TradeRES

New Markets Design & Models for 100% Renewable Power Systems

Wholesale electricity prices in fully renewable European power systems – the impact of market designs

13. Internationale Energiewirtschaftstagung an der TU Wien

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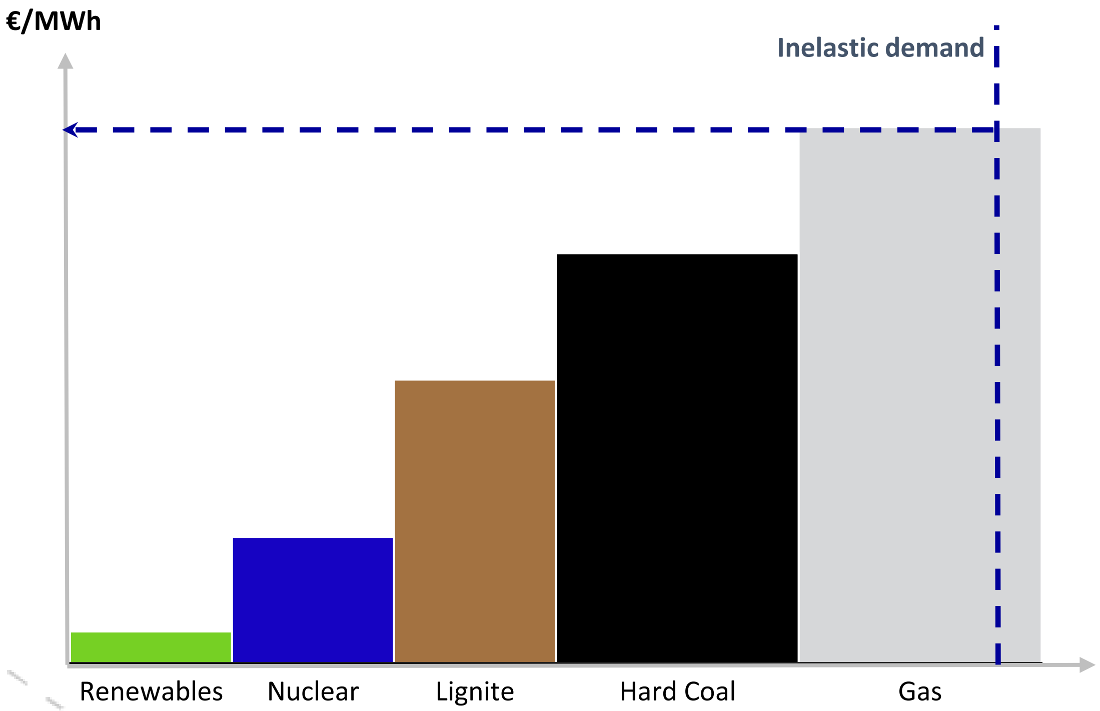
Agenda

1. Motivation
2. Research Questions
3. Method
4. Results
5. Conclusion & Outlook

1. Motivation

Present



Literature: Strbac et al. (2021), Newbery et al. (2018), Hirth (2013), Prola et al. (2020), Ruhnau (2022), Schweppe (1988)

1. Motivation

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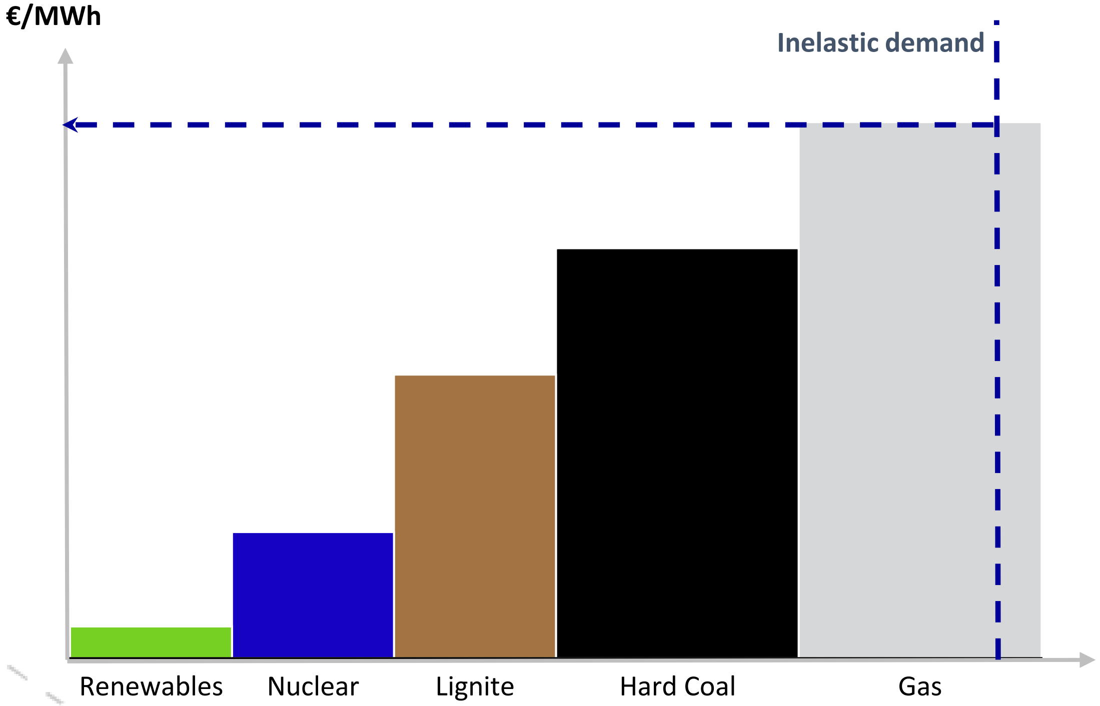
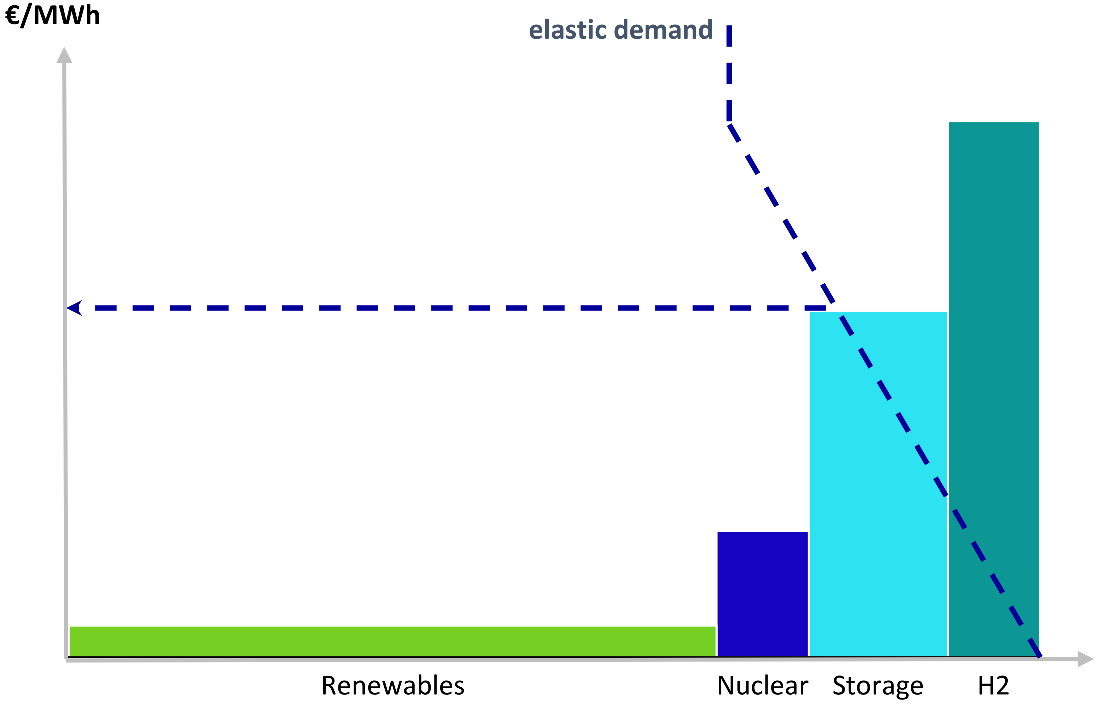


Future



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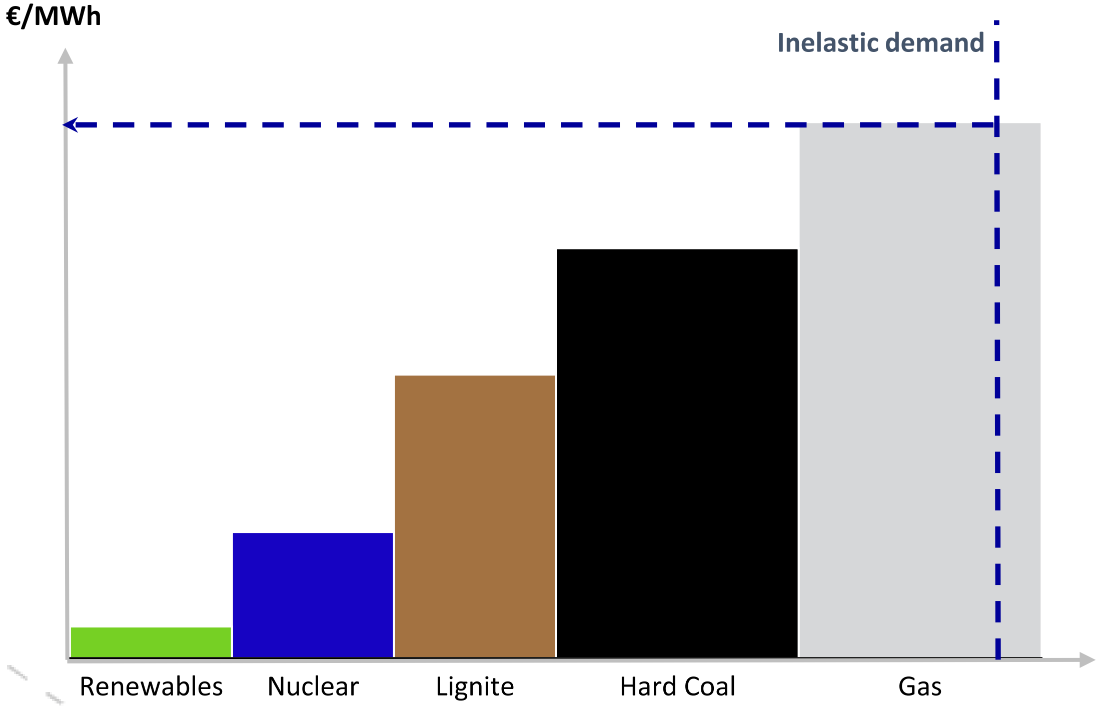

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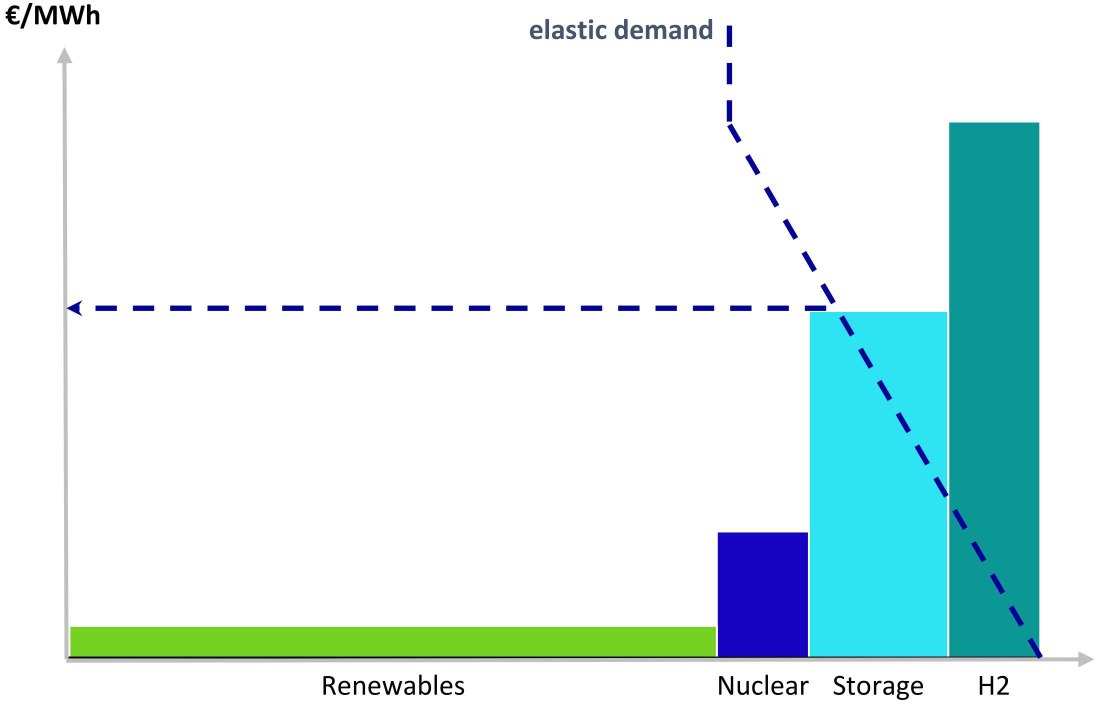

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2. Research Questions TradeRES

1) Does the energy-only-market yield **sufficient returns** to incentivize investments in different fully renewable European energy system scenarios?

