Energy Economics, Winter Semester 2024-5

Lecture 13: The Future

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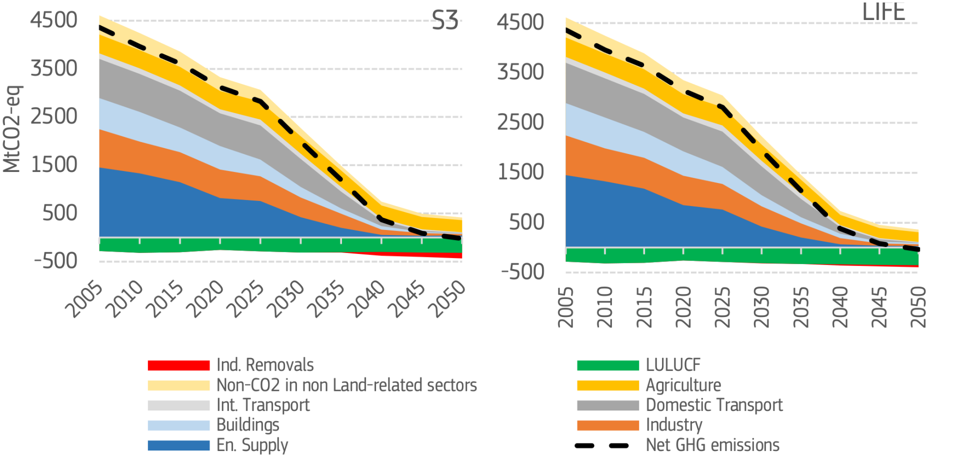
Possible Pathways

The Greenhouse Gas Challenge: Net-Zero Emissions by 2050

Paris-compliant 1.5° C scenarios from European Commission for **net-zero GHG in EU by 2050**. This target has been adopted by the EU and enshrined in the **European Green Deal**.



Source: European Commission 2040 target impact assessment, 2024

It’s not just about electricity demand...

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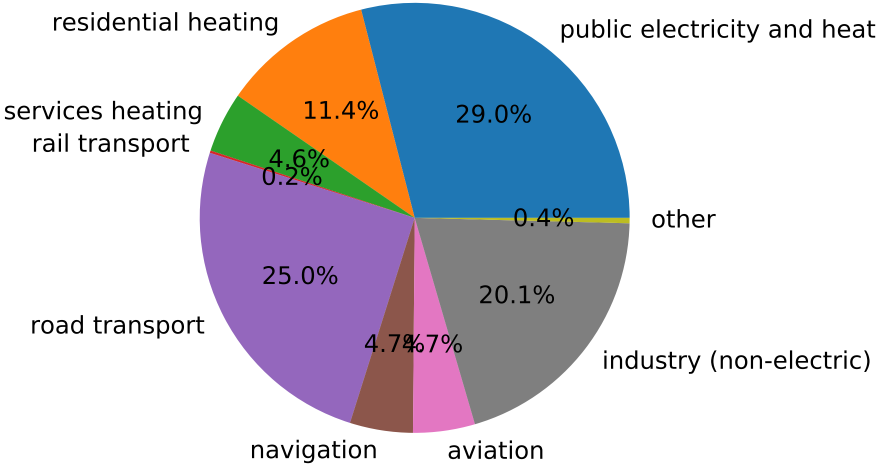
EU28 CO_2 emissions in 2016 (total 3.5 Gt CO_2, 9.7% of global):



Source: Brown, data from **EEA**

...but electrification of other sectors is critical for decarbonisation

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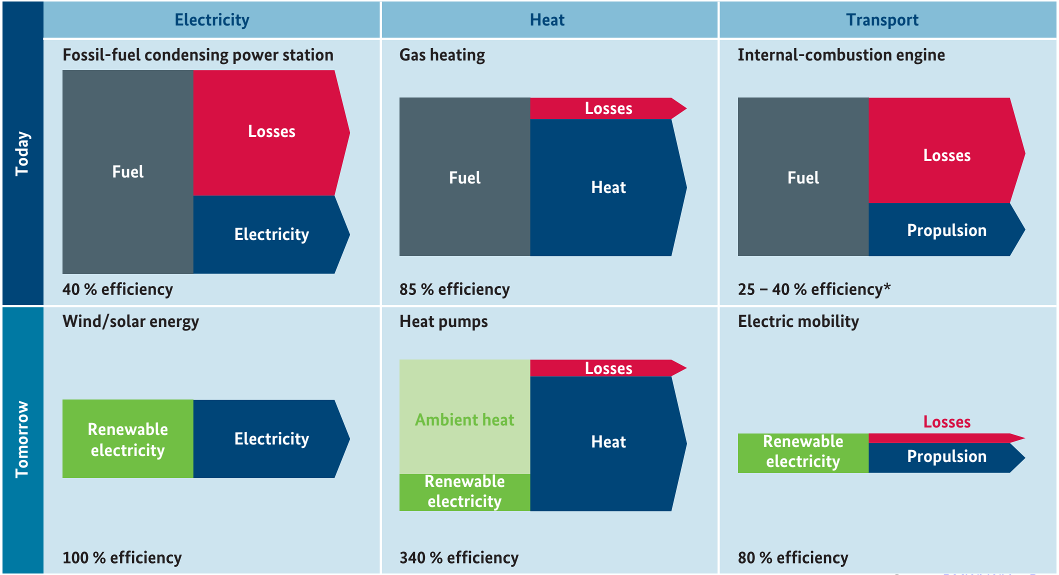
Electrification is essential to decarbonise sectors such as transport, heating and industry, since we can use low-emission electricity from e.g. wind and solar to displace fossil-fuelled transport with electric vehicles, and fossil-fuelled heating with electric heat pumps.

