

Europe's Energy Security in the Hydrogen Era

TAI 2023 - Ange Blanchard

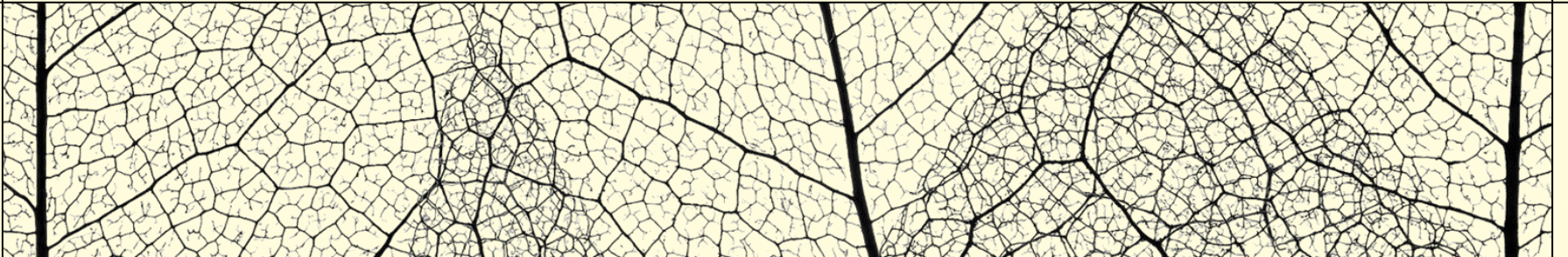


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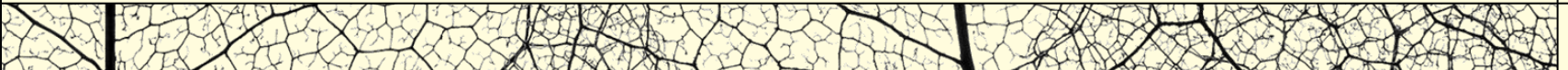
Numerical modelling

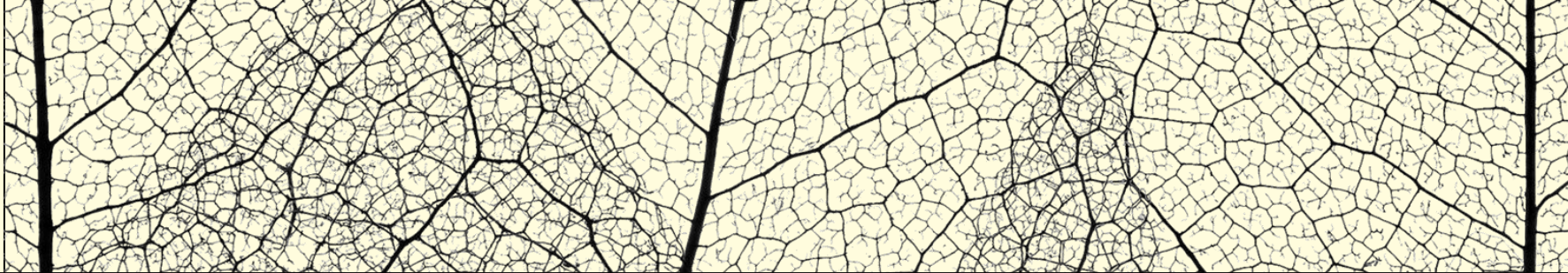
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What best option for Hydrogen security of supply?





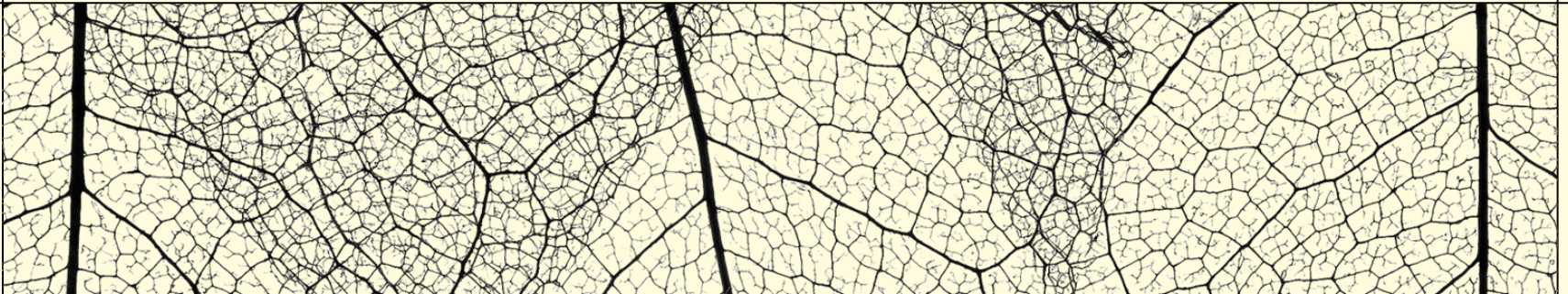
01

Motivation

The hot potato of *energy security*

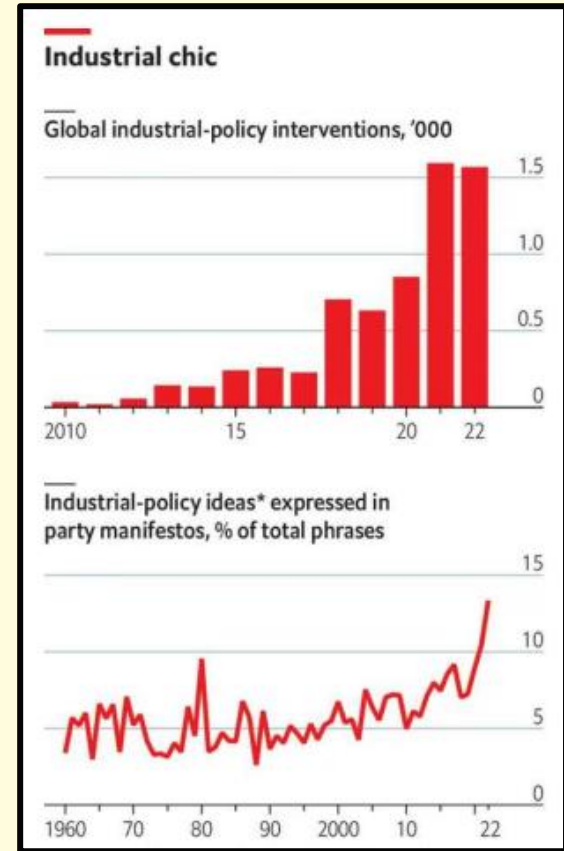
“EU will be the first major economy to set out a *strategy* on *economic security*”

— Ursula von der Leyen



The tide is turning for globalisation

- Modern crises/tensions: Subprimes (2008), USA/China trade war (2018-), Covid (2020), Ukraine (2022-)
- Response: Inflation Reduction Act (USA), Green Deal Industrial Plan (EU)
- The EU wants to produce 40% of key technologies needed for its green transition



Governments across the world are discovering « homeland economics », from The Economist, Oct 2nd 2023

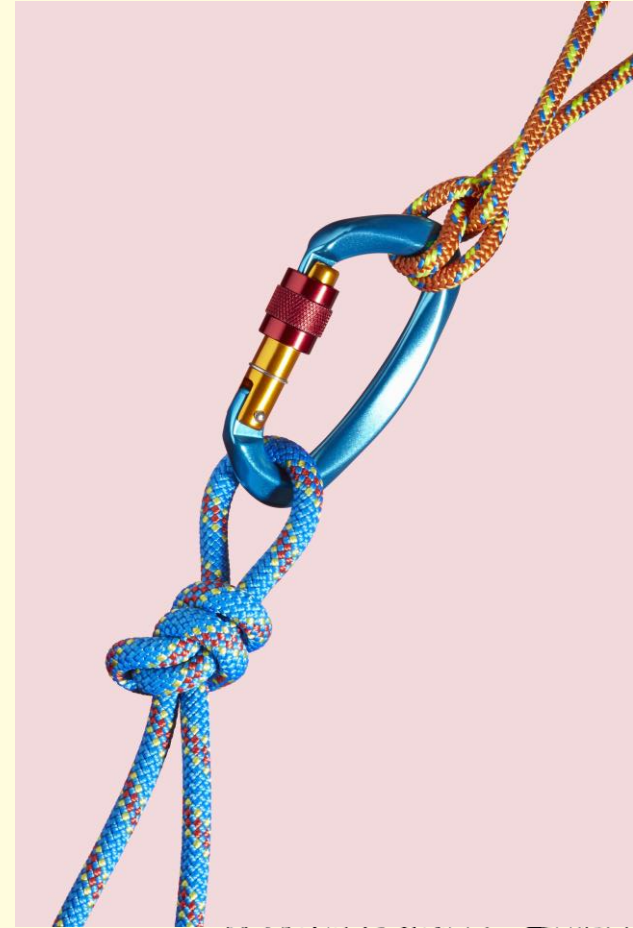
Hydrogen: EU growing ambition



- EU Hydrogen Strategy (2020), Fit-for-55 (2021): **40GW** electrolysis by 2030
- REPowerEU (2022): **>60GW** by 2030
- **NOT SUFFICIENT: 50/50** import vs local production: **Import will be needed!**

Question

How to ensure the security of supply for the hydrogen economy?



Literature

The oil-crisis literature

- Balas (1979)
- Teisberg (1981)
- Chao & Manne (1983)
- Oren & Wan (1986)
- ...

