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HYDELTA 2

Potential of hydrogen production via power-to-gas techniques as a countermeasure for handling supply-side electricity grid congestion in regional distribution grids

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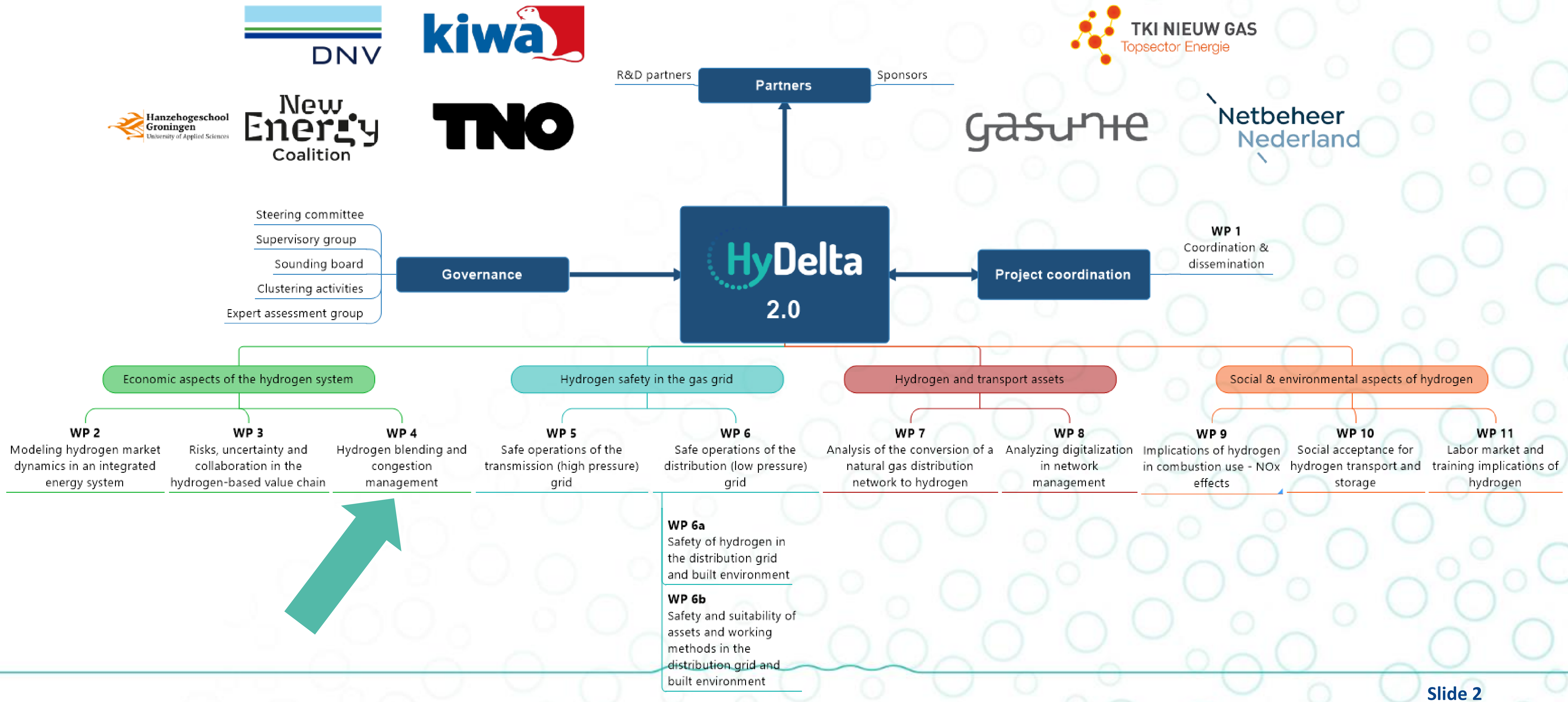
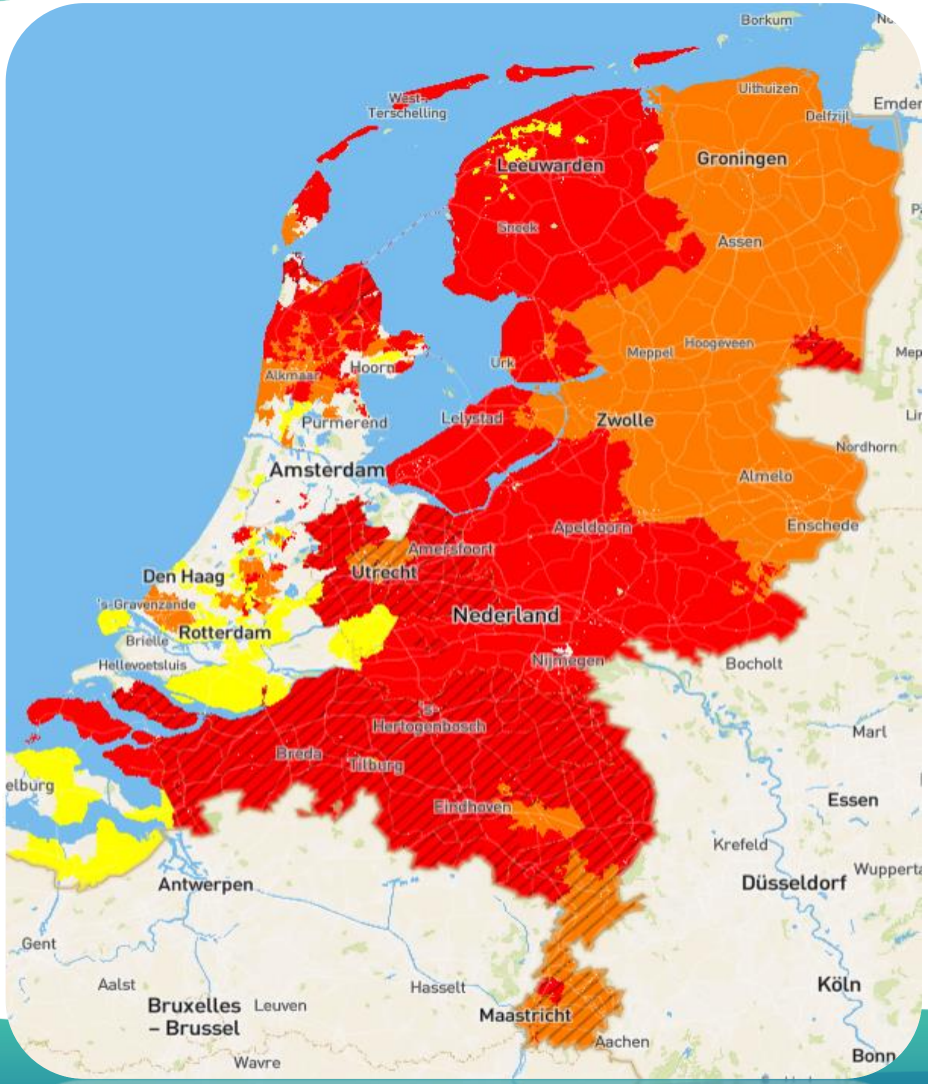
HyDelta 2 project consortium



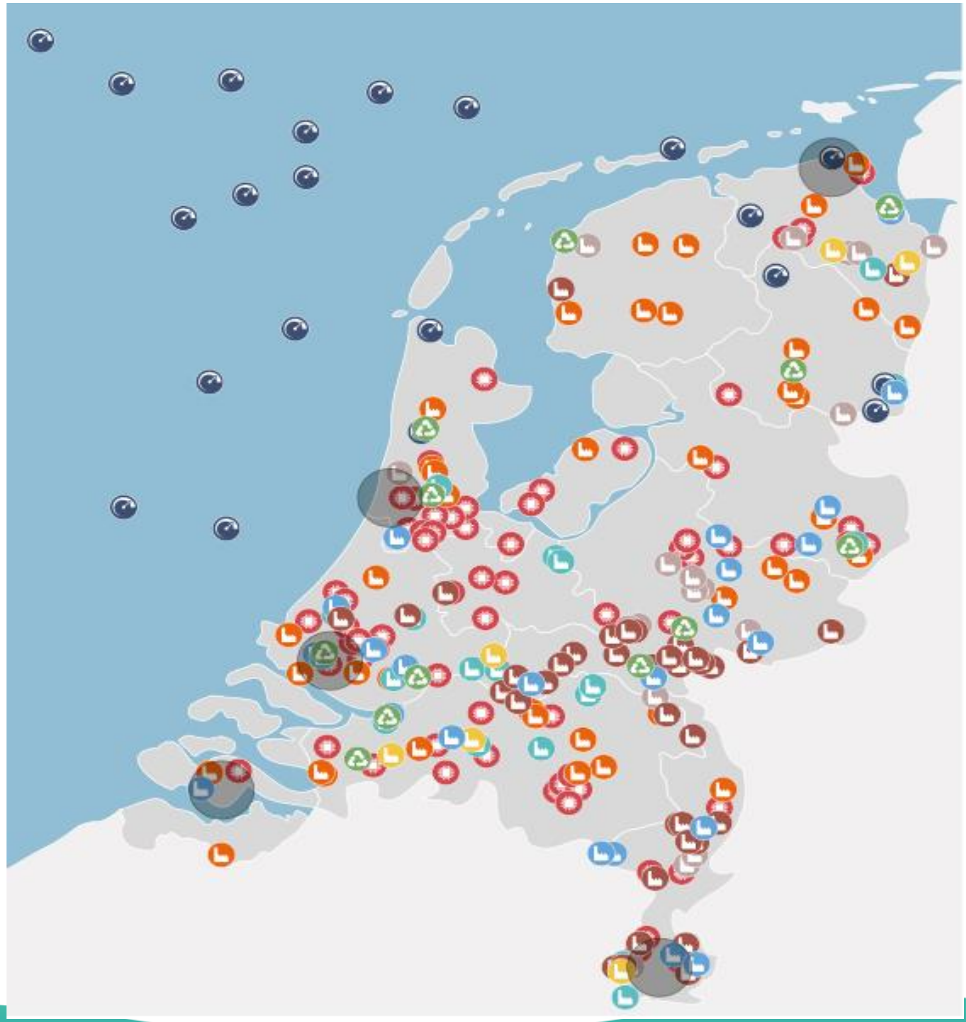
State of supply-side e-grid congestion

- Fulfilling climate targets requires an increasing uptake of renewable electricity into the grid
- E-grid capacities are scarce, and the expansion of the grid takes substantial time and costs
- DSO's face challenges in providing grid connections for customers → congestion
- The research investigates to what extent could local or regional P2G systems alleviate congestion in the e-grid via grid flexibility techniques:
  - PtG via electrolyzers
  - Utility scale batteries
  - Curtailment
- Utilizing green hydrogen in decentralized industrial clusters ('zesde cluster') and the hydrogen mobility sector