2) If **other instruments complementing the energy-only-market** are needed, how should they be designed?

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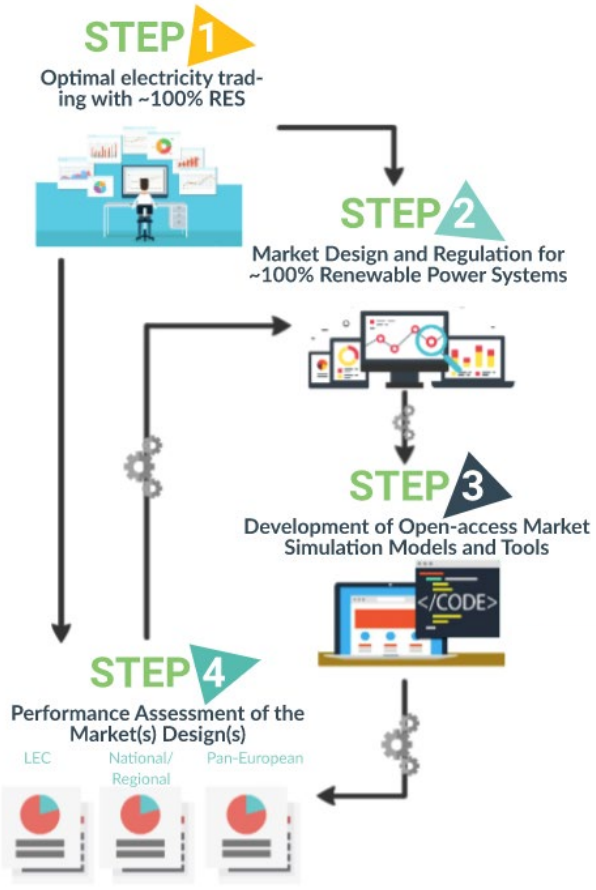
Different types of Contracts for Difference (CfDs) for variable renewables (VRE)

3. Method
TradeRES Approach



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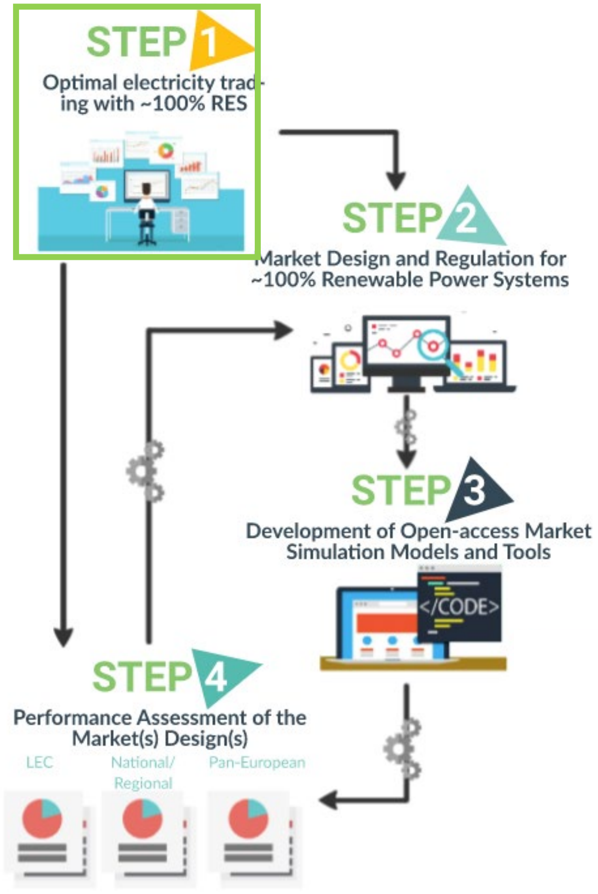

3. Method
Reference systems

Exogenous Starting Point
Entso-E's National Estimates for 2030

Optimal capacity expansion → and operation planning with **Backbone**

Endogeneous Reference System
100 % carbon-free by assumption
≥ 95 % VREs by constraint

Data: TradeRES Public Deliverable D2.1, Entso-E ERAA 2022, Entso-E TYNDP 2022, Renewables Ninja, RUB EE‘s Pypsa-to-BB, Denish Energy Agency, Gils et al. (2014)
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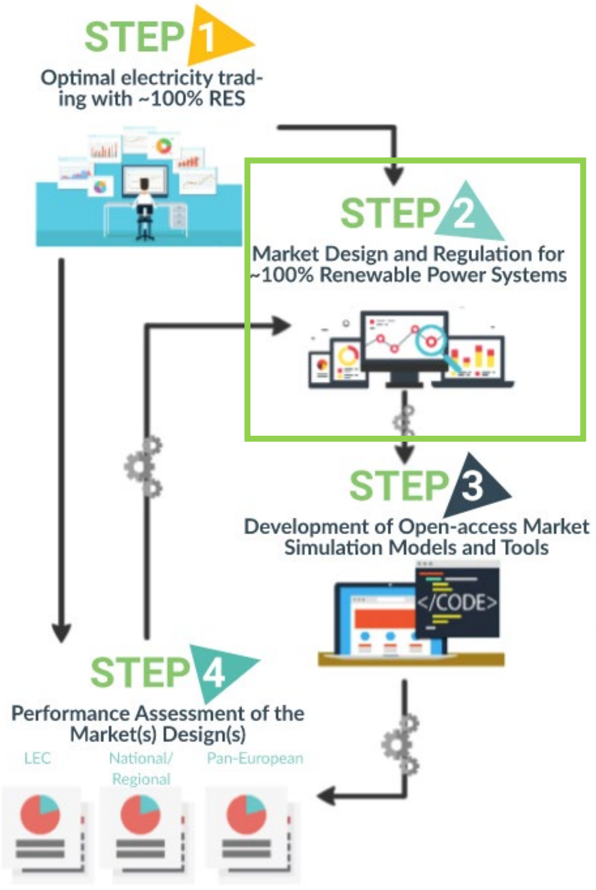
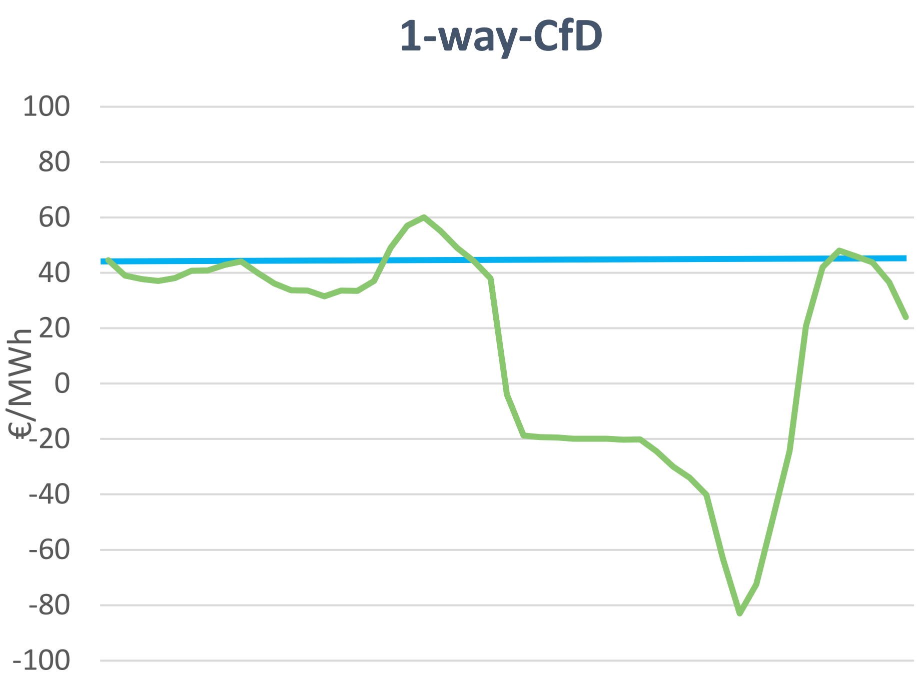
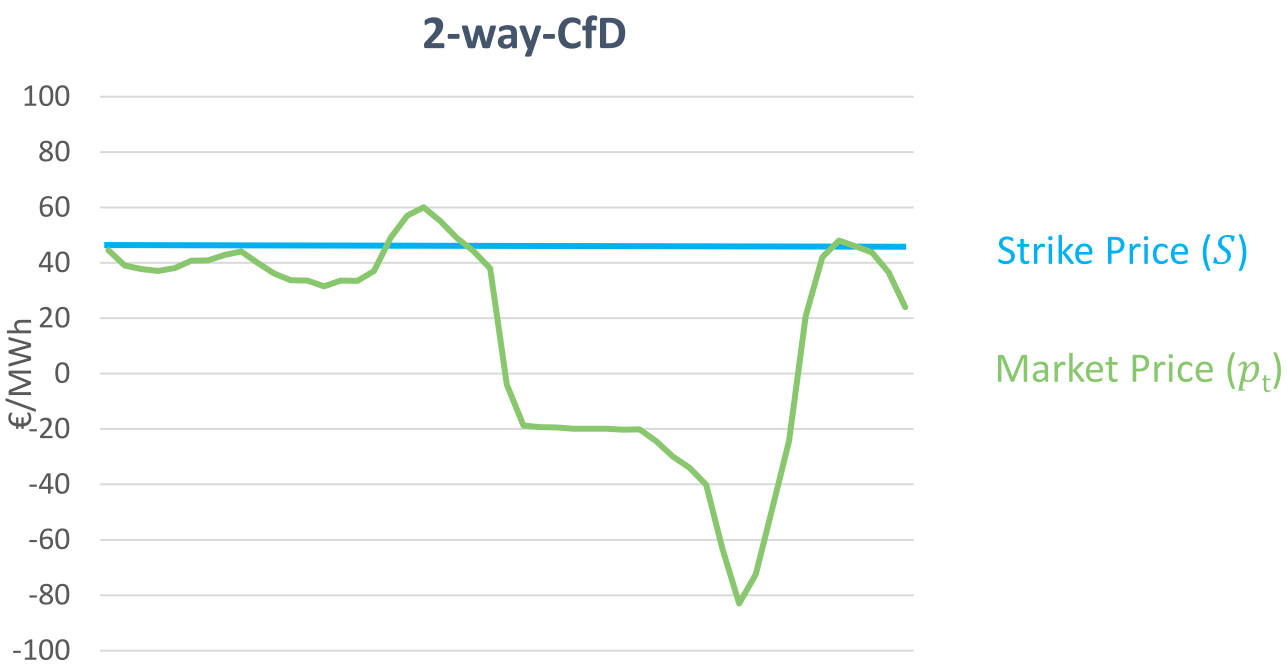
3. Method
TradeRES Approach