Some scenarios show a **doubling or more of electricity demand**.

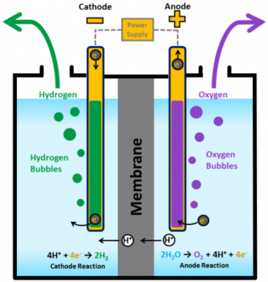
Source: Tesla; heat pump: Kristoferb at English Wikipedia

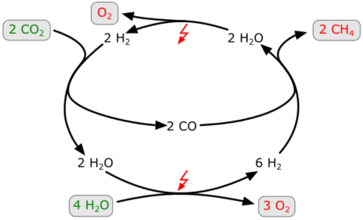
Efficiency of renewables and sector coupling



Source: BMWi White Paper 2015

Power-to-Gas (P2G)

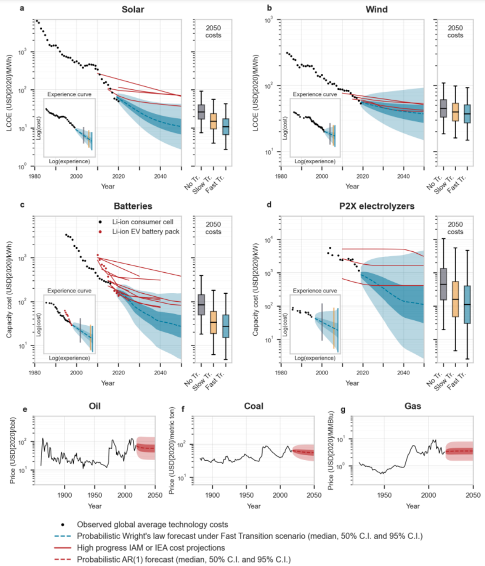




Power-to-Gas/Liquid (P2G/L) describes concepts to use electricity to electrolyse water to **hydrogen** H_2 (and oxygen O_2). We can combine hydrogen with carbon oxides to get **hydrocarbons** such as methane CH_4 (main component of natural gas) or liquid fuels C_nH_m. Used for **hard-to-defossilise sectors**:

- **dense fuels** for transport (planes, ships)
- **steel-making** & **chemicals industry**
- **high-temperature heat** or **heat for buildings**
- **backup energy** for cold low-wind winter periods, i.e. as storage

5 critical techs: wind, solar, batteries, heat pumps, electrolyzers



All critical techs for the energy transition share a small unit size, enabling fast production and installation, economies of scale in manufacturing and learning-by-doing.

- **Low-cost electricity** from wind and solar.
- **Batteries** for mobility and balancing applications.
- **Electrolytic hydrogen** (splitting water) for everything else: long-duration storage, aviation, shipping, industry.
- **Heat pumps** (missing from graphic) for building comfort and some low-T industry.