Strategic gas storage

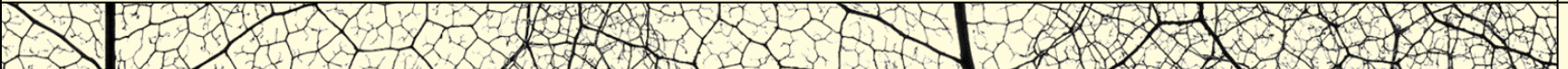
- Stern (2004)
- Weisser (2007)
- Creti & Villeneuve (2014)
- Sesini (2021)
- ...

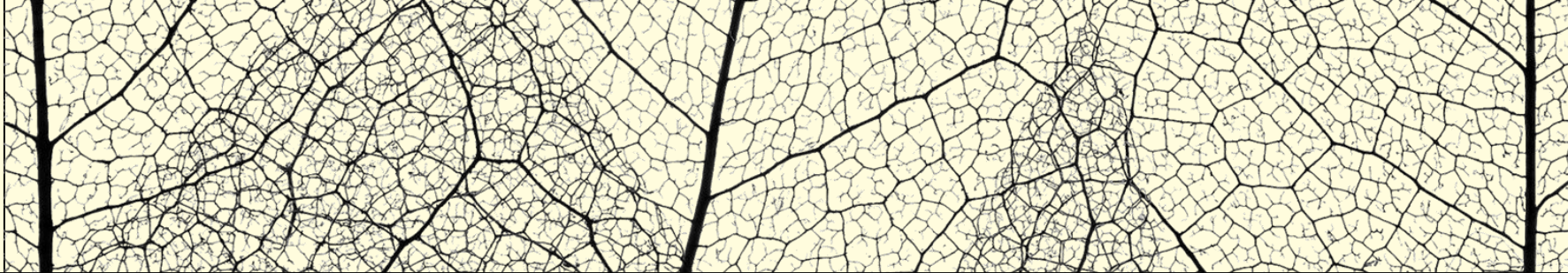
Hydrogen systems

- Bunger (2016)
- Michalski (2017)
- Gabrielli (2020)
- ...

Underground Hydrogen Storage

- Taylor (1986)
- Le Duigou (2017)
- Tarkowski (2019)
- ...



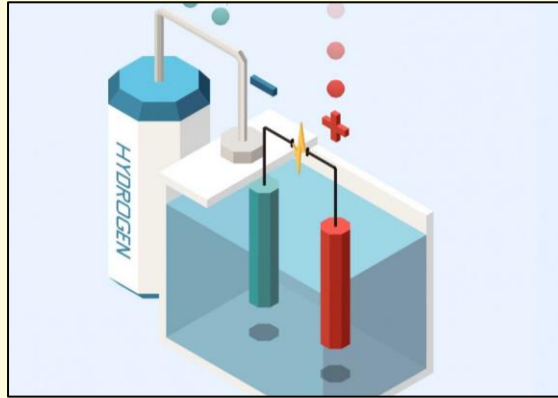


02

Analytical intuitions

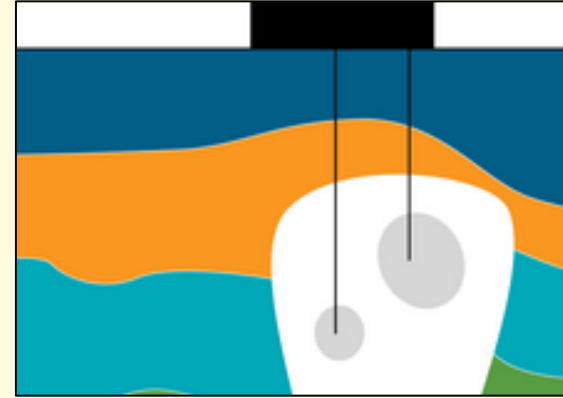
A simple model to grasp the *core idea*

Two options



Electrolysis

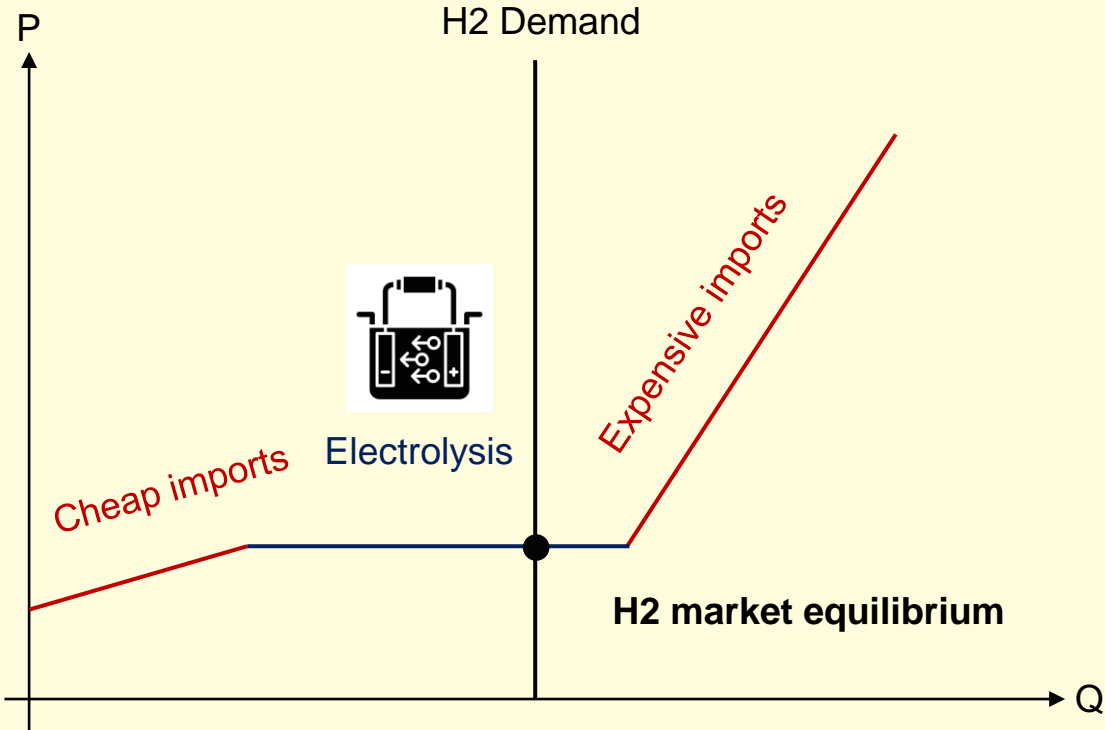
A premium on electrolysis capacity to hedge against import disruptions



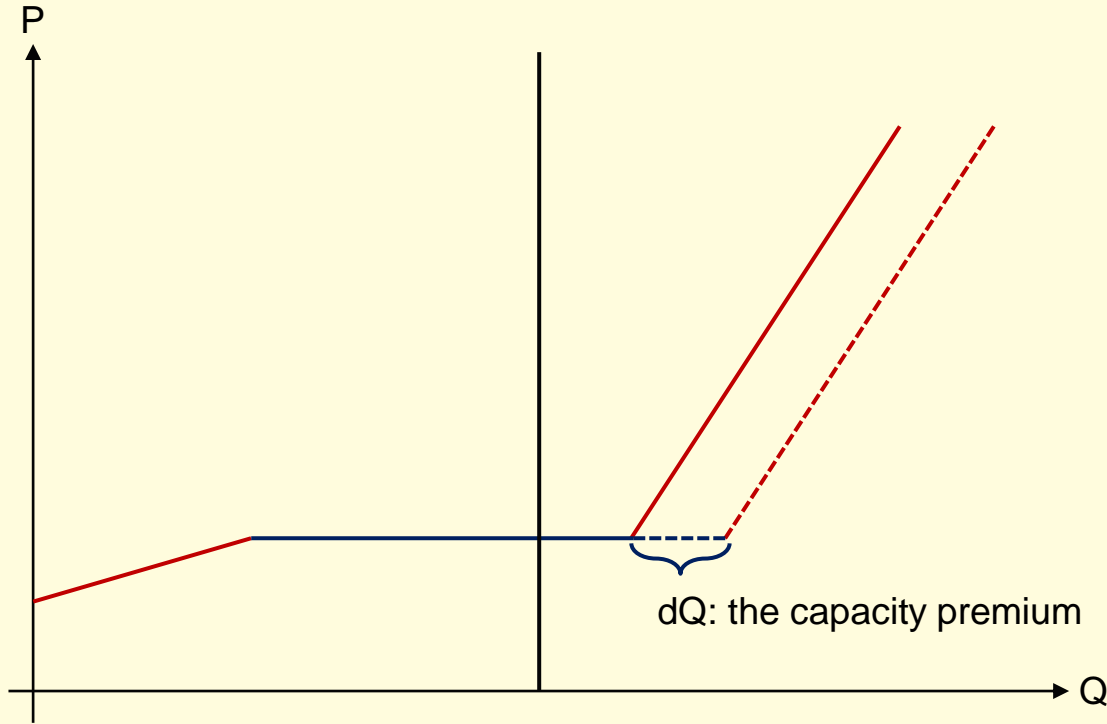
Storage (UHS)