3. Method
Market Design: Contracts for Difference





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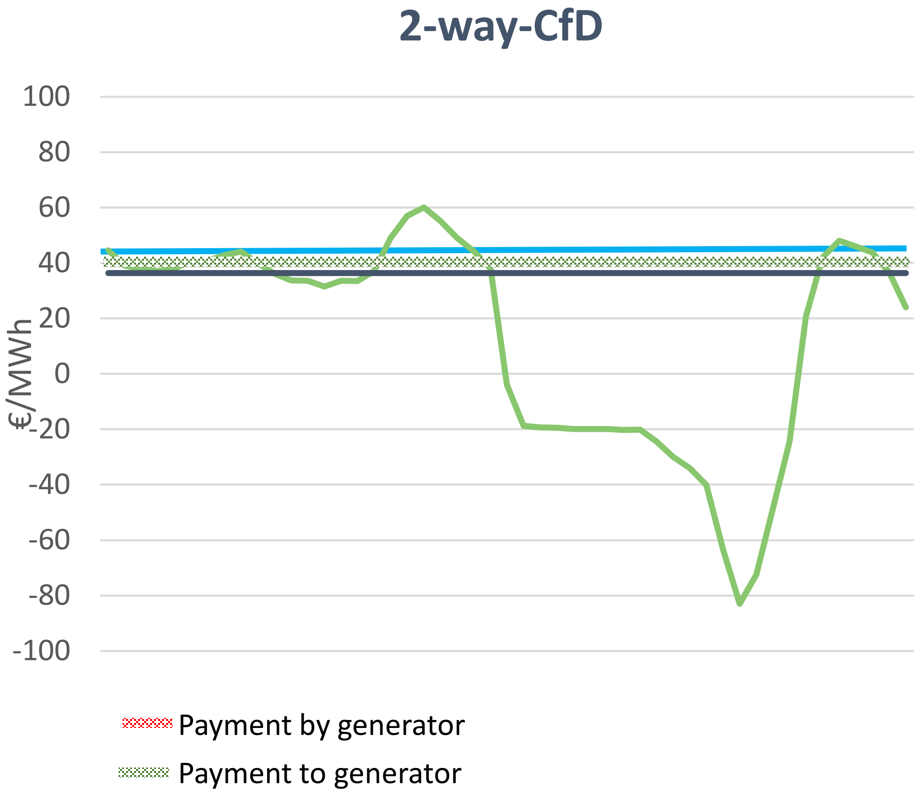
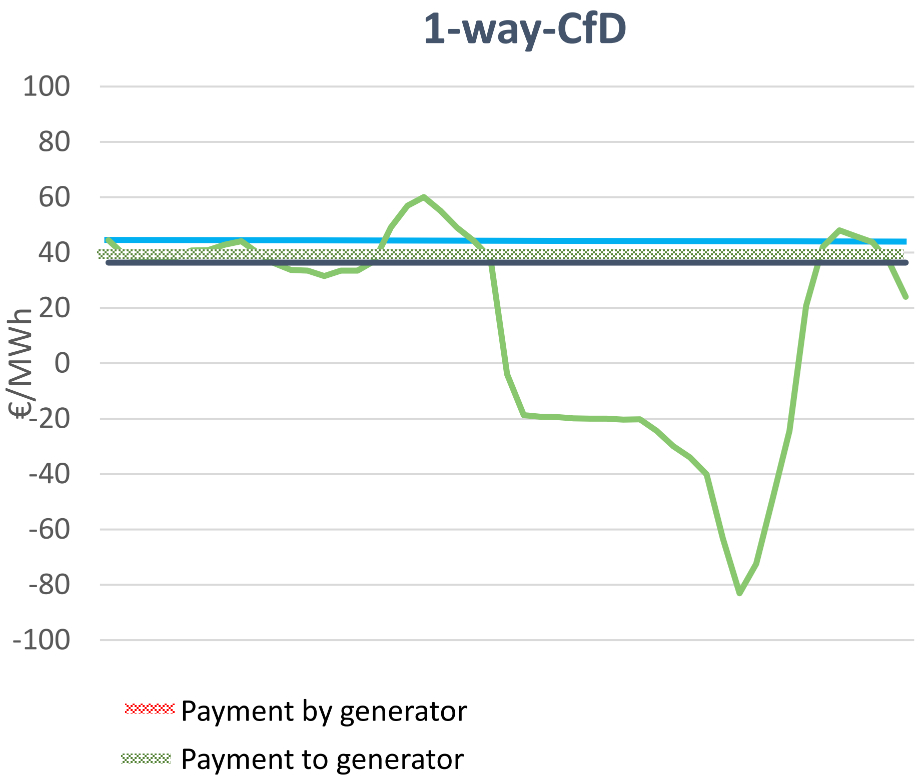
Market Design: Contracts for Difference





Strike Price (S)

Reference Price ($\bar{p}$)

Market Price (p_t)

Revenues with generation q_t: $\sum_{t}^{T}(p_t q_t - (\bar{p} - S) q_t)$

Revenues with generation q_t: $\sum_{t}^{T}(p_t q_t - (\min\{0, \bar{p} - S\}) q_t)$

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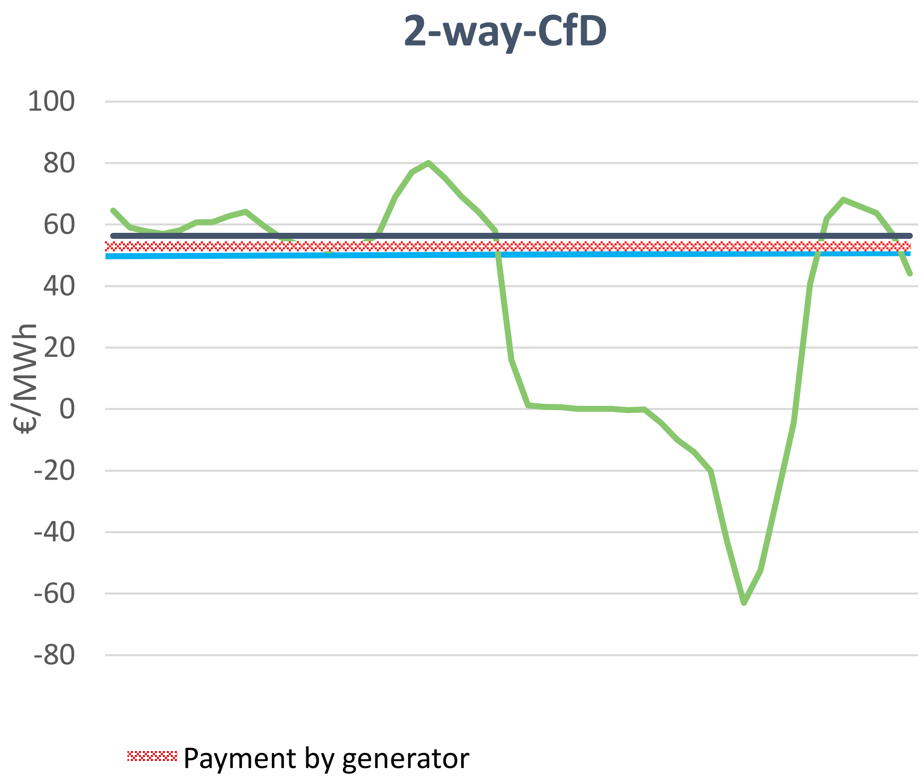

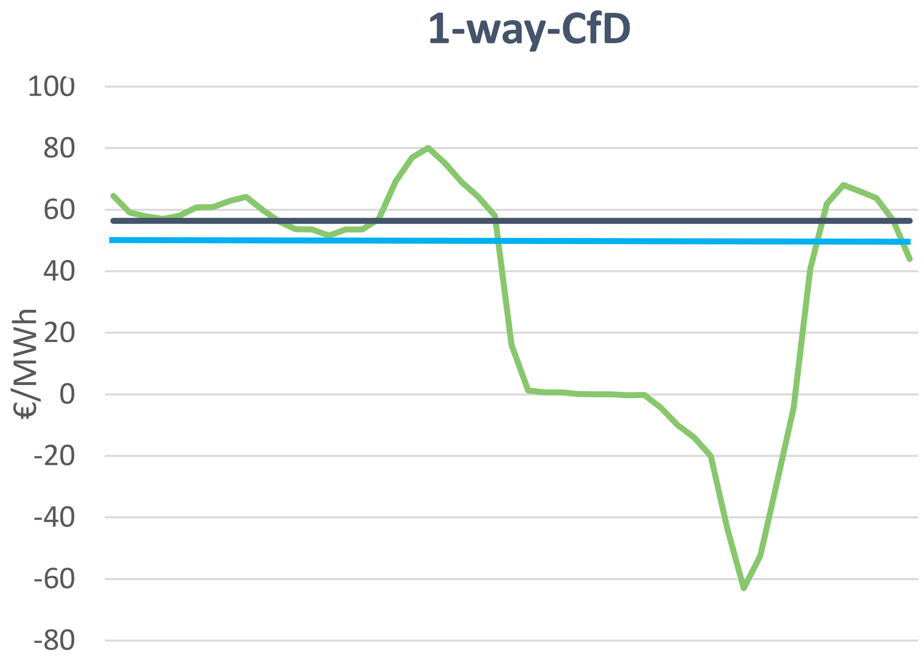

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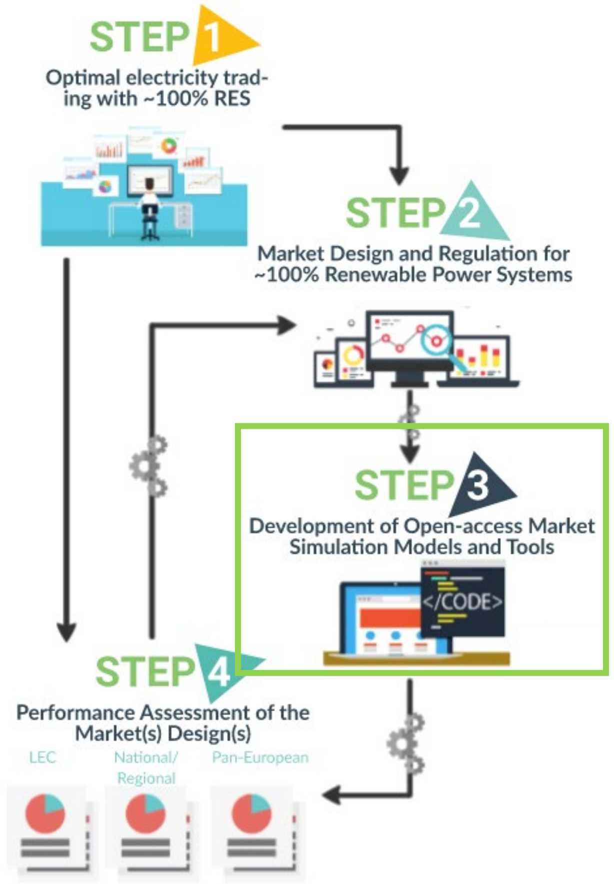
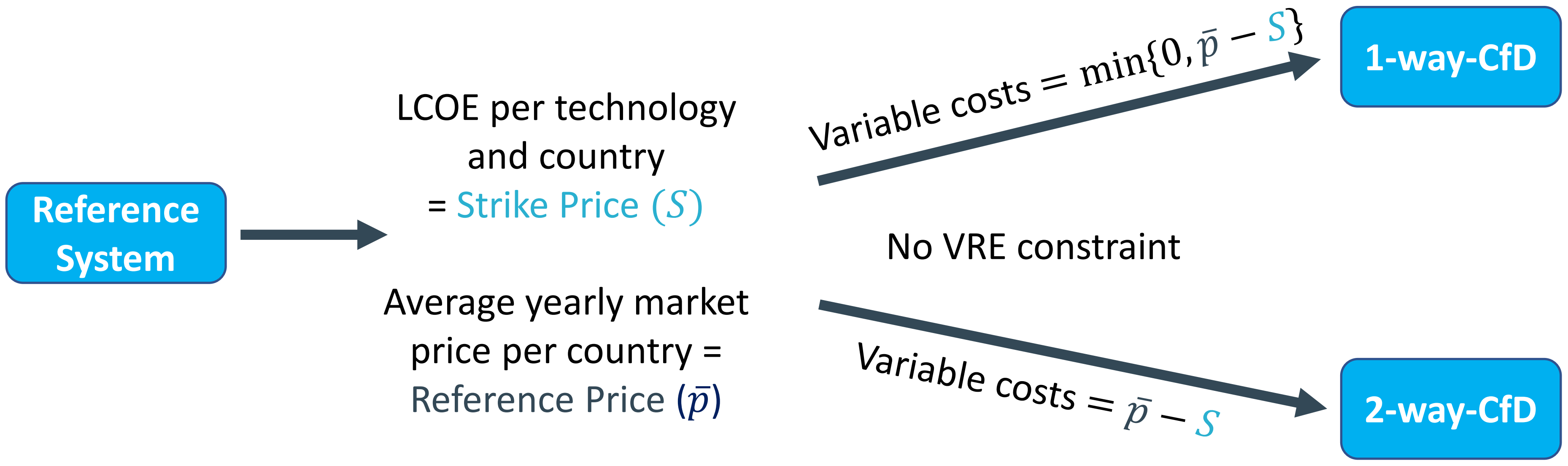
TradeRES Approach

