Waste2GridS:
Triple-mode grid-balancing plants based on biomass gasification and solid-oxide cell stacks

A promising way for large-scale application of solid-oxide technology

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Waste/biomass-to-energy

eurostat

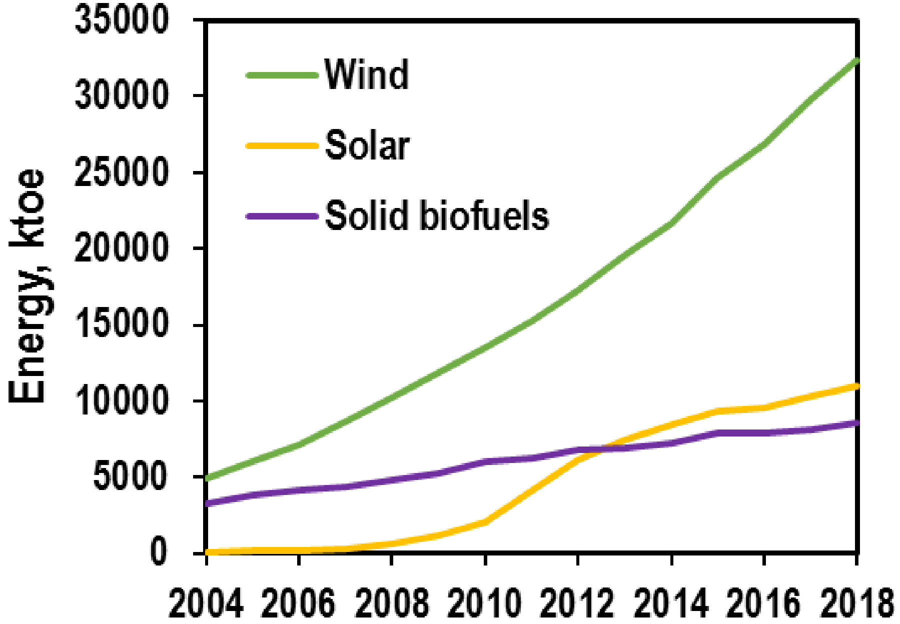
EU-28 waste/biomass utilization (2016)

Recovery
- Recycle 37.8%
- Backfilling 9.9%
- Energy recovery 5.6%

Landfill, incineration without energy recovery 46.7%

High-value waste-to-energy (electricity & bio-fuel)

RES-Electricity

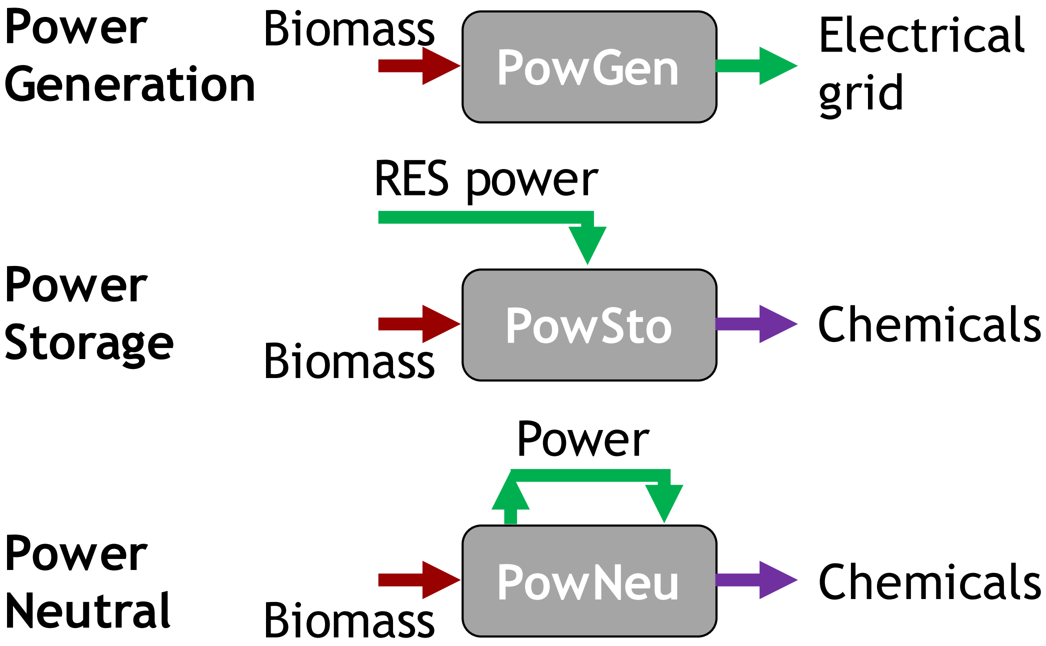


The role of biomass in electricity sector in future?