Decentralized industries

- Decentralized industries are removed from the foreseen national hydrogen backbone
- Carbon emissions: 16.5 MtC/a
- -4.3 MtC/a reduction by 2030
- Techno-economic conditions of introducing clean hydrogen in the RTL for cluster 6



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Potential locations for introduction of hydrogen in decentralized industries

Area Criteria

- Supply and/or demand side e-grid congestion
- Gas grid connection of industrial end-users is decoupled from the public distribution system
- Locally produced hydrogen can be adopted for a wider group of industries
- Propinquity to local renewable electricity sites (1MW solar or 60 MW wind)
- No other attractive alternatives exist

Potential blending endpoints

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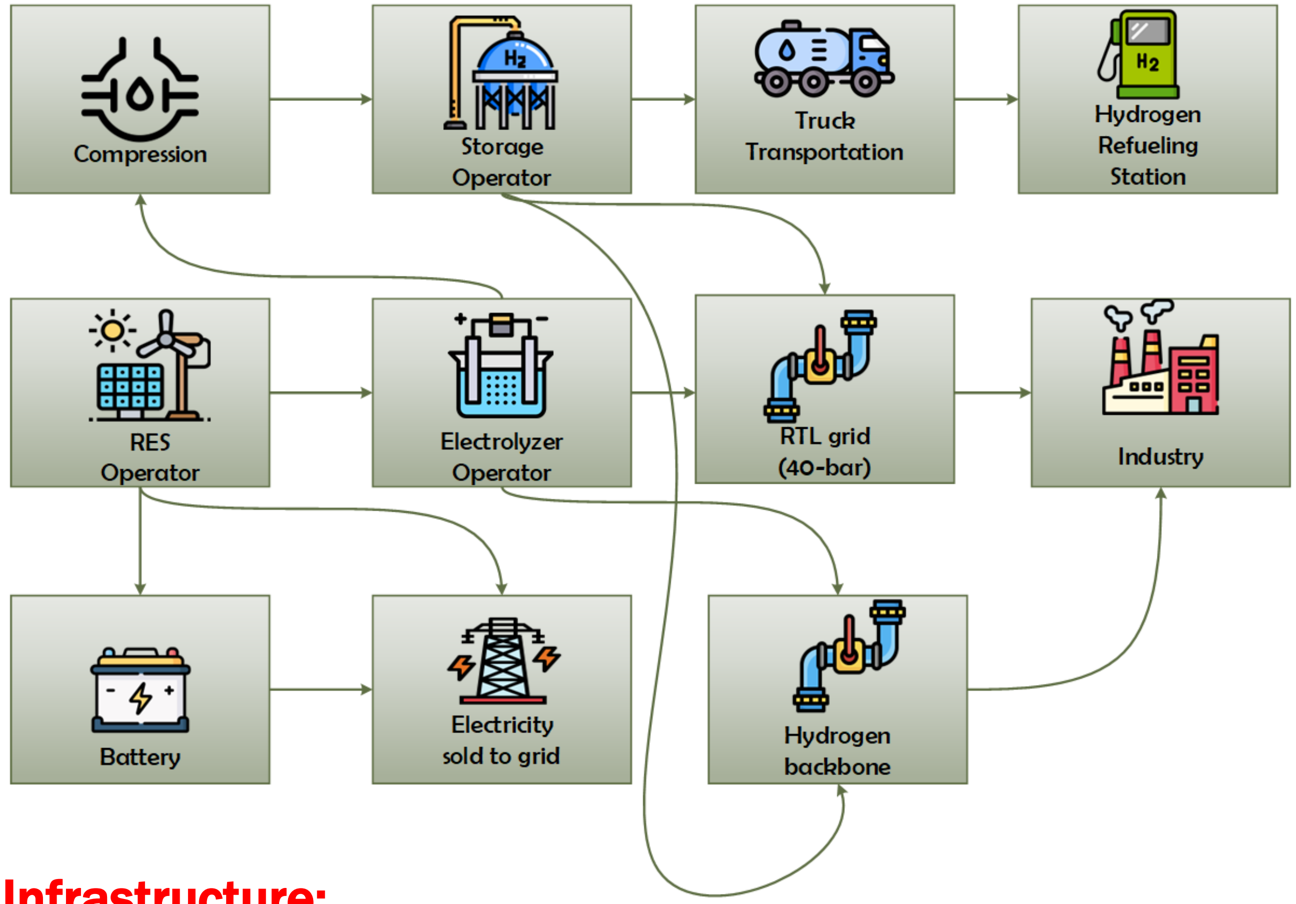
Green hydrogen within a renewable energy system

Focus points:

- When is it economically feasible for renewable electricity producers to install their own local electrolyzer capacity?
- Would the use of batteries be a better alternative than P2G for the renewable electricity producer to overcome supply-side congestion issues?
- If hydrogen is produced decentrally, what is the best option? Injection into the regional transmission pipeline or to sell it to the local mobility market?



Infrastructure:

- **RTL grid (40-bar) / Hydrogen Backbone**
- **Truck transportation**

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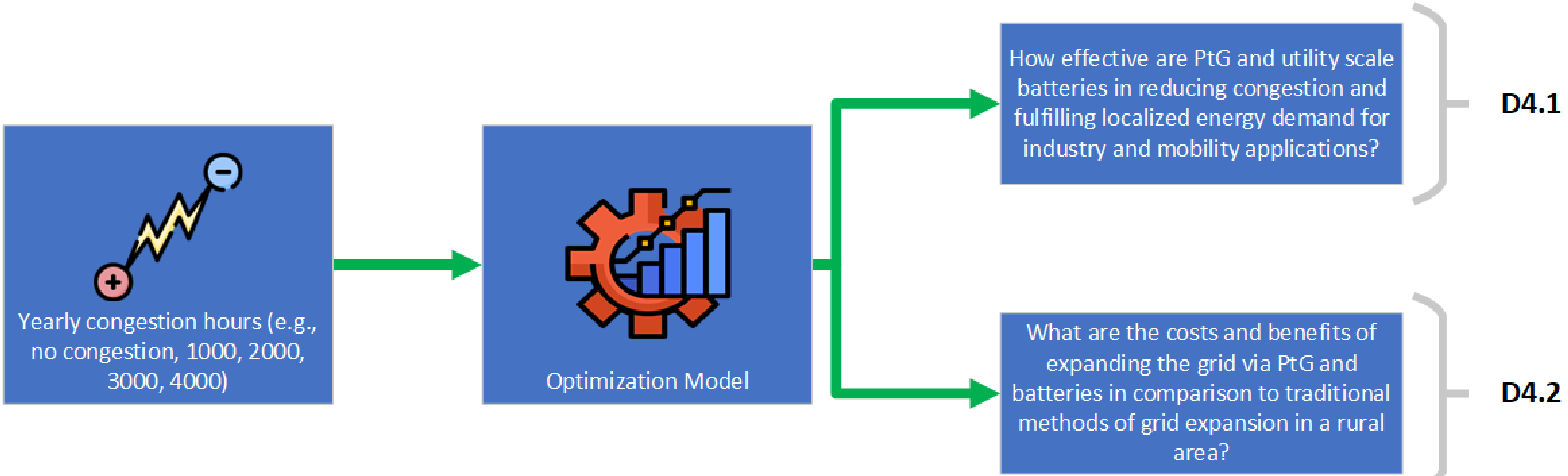
Optimization Model



The aim of the model is to optimize the annual profitability based on capacity and operational decision for each asset, or issues such as:

- How much capacity of wind, solar, electrolyzer and hydrogen storage should be installed?
- Which hours should electricity either be sold to the market, or used for hydrogen production?
- Which hours should hydrogen be stored or sold to off-takers?