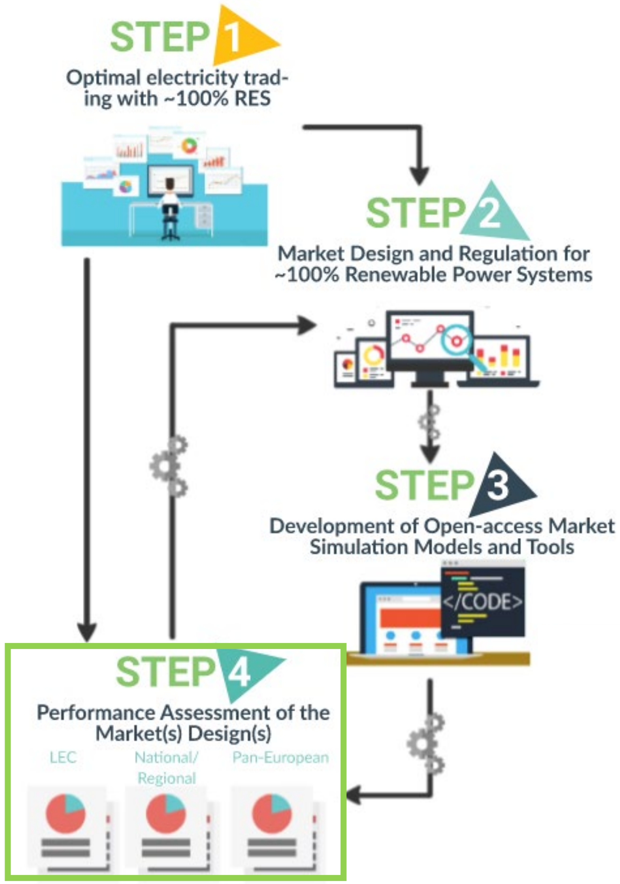


3. Method
Implementation in our model



Literature: Frey et al. (2020), Gillich & Hufendiek (2022)

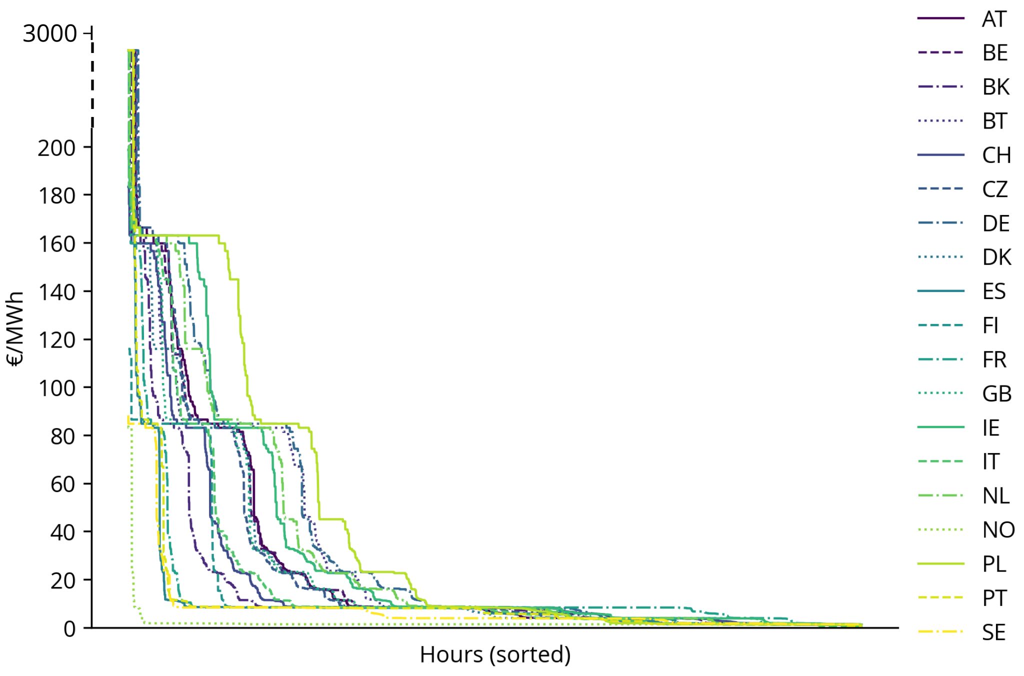
3. Method
TradeRES Approach: Evaluation



Reference System ↔ 1-way-CfD / 2-way-CfD

4. Results: Reference System Prices and Generation Mix

Price Duration Curves



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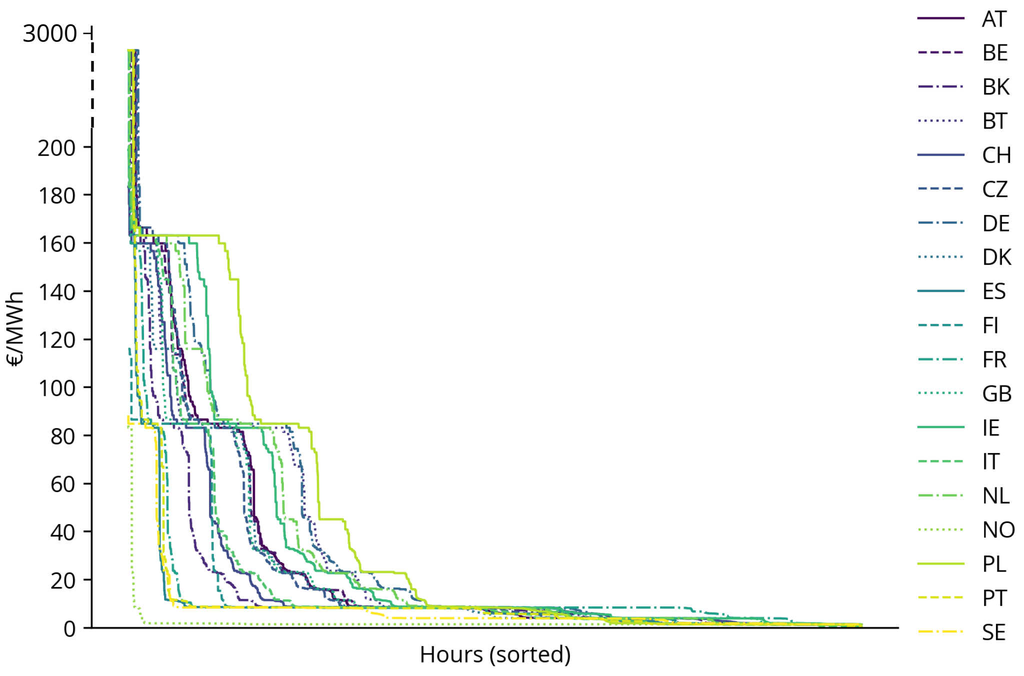
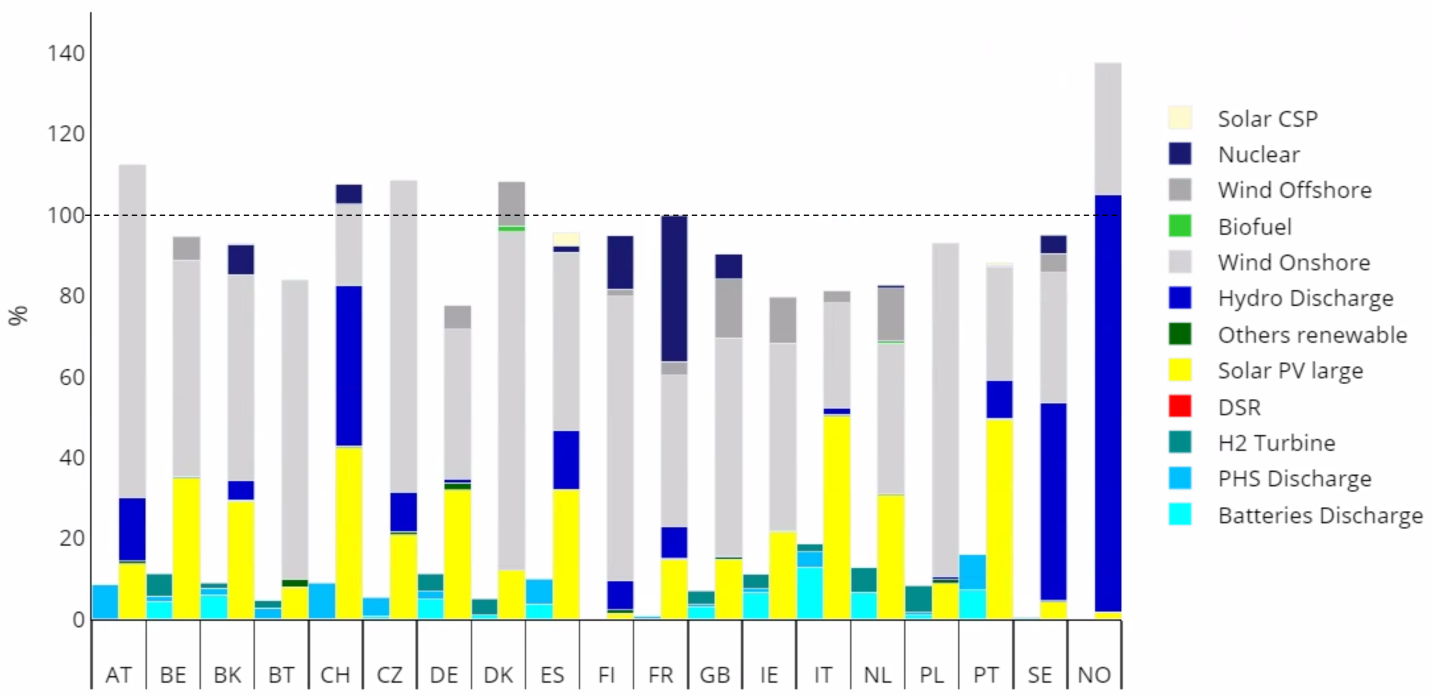
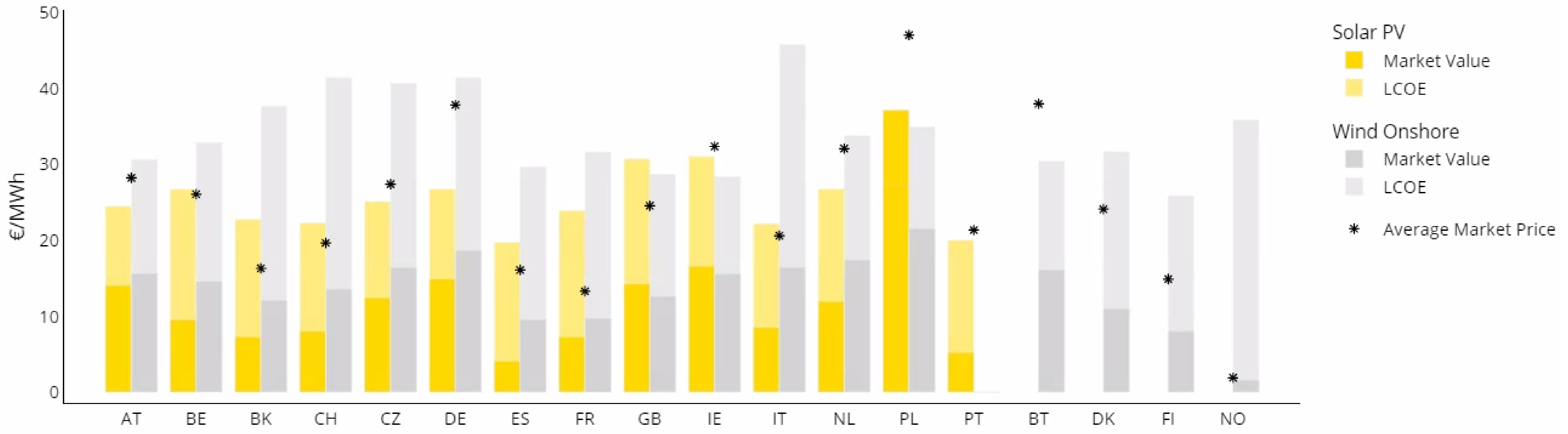