A premium on hydrogen storage, acting as a strategic reserve

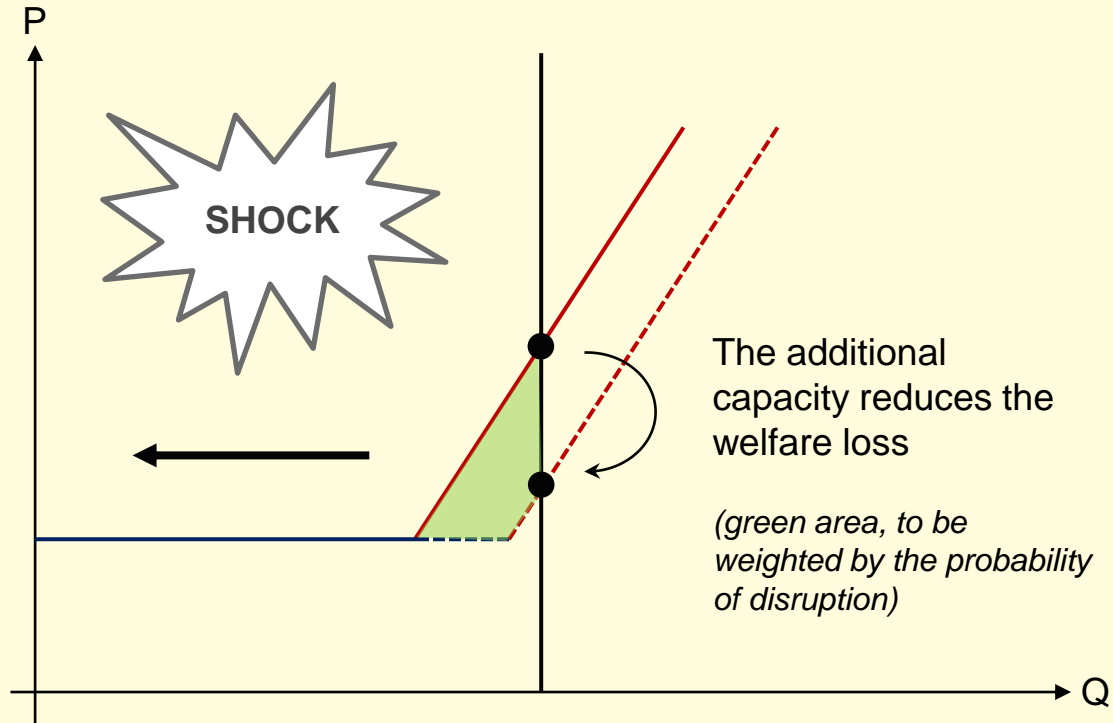
A premium on Electrolysis capacity?



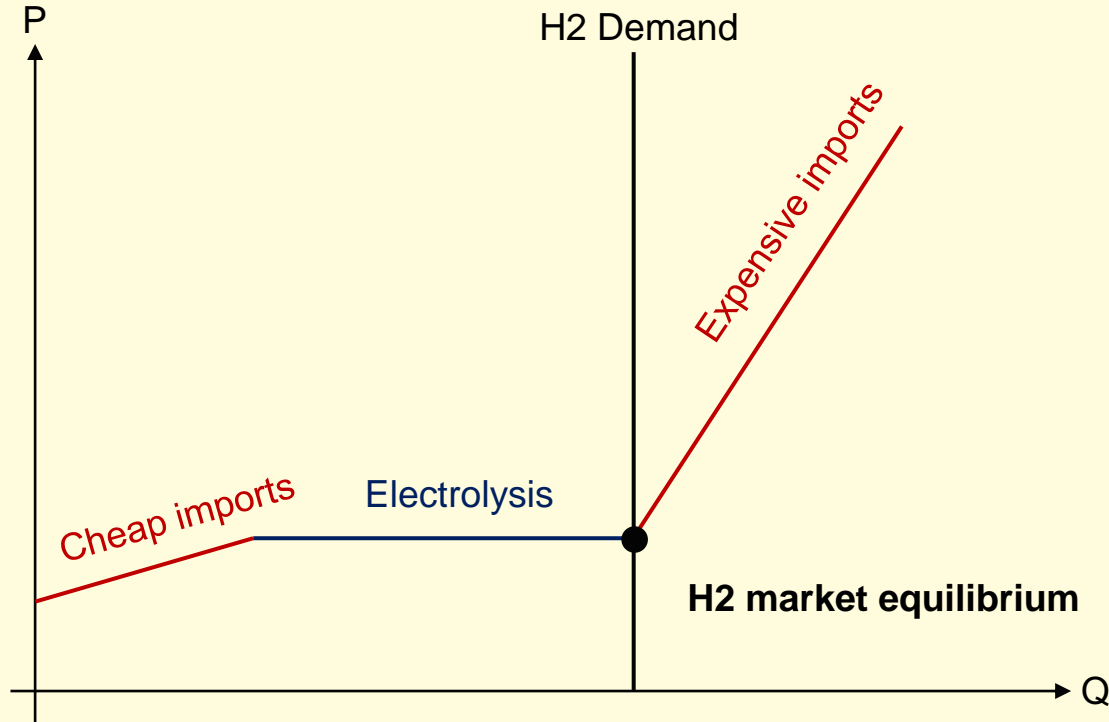
A premium on Electrolysis capacity?



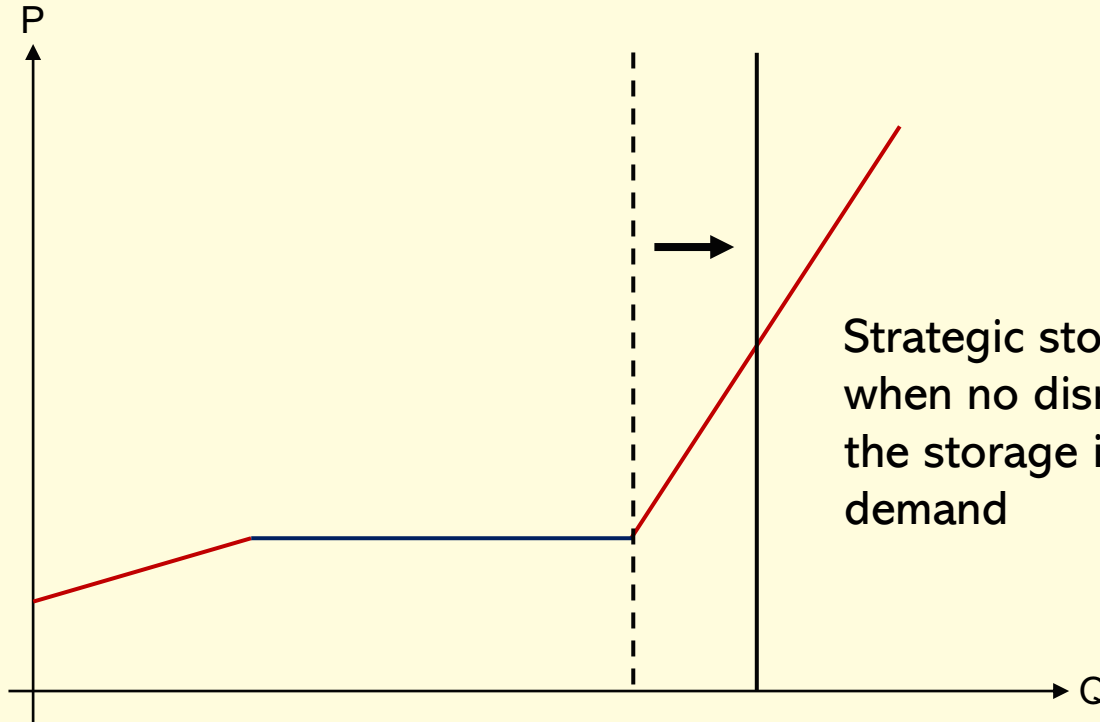
A premium on Electrolysis capacity?



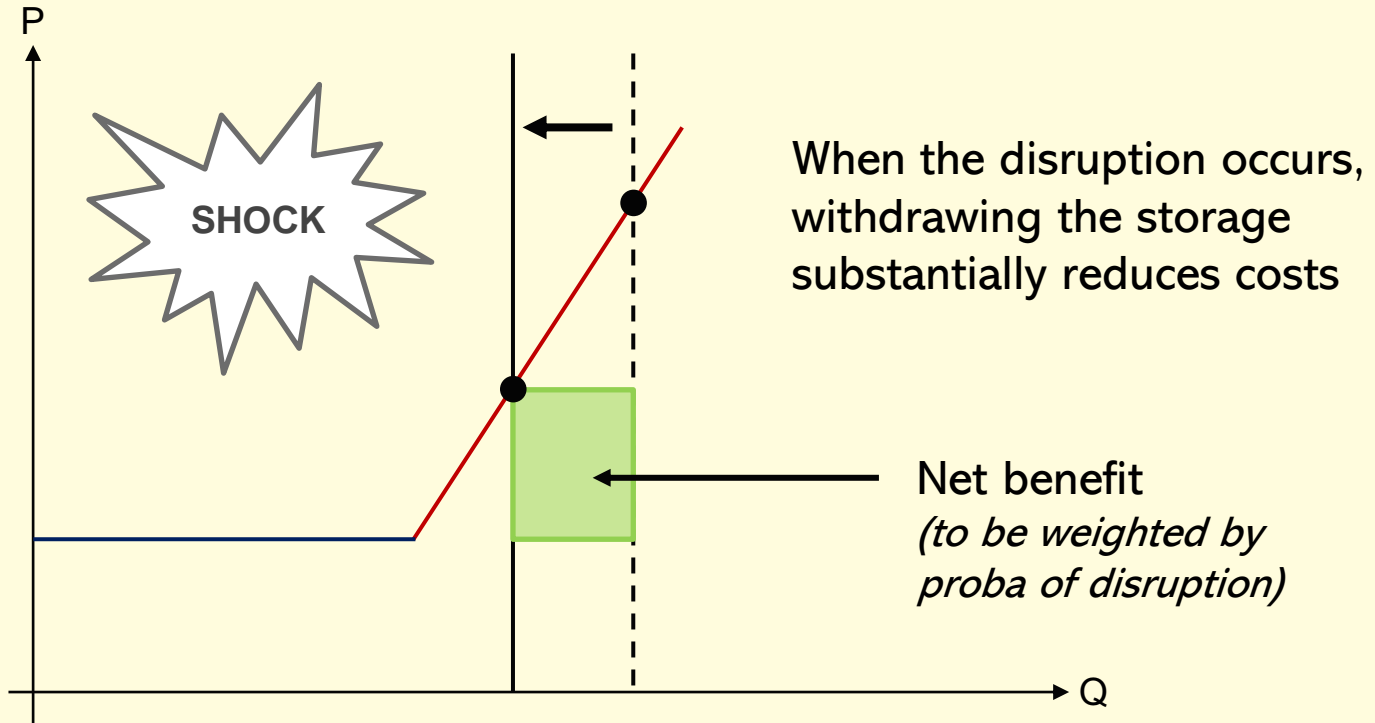
A premium on UHS capacity?