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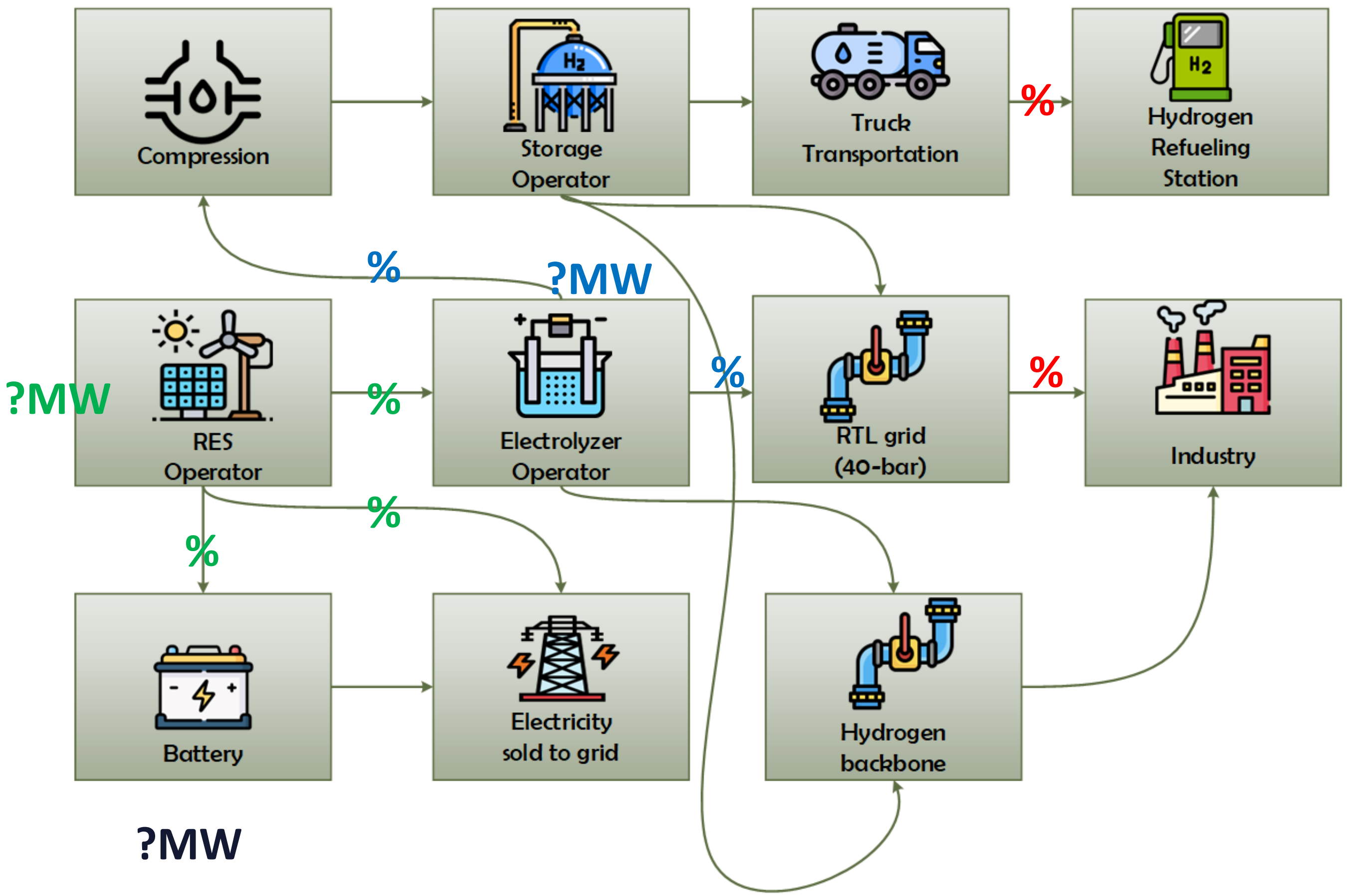
KPI's



Investigated category	KPIs
RES operator	•Capacity (MW) •LCOE (€/MWh) •Sold to grid operator (%) •Sold to electrolyzer operator (%) •Curtailed electricity (%)
Electrolyser and storage operator	•Capacity (MW) •Utilization (%) •Storage capacity (kg) •LCOH (€/kg) (without considering electricity costs) •H_2 to industry (%) •H_2 stored (%) •H_2 to mobility (%)
End-users	•Potential industrial demand utilized (%) •Potential mobility demand utilized (%)
Annual Profits	•Revenues (M€)
Battery	•Capacity (MW) •LCOE of battery storage (€/MWh)

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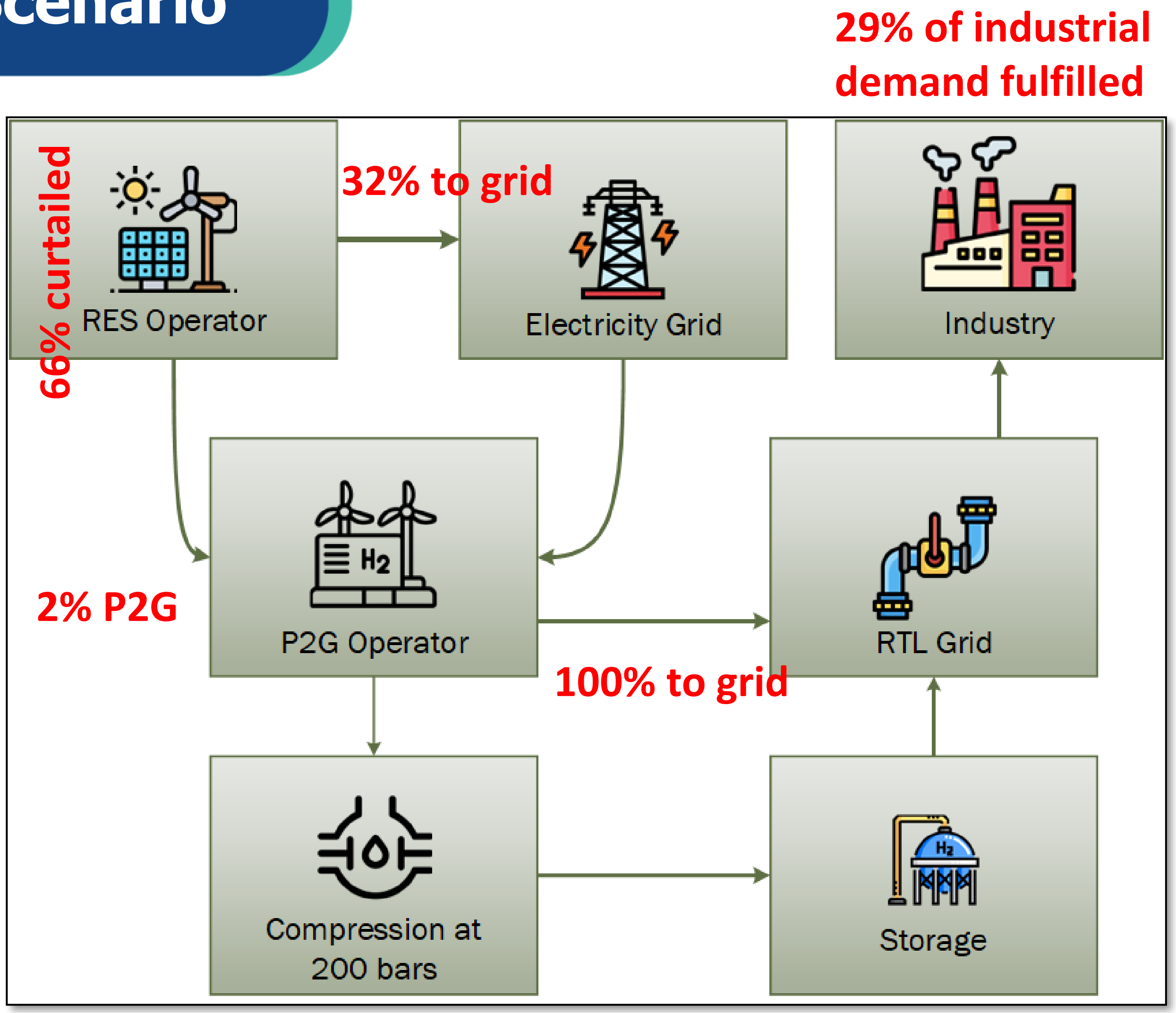
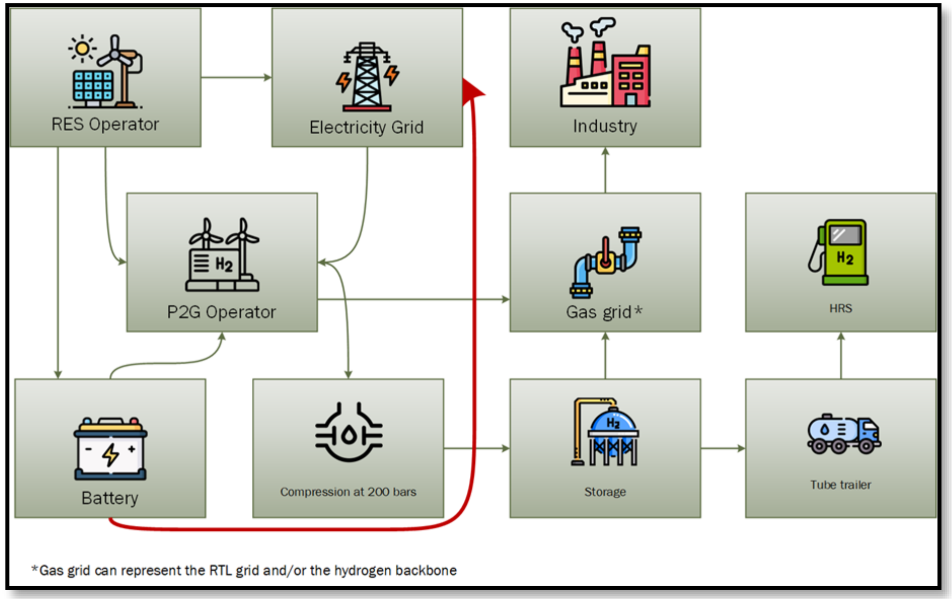
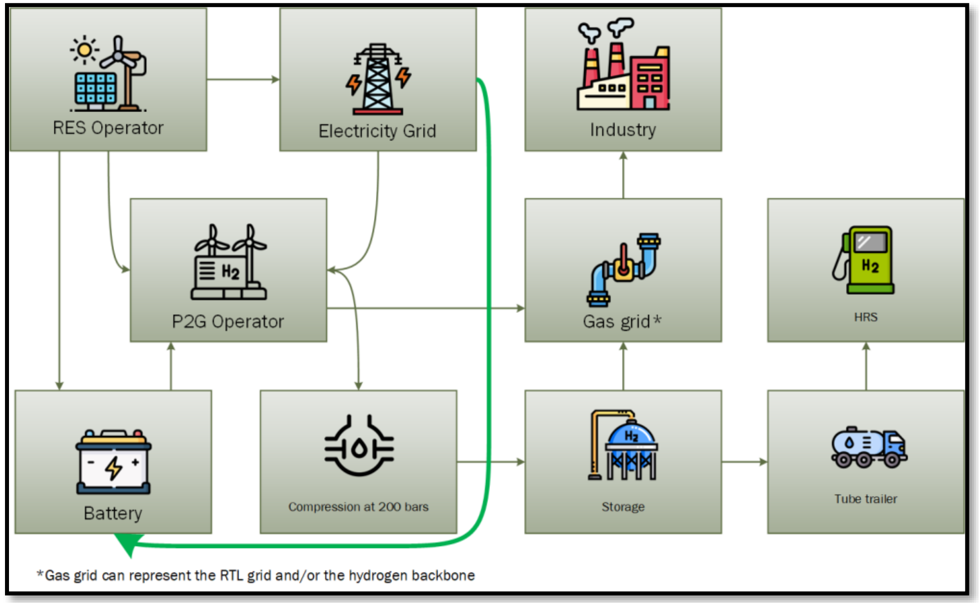
Baseline Scenario