Electricity Generation Share by Type



4. Results: Reference System Profitability of VRE

Market Values, LCOEs and Average Prices



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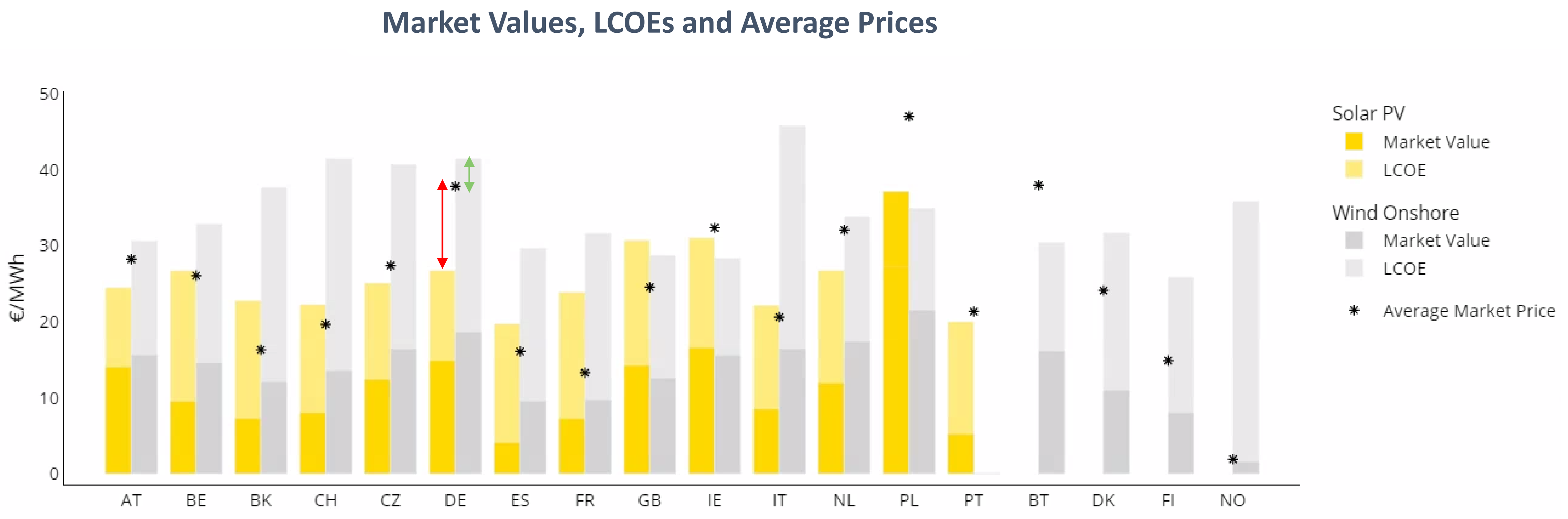
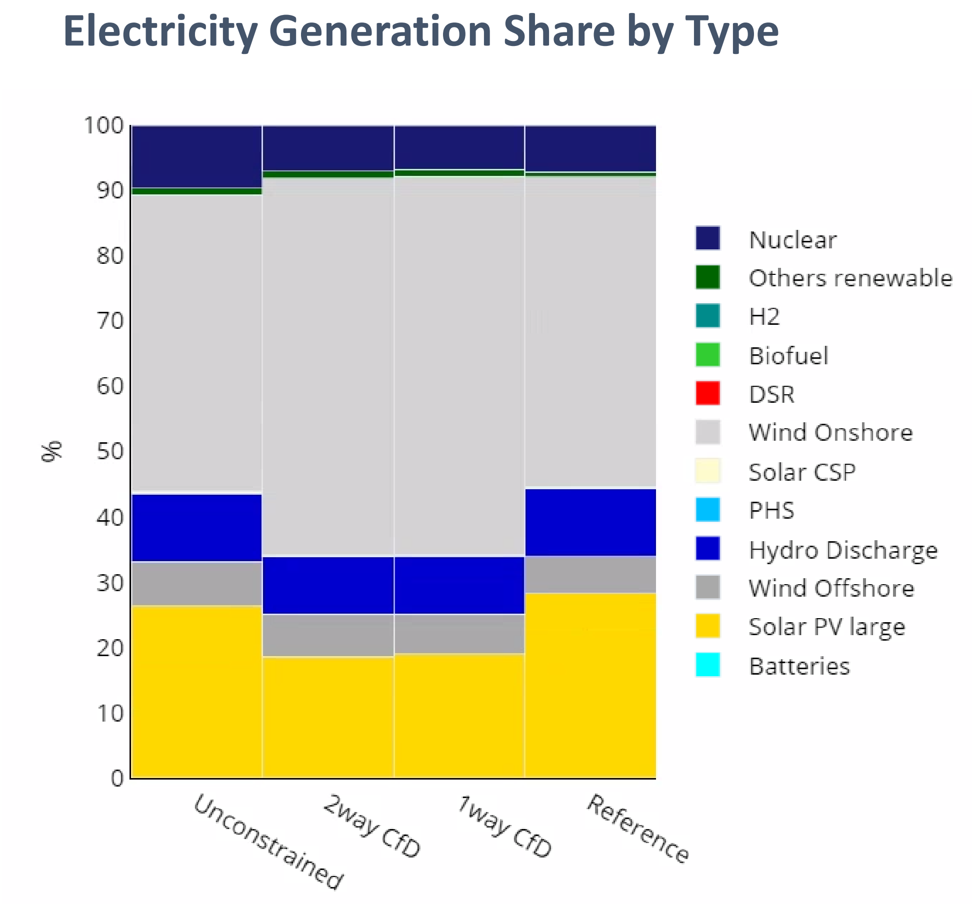


4. Results: Scenario Comparison VRE Share ≥ 95%?



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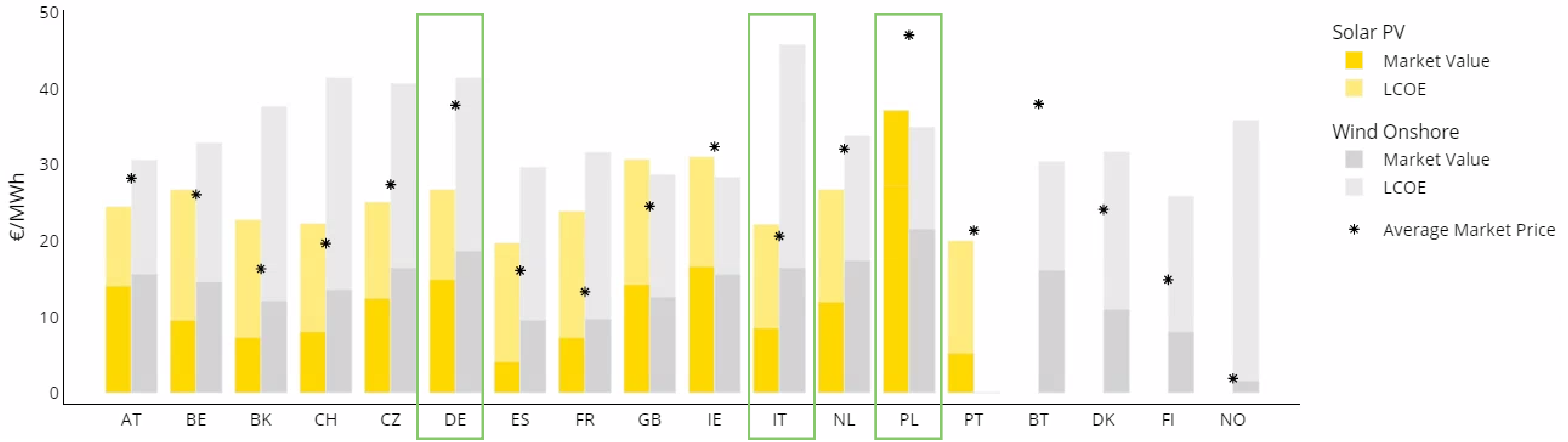
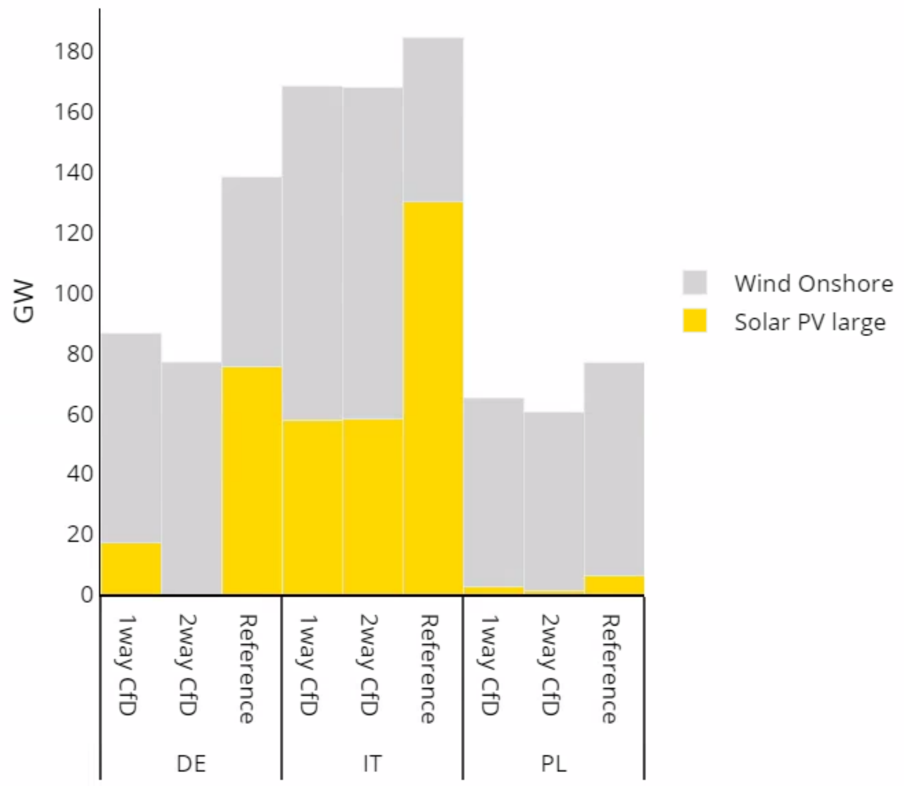
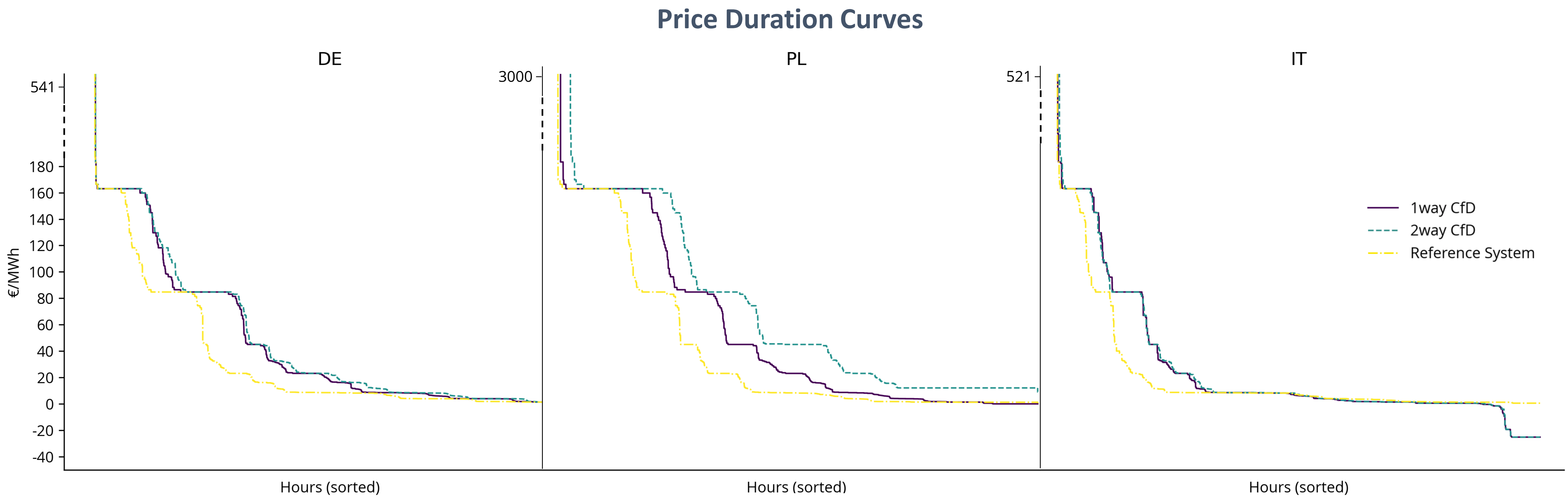