Source: Way et al, 2021

2050 scenarios for EU: power demand doubles, mostly met by VRE

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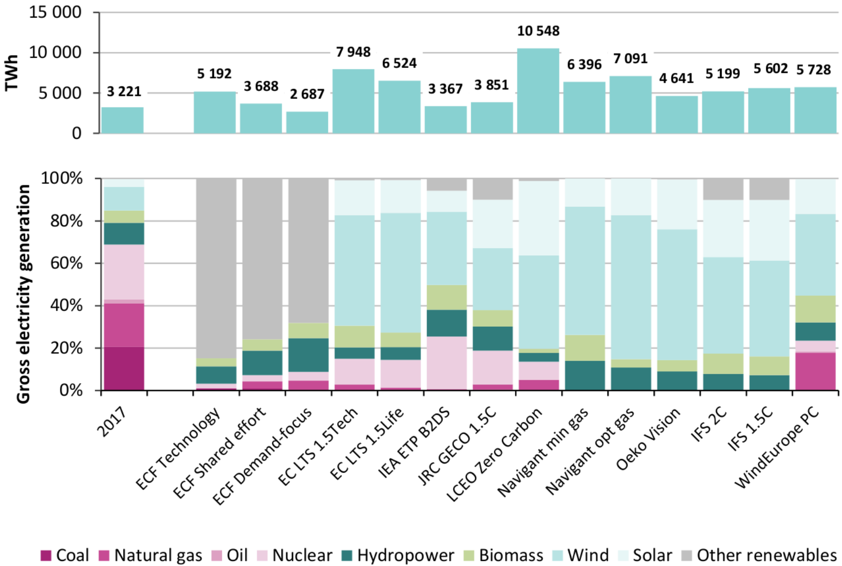
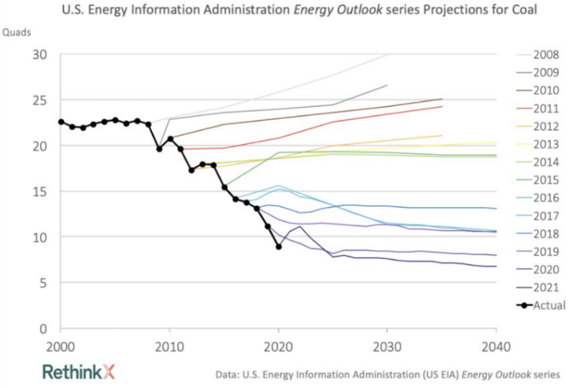
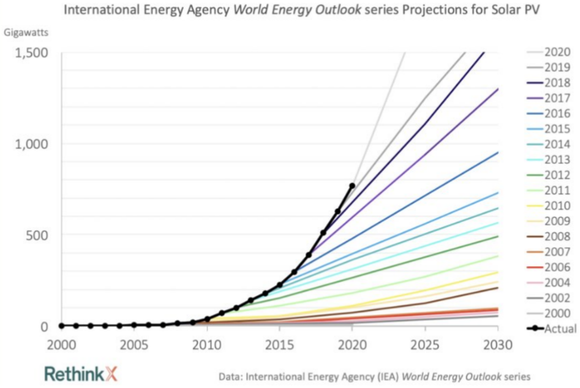


Source: JRC, 2020

Not all predictions are reliable, especially about the future

We are working under **deep uncertainty**, with many potential **non-linear changes**.





Source: RethinkX

Example Zero-Emission Systems

The following online toy model optimises a combination of wind, solar, batteries and hydrogen storage to meet a baseload demand, using weather data from any location in the world.

https://model.energy/

Look at the differences of wind and solar feed-in and optimal storage solutions for:

- **City: Berlin**
- **Country: Germany**
- **Continent: Europe**

What do you notice?

Storage charges at low prices, discharges at high prices

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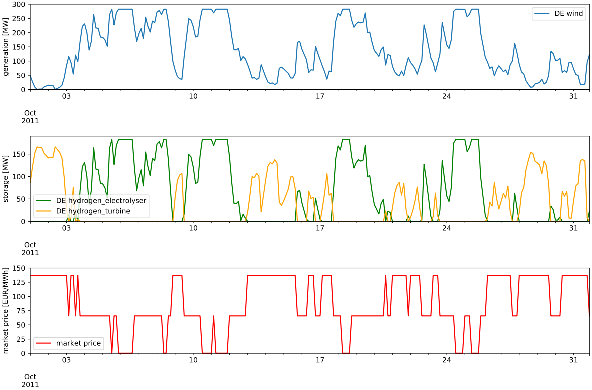
Simplified example from **https://model.energy** for Germany with only wind and hydrogen storage to meet a flat 100 MW demand.

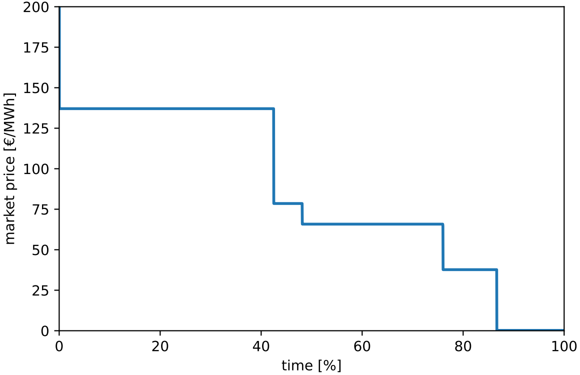
Average charging price (with electrolyser): 43 €/MWh

Average discharging price (with turbine): 144 €/MWh



Storage charges at low prices, discharges at high prices

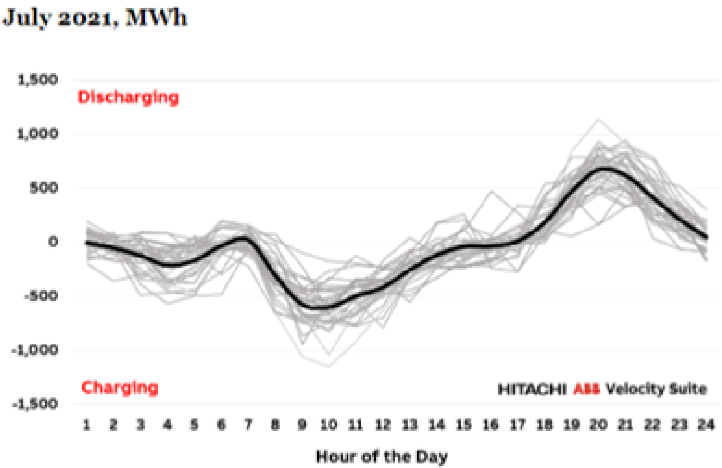
How are prices when there is only zero-marginal-cost wind/solar and storage but no fuels?