- € Electricity > € Hydrogen
- High electricity prices in 2022 resulted in high levels of profits even with congestion
- Only profitable to install an electrolyzer of a capacity that can be utilized enough
  - 3000 congestion hours yield competitive production of hydrogen
  - 2% was utilized by the P2G system – 32% sold to grid – 66% curtailed
  - Electrolyzer capacity was 0.5 MW
  - 29% industrial demand fulfilled (out of 350TJ)



Battery Scenario's





Baseline + Subsidy + Mobility + Battery (I)

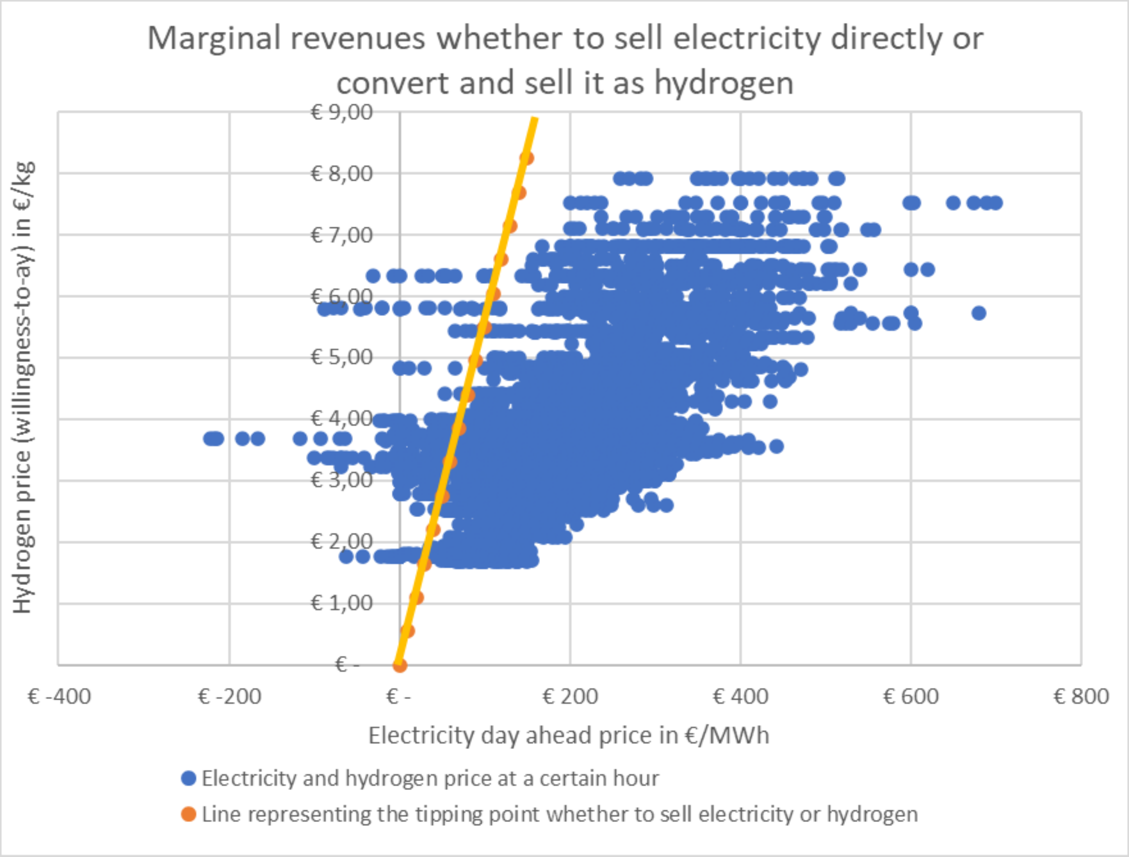
- Installing local battery capacity > hydrogen production → due to:
  - lower investment costs of batteries (€200/kW vs.€1800/kW)
  - Significantly larger share of curtailment was avoided
  - 0% electrolyzer utilization

Baseline + Subsidy + Mobility + Battery (II)

- Battery in front of the electrolyzer → effective method to increase electrolyzer utilization → lower local hydrogen production costs
- Mobility utilization > Industrial Utilization (Better profit margins)

What determines selling electricity over hydrogen?

- Blue dots on the left side of the orange line show the hours in which it is more beneficial to sell hydrogen, while the dots on the right side show the hours in which it is more beneficial to sell the electricity directly.
- The figure clearly shows that there are more hours in the analysed period in which it was more beneficial to sell the electricity directly.
- In order to avoid curtailment due to congestion, it is only profitable to install an electrolyser of a capacity that can be utilized enough.



