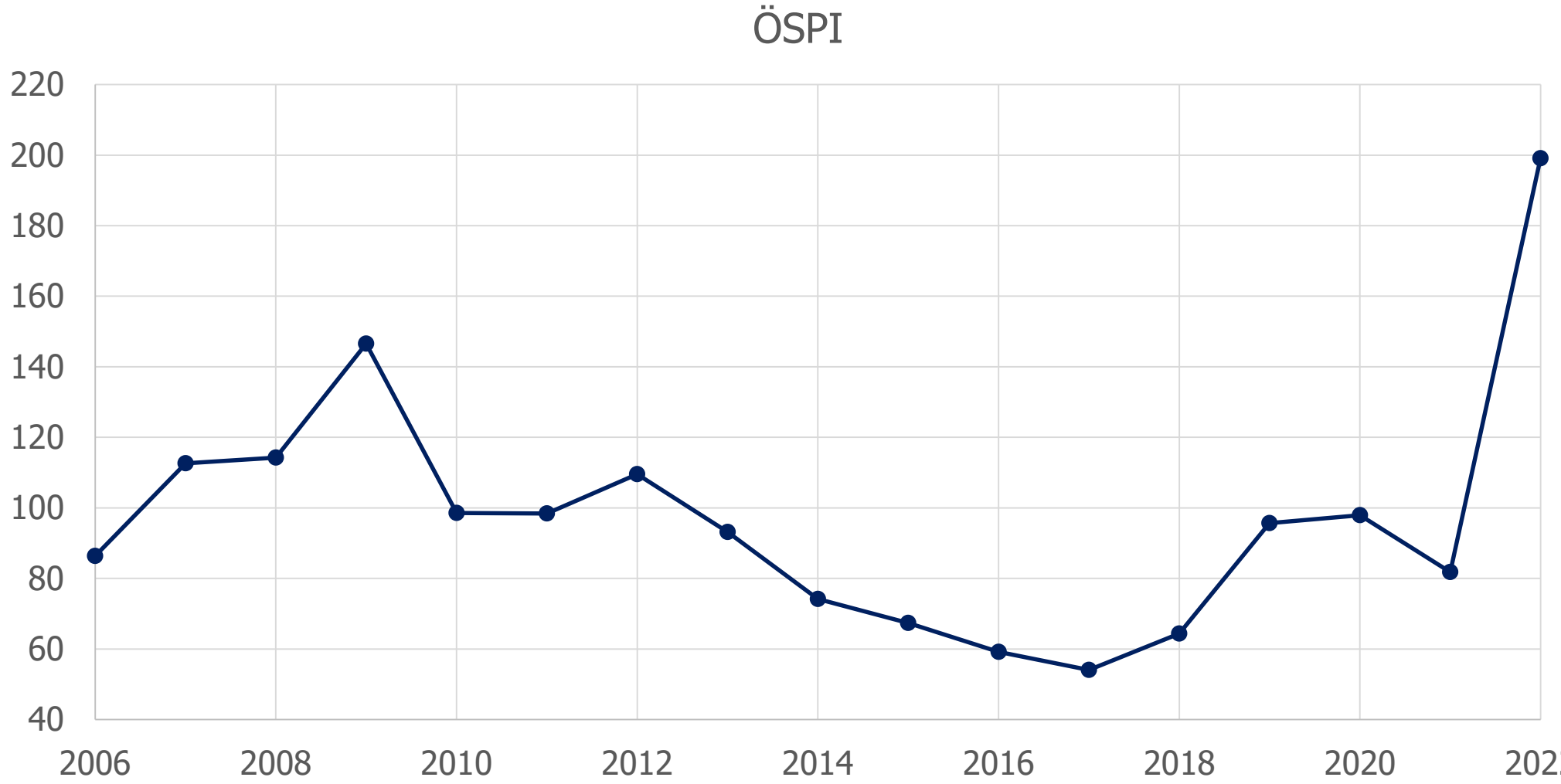
Wind Power in Austria

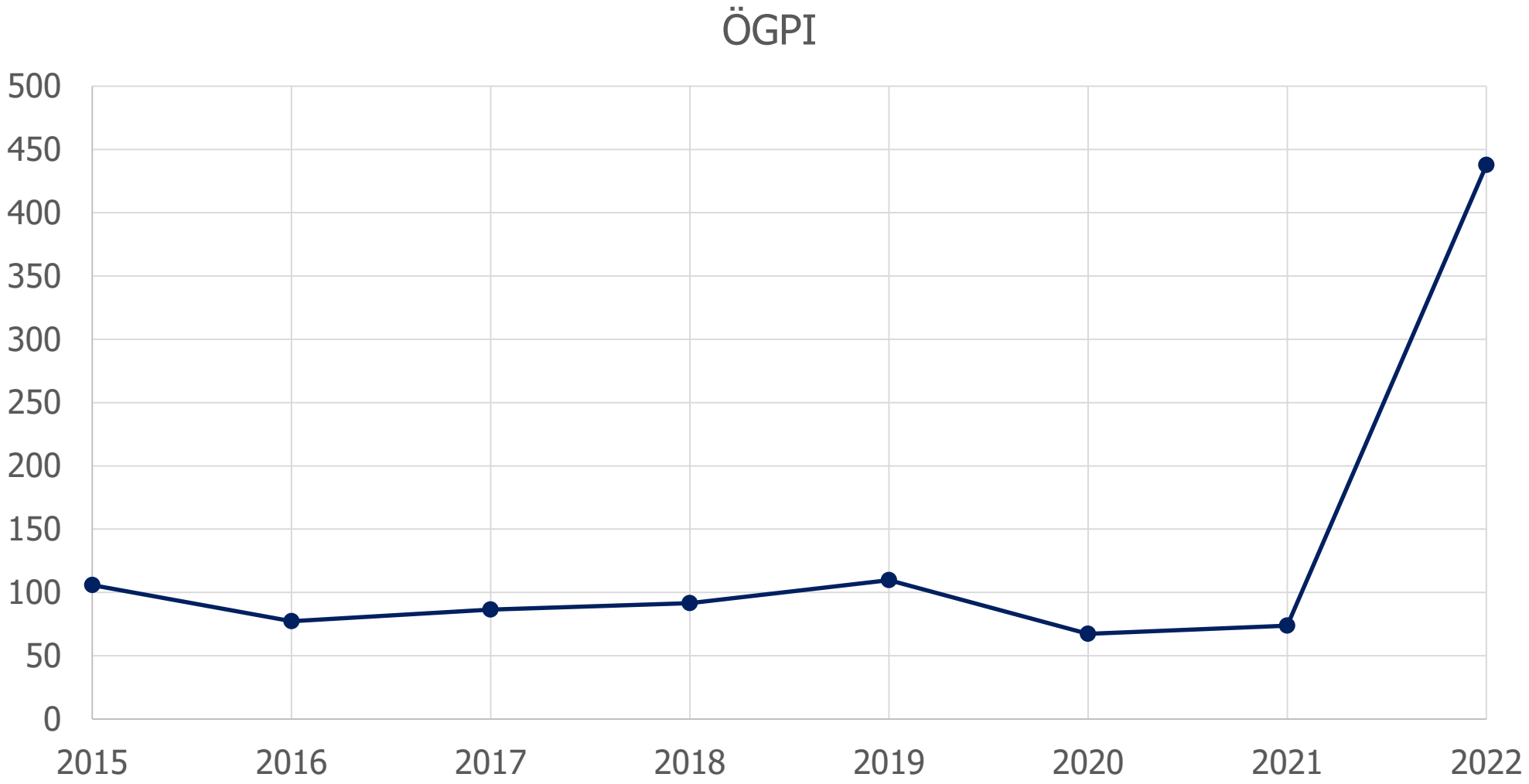


Source: IG Windkraft, January 2022.

Electricity Price



Gas Price


ÖGPI
500
450
400
350
300
250
200
150
100
50
0
2015
2016
2017
2018
2019
2020
2021
2022

Introduction

- **Motivation**
  - Subsidized feed-in tariffs are limited in time
  - Transition of energy systems only possible with sector coupling
    - Coupling of electricity with heat sector in district heating networks (power-to-heat)
    - Coupling with gas sector still challenging (power-to-gas)
    - Integration of electrolyzers yields potential to produce green hydrogen