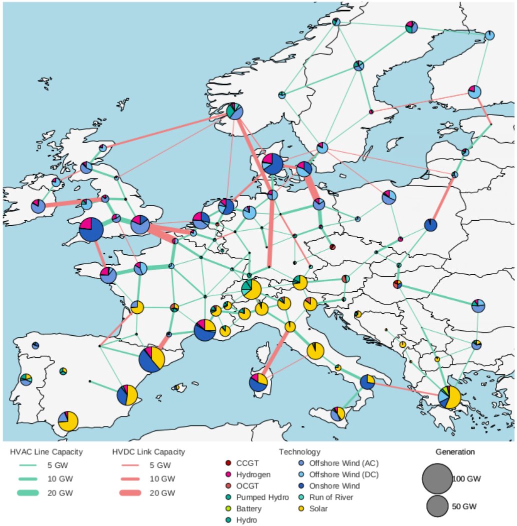
- When wind is scarce for ∼40% of time, hydrogen turbine sets price high enough to cover their costs. Green hydrogen costs money, just like fossil fuel!
- Electrolyser is willing to bid more than zero for electricity (since it earns selling hydrogen to turbine), so demand sets non-zero price ∼45% of time.
- Only when electrolyser is at capacity, do we curtail wind and price is zero ∼15% of time.

Storage charges at low prices, discharges at high prices

We see batteries in California behaving exactly in this way today.



Source: ABB Hitachi



For more detailed research-level modelling of future net-zero energy systems that include:

- All low-carbon generators
- Network modelling
- Other sectors (heating, transport, industry)
- Green hydrogen and materials
- Accounting for public acceptance

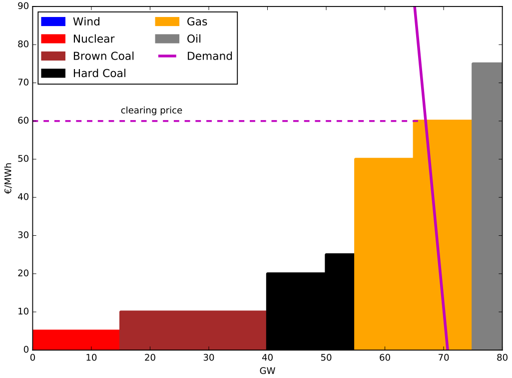
Come to the Energy Systems course in Summer Semester!

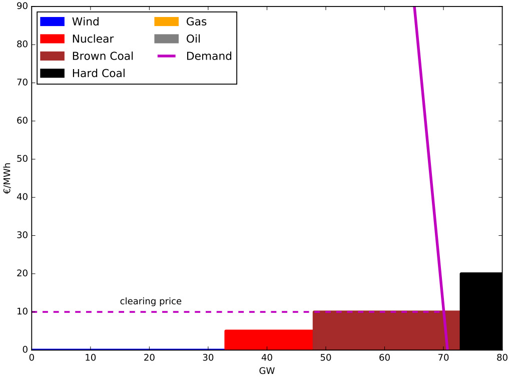
Source: Neumann & Brown, 2020

Market Integration of Renewables

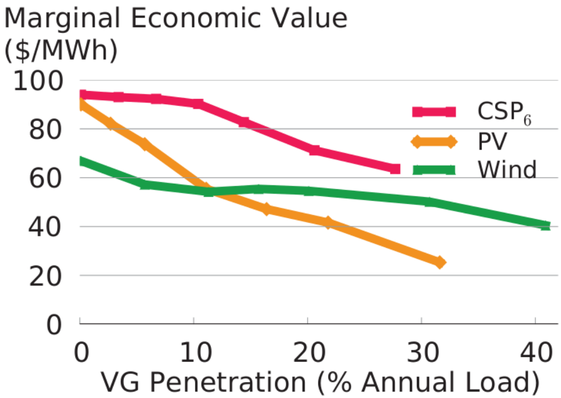
Traditional ‘primal’ view of market value of wind and solar

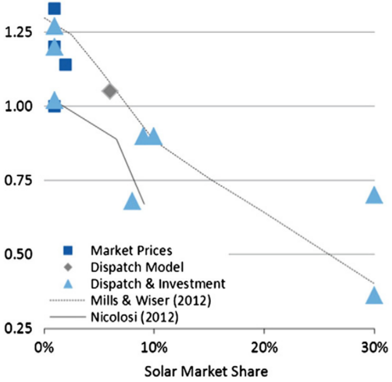
Prices are **depressed** by zero-marginal-cost wind and solar, which **‘eat their own revenue’**.





