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Technologically constrained EU mitigation pathways in the light of geopolitical and technological risks

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This study has been submitted at the Energy Strategy Reviews (*under Review*)

Overview

Title:	A multi-model assessment of technological constraints on Europe's energy transition
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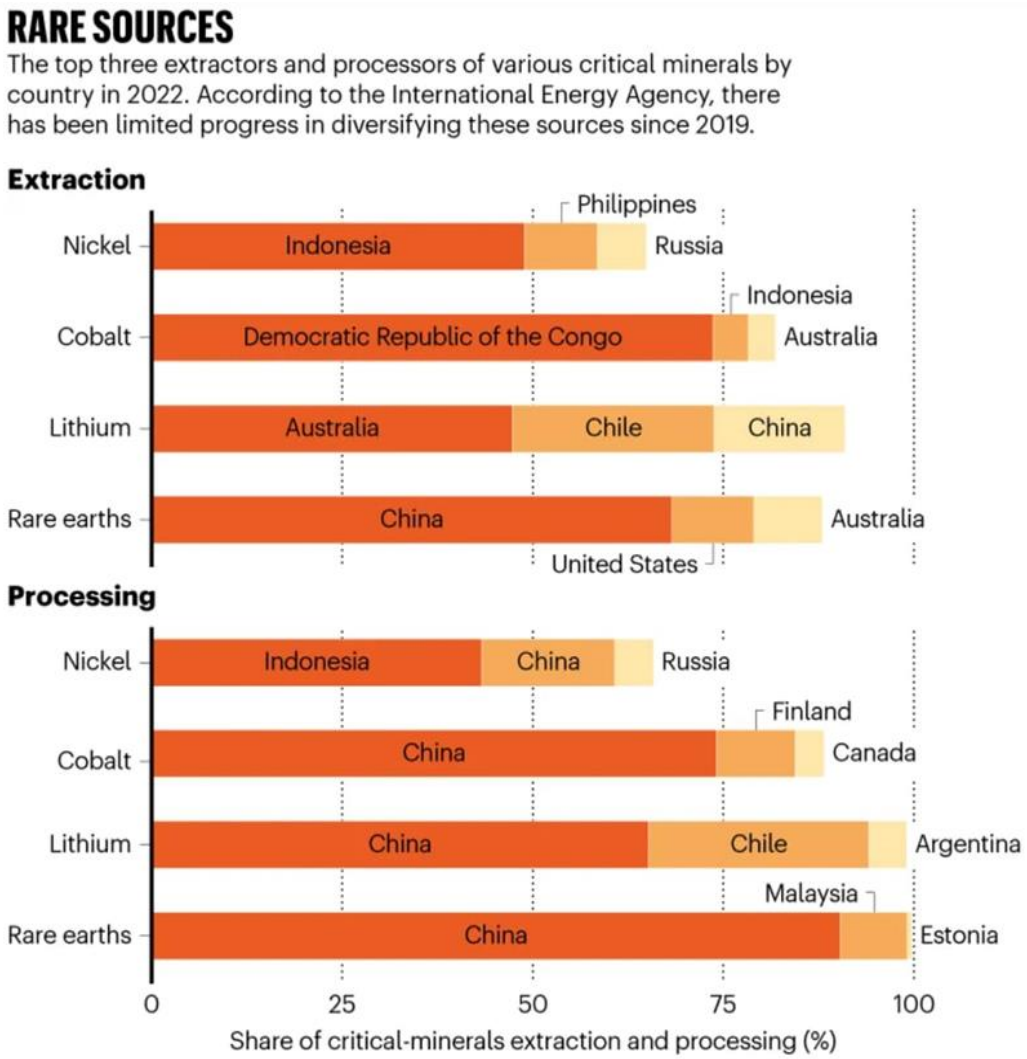
Highlights	• We simulate impacts of trade/geopolitical and technological constraints on EU net-zero • Limited uptake of renewables intensifies reliance on gas, slowing the EU's transition • Biomass unavailability challenges the bloc's energy security, increasing fuel imports Constraints on CCS development hamper biomass use & enhance the role of nuclear • Our modelling exercise highlights the need for resilient energy system transformation
Keywords	European Union; Integrated Assessment Model; Technology; Climate Policy; Geopolitics; Trade

Importance of the study



EU's net-zero pathway depends on few critical technologies

- Renewables, batteries, biomass, CCS

These technologies rely on global supply chains

- Vulnerable to geopolitical tensions, trade restrictions, and material shortages
- (Ukraine war, material concentration in China—could limit access to these technologies)

Most existing studies assume smooth technology deployment

- They do not test what happens when disruptions occur

If key technologies are delayed or constrained

- The EU may face higher emissions, energy insecurity, and rising costs

Modelling tools

Model Name	Model Type	Solution Horizon	Tech choice
GCAM	Partial equilibrium	Recursive-dynamic (myopic)	Logit choice
PROMETHEUS	Energy-system	Recursive-dynamic (myopic)	Logit choice
TIAM	Partial equilibrium	Intertemporal optimisation (perfect foresight)	Winner takes all
MARIO	Input – Output	Comparative-static simulation	-