Triple-mode grid-balancing plant enabled by solid-oxide technology

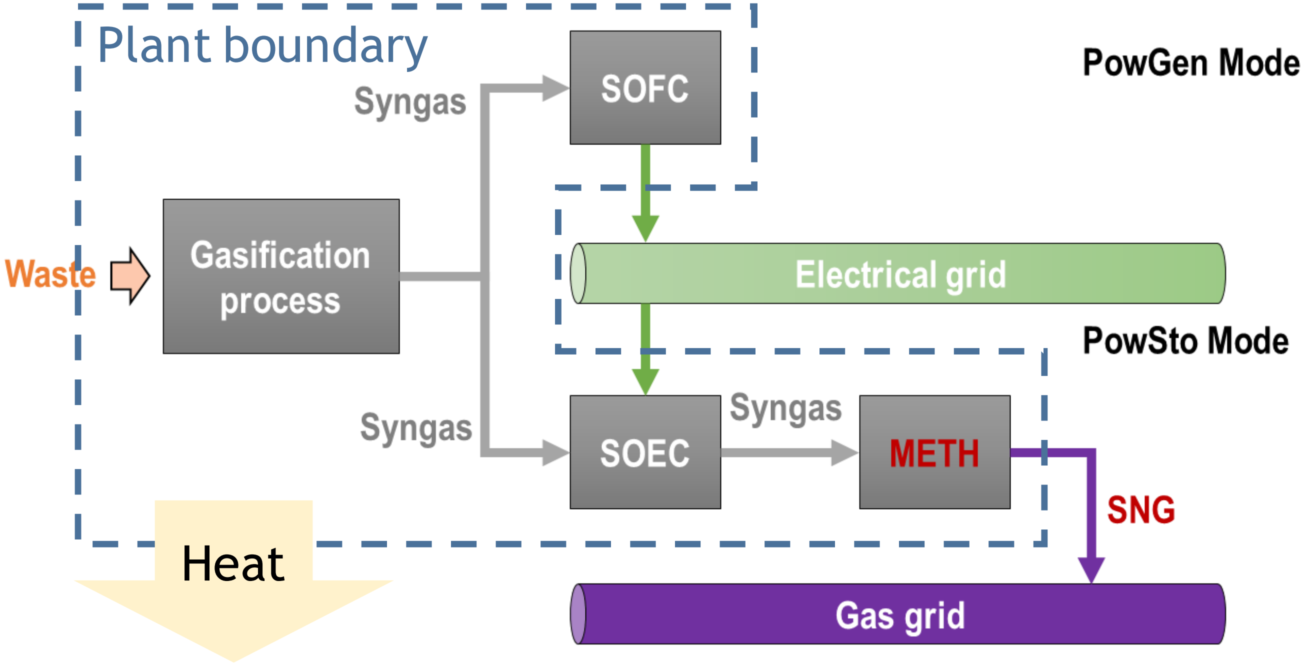
A biomass power plant with **power-to-fuel capability**

- Reversible operation
- High reactant flexibility



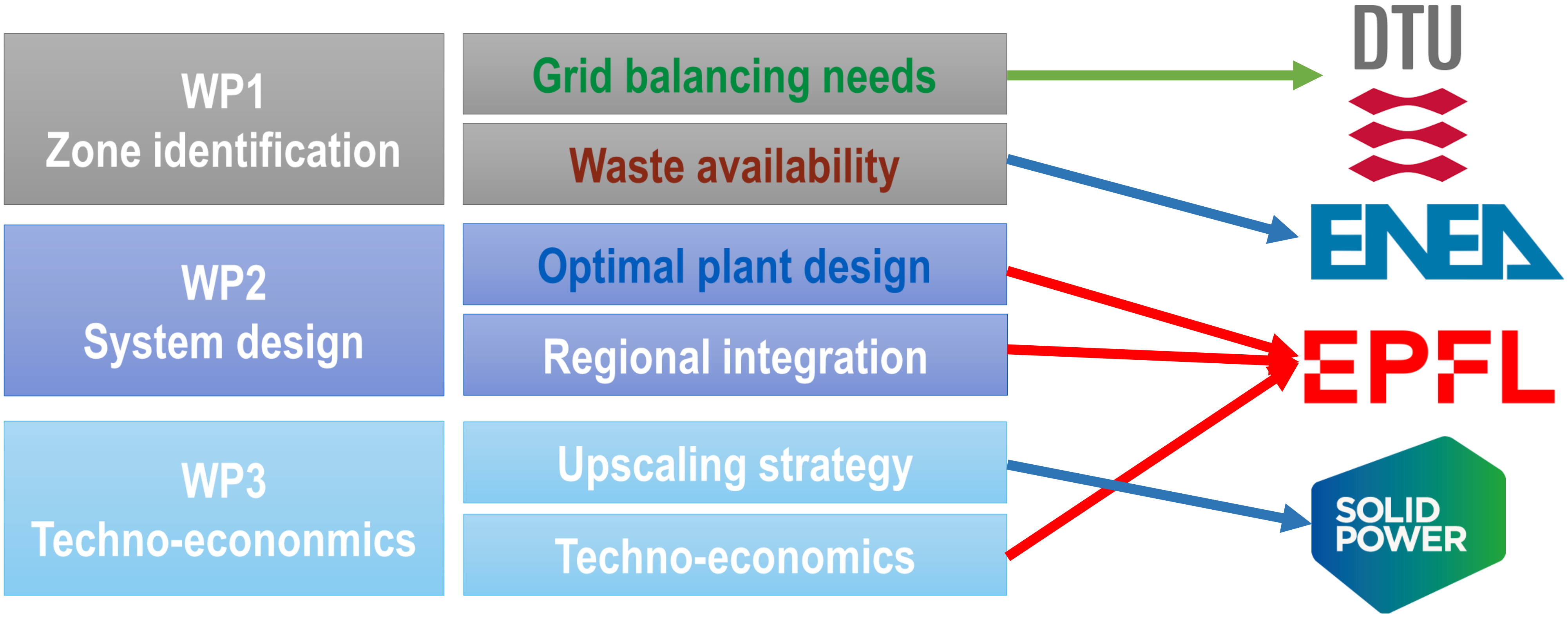
✓ Grid-scale application: Gasification → Syngas → rSOC → Methane