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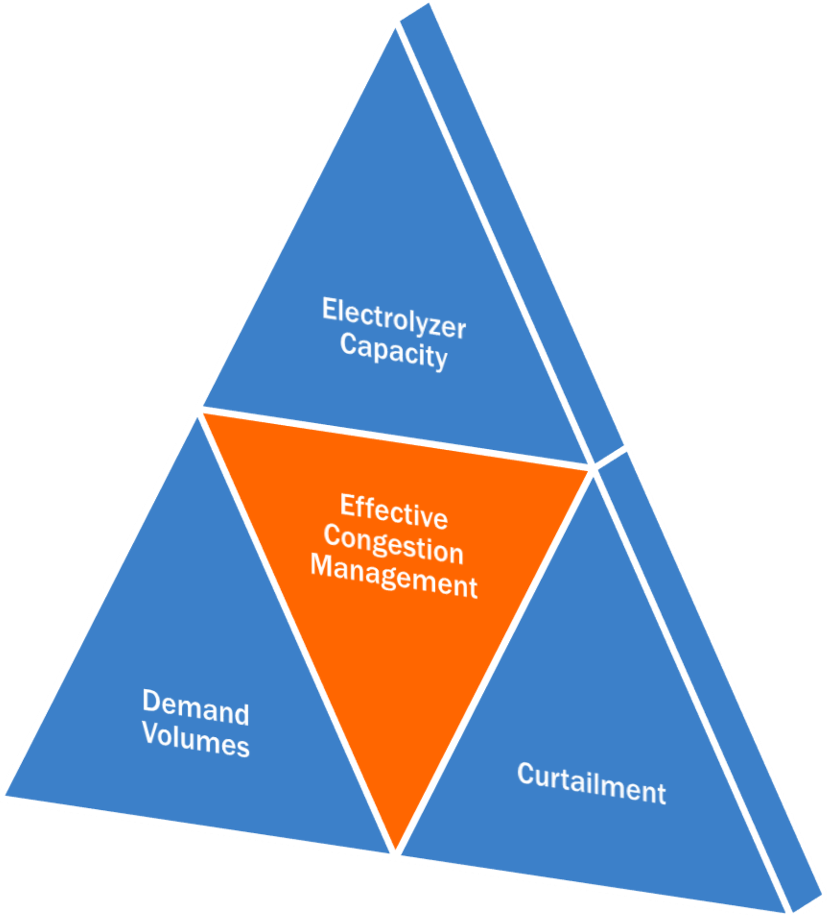
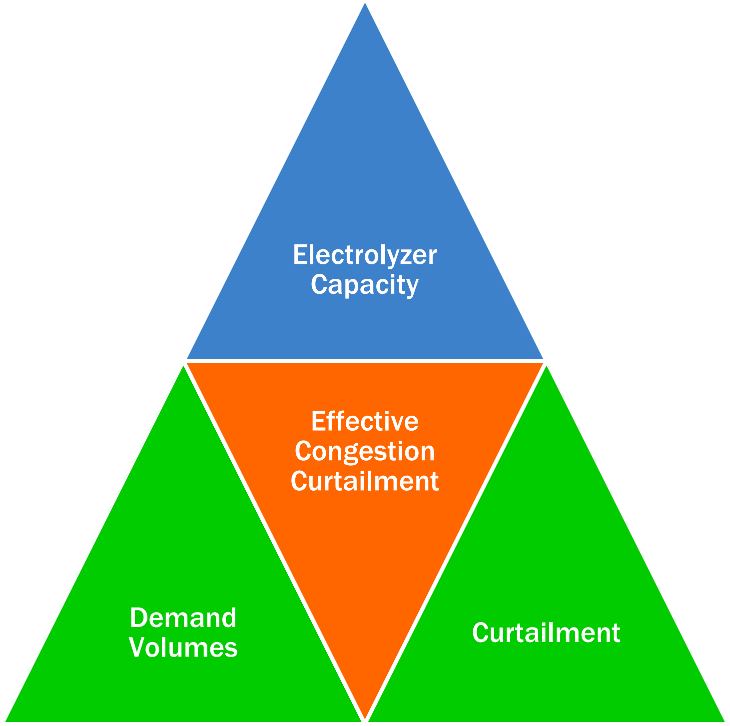
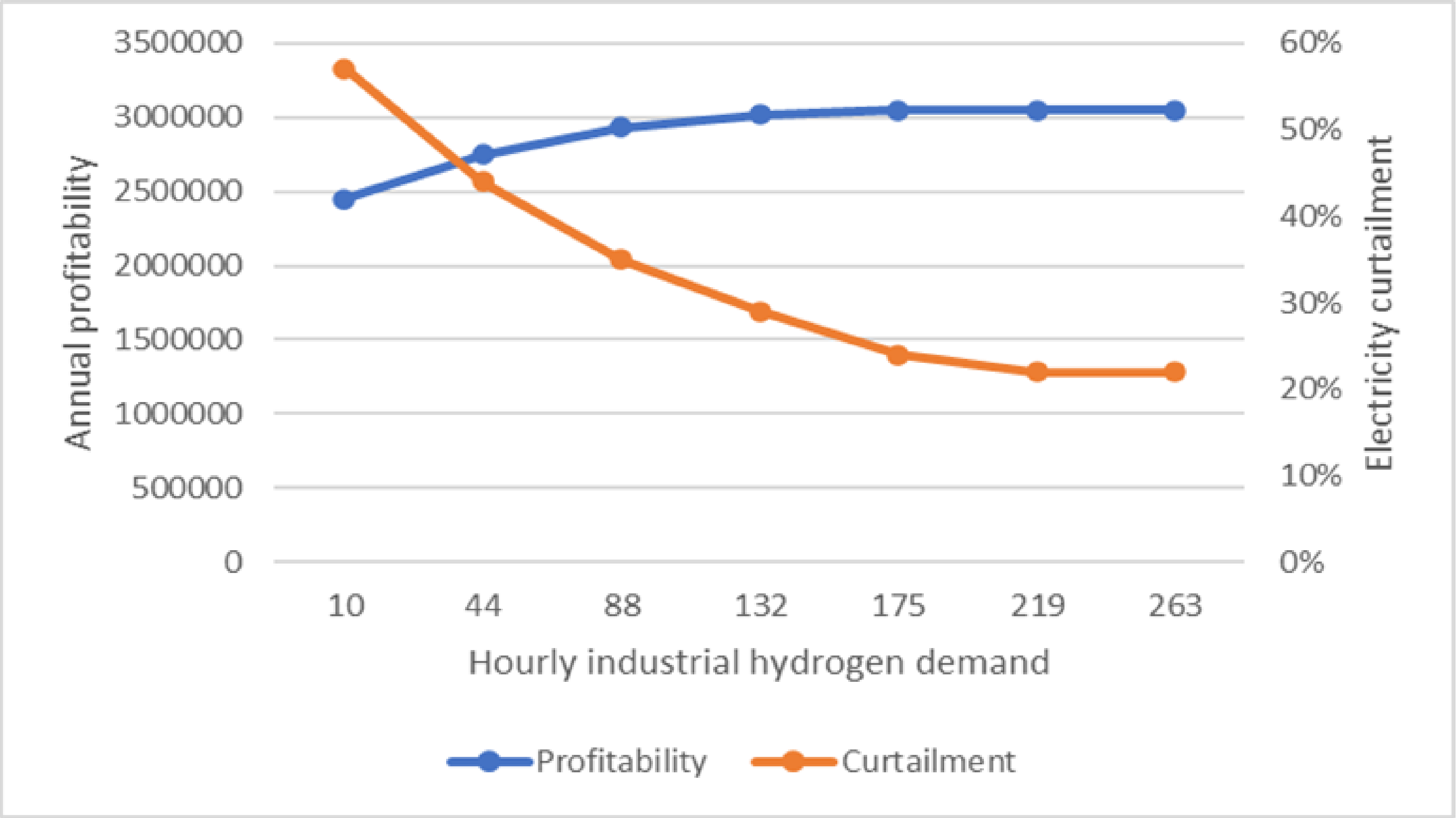
Contingencies

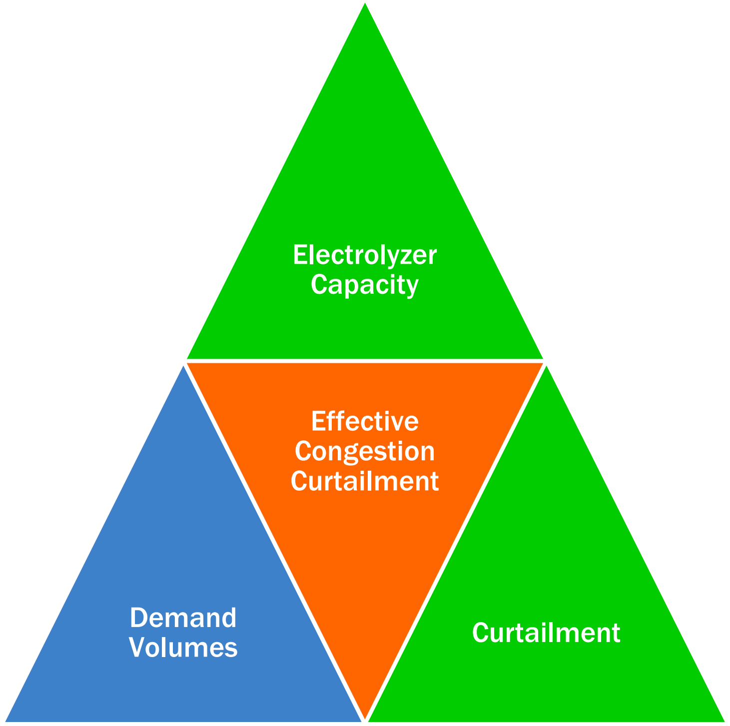


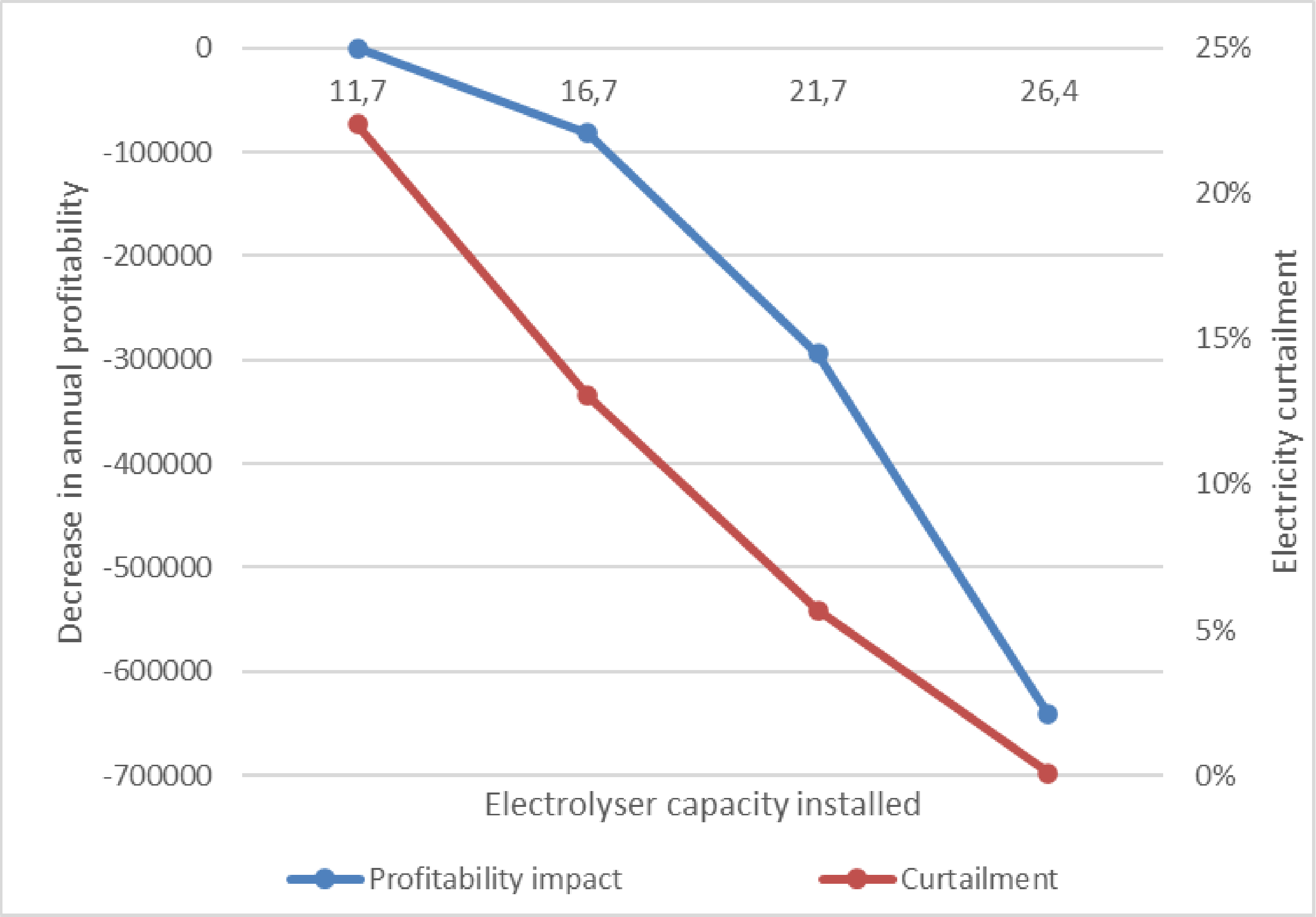
Contingency of Hydrogen Demand Volume and Curtailment