Market value, i.e. average price generator gets for feed-in, **declines with penetration**.





Source: Mills & Wiser (2014), Hirth (2013)

What the literature says about market value of wind and solar

- "Market value of wind and solar always declines with penetration - VRE eat own revenue."
- "Variability is the fundamental cause of market value decline."
- "Declining market value implies wind and solar become uneconomical at high shares."
- "Market integration of large shares of variable renewables is impossible."
- "New low-carbon technologies will be necessary at high penetrations."

Source: Diverse energy economics literature.

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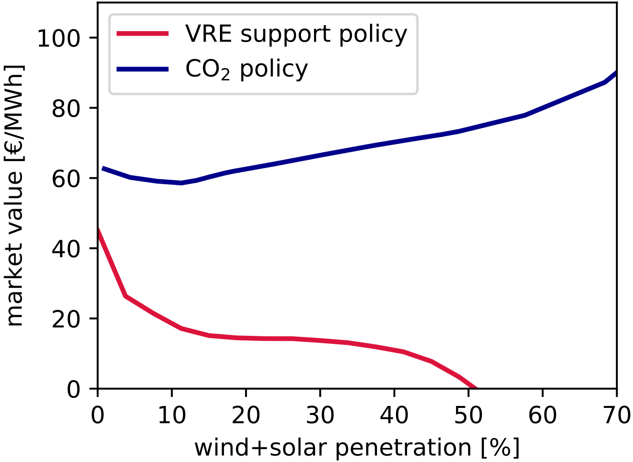
We show that from a **dual perspective**, each of these statements is **wrong**.

Source: Diverse energy economics literature.

Market value decline depends on market structure

Implicit assumption in literature: VRE are forced in with subsidies or quotas, pushing MV down.

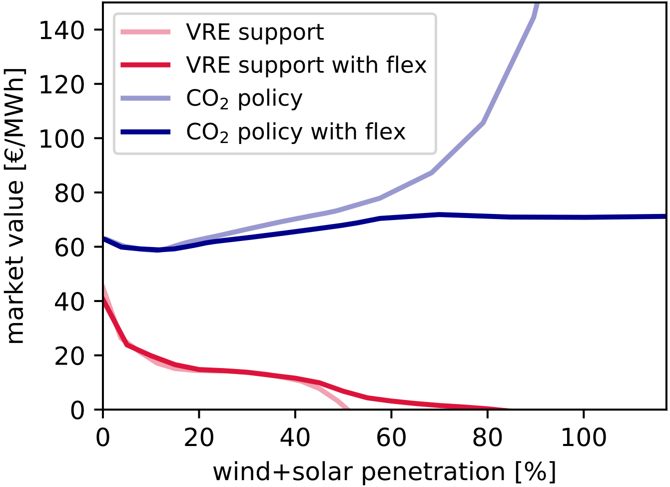
However, if VRE are drawn in with CO_2 pricing, MV does not decline.



Source: Brown & Reichenberg (2021)

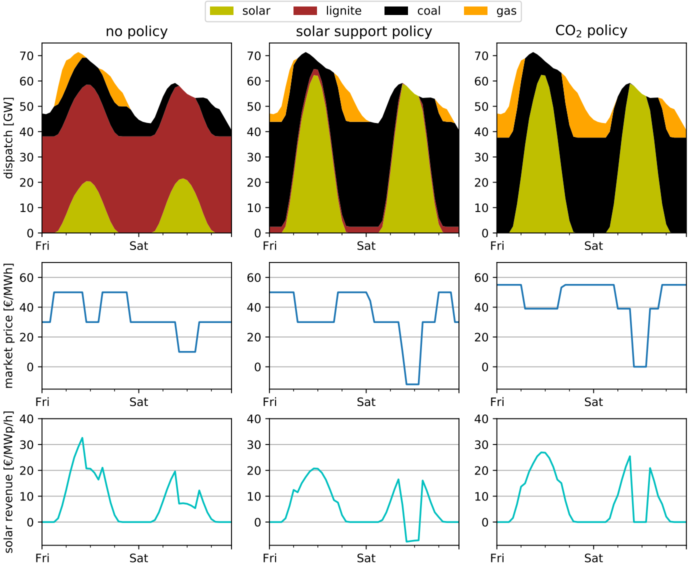
This holds even up to 100% wind and solar...

...provided there is **flexibility** from long- and short-term storage and/or transmission expansion.



