Université
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Towards carbon neutrality and energy independence in Europe:

Can new storage and renewables push fossil fuels out?

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Context

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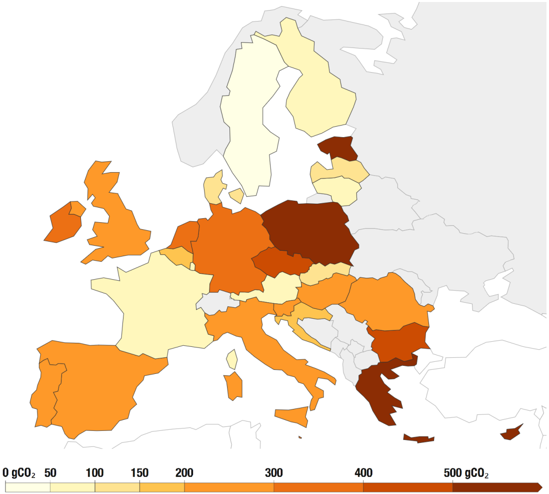


1. Reaching net zero by 2050
   1990-2020: - 54%
   Today: 230 gCO_2/kWh

2. Fossil dependence and geopolitical risks (rising prices, Ukraine)

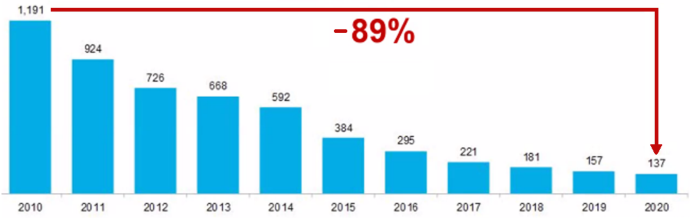
How to substitute coal and gas?
(→ Nuclear)
→ Variable renewable energies (VRE)

Need backup (Marques *et. al* 2019)
Replace 1/10th of fossil (York 2012)

Context

- Energy storage is becoming more interesting:

  → Volatility increased (Ketterer 2014, Clò *et. al* 2015)
  → Strong dynamics supported by the automotive sector
  → Massive costs reduction



Battery pack price in $2020/kWh (BloombergNEF)

Literature review

Literature review

Storage to increase value of VRE:

- Wind (Braff *et al.*, 2016)
- Solar (McLaren *et al.* 2019, Pommeret & Schubert 2019)

Profitability on multiple markets:

- Different revenue streams (Xi *et al.*, 2014)
- PJM (Sioshansi *et al.*, 2009), Australia (McConnell *et al.*, 2015)

Market design and imperfect competition:

- Ownership affects investments and storage usage (Sioshansi 2010)
- Firms' integration inefficiencies (Andrès-Cerezo & Fabra, 2020)
- Competition between storage technologies (Gaudard & Madani, 2019)

Literature review

Storage development potential:

- Capacity planning model (Steffen & Weber, 2013)
- Europe towards 100% renewables (Child *et al.* 2019)
- Role of CO_2 pricing in storage development (Ambec & Crampes 2019)

The ambiguous environmental role of storage

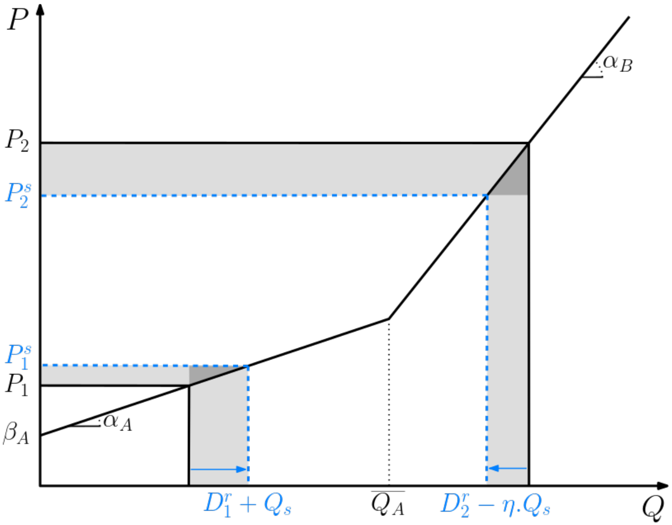
- Impact of storage costs on CO_2 emissions (Linn & Shih, 2019)
- The investment effects (Bistline & Young, 2021)

Our contributions:

- Accounting for the current European power system and its transition
- Competition between storage and fossil fuel power plants subject to policy
- A long-term equilibrium and stochastic framework