A premium on UHS capacity?



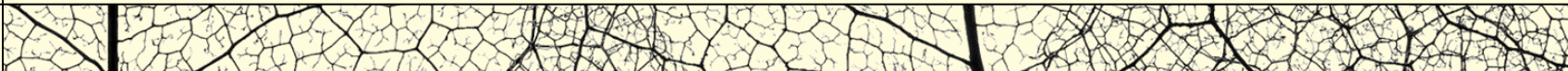
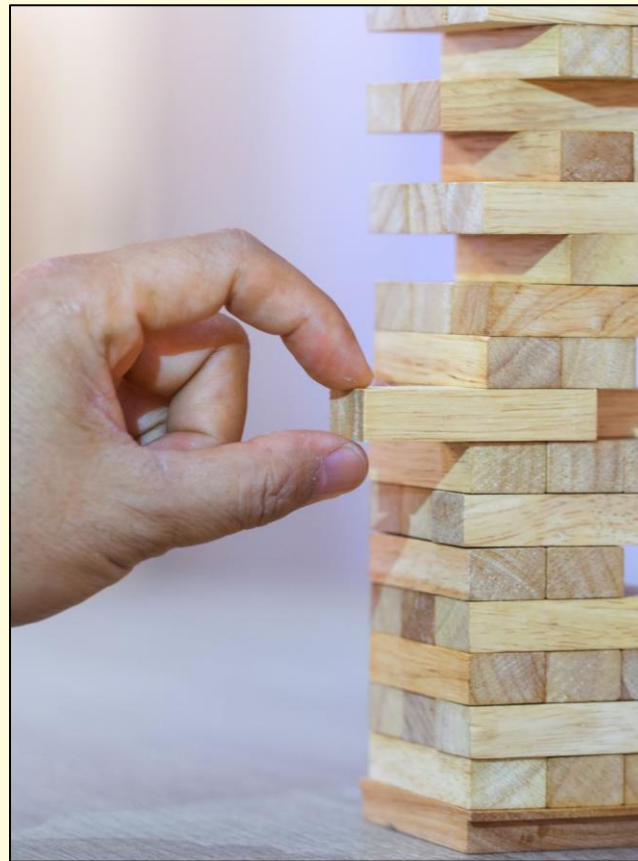
A premium on UHS capacity?





What option to choose?

We can expect complementarity of both, but to what extent? How to hedge optimally?





Limits of the analytical approach

The electrolysis marginal cost is in fact, endogenous

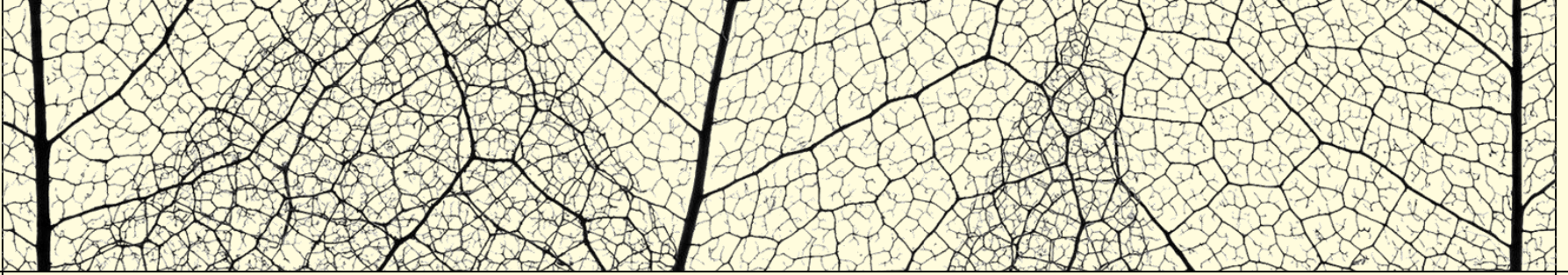
Depending on the power mix, the relevance of electrolysis vs UHS changes

A multi-stage stochastic problem

Renewable production and H2 disruption are both unknown

The disrupted state duration is uncertain

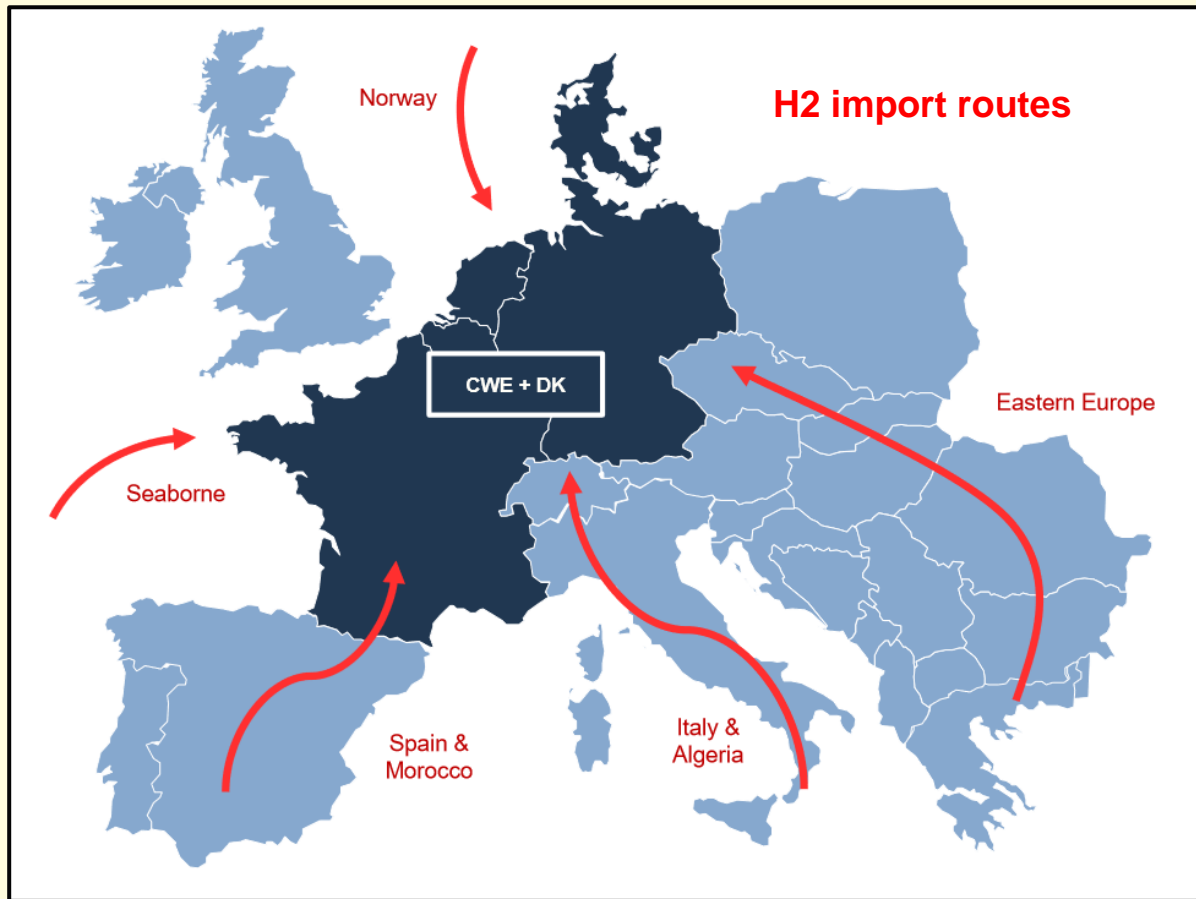
The temporal trade-off for storing hydrogen depends on it



03

Numerical model

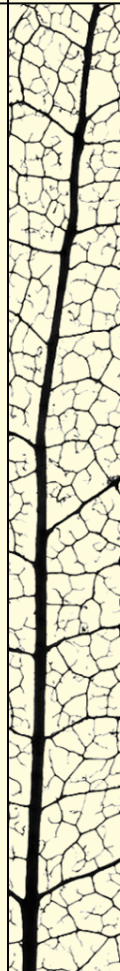
A more realistic model and application to Western Europe