Contingency of Electrolyzer capacity and Curtailment





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Three key takeaways from D4.1

- Currently, P2G is a difficult business case from the perspective of energy suppliers:
  - Current market prices of green hydrogen
  - Local industry demand levels

- Utility-scale batteries offered a higher utilization rate and turned out to be more cost-effective
  - Scalability is easier
  - CAPEX-levels are lower than electrolyzers
  - Electricity trading margins are better due to high electricity prices
- Volume of green hydrogen demand from local mobility > local decentralized industry
  - Due to HBE-certificates (*hernieuwbare brandstofeenheden)* mobility is expected to offer much higher green hydrogen returns than industry
  - … but both prices and demand volumes are more uncertain compared to industry and demand volumes will probably fluctuate more heavily

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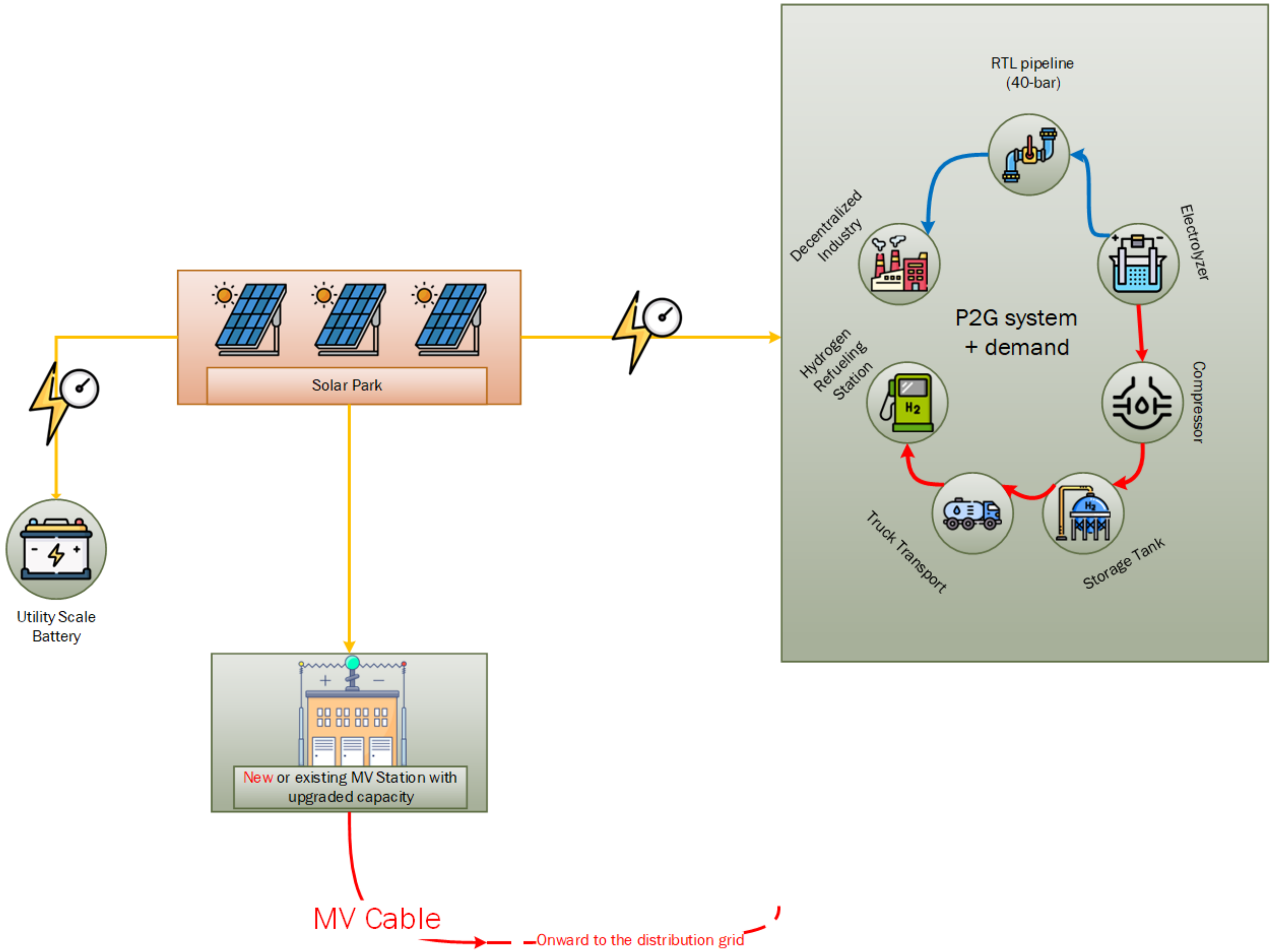
Effect of alternative flexibility methods on cost and benefits of grid expansion



Determining cost effective solutions to grid expansion:

Net costs of alternative supply-side grid flexibility solutions have been compared with those of traditional grid expansion techniques.

Comparative analysis via a case study in the context of a quasi-realistic setting in which a 38 MWp solar park is introduced where electricity supply exceeds demand.

Exploring sensitivities to analyze the impact of parameter changes on the behavior of flexibility components:

- E-prices and hydrogen process
- Capacity of the solar park
- Changes in electricity demand
- Etc.

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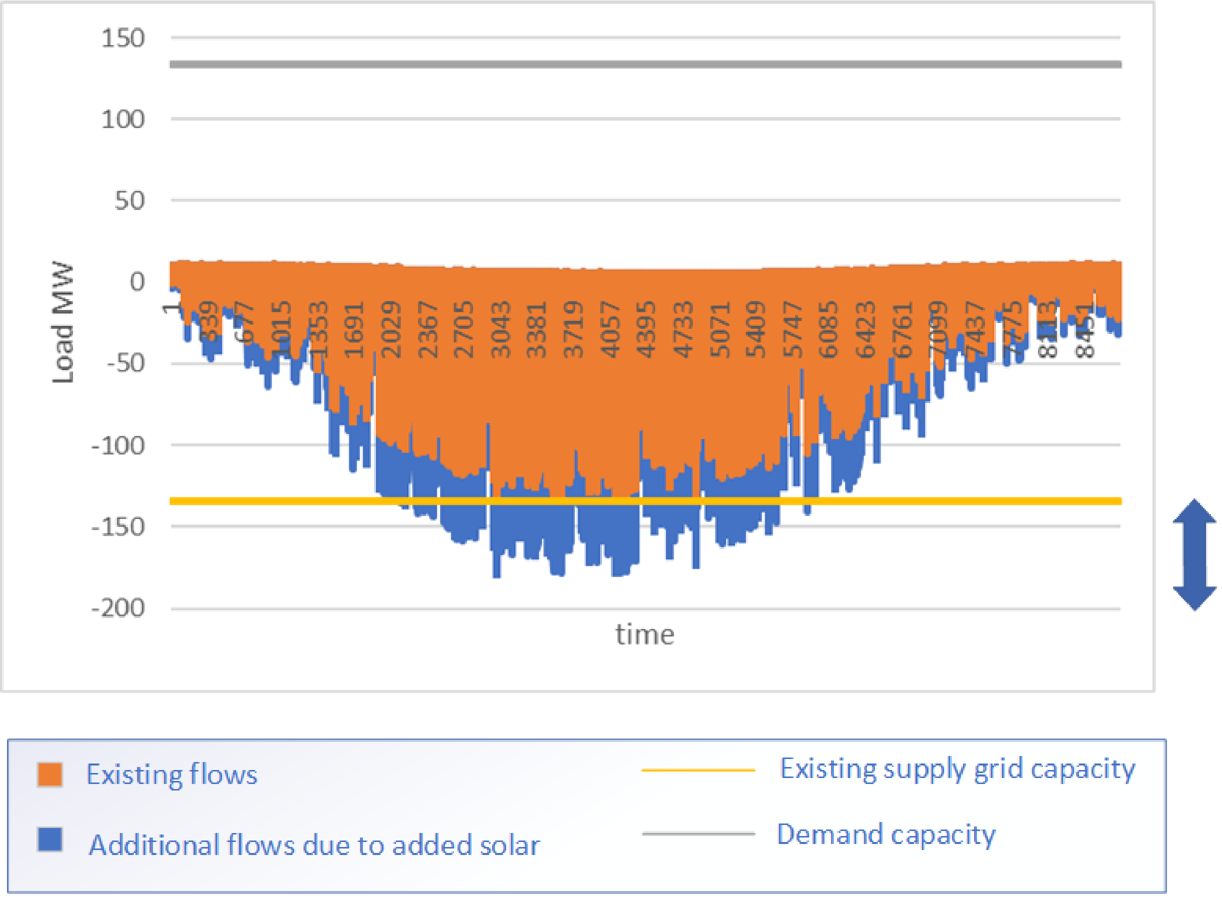
Flexibility techniques for peak shaving