4. Results: Scenario Comparison Investment in VRE

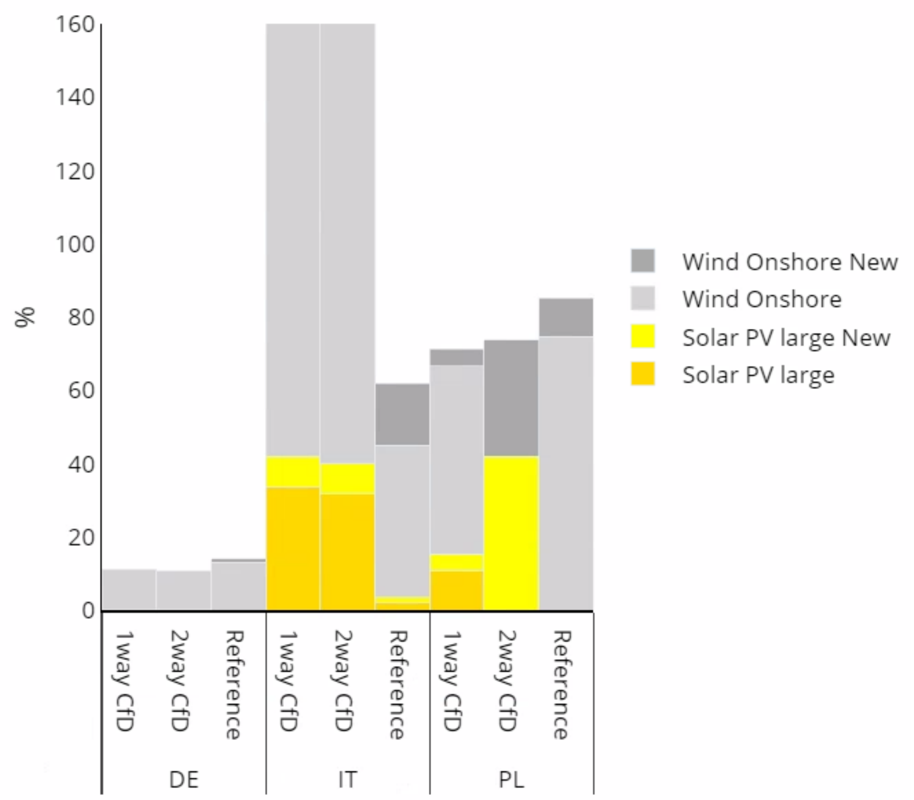


4. Results: Scenario Comparison Possible distortions

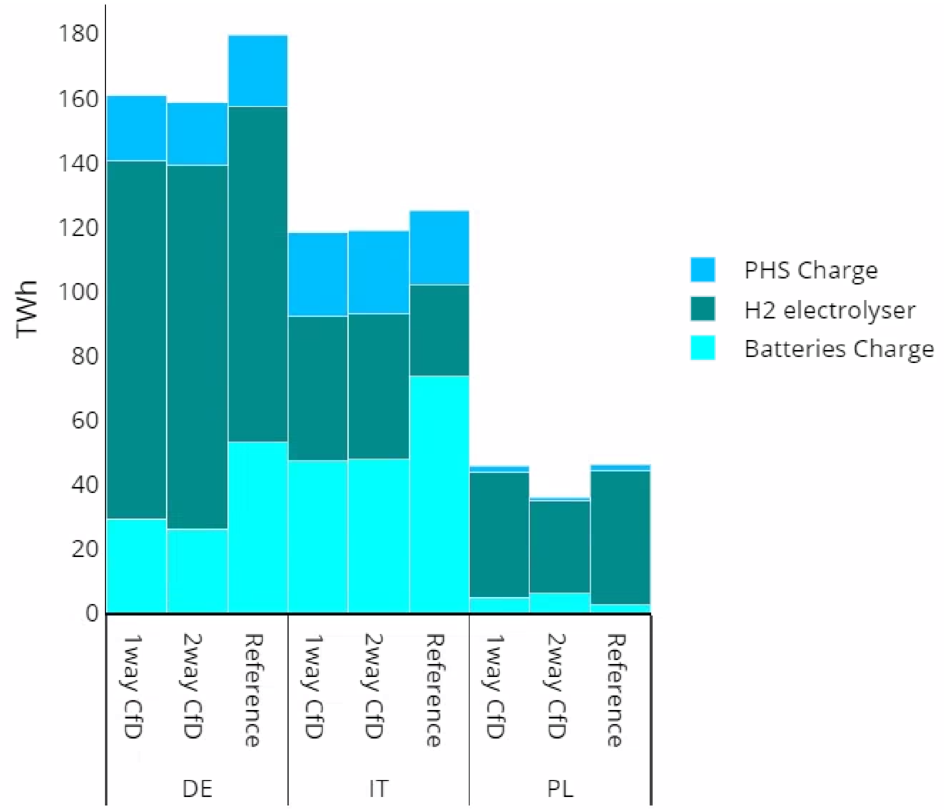


4. Results: Scenario Comparison Possible distortions

Curtailment

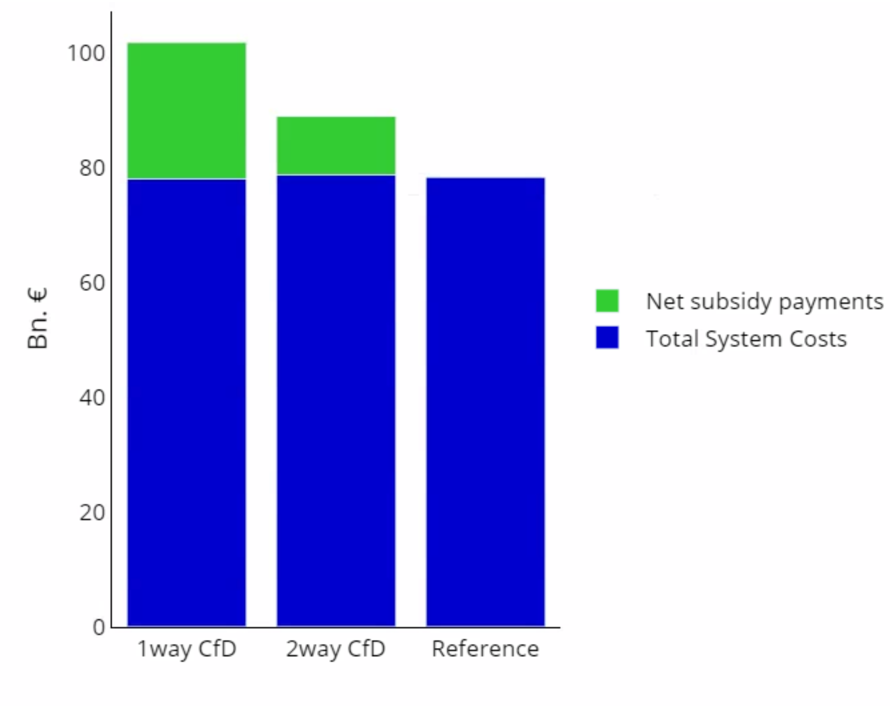


Storage activity

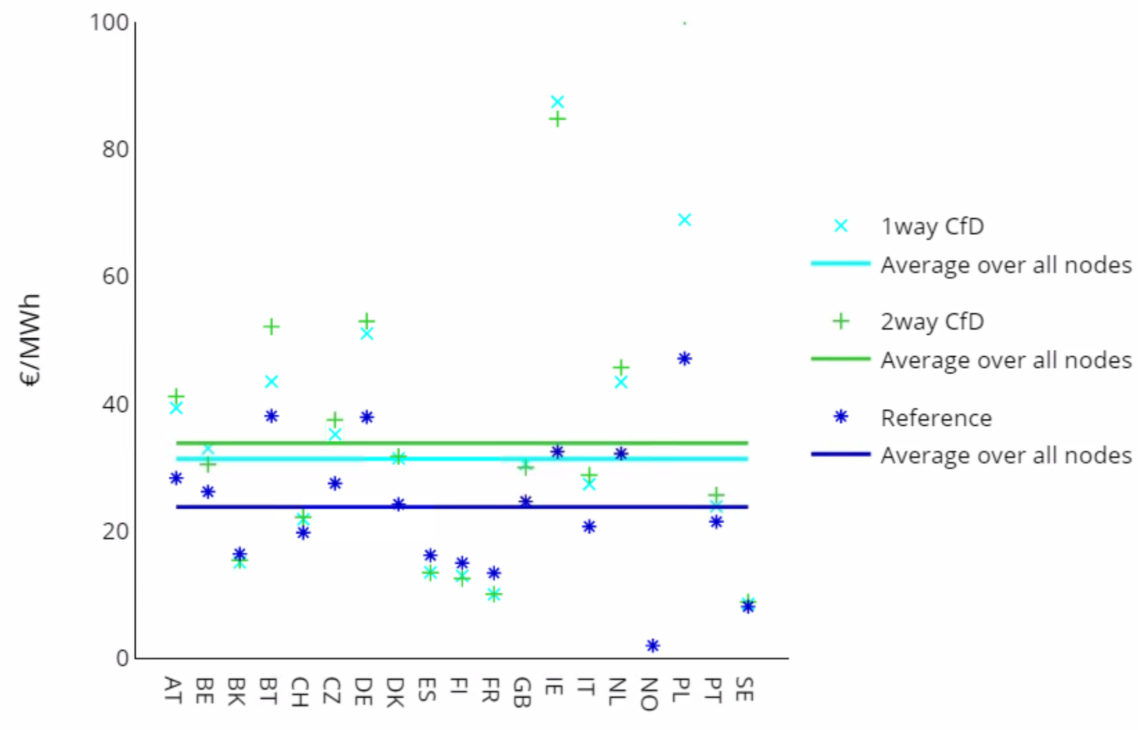


4. Results: Scenario Comparison Consumer perspective

Total system costs



Average wholesale electricity prices



5. Conclusion and Outlook

Conclusion:

- CfDs are able to incentivize invest to achive a higher share of variable renewables
- Yet, in our design, CfD payments distort investments towards more expensive technologies in terms of LCOE
- Anticipation of CfD payments by generators can harm invest and increase curtailment
- Both types of CfDs distort prices and therefore, curtailment and storage activity
- Total system costs and average prices are lower in the 1-way-CfD-case, yet at the price of higher subsidies

→ CfDs can successfully lead to meeting certain targets,
but messing with price signals always causes inefficient distortions!