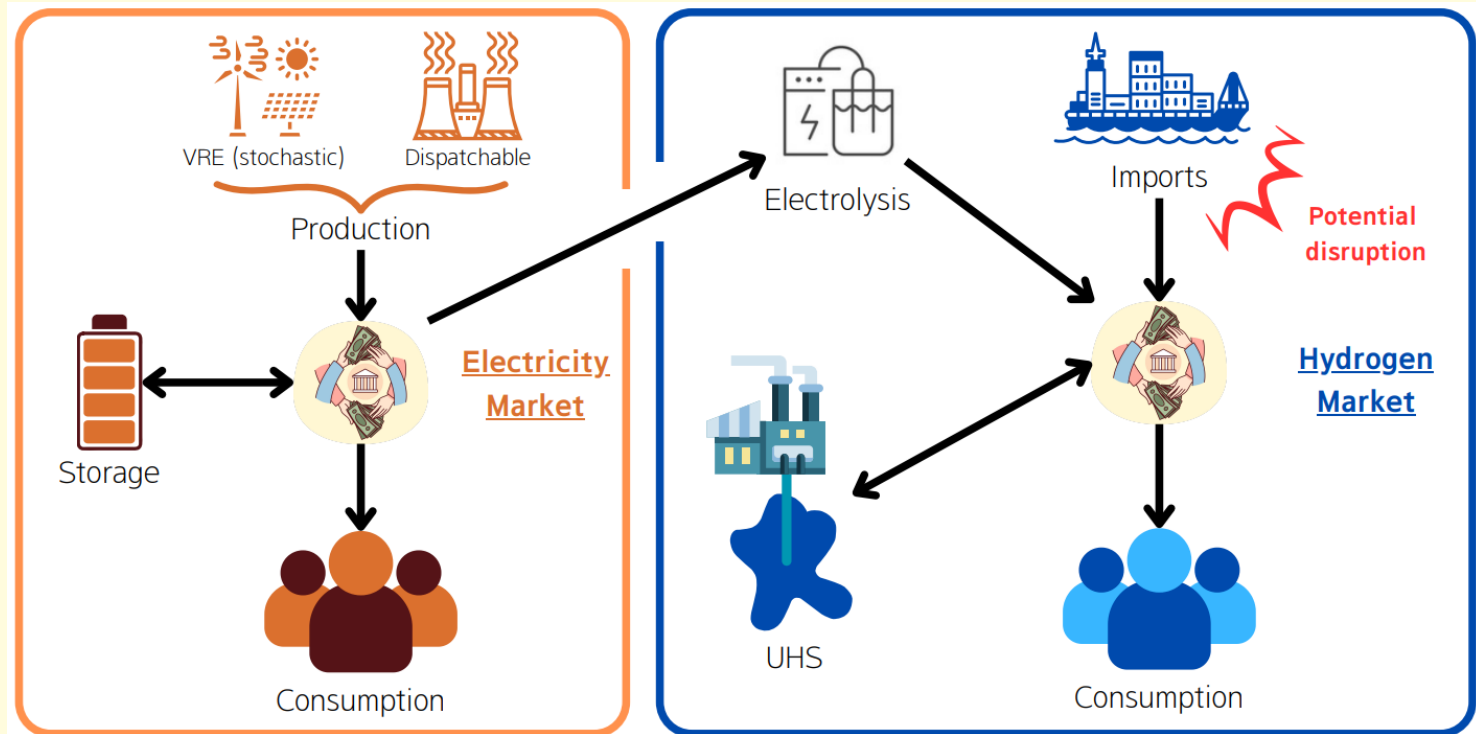
Central Western Europe + Denmark in 2035.

Most important region for Hydrogen (industries, density, pipeline network for H2...)

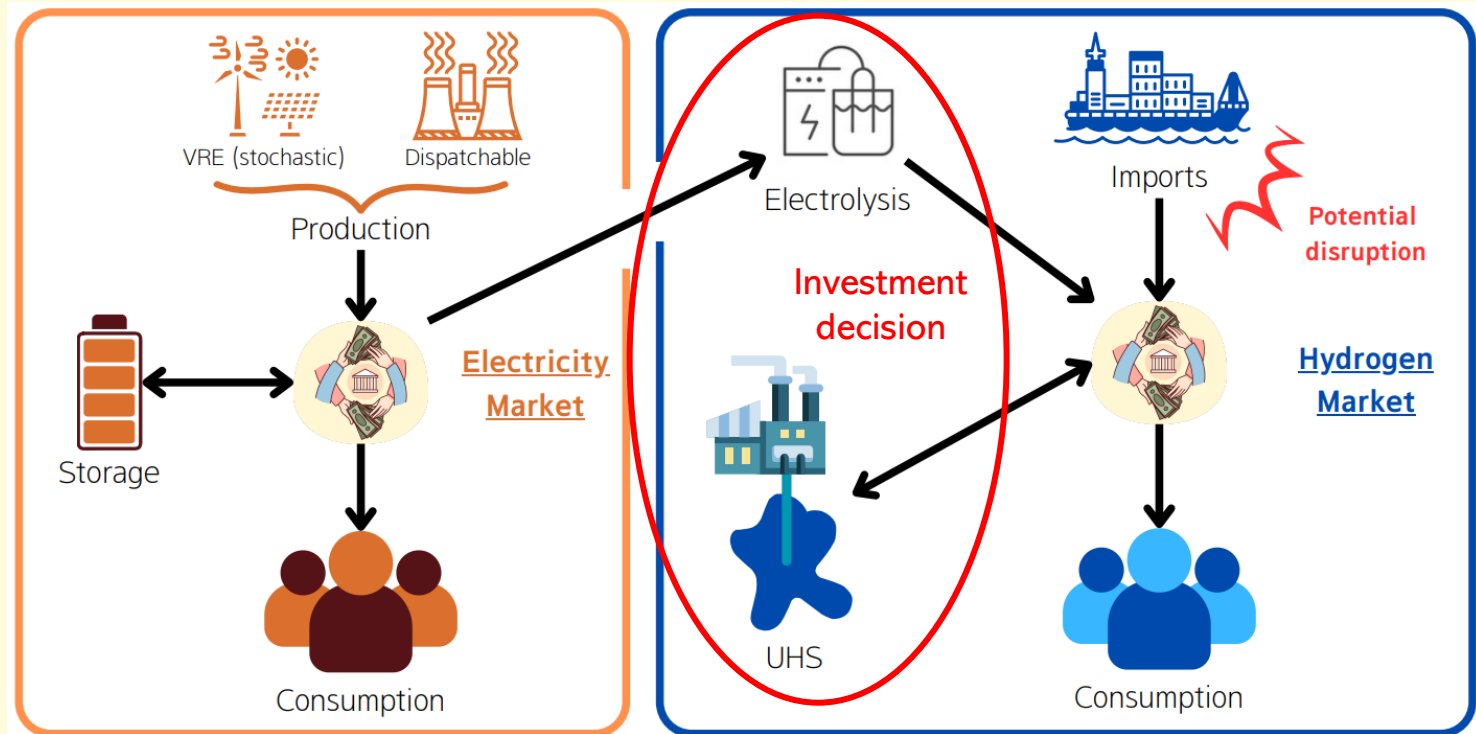
Full year of 2190 time steps (6 per day)



Overview



Overview



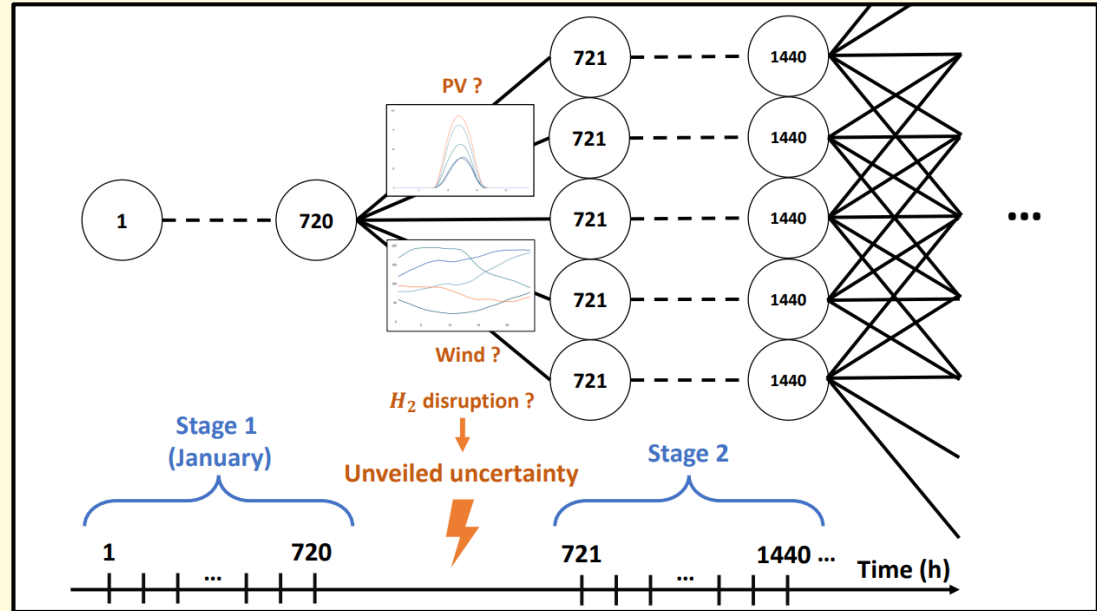
A Stochastic Dynamic Programming framework

Random variables:

- VRE production
- H2 disruption

Each month, the uncertainty is unveiled.