Waste2GridS plant concept

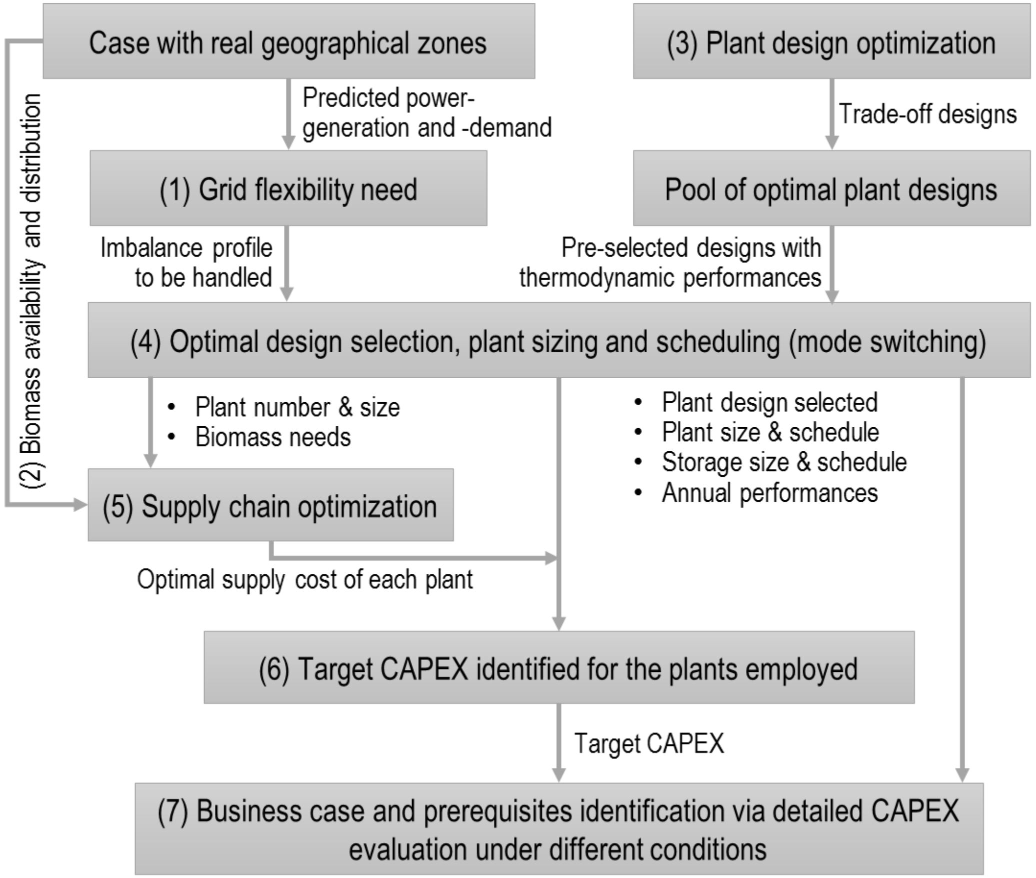


- ✓ Additional profits from
  - ✓ Electricity sale
  - ✓ Chemical sale
  - ✓ Energy balancing
  - ✓ Capacity reserve
- ✓ Enhanced annual operating hours
- ✓ Reduced CAPEX by sharing the stacks & others
- ✓ Enhanced balancing capability and capacity
- ✓ Unlimited energy storage capacity
- ✓ No CO_2 capture needed for waste-to-biofuel

Waste2GridS project (2019—2020)
Economic feasibility study for 2030



A comprehensive decomposition-based optimization methodology



- ❑ Economic evaluation is more rational by considering
  - ✓ Biomass supply chain & varied plant design
  - ✓ Multiple centralized plants deployed with optimal sizing and scheduling to address hourly imbalance

Plant CAPEX target (n) =

$$\frac{\sum_n \frac{\sum_{i,td} \alpha_{td}\left(R_{td,i}^{be} - R_{td,i}^{O_2}\right) - R_n^{bio}}{(1+r)^n} - R^{tank}}{\textit{number of reference stacks of all plants installed}}$$

***reference stack*: a stack with 5120 cm² active area**

n	payback time, year
$R_{td,i}^{be}$	benefit of grid-balancing (energy and capacity)
$R_{td,i}^{O_2}$	cost of oxygen
R_n^{bio}	annual cost of biomass supply
R^{tank}	cost of onsite storage tanks

More details in *Appl. Energy* 115330, 115987, under review; *Renew. Sust. Energ. Rev.* 109465.

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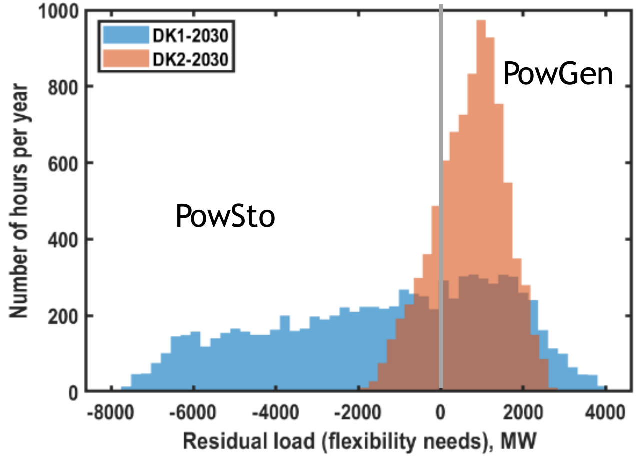
Theoretical grid flexibility needs 2030 of variable RES-dominated zones