An introductory stylized model

A two-period model



1 Off-peak period

Solar (p_{solar})
+ Wind (p_{wind})
+ technology A
- storage

2 Peak period

Wind (p_{wind})
+ technology A
+ technology B
+ storage

Short-term impacts of storage

- **Short-term impacts of storage on emissions:**

$$\frac{\partial E_{CO_2}}{\partial Q_s} = e_A - \eta . e_B \tag{1}$$

- **Short-term impacts of storage on VRE:**

$$\Delta R_{solar} = p_{solar} . \overline{Q^{solar}} . \alpha_A . Q_s \geq 0 \tag{2}$$

$$\Delta R_{wind} = p_{wind} . \overline{Q^{wind}} . (\alpha_A - \alpha_B . \eta) . Q_s \tag{3}$$

Long-term impacts of storage

- **Long-term impacts on VRE without new base-load capacities:**

$$\frac{\partial Q^*_{solar}}{\partial Q_s} \geq 0 \qquad \frac{\partial Q^*_{wind}}{\partial Q_s} = \frac{C.(1 - p_{solar}) - \eta}{1 + C.(1 - p_{wind}.p_{solar})} \tag{4}$$

- **Long-term impacts on VRE with new base-load capacities:**

$$\frac{\partial Q^{**}_{solar}}{\partial Q_s} \geq 0 \qquad \frac{\partial Q^{**}_{wind}}{\partial Q_s} = 0 \tag{5}$$

$$\frac{\partial Q^{**}_{A}}{\partial Q_s} = \frac{C.(1 - p_{solar}) - \eta}{1 + C.(1 - p_{solar})} \tag{6}$$

Long-term impacts of storage

There exists a concavity index C_0 such that storage reduces emissions:

- If $e_B \geq \frac{2}{1+\eta}.e_A$ and $C \geq C_0$
- Or $e_B \leq \frac{2}{1+\eta}.e_A$ and $p_{solar} \geq \frac{1-\eta}{1+\eta}$ and $C \leq C_0$

Drivers of emissions reduction are a low-carbon base-load technology ($e_A \ll e_B$) or a high solar potential.

Investment effects are ambiguous.

It depends on the shape of the supply curve and the matching of VRE production with demand.

A numerical model for the European energy transition

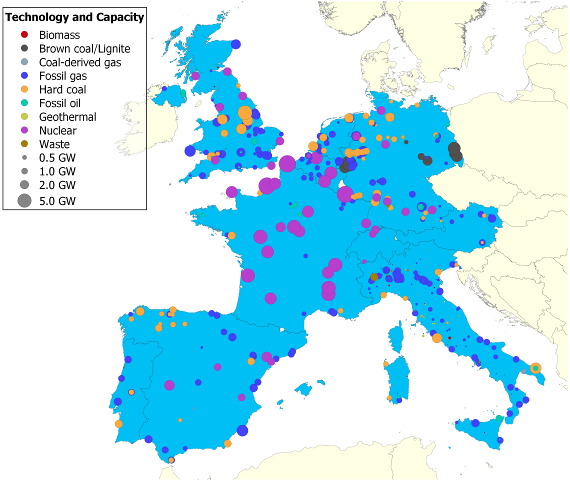
Optimal mix to phase-out coal

Exogenous

→ Inelastic demand
→ Pre-existing conventional plants
→ Number of electric vehicles
→ Interconnections

Endogenous

→ VRE
→ Vehicle-to-grid (V2G)
→ Stationary batteries
→ Power-to-hydrogen
→ New gas power plants



Data and modeling plan

Price structures in Europe

- JRC Open Power Plants Database (Bocin *et al.*, 2019)
- ENTSO-E Transparency Platform, 2015-2020
  + Calibration on the current day-ahead market ⏩

Availability of solar and wind energy

- Renewables Ninja, 1980-2019 (Pfenninger and Staffell, 2016)
- National energy and climate plans (EC, 2020) to derive VRE pathways towards 2040