Trade-off between current and expected future costs



Hydrogen import function

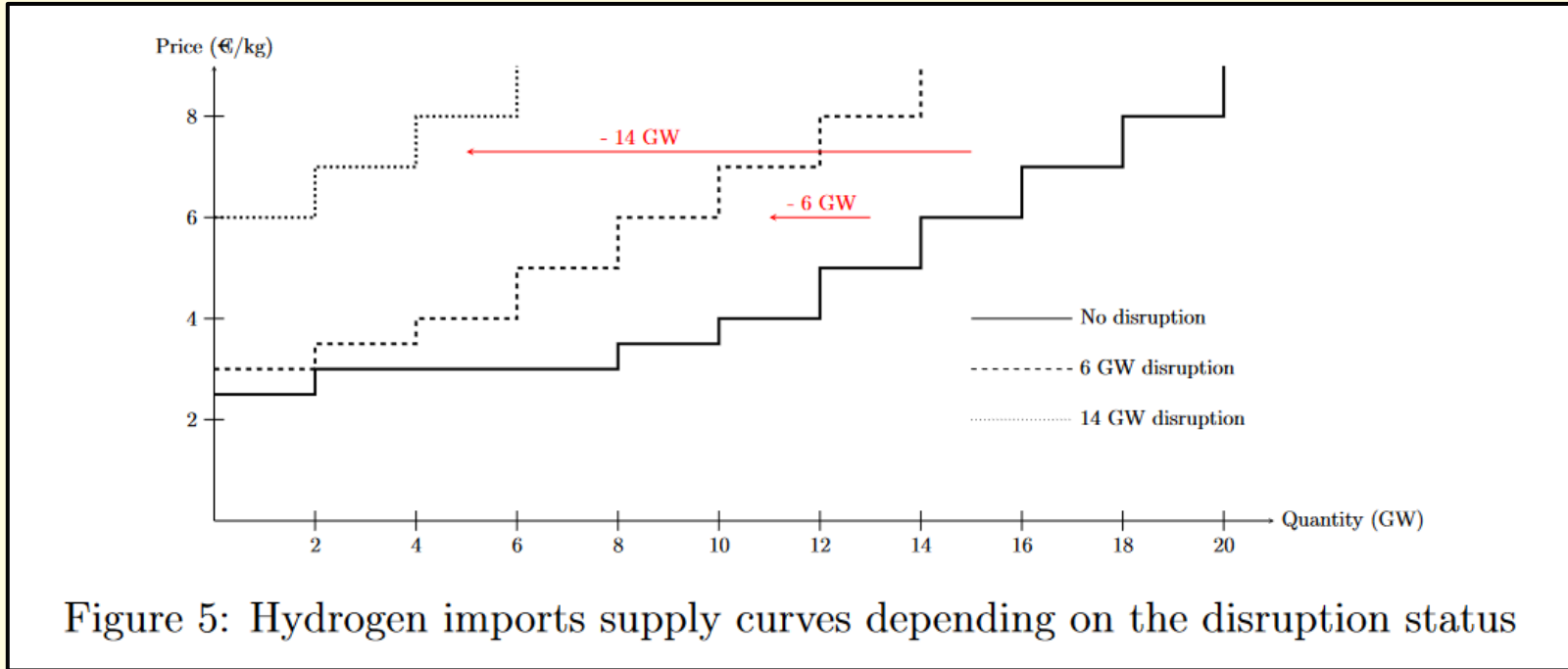


Figure 5: Hydrogen imports supply curves depending on the disruption status

H2 disruption: A Markov-Chain approach

Type of disruption, Month m	Type of disruption, Month m+1		
	Normal	6 GW	14 GW
Normal	0.95	0.03	0.02
6 GW	0.25	0.70	0.05
14 GW	0.10	0.20	0.70
Long-run stationary probabilities	0.80	0.13	0.07

Table 1: Base Case Disruption Probability Transition Matrix

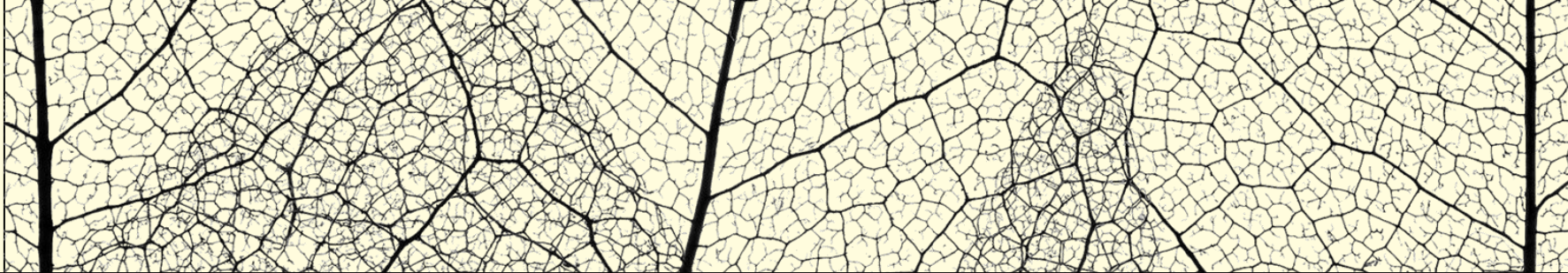
The alternative case
is **3 times** more
pessimistic than the
Base Case

3 states of the world:

- Normal (no disruption)
- 6 GW disruption
- 14 GW disruption

Type of disruption, Month m	Type of disruption, Month m+1		
	Normal	6 GW	14 GW
Normal	0.85	0.09	0.06
6 GW	0.25	0.7	0.05
14 GW	0.1	0.2	0.7
Long-run stationary probabilities	0.57	0.28	0.16

Table 2: Pessimistic Alternative Disruption Probability Transition Matrix

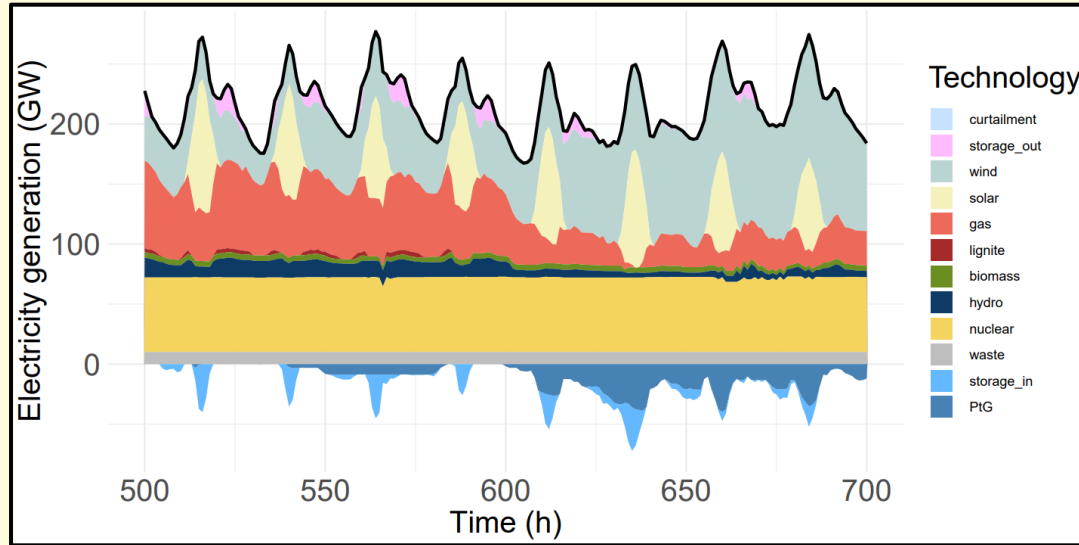


04

Results

What best option for Hydrogen *security of supply*?

A typical week of electricity dispatch



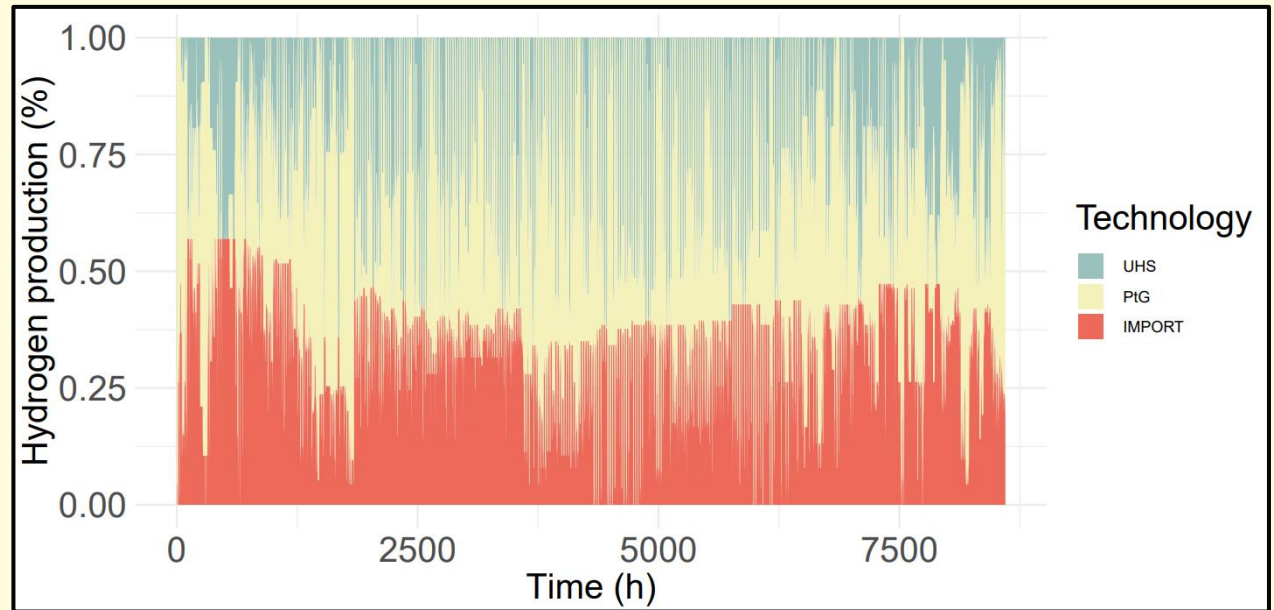
We find typical outcomes:

- Storage used for evening peaks
- Electrolysis used when important VRE production