5. Conclusion and Outlook

Outlook:

- Use market value of a reference power plant as reference price
- More distinct renewables within a country
- Model more types of CfDs (financial wind CfDs)
- No subsidies for LCOE > p_{max} to account for precedent auction for CfDs with maximum price
- More iterations to account for more „clever“ market actors
- TradeRES: will cover more market designs and include demand flexibility from other sectors

Thanks ☺

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www.traderes.eu

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References

Strbac, G., & al., e. (2021). Decarbonization of Electricity Systems in Europe: Market Design Challenges. IEEE Power and Energy Magazine, vol. 19, no. 1, pp. 53-63.

Newbery, D., Pollitt, M., Ritz, R., & Strielkowski, W. (2018). Market design for a high-renewables European electricity system. EPRG Working Paper 1711.

Hirth, L. (2013). The market value of variable renewables The effect of solar wind power variability on their relative price. Energy Economics, 38, pp. 218-236.

Prola, J. L., Steininger, K. W., & Zilbermanca, D. (2020). The cannibalization effect of wind and solar in the Californiawholesale electricity market. Energy Economics, 85.

Ruhnau, O. (2020). Market-based renewables: How flexible hydrogen electrolyzers stabilize wind and solar market values. ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg.

Schweppe, F., et al.: Spot pricing of electricity,Springer Science & Business Media (2013).

Schlecht, I., Hirth, L., & Maurer, C. (2022). Financial Wind CfDs.

Newbery, D. (2021). Designing an incentive-compatible efficient Renewable Electricity Support Scheme.

Frey, U. J., Klein, M., Nienhaus, K., & Schimeczek, C. (2020). Self-reinforcing electricity price dynamics under the variable marketpremium scheme. Energies, 13(20), 5350.

Helistö, N., Kiviluoma, J., Ikäheimo, J., Rasku, T., Rinne, E., O'Dwyer, C., ... & Flynn, D. (2019). Backbone—An adaptable energy systems modelling framework. Energies, 12(17), 3388.

Finke, J., Bertsch, V., & Di Cosmo, V. (2022). Exploring the Feasibility of Europe's 2030 Renewable Expansion Plans Based on Their Profitability in the Market. Available at SSRN 4336187.

Gillich, A., & Hufendiek, K. (2022). Asset profitability in the electricity sector: an iterative approach in a linear optimization model. Energies, 15(12), 4387.

3. Method
Energy System Model

Model

- Flexible open-source energy system modelling framework **Backbone**
- Cost-minimizing **capacity expansion planning** and subsequent **unit commitment**
- Minimum share of variable renewables as **constraint**
- Interpretation of **marginal system costs as electricity prices**

Power Plants

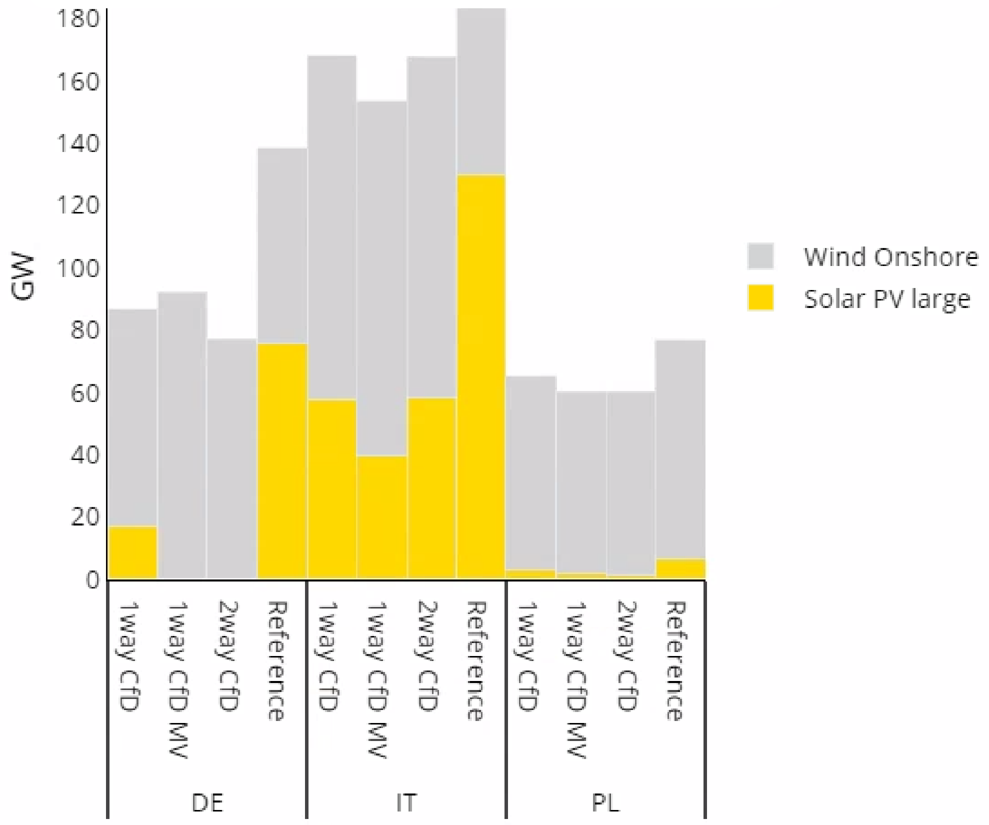
- **VRE:** Solar PV, Solar CSP, Wind onshore and offshore, Run of river hydro (weather year 2019)
- **Thermal:** Biofuel, waste, nuclear and hydrogen CCGT
- **Storage:** Pumped hydro and reservoir hydro, batteries and hydrogen storage with electrolysers
- Industrial load shedding units
- Maximum price = 3000€
- Exogeneous and unlimited endogeneous capacities for all technologies except hydro power

Geographical Scope

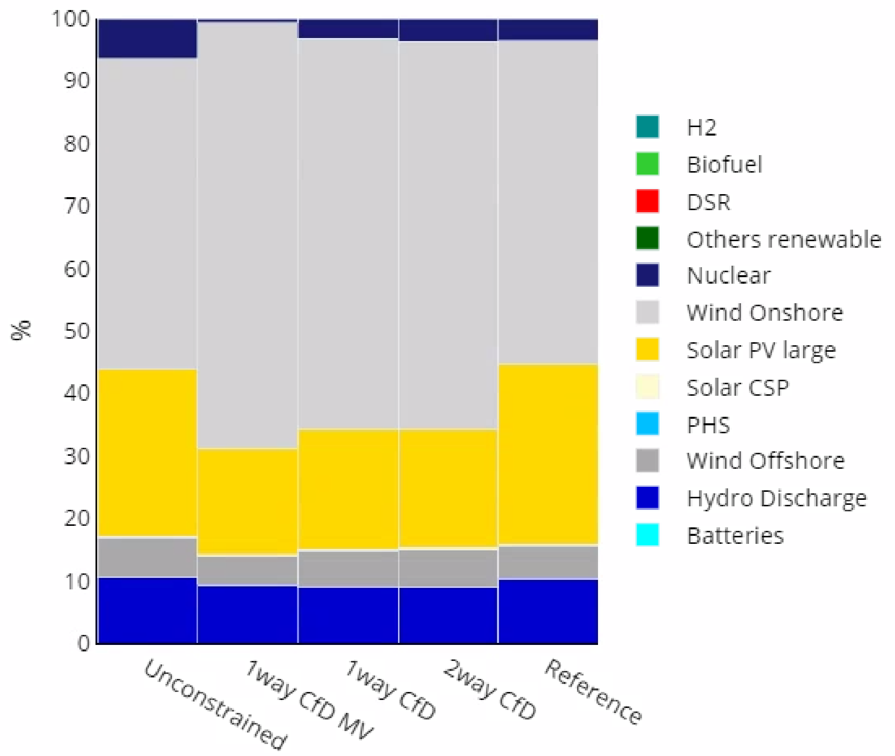
Data: TradeRES Public Deliverable D2.1, Entso-E ERAA 2022, Entso-E TYNDP 2022, Renewables Ninja, RUB EE‘s Pypsa-to-BB, Denish Energy Agency, Gils et al. (2014)
Literature: Helistö et al. (2019), Böttger et al. (2022), Gillich & Hufendiek (2022), Finke et al. (2023)