New capacities on the market

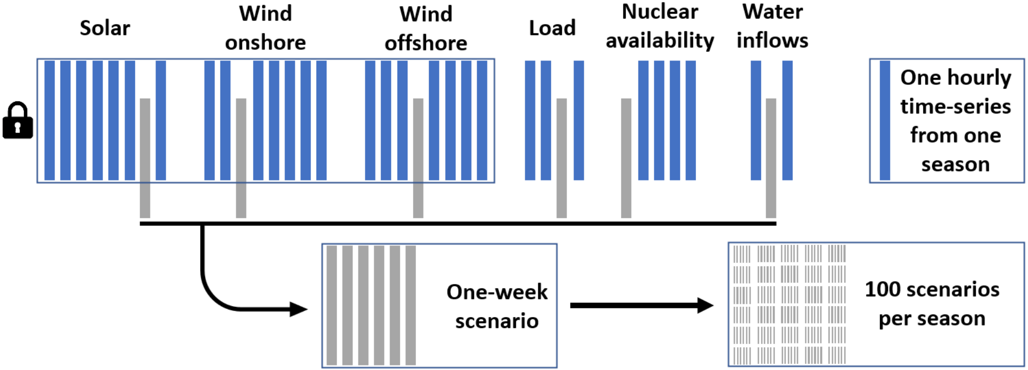
- Stochastic approach with scenarios (Conejo et. al, 2010) ⏩
- Long-term equilibrium

Generation strategy

- Linear optimization and unit commitment (Soroudi, 2017)

Scenarios to represent uncertainty

- Monte-Carlo: 600 weekly scenarios ($\approx$ 10 years) over 6 two-month seasons



Solving the model

Minimization of the total cost of the power system:

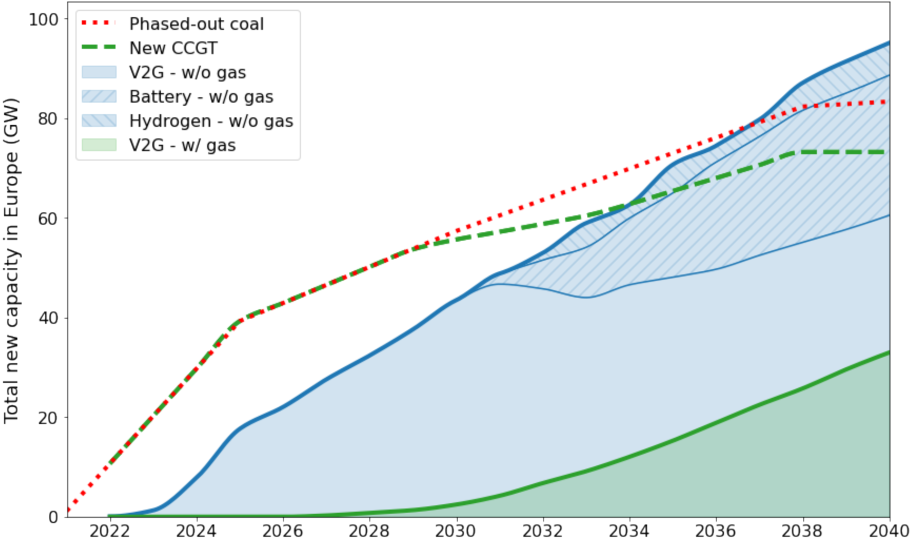
$$\min_{\overline{X}} \mathbb{E}\left[\min_{Z_{\zeta,t}} \sum_{t=0}^{T} \left(\sum_{j\in\mathcal{J}} y_{j,\zeta,t}.MC_j + \sum_{c\in\mathcal{C}} V_c.LL_{c,\zeta,t}\right) + C\left(\overline{X}\right)\right] \tag{7}$$

The problem is solved in two policy cases:

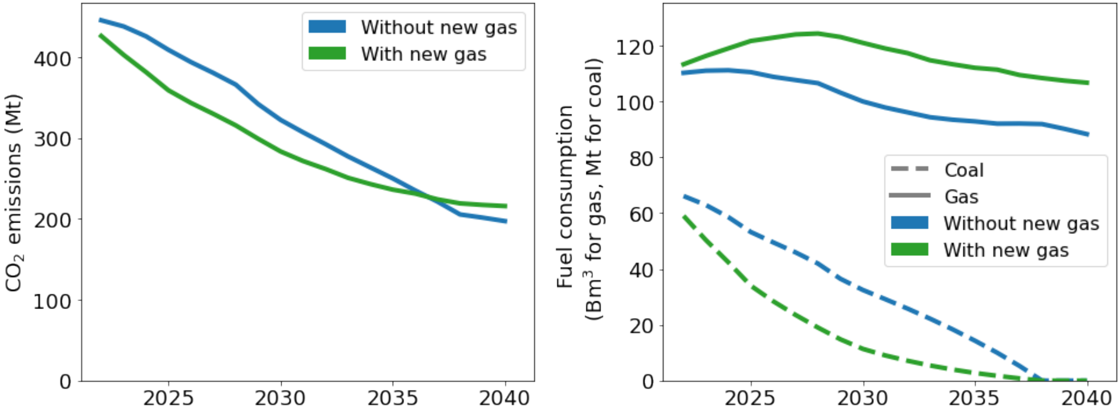
1. With new gas (CCGT) that can replace phase-out coal capacities
2. Without new gas, and only storage