Source: **Brown & Reichenberg (2021)**

Example from primal perspective: solar support versus CO_2 pricing



Source: **Brown & Reichenberg (2021)**

Market value decline: primal versus dual perspective

Primal perspective:

- Market value declines because zero-marginal-cost VRE pushes out other generators
- Variability is the fundamental cause
- Only affects wind and solar generators

Dual perspective:

- Market value declines because share of generation is forced beyond equilibrium
- Policy is the fundamental cause
- Affects all generators which are forced beyond equilibrium

Market value decline: primal versus dual perspective

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Dual perspective:

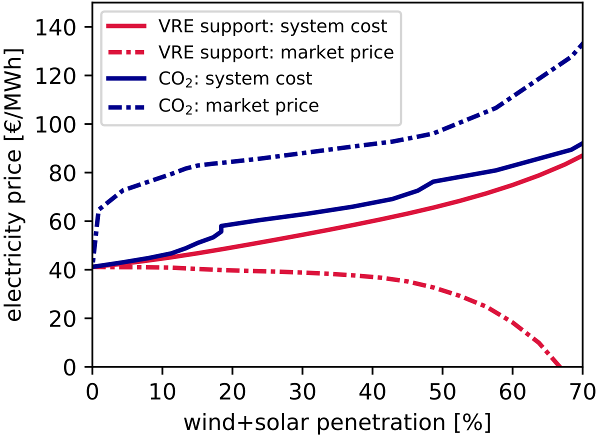
- Market value declines because share of generation is forced beyond equilibrium
- Policy is the fundamental cause
- Affects all generators which are forced beyond equilibrium

Perspectives and framing have consequences!

System cost

With VRE as the only low-C generators, system costs **barely differ** between policies.

⇒ MV collapse under support policy does not necessarily indicate system is pathological.

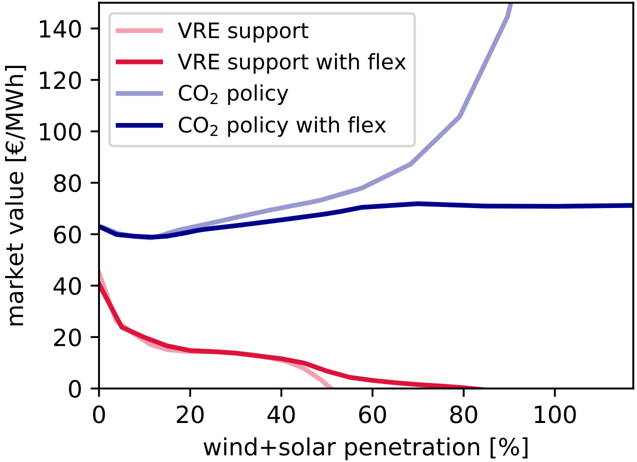


Source: **Brown & Reichenberg (2021)**

Role of flexibility

Flexibility only **delays** market value decline for support policies.

For CO_2 policies it **stabilises** LCOE = MV above penetrations of 70%.



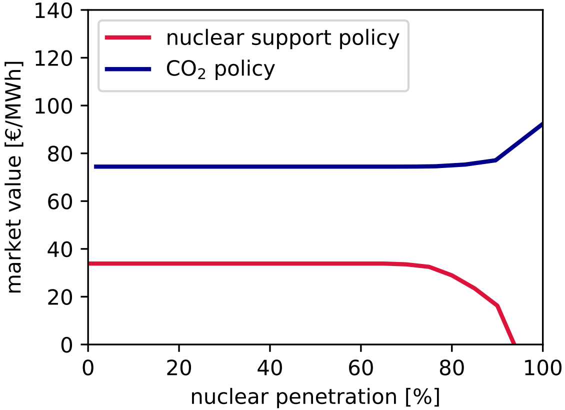
Flexibility added here:

- short-term storage (batteries)
- long-term storage (hydrogen)
- transmission expansion

Source: Brown & Reichenberg (2021)

Support policy for nuclear shows similar results

Nuclear revenue is also suppressed under a support policy, declining to zero at high penetrations because of the variable demand. A CO_2 price avoids this behaviour.



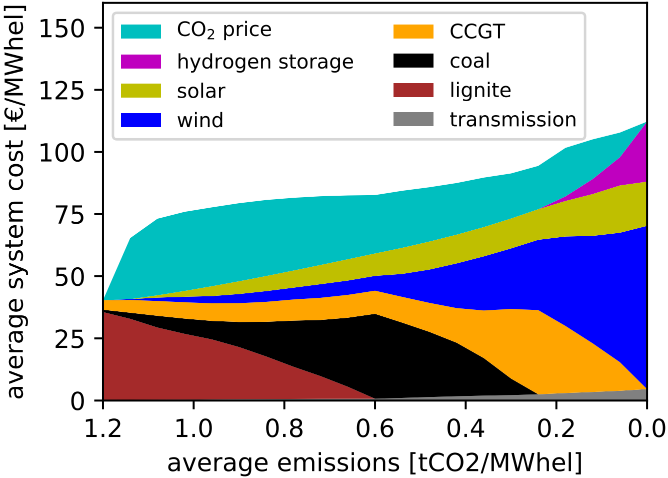
⇒ **Nothing specific to VRE about MV suppression**.

⇒ **Policy is responsible for MV decline**, variability only affects the speed.

Source: **Brown & Reichenberg (2021)**

System costs for CO_2 policy

In breakdown of system costs, hydrogen storage balances the system at high penetrations.