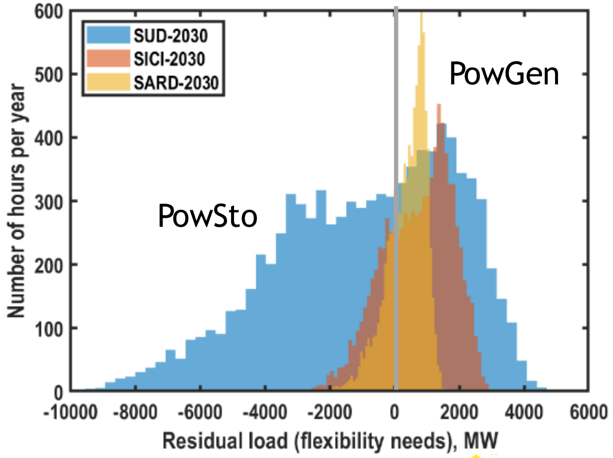
- ❑ Hourly flexibility needs predicted for 2030

- ❑ Flexibility needs in capacity

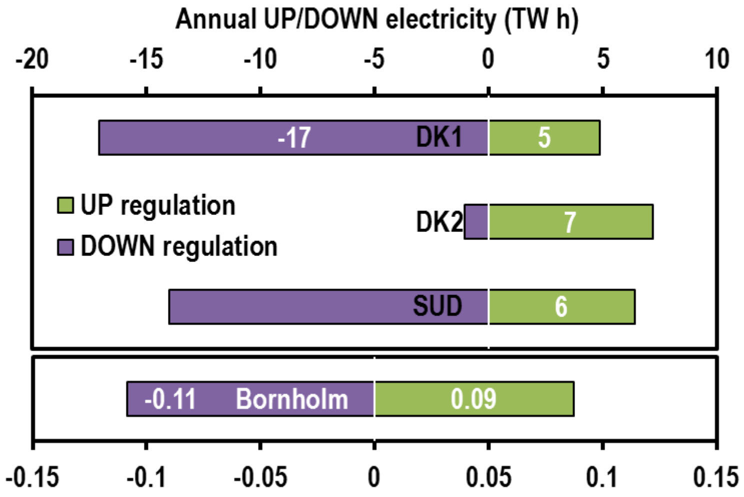
DK1



SUD



- ❑ Flexibility needs in energy

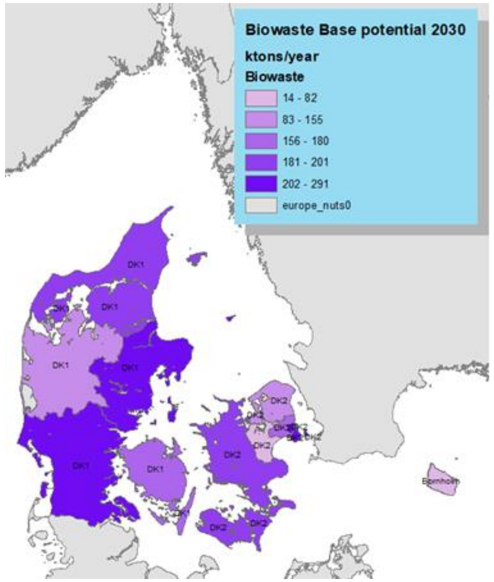


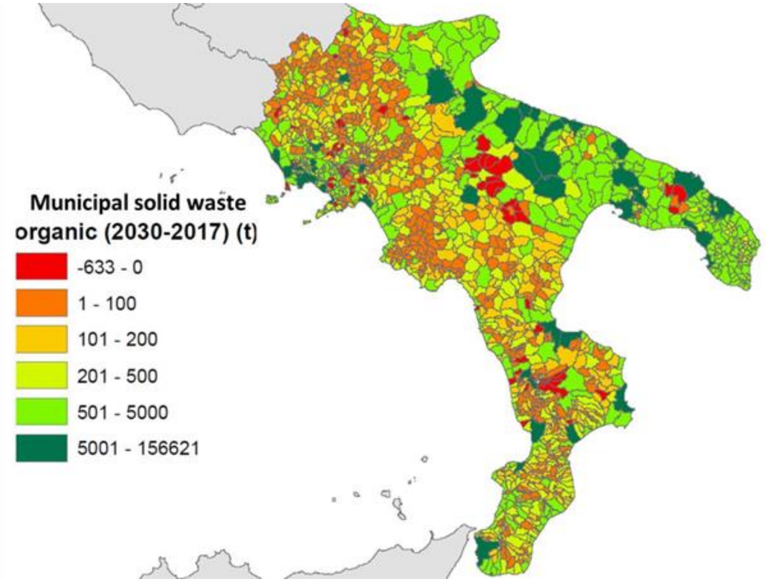
✓ Large flexibility needs in 2030 both in capacity or energy, however, balancing market will be **much less**

✓ **Hourly variation** considered for economic evaluation for optimal plant sizing

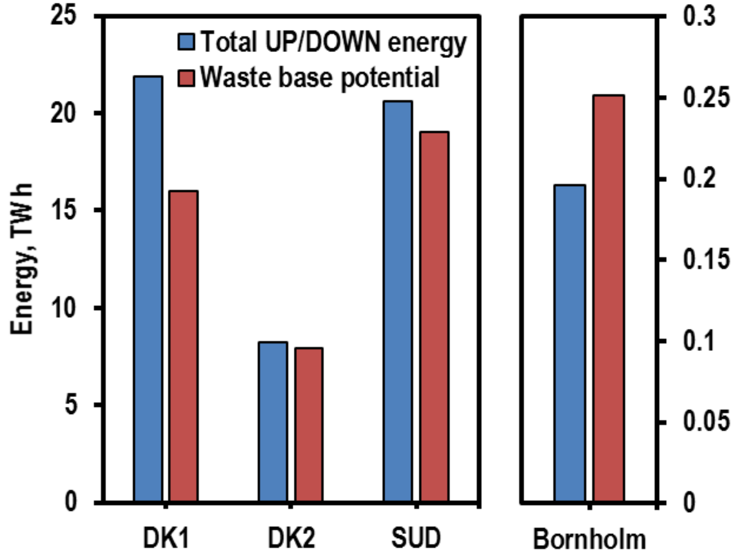
Local technical waste potential 2030

- ❑ Waste info with GIS at high resolution up to 100 m **for biomass supply chain optimization**