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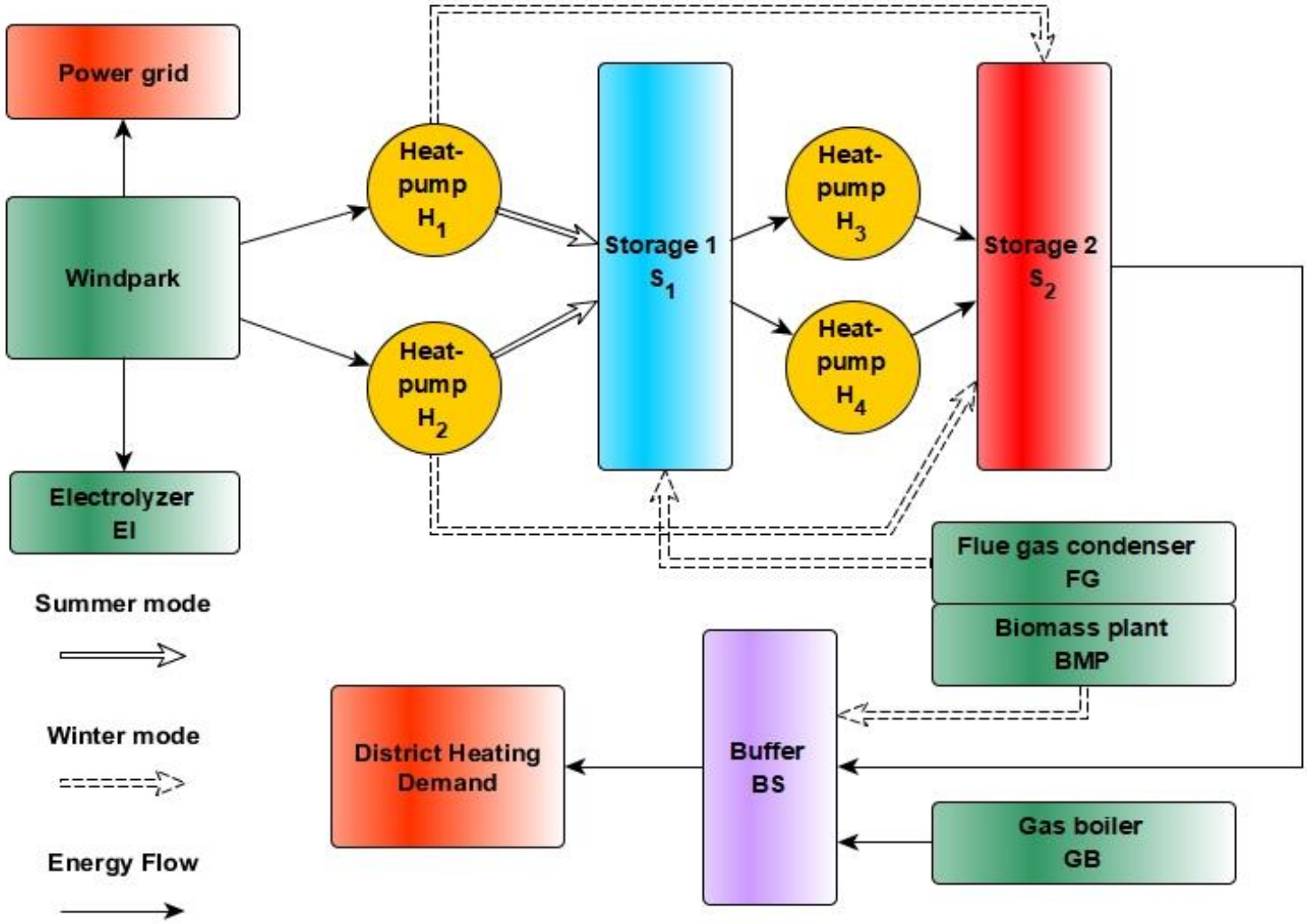
Energy Hub

- **Components**
  - Wind park
  - Heat pumps
  - Thermal storages
  - Electrolyzer
  - Biomass plant with flue gas condenser
  - Gas boiler

Energy Hub


Power grid
Windpark
Electrolyzer
El
Heat-
pump
H1
Heat-
pump
H2
Storage 1
S1
Heat-
pump
H3
Heat-
pump
H4
Storage 2
S2
Flue gas condenser
FG
Biomass plant
BMP
Buffer
BS
District Heating
Demand
Gas boiler
GB
Summer mode
Winter mode
Energy Flow

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Optimization Model

- **Overview**
  - System modeled using mixed-integer linear optimization approach
  - Linearization and approximations necessary
  - Components modelled in python utilizing pyomo[1]
  - Objective function minimizes yearls costs of energy hub

[1]Bynum et al. *Pyomo – Optimization Modeling in Python.* 2nd edition. Vol 67. Springer, 2021.