4. Results: Scenario Comparison Adding a CfD with MV=Reference Price

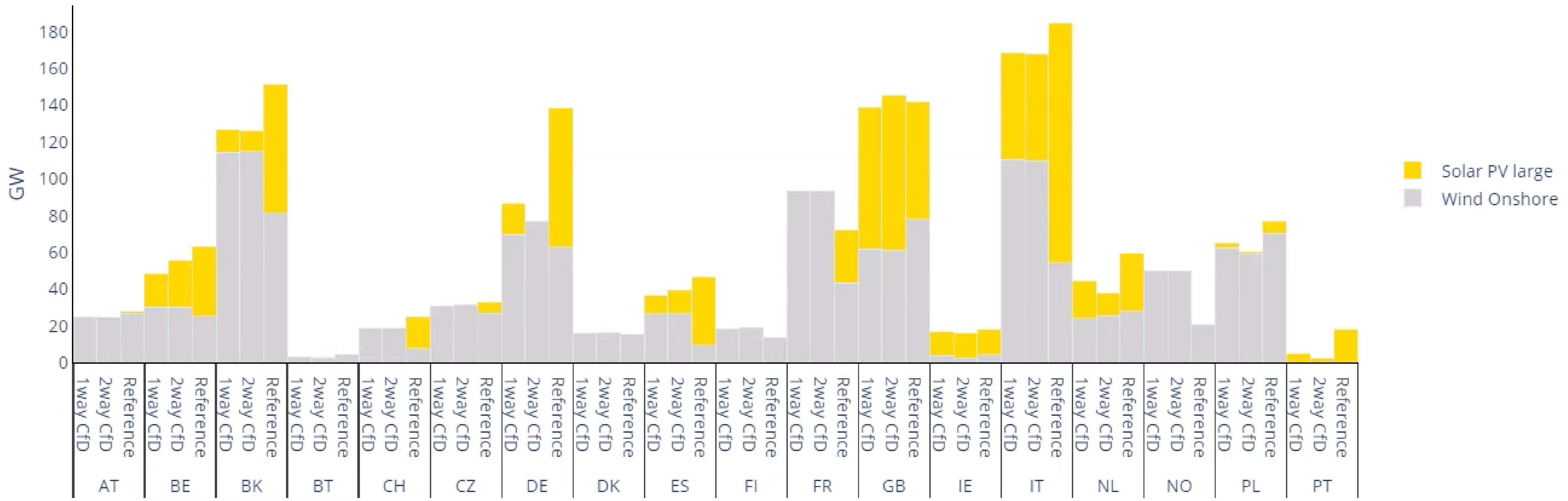
Investment



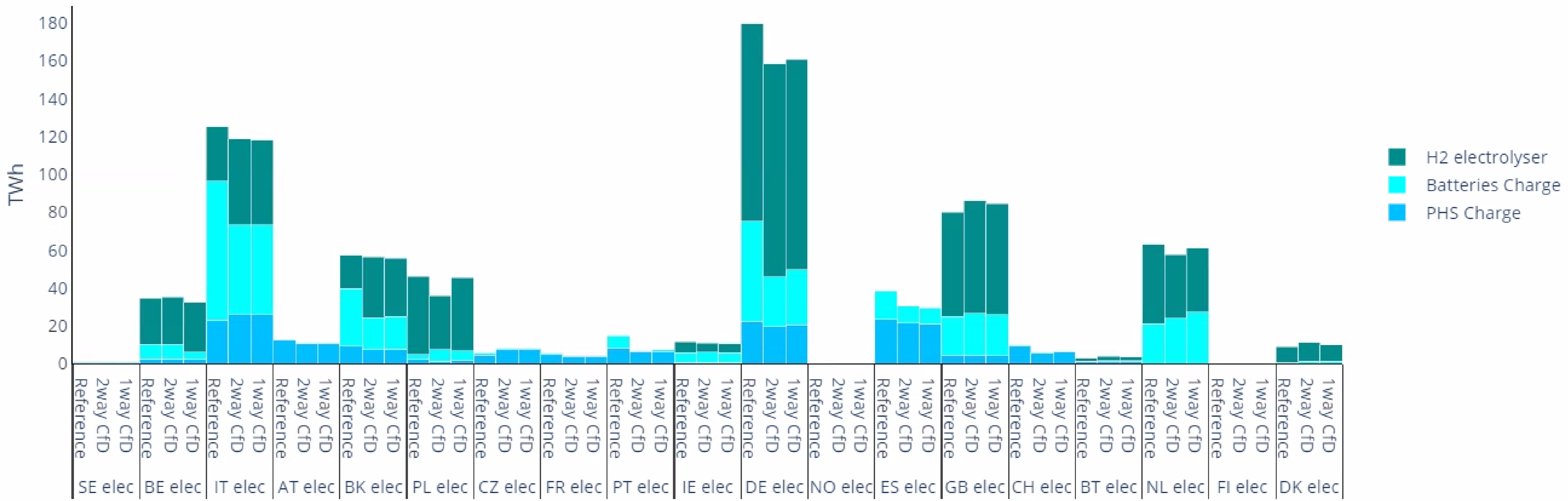
VRE Share



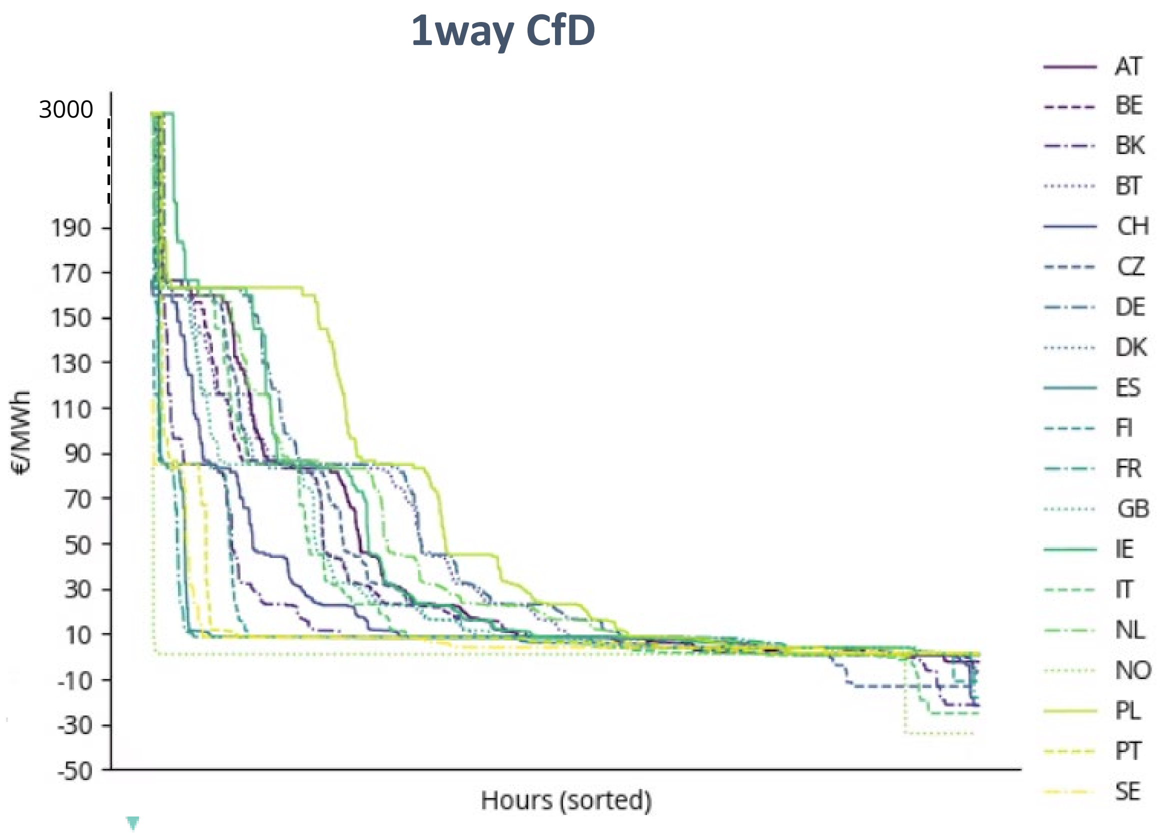
4. Results: Scenario Comparison Investment all over Europe

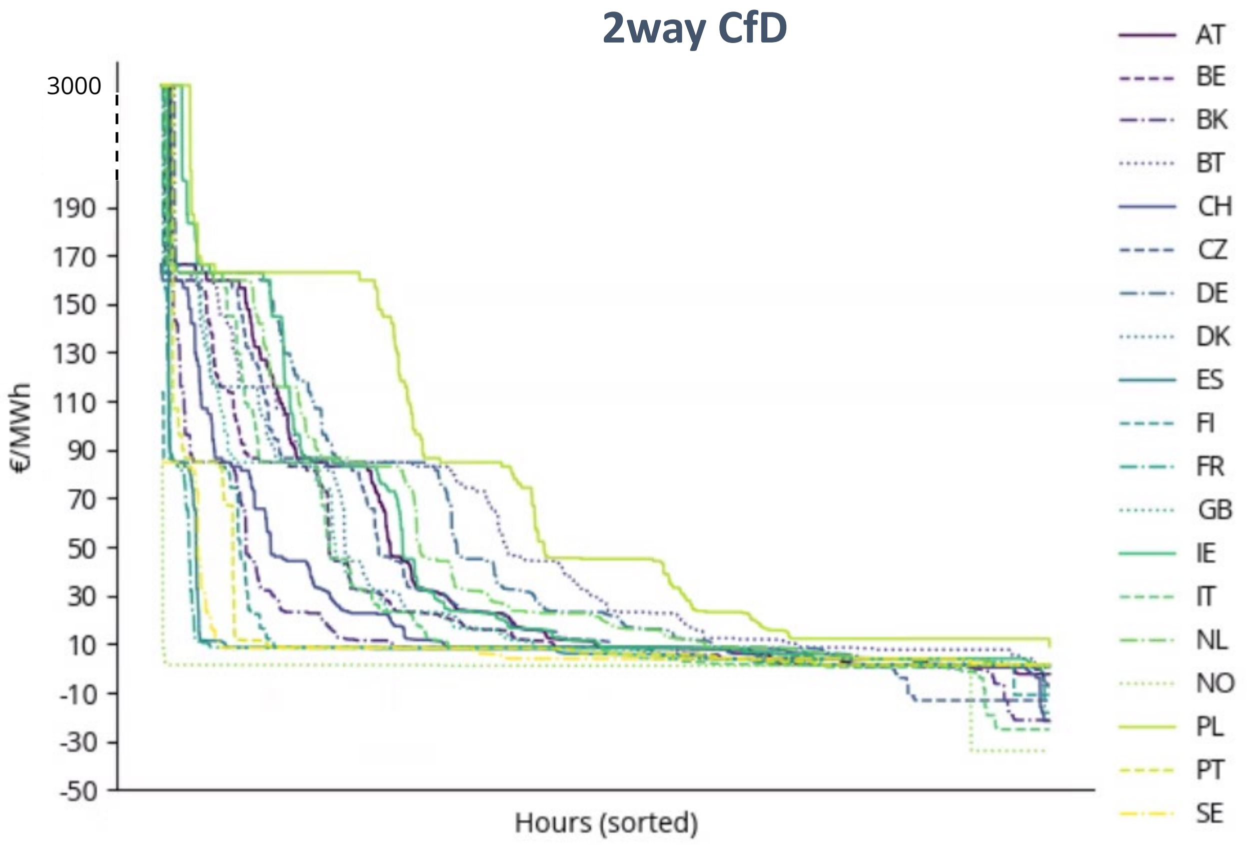


4. Results: Scenario Comparison
Storage activity all over Europe

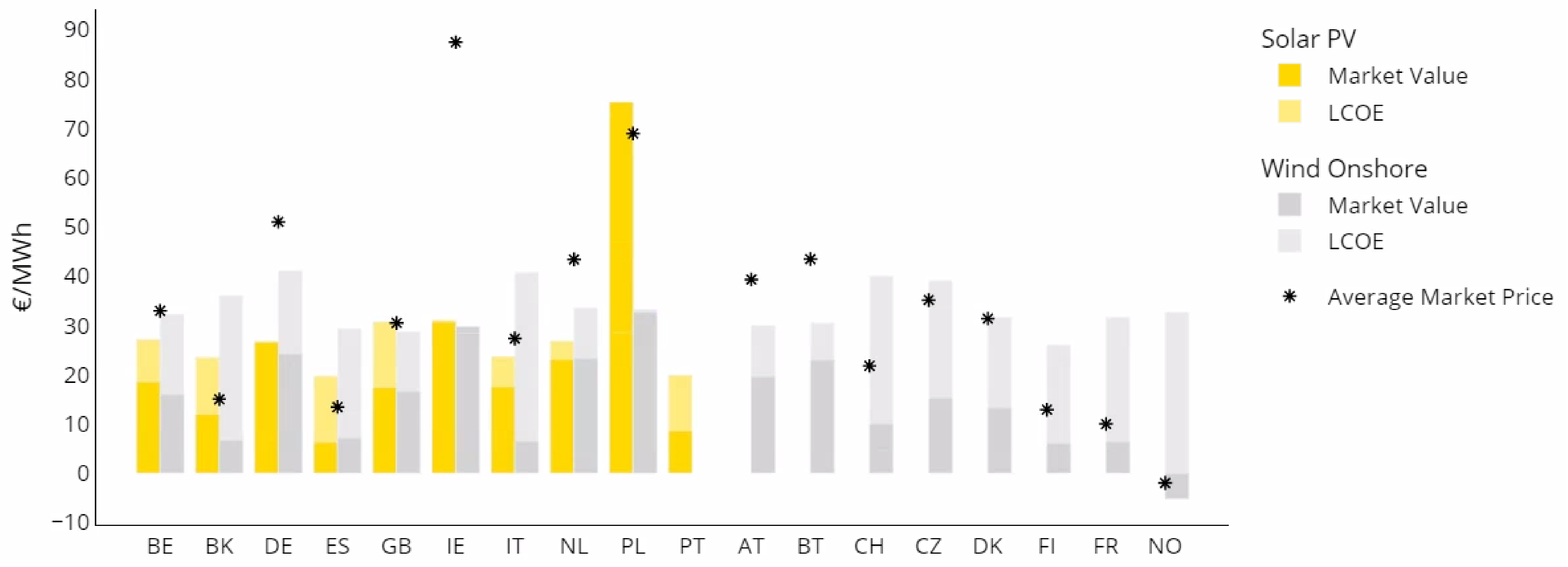


4. Results: Market Designs Price Duration Curves





4. Results: 1way CfD MV and LCOE



4. Results: 2way CfD MV and LCOE