- ❑ Waste energy excluding competing use v.s. **theoretical** flexibility needs



✓ Local wastes are **ENOUGH** to support W2G plants cope with the real balancing capacities needed

Front. Energy Res., 2020, under review

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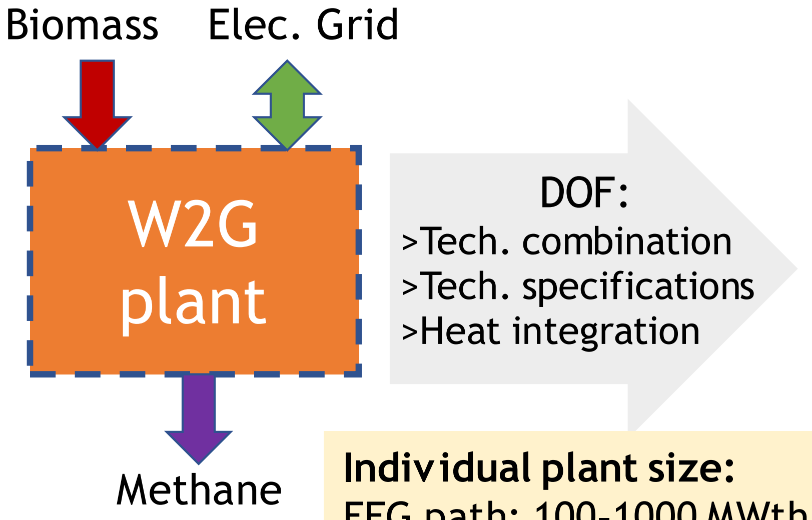
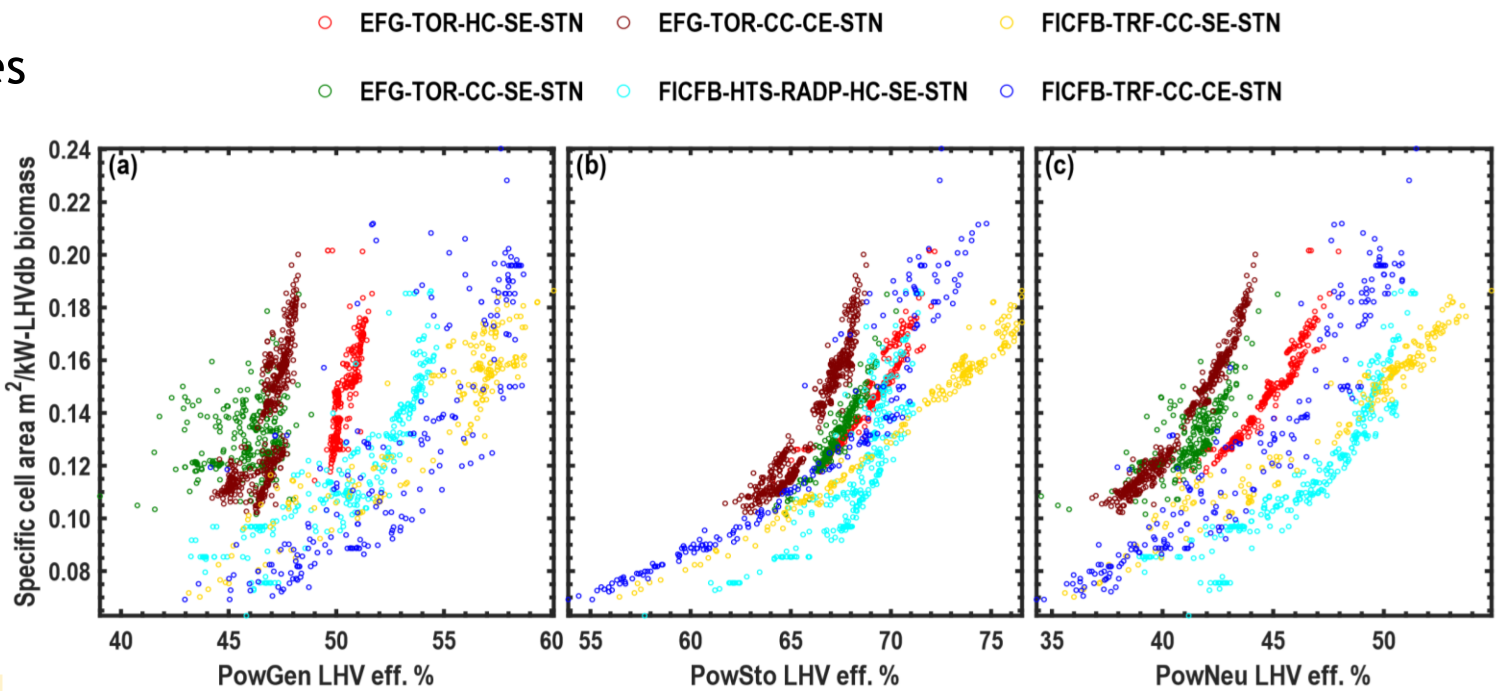
Application-independent optimal plant design

- ❑ For plants with the same size of stack, the design of W2G plants varies the magnitude of their interactions with elec. grid for each mode.