Optimization Model

- **Components I**
  - Heat pump model based on COP value $\dot{Q}_{th,HP}(t) = P_{el,HP}(t) \cdot COP_{HP}(t)$
  - Biomass plant assumed to yield specific power at timestep t
    - Utilized only in cold months
    - Cost function $\min\left(\sum_t P_{th,BMP}(t) \cdot p_{BMP} \cdot \eta_{BMP}^{-1} \cdot T\right)$
  - Flue gas condenser delivers share of biomass plant power $P_{th,FG}(t) = P_{th,BMP}(t) \cdot \eta_{FG}$

Optimization Model

- **Components II**
  - Gas boiler based on simple linear model with $P_{th,GB}$ and η_{GB}
    - Costs implemented directly in objective function $\min(\, P_{th,GK}(t) \cdot \mathrm{p}_{GK} \cdot \eta_{GK}^{-1} \cdot T)$
  - Grid connection allows for marketing wind energy
  - Thermal storages modeled with simple linear approach

$$SOC_{st}(t) = SOC_{st}(t-1) + T \cdot (SOC_{charge}(t) - SOC_{discharge}(t))$$

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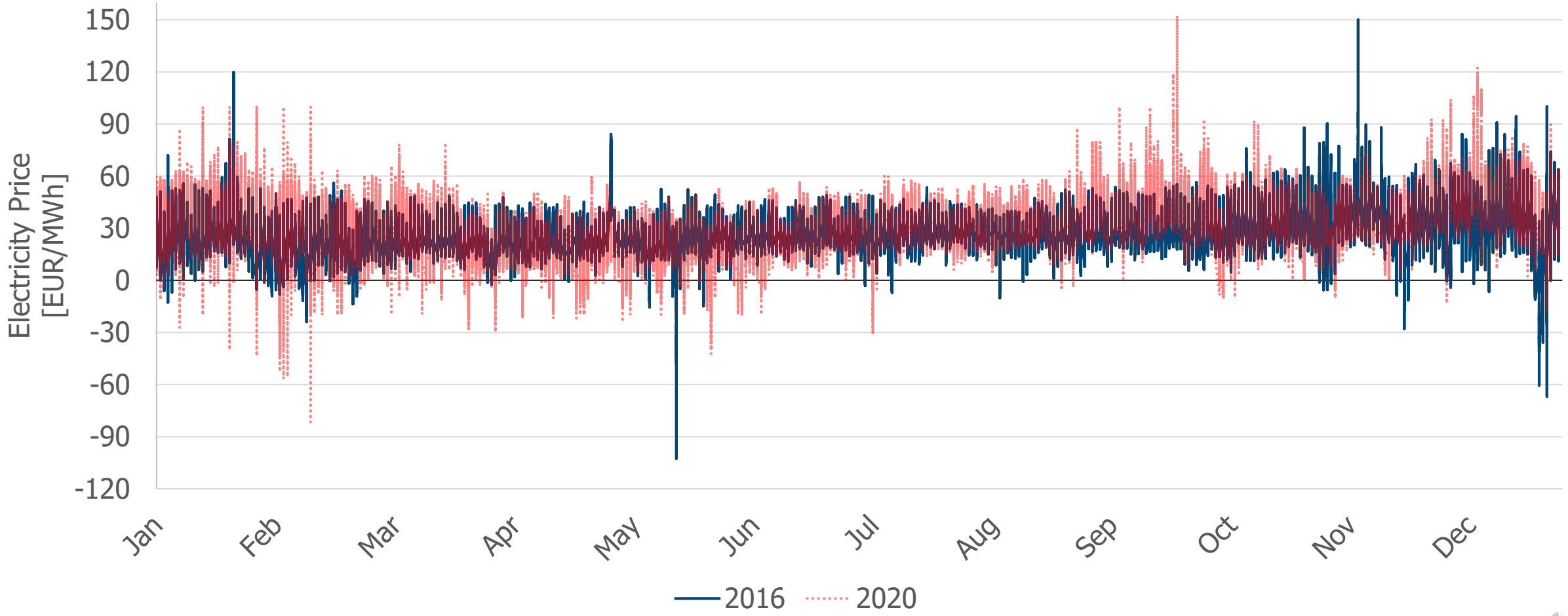
Results