Results

Storage long-term capacities



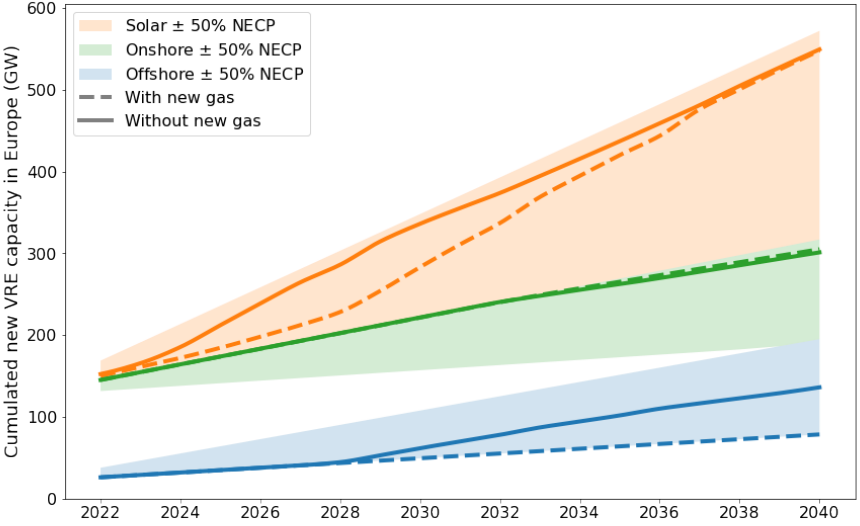
CO_2 emissions and fossil consumption



National metrics

	CO_2 intensity			RE share		
New gas	w/o	w/o	w/	w/o	w/o	w/
Date	2022	2040	2040	2022	2040	2040
Germany	417	**93**	150	38	**66**	44
Netherlands	315	85	85	28	**78**	74
Italy	251	145	**94**	41	62	**73**
United Kingdom	188	**66**	82	30	**70**	59
Belgium	164	**92**	105	21	**45**	38
Austria	150	124	**38**	64	72	**90**
Portugal	121	29	**18**	67	92	**95**
Spain	114	36	**34**	50	81	81
France	44	14	14	21	**50**	46
Switzerland	0	0	0	40	54	54

Impact on VRE



Conclusion

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- We used a stochastic long-term equilibrium model to evaluate the impact of storage on the European markets by 2040.

- We find evidence that:

  → Without a public support scheme (higher RE shares, coal phase-out, freeze gas investments), storage will not massively enter the energy-only market

  → The effect of storage on fossil fuels is limited: new gas benefits from a competitive advantage and existing gas is still required

  → VRE mutually develop with storage systems, contrary to new gas

- Policy implications of restricting new gas facilities (green taxonomy) and supporting innovation in storage

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Thank you for your attention

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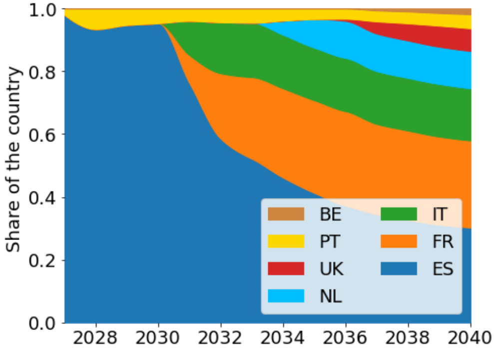
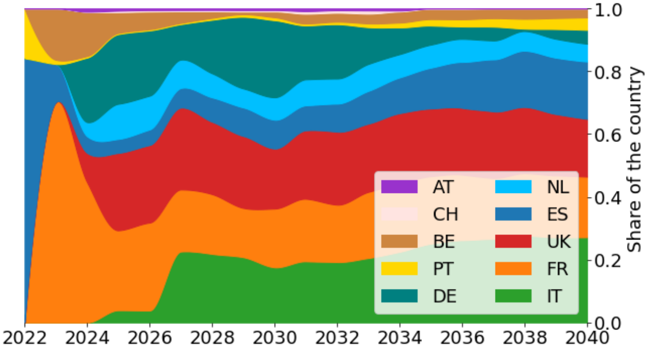
Appendices

Contribution of countries in storage development



With new gas



Without new gas