Individual plant size:
EFG path: 100–1000 MWth
EICFB path: 10–100 MWth

- ❑ Application-independent design pool



- ✓ High efficiency reached for all modes, much higher than SoA
- ✓ PowNeu efficiency lower than PowGen & PowSto eff

More details in *Appl. Energy* 115987

Plant CAPEX target: Scenarios & Assumptions

Scenarios

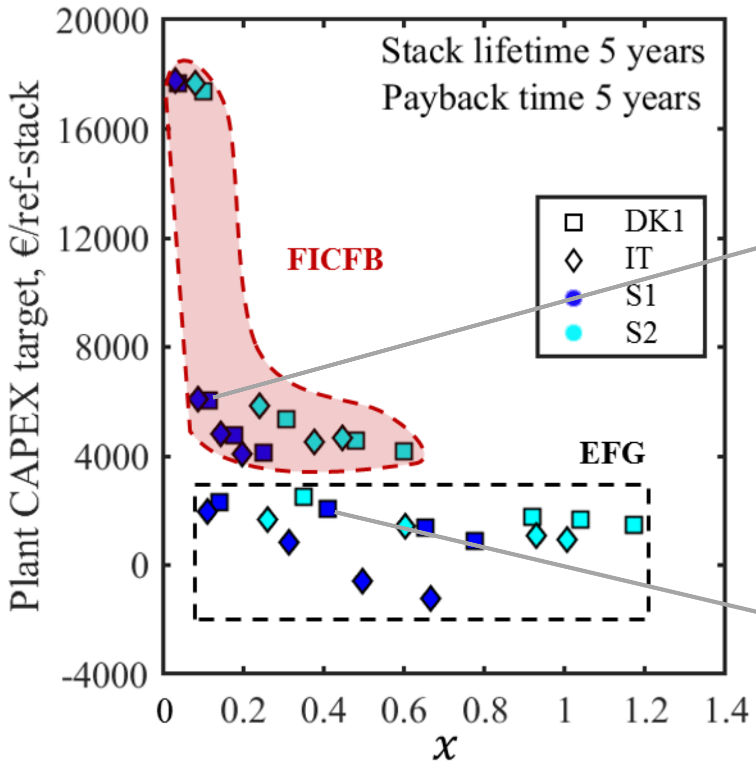
- ~~*S0: Theoretical flexibility needs all addressed by W2G plants*~~
- *S1: Excluding interconnections:*
  - ✓ 66% of theoretical UP regulation needs
  - ✓ 68% of theoretical DOWN regulation needs
- *S2: Excluding interconnections, batteries, classic plants*
  - ✓ 14% of theoretical UP regulation needs
  - ✓ 30% of theoretical DOWN regulation needs

Communications made with DK, IT, BE TSOs, no specific data available for DK and IT. Real balancing market and contribution of W2G plants can hardly be predicted. Thus, we employ simply some data from Elisa (Adequacy and flexibility study for Belgium 2020 – 2030 EN, FIGURE 4-32) to scale the flexibility needs to the part addressed by W2G plants.

Assumptions

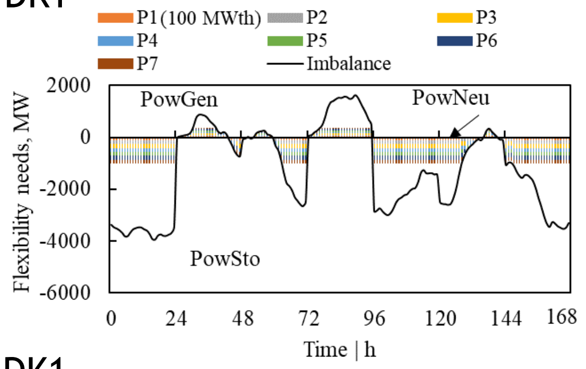
- Electricity profiles addressed
- Both energy balancing and capacity reserves
- Reference energy balancing price 40 €/MWh, sensitivity analysis within 20-80 €/MWh.
- Reference payback time 5 years, sensitivity analysis within 1-5 years
- Stack lifetime: 5-year continuous operation

Plant CAPEX target (40 €/MWh, 5 years)

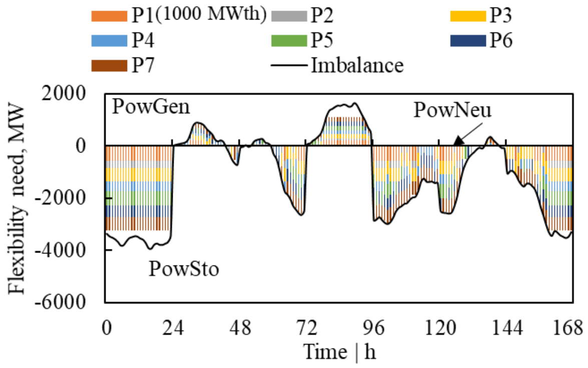


$$x = \frac{Cap_{\mathrm{PowGen}} + Cap_{\mathrm{PowSto}}}{P_{\mathrm{UP}}^{\max} + P_{\mathrm{DOWN}}^{\max}}$$