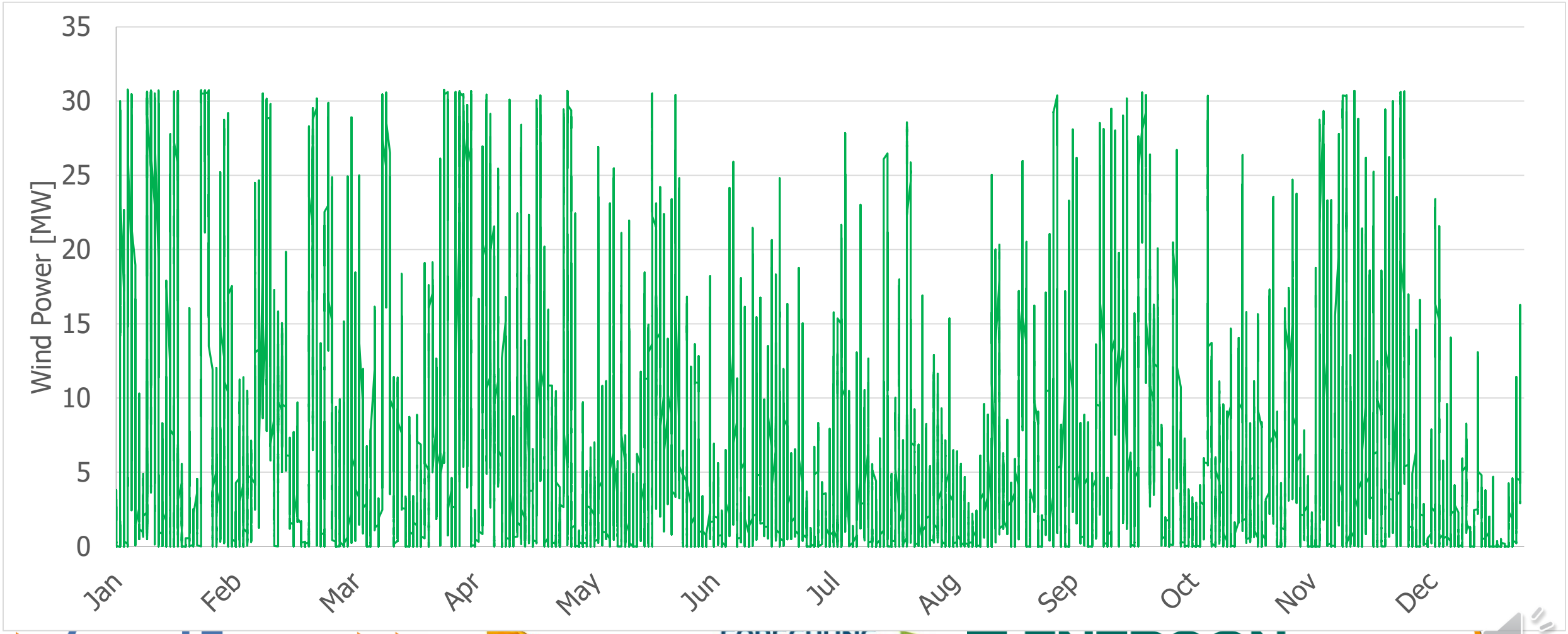
- **Model assumptions**

  - Aggregated heat pump power around $750 - 800\ kW_{el}$
  - BMP power between $520 - 2{,}600\ kW$ and a 15-min gradient of $780\ kW$
  - Flue gas condenser with efficiency of $27\ \%$
  - GB maximum power at $3{,}900\ kW$
  - Storage units with $13{,}300\ l$ for S_1 and $18{,}200\ l$ for S_2
  - Buffer storage with $300{,}000\ l$
  - Electrolyzer with $5{,}000\ kW$
  - Hydrogen price assumed with $6\ €/kg$

Results


150
120
90
60
30
0
-30
-60
-90
-120
Electricity Price [EUR/MWh]
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2016
2020