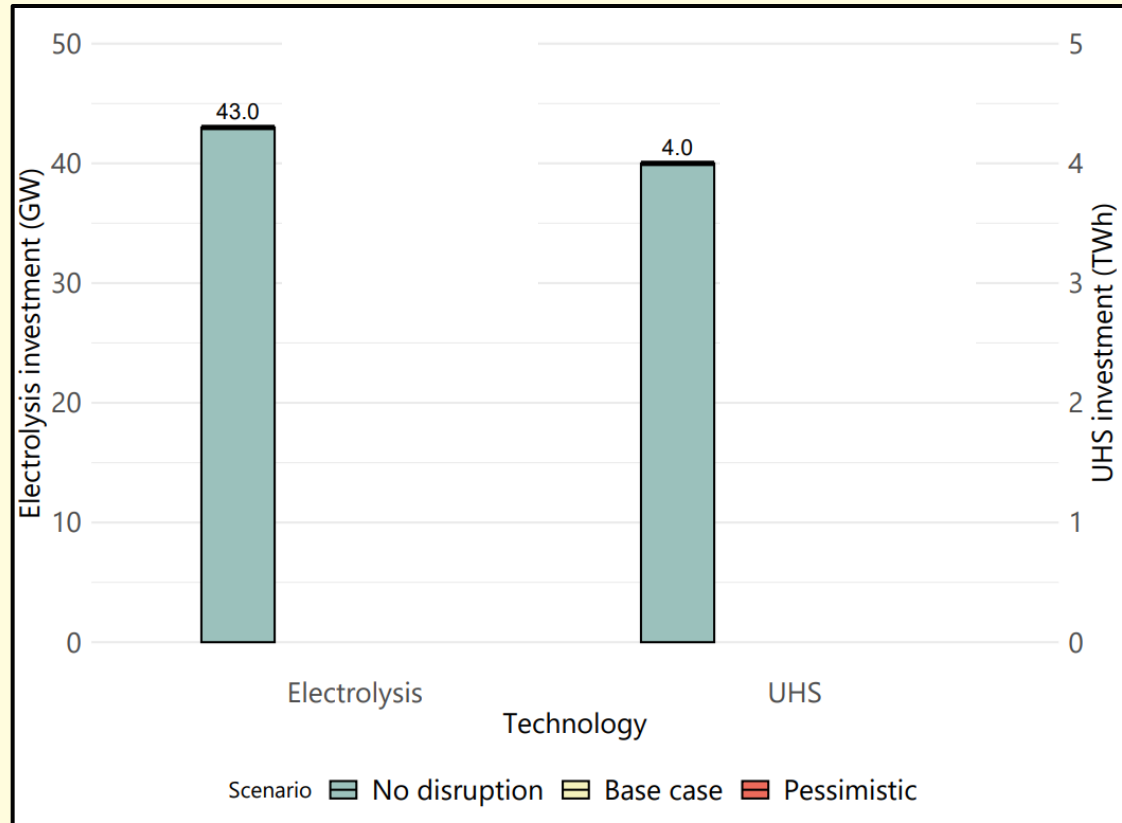
The hydrogen supply

45% electrolysis vs. 55% imports

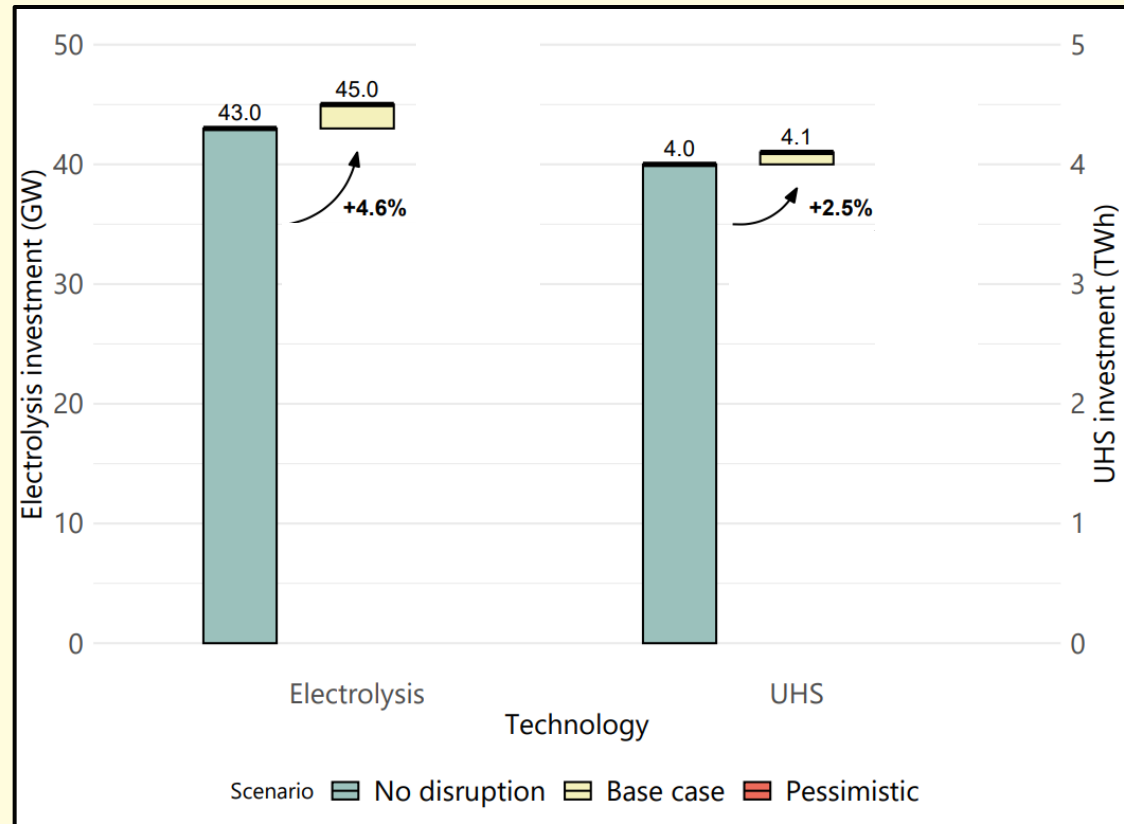
More local
production
(*electrolysis,*
denoted as PtG)
during
summer



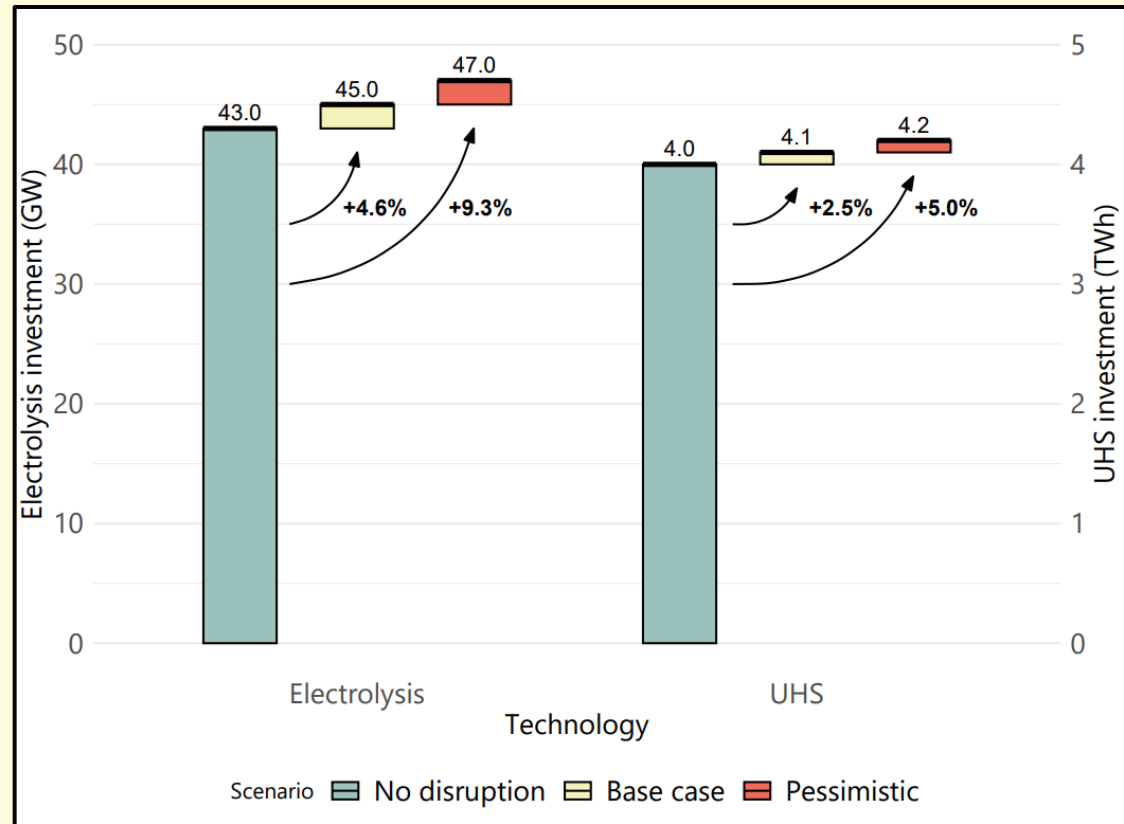
Investment in Electrolysis & UHS



Investment in Electrolysis & UHS



Investment in Electrolysis & UHS



+9.3%

In Electrolysis capacity

+5%

In UHS capacity

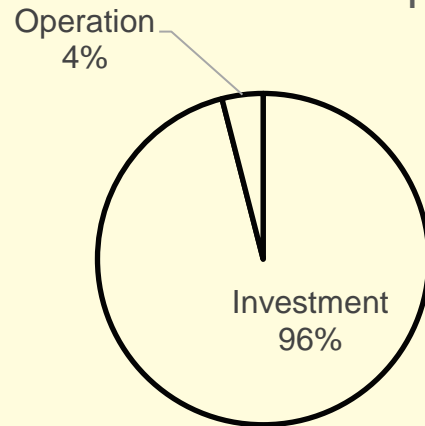
Complementarity

Electrolysis and UHS complement each other,
but **Electrolysis dominates**



Disentangling Investment & Operation

Cost-benefit of Investment & Operation respectively (average on 100 simulations)