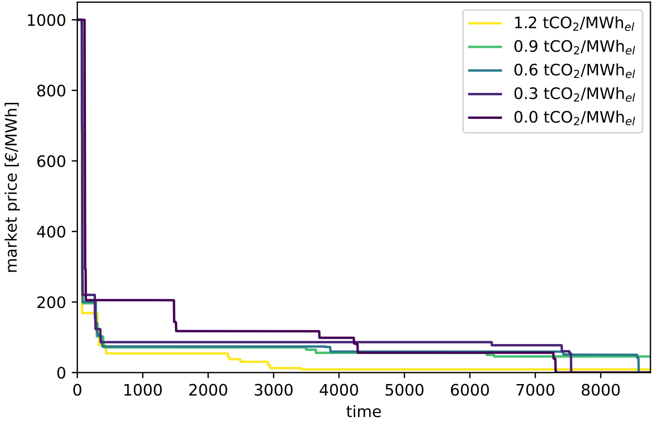


Source: Brown & Reichenberg (2021)

Price duration curves under a CO_2 policy

CO_2 price raises prices when fossil generators on margin, but also storage bids **high opportunity costs** when discharging, while charging bids reduce hours when prices are zero.

⇒ Market does not degenerate into bifurcation of prices between zero and very high.

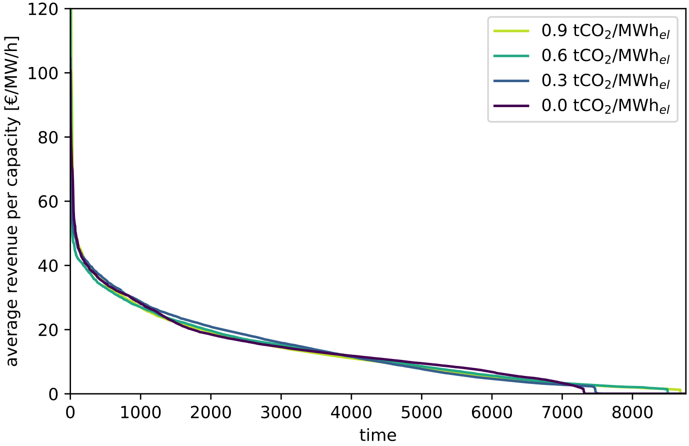


Source: Brown & Reichenberg (2021)

Average revenue per capacity per hour

The distribution of hours when VRE earns its money barely changes as CO_2 emission reduce.

⇒ VRE does not become dependent on only a small number of hours to make money.



What we say about market value of wind and solar

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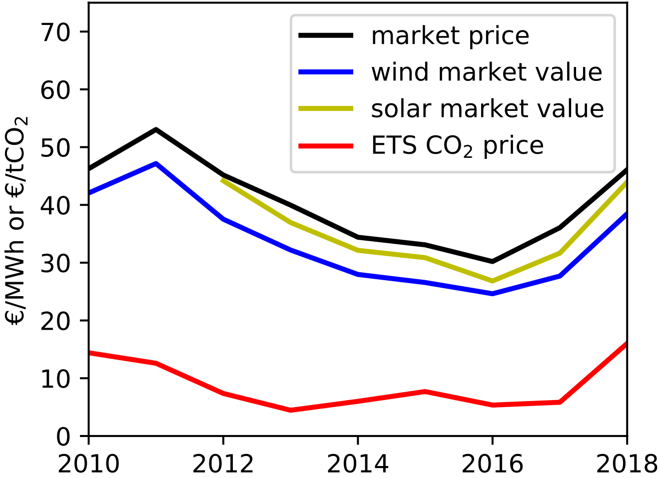
- "Market value of wind and solar always declines with penetration - VRE eat own revenue."
  - **No**, if drawn in with a CO_2 price, market value does not decline.
- "Variability is the fundamental cause of market value decline."
  - **No**, policy is the fundamental cause (no policy, no decline), but variability affects speed.
- "Declining market value implies wind and solar become uneconomical at high shares."
  - **Not necessarily**: market value can decline even when system cost is close to optimal.
- "Market integration of large shares of variable renewables is impossible."
  - **No**, wind and solar can be integrated into markets with sufficient flexibility.
- "New low-carbon technologies will be necessary at high penetrations."
  - **Not necessarily**, but they may help to reduce system costs.

Conclusions

- From a **dual perspective**, market value decline is **guaranteed** if generators pushed in with subsidy/quotas
- Can construct reasonable market designs with CO_2 pricing that show **no market value decline** as the penetration for wind and solar rises (even up to 100%)
- To preserve market value of wind and solar, choose to **value their low emissions**
- In markets that rely on subsidies alone, market value decline **does not necessarily indicate problems** (i.e. can still be close to system optimum for CO_2 reduction)
- Can **combine** CO_2 pricing with support to maintain market value & reduce investor risk
- Given its policy-dependence, **use market value with caution** (like LCOE) & **focus on system cost** instead

Further reading: Brown & Reichenberg, "Decreasing market value of variable renewables can be avoided by policy action," Energy Economics (2021), doi:10.1016/j.eneco.2021.105354.