S1, DK1

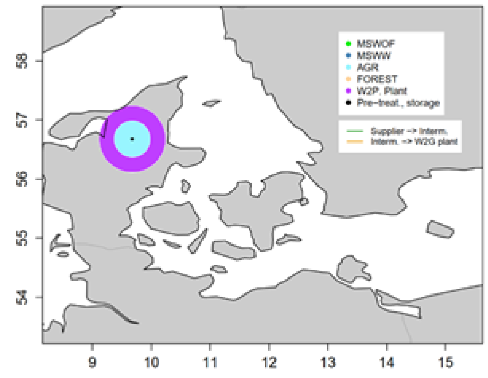


S1, DK1

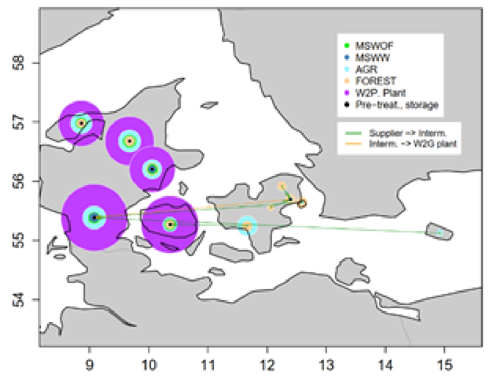


Optimal biomass supply chain

Biomass needed by each plant



Biomass needed by each plant



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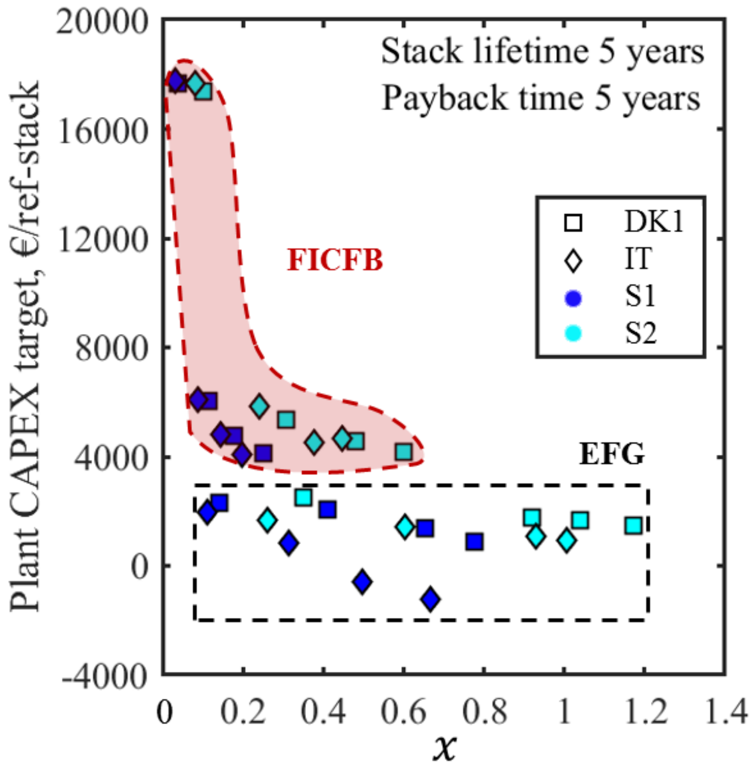
Plant CAPEX target (40 €/MWh, 5 years)

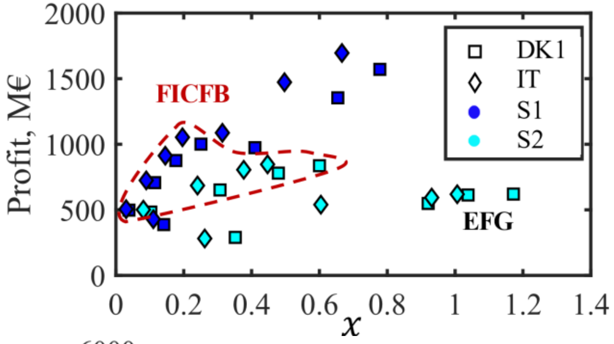


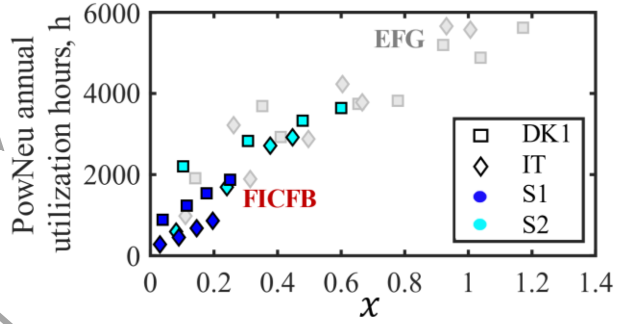
- ✓ 4-18 k€/ref-stack (40 €/MWh, 5 years)

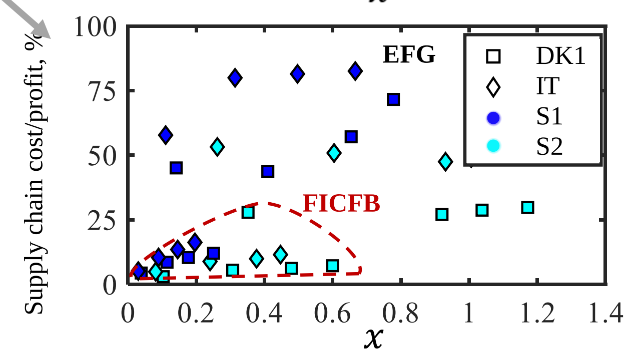
- ✓ Increasing total plant capacities, in general, increases the total profits, but will reduce *Plant CAPEX target* due to the increased use of PowNeu mode

- ✓ Very large single plants (100-1000 MWth) largely limited by the biomass supply, hardly economically-feasible