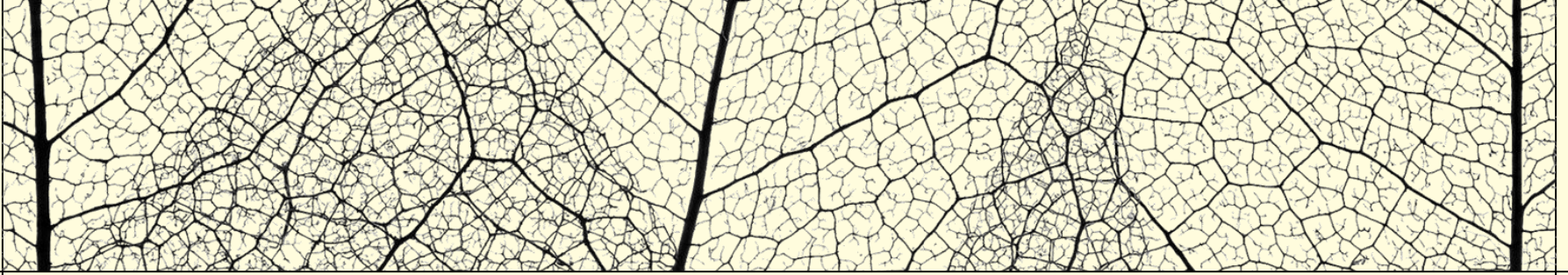


What is most important?

- Investing in a premium?
- Operating this premium having in mind the possible disruption?

Even if managed Business as usual, **96% of the benefits will be saved** in average.

Commercial and strategic values overlap



Conclusion

Principal insights

In a nutshell

01

A stochastic dynamic modelling

Endogenous modelling of electrolysis with possible H2 import disruption

03

Electrolysis is more suited for strategic concerns

Twice the relative level of investment in electrolysis than UHS for a given risk

02

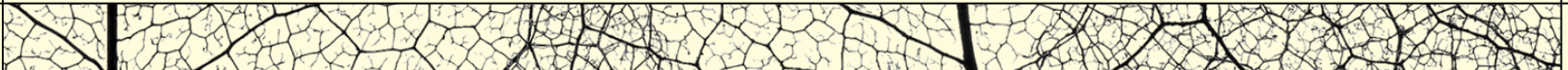
UHS & Electrolysis are complementary

Both for the commercial and strategic concerns

04

Investment is key

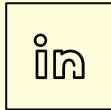
Almost all the hedging value is from investment, not operation



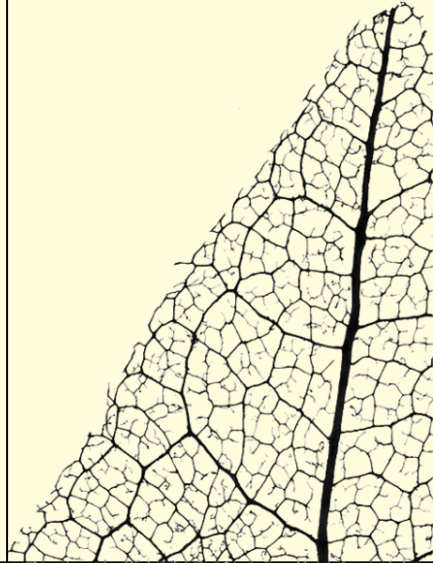
Thanks!

Do you have any questions?

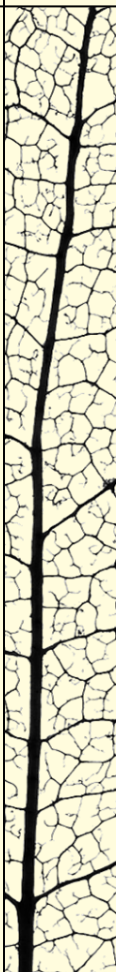
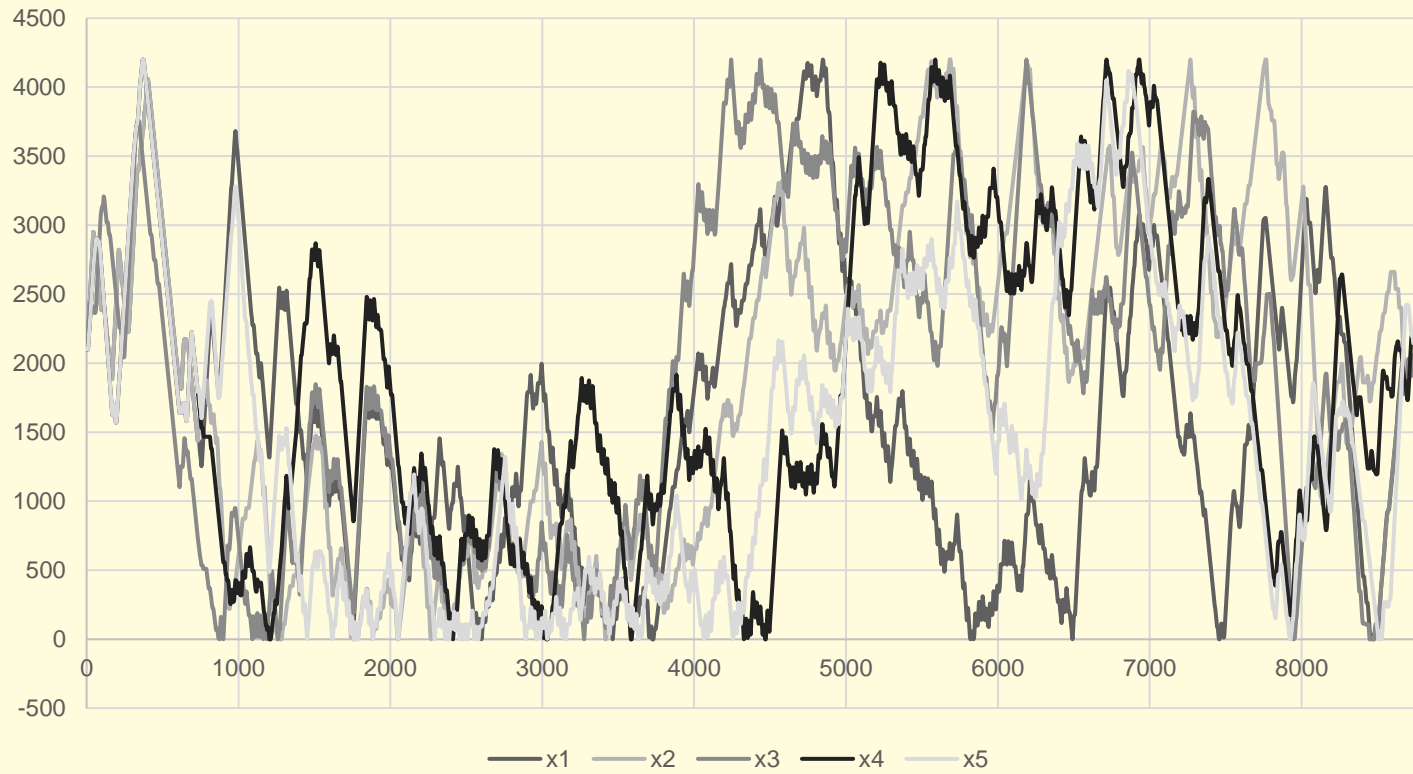
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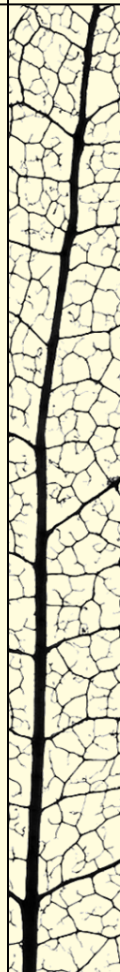


UHS filling levels over the year for 5 simulations



Technology	Installed Capacity (GW)					MPC (€/MWh)
	BeNeLux	DE	FR	DK	TOTAL	
Waste	0.8	5.9	2.5	2	11	2
RoR	0.6	4.1	11.7	0	16	0
Hydro	0	0	9	0	9	0
Biomass	1.8	1.4	0.5	1.4	5	69
CCGT/CHP	21.1	36.4	9.2	1	68	89-115
OCGT	10.2	49.9	0.6	0	61	122-179
Nuclear	3	0	60	0	63	13
OCOT	1.3	2.2	3.9	0	7	242
Lignite	0	6.4	0	0	6.4	135
Solar PV	38.3	220	48.3	4	311	0
Wind (Offshore)	18.9	40	7.4	13	79	0
Wind (Onshore)	13.8	115	47.8	5.5	182	0
PHS	2.1	9.8	5.5	0	17.4	0
Battery	10.7	33.8	18.7	3.5	66.7	0

Table 3: Electricity system assumptions ¹



Technology	CAPEX	OPEX	Disc. factor	Total inv. cost (annualised)
Electrolysis	700 €/kW	3%	0.08	125 €/kW
UHS	380 €/MWh	4%	0.08	50 €/MWh

Table 4: Investment costs for UHS and electrolysis

Variable	Value
Investment in electrolysers	43 GW
Investment in UHS	3.9 TWh
Electrolysers' load factor	0.34
H2 imports (Total)	63.7 TWh
Maximum H2 import	13 GW
Electricity curtailment (Total)	19.7 TWh
Electricity price (Average)	71€/MWh
Hydrogen price (Average)	3.5€/kg

Table 5: Key results on power and hydrogen production