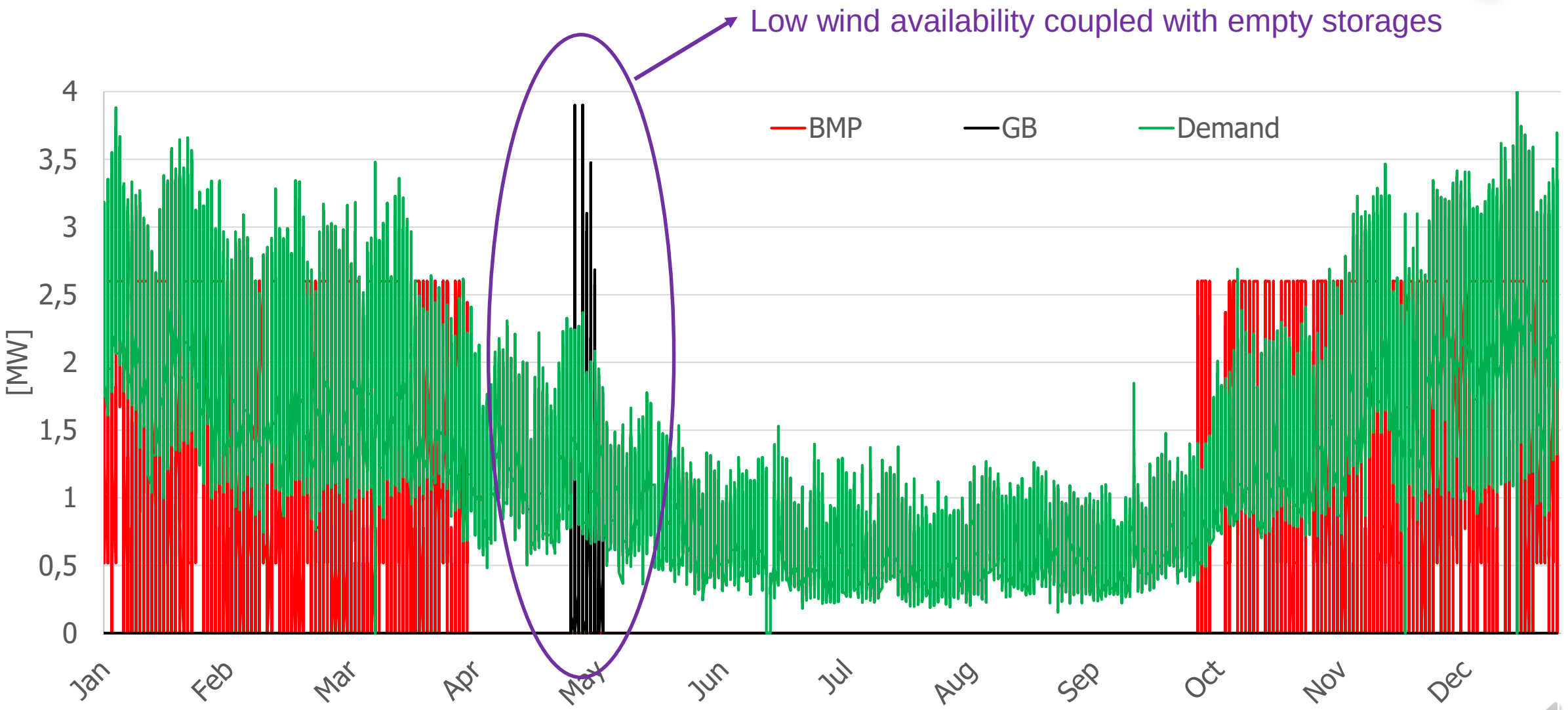
Results


Wind Power [MW]
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Results


4
3,5
3
2,5
2
1,5
1
0,5
0
[MW]
BMP
GB
Demand
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Results


Low wind availability coupled with empty storages
BMP
GB
Demand
[MW]
4
3,5
3
2,5
2
1,5
1
0,5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Results

- **Electrolyzer**
  - Produces almost constantly hydrogen
  - With the specified electrolyzer parameters around $18\ t$ of hydrogen
  - However, degradation and other technical effects not yet implemented in the optimization model

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Conclusions

- RESs can provide the lion's share of energy for an energy hub
- Backup solutions, e.g., gas, necessary
- Feasibility of electrolyzers depending on specific requirements
  - Hydrogen consumers
  - Storage and transportation options
  - Price of green, grey and black hydrogen
  - Technical details of electrolyzer technology