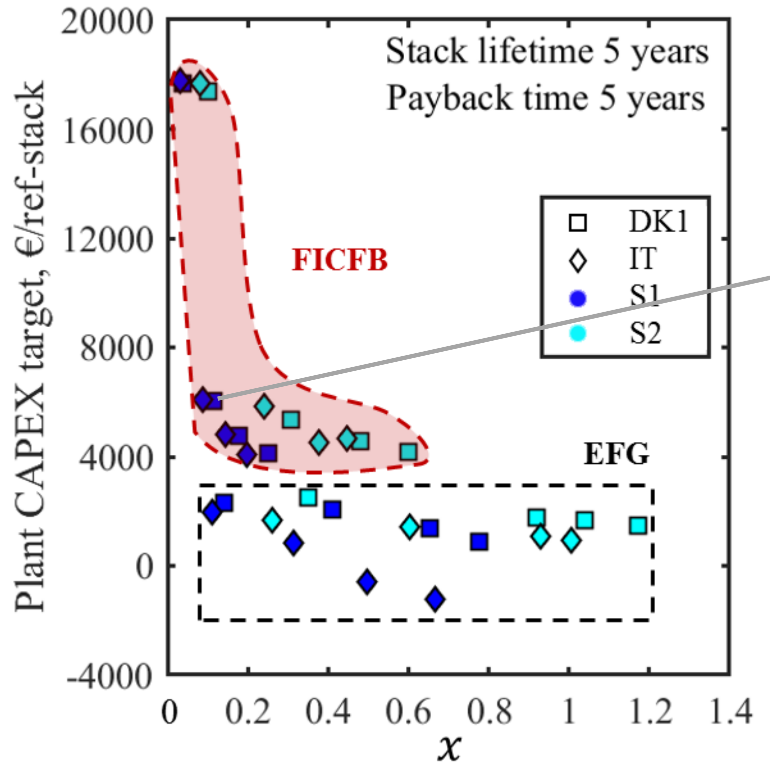
- ✓ Smaller single plants of up to 50-100 MWth (biomass), 20-60 MWe (PG), 50-160 MWe (PS), seem to be preferred

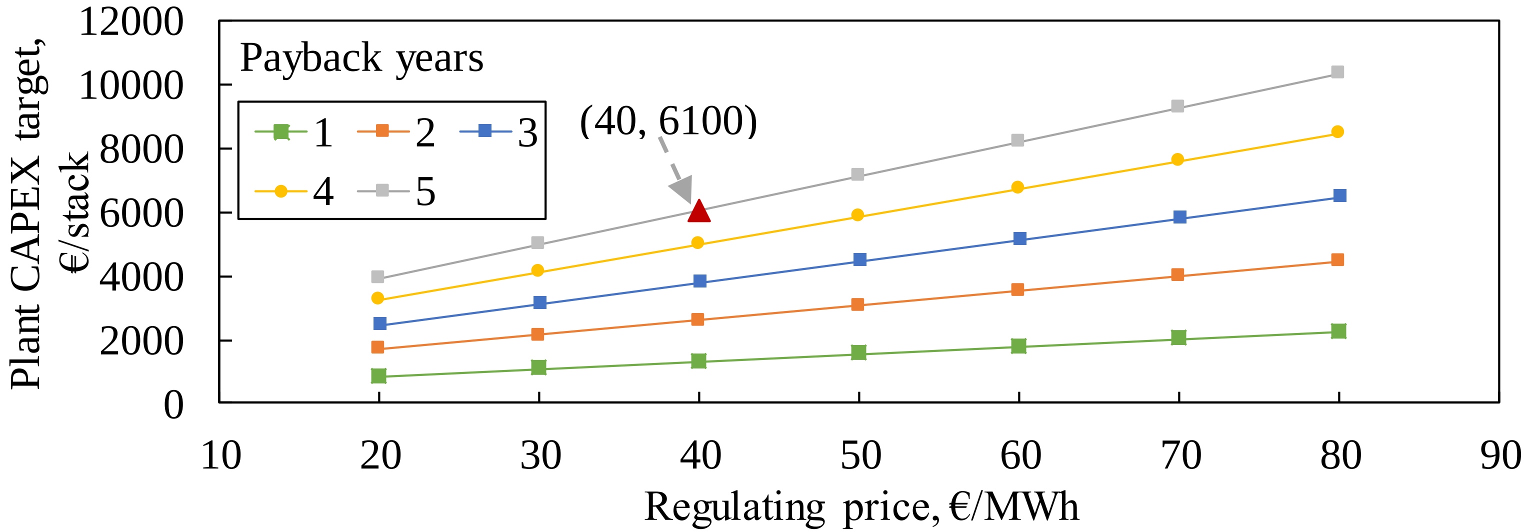






Plant CAPEX target (sensitivity analysis)





- ✓ 4-18 k€/ref-stack (40 €/MWh, 5 years)

- ✓ For 5 payback years, with the increase in regulating price up to 80 €/MWh, *Plant CAPEX target* reaches 10000 €/ref-stack
- ✓ For 3 payback years, *Plant CAPEX target* still be over 4000 €/ref-stack, indicating potential good economic feasibility

Conclusions

- ✓ A concept to integrate biomass gasification and SOC technology for grid balancing
  - ✓ A new opportunity of win-win situation for biomass and SOC for future.
- ✓ A comprehensive optimization-based methodology proposed and applied for evaluating the economic feasibility.
- ✓ Biomass amount is not a limiting factor but the biomass supply chain,
  - ✓ Very large single plants not economically feasible.
- ✓ **Economically feasible with individual plant size of around 50-100 MWth (biomass), 20-60 MWe (PowGen), 50-160 MWe (PowSto) for 2030**
  - ✓ Economic feasibility increases significantly with the increase in regulating price.
  - ✓ *Plant CAPEX Target* could be over 8-18 k€/ref-stack (potential business cases).
  - ✓ This *Plant CAPEX Target* can be further enlarged by a longer stack lifetime.

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W2G Waste2GridS

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