Before 2016 market value declines with rising subsidies; after 2016 it rises as CO_2 prices rise.

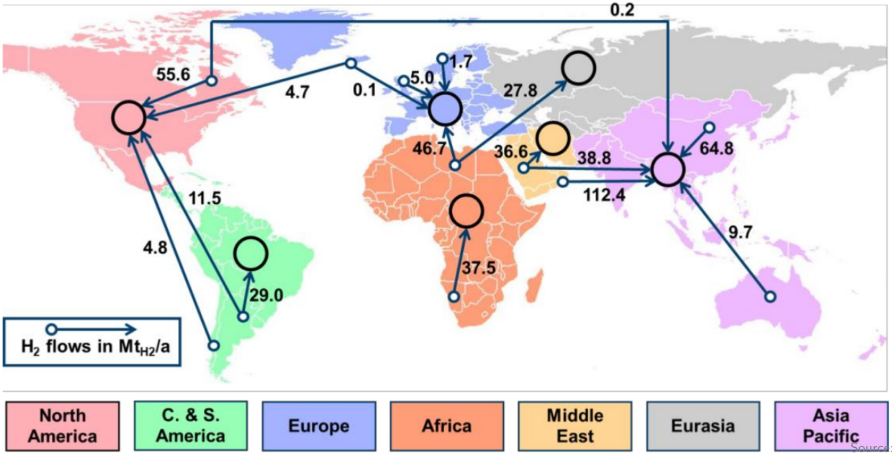


Source: Brown & Reichenberg (2021)

Markets for Green Fuels

Worldwide trade in synthetic fuels

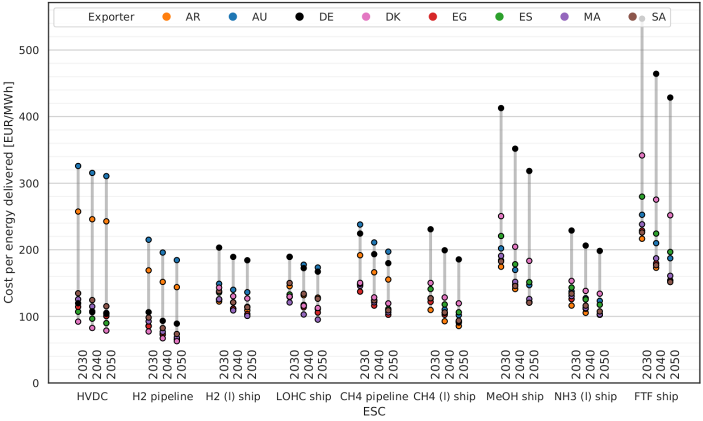
Today fossil fuels are traded across the globe. Electrolytic-hydrogen-based synthetic fuels (e.g. hydrogen, ammonia, methane, liquid hydrocarbons and methanol) could also be piped/shipped worldwide. Possible future scenario for hydrogen trade from Helmholtz colleagues at FZJ IEK-3:

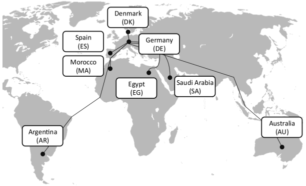


Source: Heuser et al, 2020

Synthetic fuels from outside Europe?

Green hydrogen with pipeline transport costs around ∼ 80 €/MWh in model. Shipping green hydrogen from **outside Europe** in liquid, LOHC or NH_3 form may not compete on cost (depends e.g. on WACC), but scarce land in Europe may still drive adoption.





Source: Hampp et al, 2021

German H2Global scheme

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The German H2Global scheme provides support for the production of renewable hydrogen in non-EU countries, to be imported and sold in the EU.

It makes available €900 million over 10 years to cover the difference between production costs and what consumers are willing to pay.

This difference is determined by a double auction: producers bids for **hydrogen purchase agreements (HPA)** that run for 10 years, providing investment security, while consumers bid for hydrogen service agreements (HSA) of duration one year.

H2Global was **approved** by the European Commission to comply with EU state aid rules in December 2021. It was topped up from €900 million to €4 billion in 2022. See **H2Global website**.

The EU will also start a €3 billion **European Hydrogen Bank** in 2023.

Source: **ArgusMedia, 2021**

Global Outlook

Could end up in a situation with following characteristics:

- Most electricity is **sourced locally** from variable wind and solar
- Backup is provided either by **electricity storage** or **imported hydrogen-based fuels**
- Many demand sectors are **directly electrified** (e.g. heat pumps in buildings, electric vehicles in transport) or with green-hydrogen-based fuels (e.g. industry)
- Hydrogen-based liquid fuels (ammonia, methanol, diesel/kerosene) and materials (direct-reduced iron) are **traded globally**
- Since wind and solar can be found everywhere, less market concentration than fossil fuels $\Rightarrow$ **geopolitical reordering** (different countries have relevant resources, market power of producers is weakened, shift to more capex-intensive energy sector)