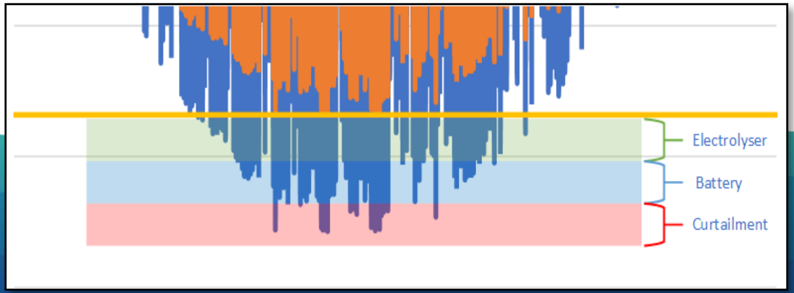
Curtailment: limit grid reinforcements that are only required to facilitate injection of the highest solar generation overshoots for a (very) small number of hours during the year.

Batteries: optimization of e-grid capacity use and matching between generation and demand

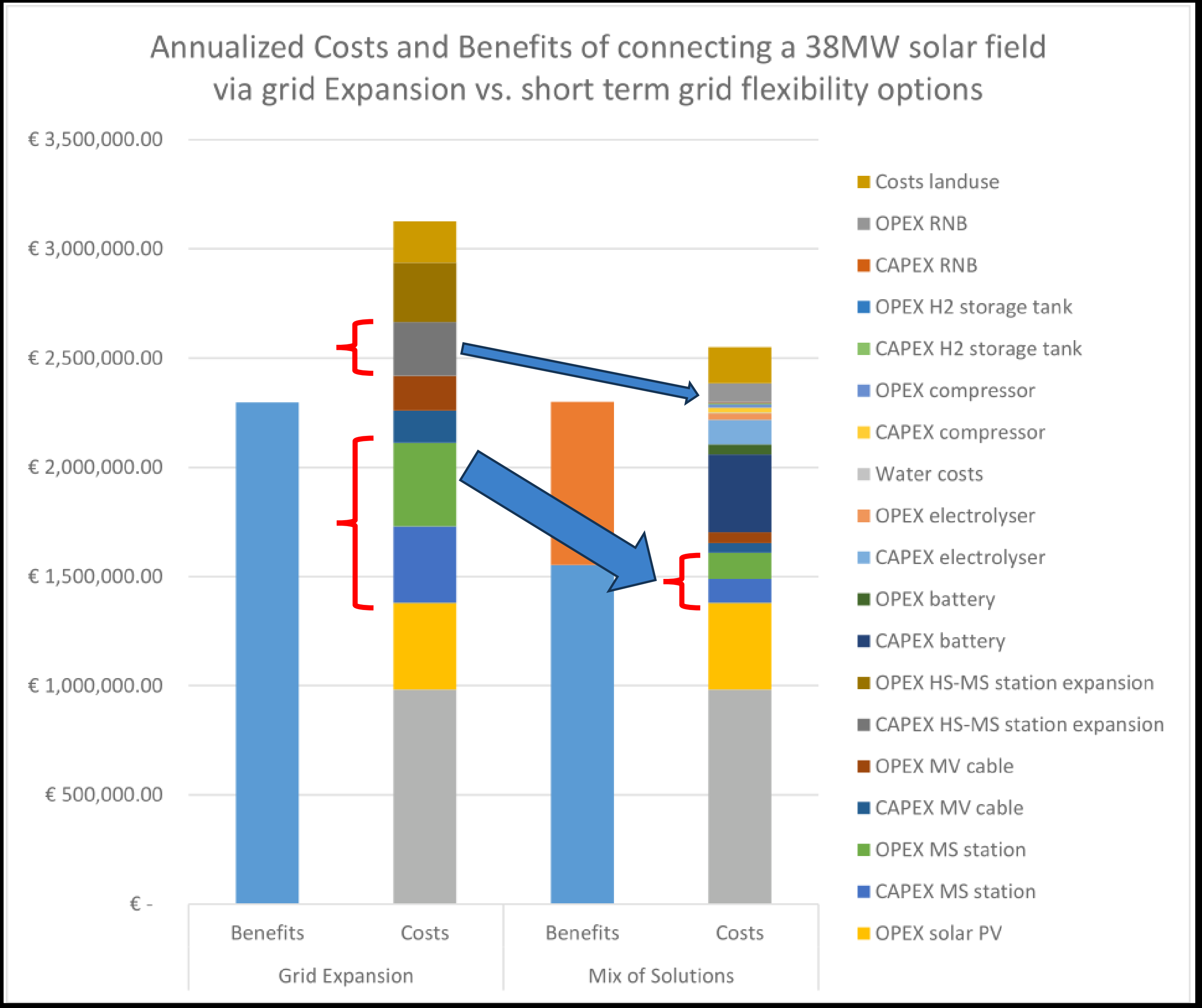
PtG: helps to better match local supply and demand of energy, especially if there are more structural overshoots



How to deal with this excess production? Options: connect to the grid?/electrolyzer?/battery?/curtailment?



38MWp solar park via grid expansion vs. short-term grid flexibility options



Cost elements for Grid Expansion:

- CAPEX and OPEX of Solar PV's
- CAPEX and OPEX of MV stations
- CAPEX and OPEX of MV cables
- CAPEX and OPEX of HV-MV station expansion
- Costs of land use

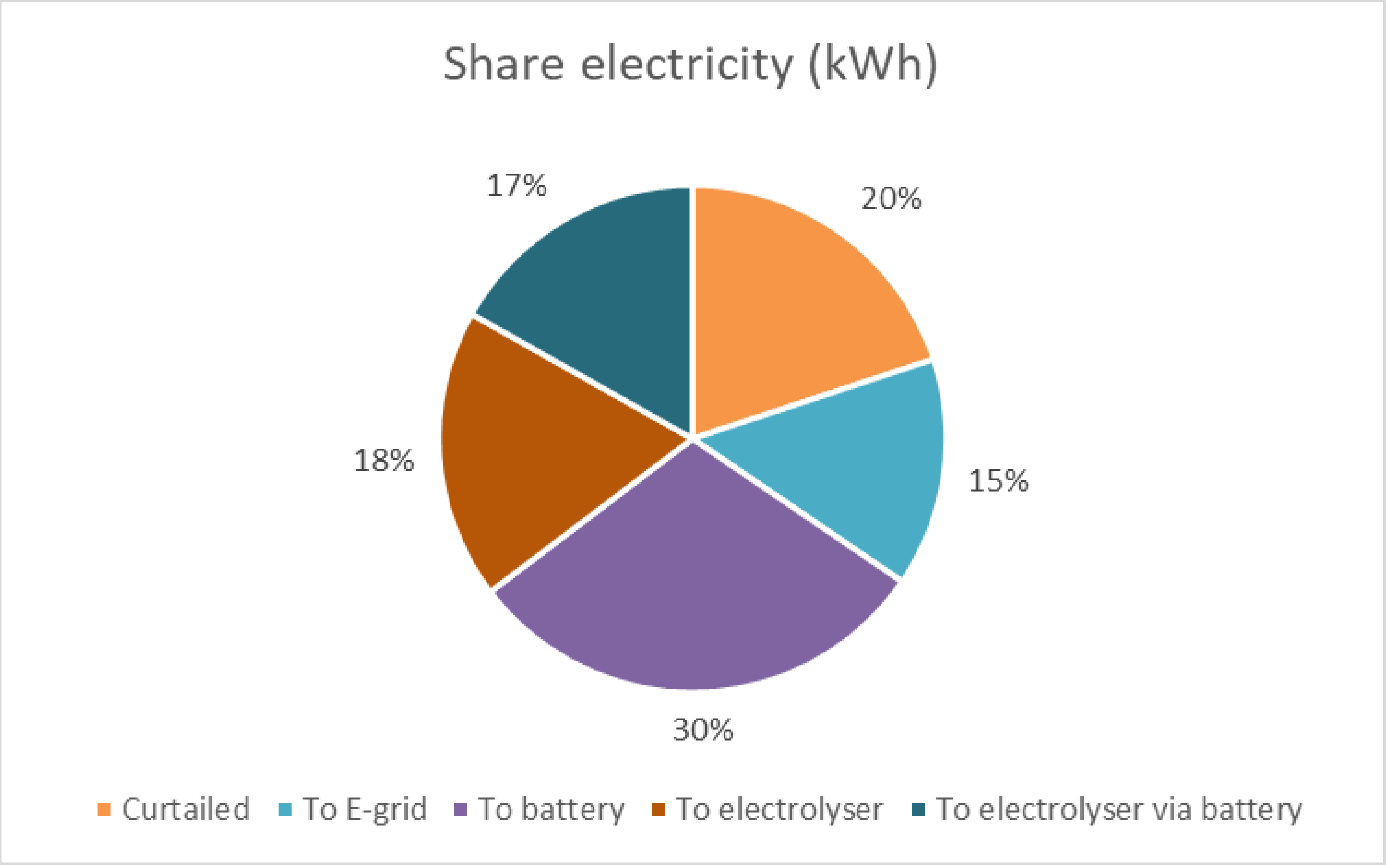
Cost elements for Mix of Solutions:

- CAPEX and OPEX of Solar PV's
- CAPEX and OPEX of MV stations
- CAPEX and OPEX of MV cables
- CAPEX and OPEX of batteries
- CAPEX and OPEX of electrolyzer
- CAPEX and OPEX of H2 Storage Tank
- OPEX of RNB

Electricity Distribution shares for solar farm

Utilization:

- 20% curtailed
- 15% to e- grid
- 30% to battery,
- 18% to hydrogen,
- 17% battery + electrolyzer; hence with a battery in the process the electrolyzer is utilized 35% of the time



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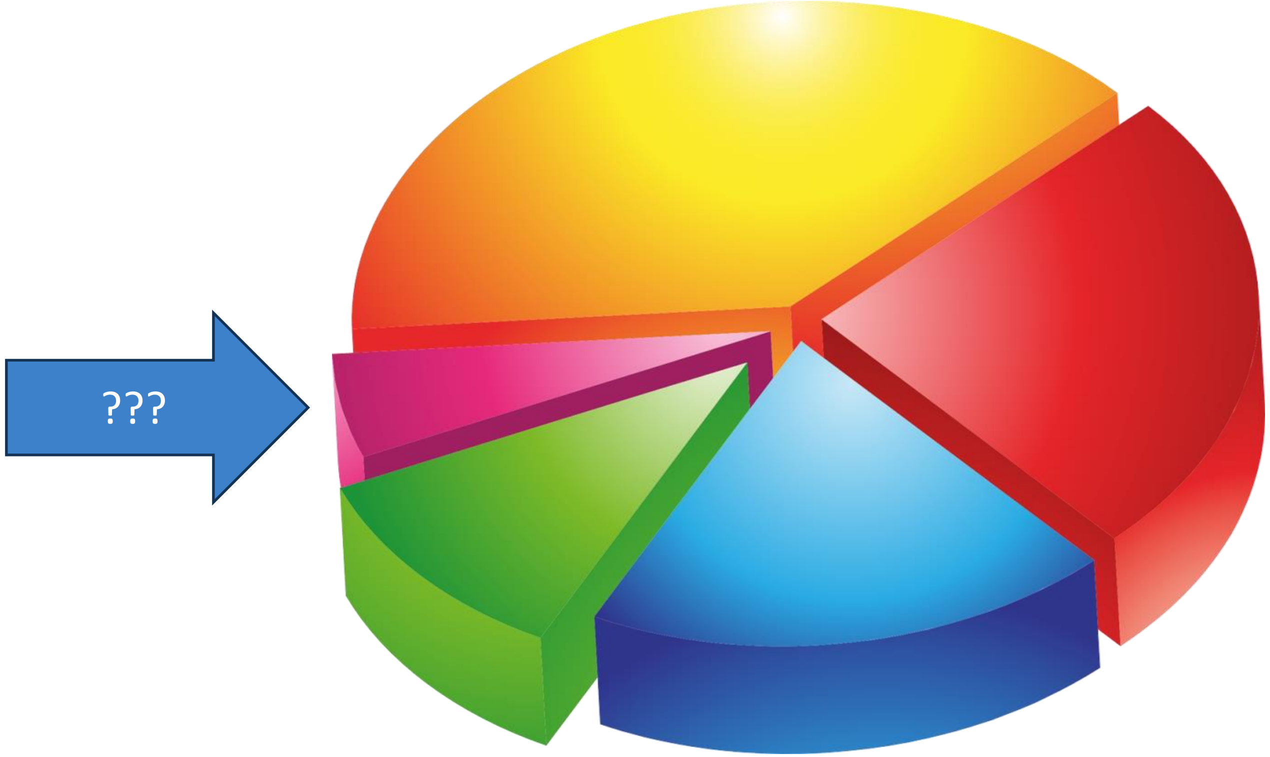
Sensitivities

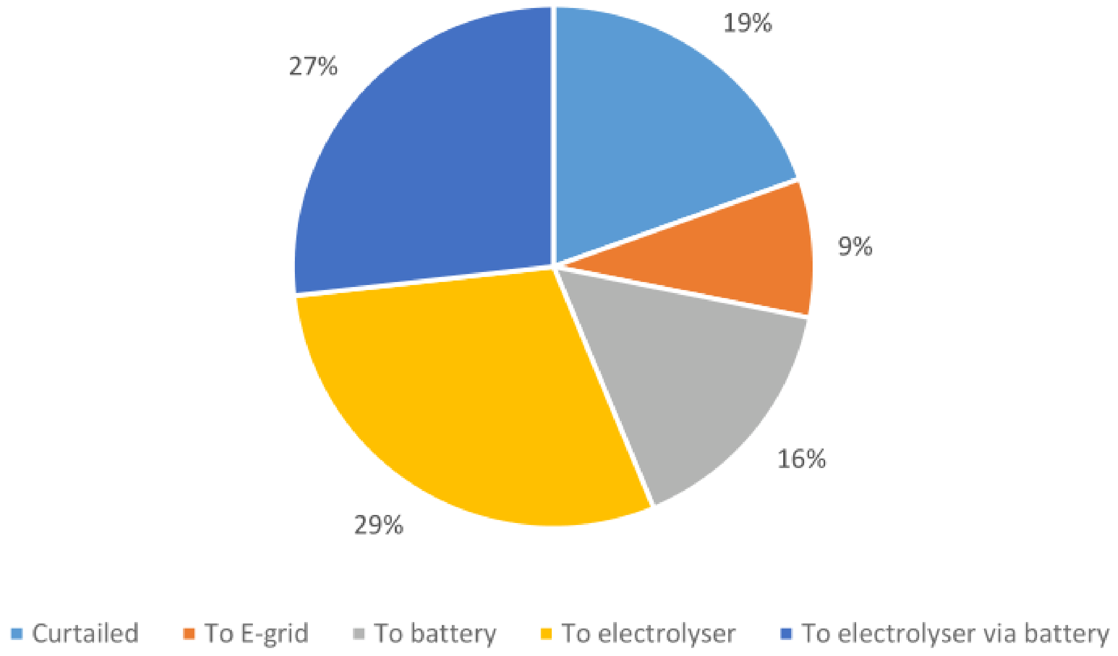
Sensitivity analysis:

- **Distance**
  - Distance of the Solar PV farm to the Hydrogen Refueling Station
  - Electricity cable length between MV and HV/MV station
- **Electricity supply and demand**
  - ± installed PV capacity by 500%
  - ± electricity demand by 50%
- **Hydrogen and electricity prices**
  - Increasing and decreasing prices (€/kg - €/MWh)
- **Changing the mode of hydrogen transport**
  - Trucks vs. RNB/RTL pipelines
- **Doubling the demand of hydrogen for mobility**
- **Decreasing the CAPEX of electrolyzers**
- **Sourcing the electricity for the electrolyzer from the e-grid**



Main takeaways from sensitivity analysis

- If regions have a large solar electricity generation capacity relative to their electricity demand
- Price received for hydrogen is high relative to the electricity price, and electrolyzer CAPEX costs come down (7€/kg for mobility was sufficient to activate PtG)
- If hydrogen could be delivered to several end-use entities (two HRS's lead to more benefits than one)
- If RNB pipeline sections are available for re-using for hydrogen transport



Main conclusions

- Under current market conditions selling electricity is more profitable than producing and selling hydrogen
- Only if a certain amount of congestion hours is in place, it is worth considering to install an electrolyzer
- Installing batteries or selling hydrogen to the mobility market generally is considered more feasible than local blending of hydrogen
- A good match between local RES capacity and it's potential hydrogen offtake is required to effectively reduce the share of curtailed electricity due to congestion
- As congestion can be temporary, a long-term perspective is required to take investment decision on electrolyzer capacities
- It should be mentioned that the proposed mix of solutions is not likely to be seen in practice, among others due to current legislation and market regulations but indicate that a mix of solutions can reduce electricity grid investments significantly if legislation will support these options to be aligned according to the local grid needs.

Legislative suggestions

- Identifying which measures would be required to provide right incentives for RES operators, regional grid operators, electrolyzer and battery operators so maximum green benefits are achieved
- Identifying regions where electricity supply will exceed demand regularly → most promising locations for decentral hydrogen production → making the information public so that investors alongside distribution grid operators could investigate together options to integrate additional electricity
- Special subsidy regimes for investment in a combination of power-to-gas and utility scale batteries or comparable energy storage facilities
- Dedicated per kg hydrogen subsidy as well as a comparable CAPEX subsidy for battery investment
- Overcoming uncertainty of if and when the gas TSO and/or DSOs are legally allowed and/or capable to facilitate a 'pure' hydrogen transport connection to the gas grid, or, in the preceding stages, to apply blends of hydrogen in the grid

Opportunities and Challenges

Opportunities

- Local P2G and hydrogen blending is a first step towards local integration of electricity and gas systems
- A steppingstone to synergistically serve other ends users (mobility, built environment)
- Market conditions for PtG are generally expected to improve as technologies scale-up

Challenges

- Fate of local e-grid congestion is unclear. Profitability of investing in electrolyzers is uncertain if congestion is medium-term issue.
- Decarbonization impacts remain small if small hydrogen blends are used (10% H2 blend ≈ 3% emission reduction)
- P2G investments to deal with congestion remain tricky until limits exist for the using pure hydrogen in the gas grid

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THANK YOU FOR YOUR ATTENTION!

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