Main research questions

- *What are the implications of limiting access to critical low-carbon technologies (renewables & batteries, biomass & CCS) on EU's ability to achieve its 2030 and 2050 climate targets?*
- *How would these technological constraints affect the EU's energy mix, fossil fuel dependence and overall system costs?*
- *Which sectors are most vulnerable to constraints in each technology, and at what points in time?*

Methodology: Model soft-link and Iteration

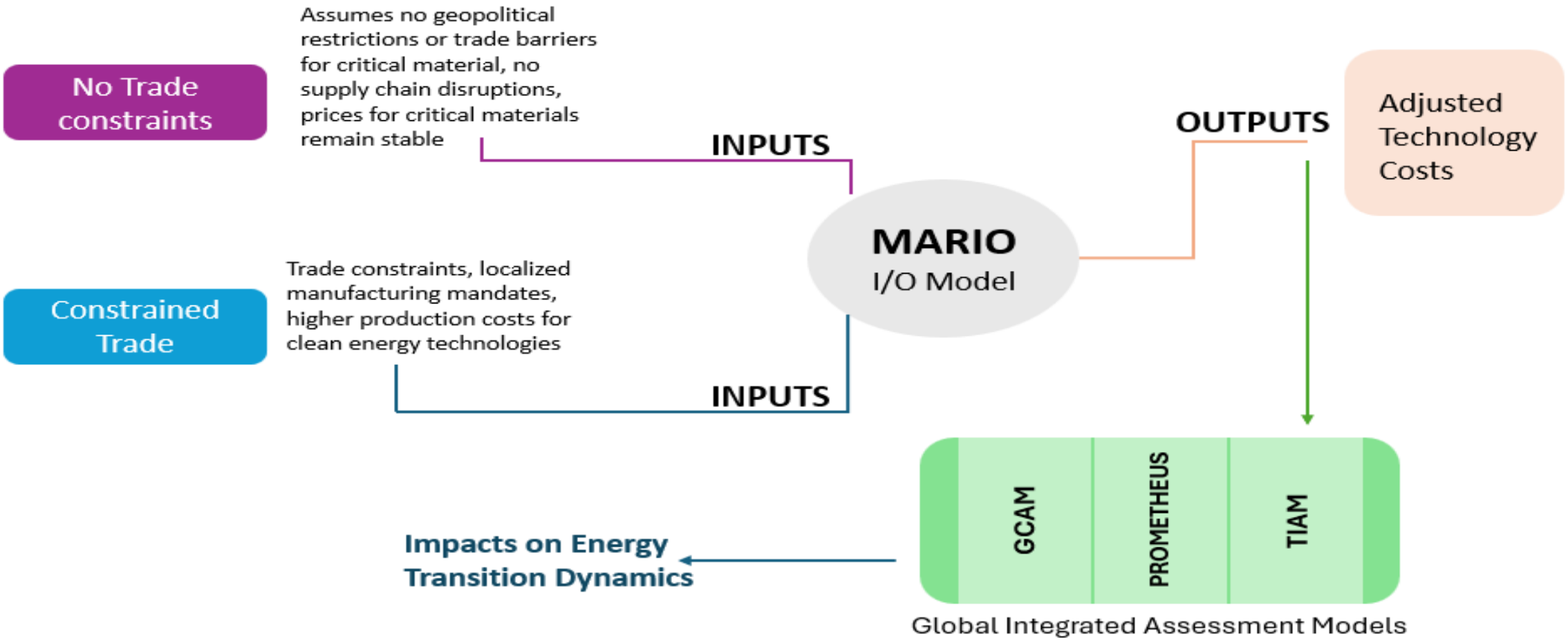


***Figure 1**. Methodological framework for examining the effect of geopolitical factors impeding the diffusion of RES and energy storage in the EU: integration of MARIO projections with the global IAMs to quantify geopolitical and supply-chain impacts on the energy transition.*

Scenarios

Scenario	Short description
NDC-LTT	Implementation of the NDC targets for 2030 and long-term targets for 2050 (e.g., net zero by 2050 in the EU)
NDC-LTT-LimRES	Limited expansion of RES and energy storage, including batteries, due to material unavailability and geopolitical tensions: **cleantech costs increase** due to import constraints in materials and clean technologies, as quantified with MARIO, and act as moderating factors on the growth of RES and battery.
NDC-LTT-LimBIO	Restricted use of biomass for energy purposes in the EU, with a cap set at 5-6 EJ by 2050.
NDC-LTT-LimCCS	Restricted deployment of CCS in the EU, with a cap set at 10-20 Mt CO_2 by 2050.

Attainability of net zero by 2050 in light of technology constraints

- **Clean tech constraints raise emissions**: Limiting the scale-up of renewables, batteries, or biomass significantly increases EU CO_2 emissions, especially post-2030, due to higher reliance on fossil fuels.
- **Biomass and CCS are critical**: Constraints on biomass and CCS lead to the largest emission spikes, as they are hard to replace in industry, transport, and for CDR.

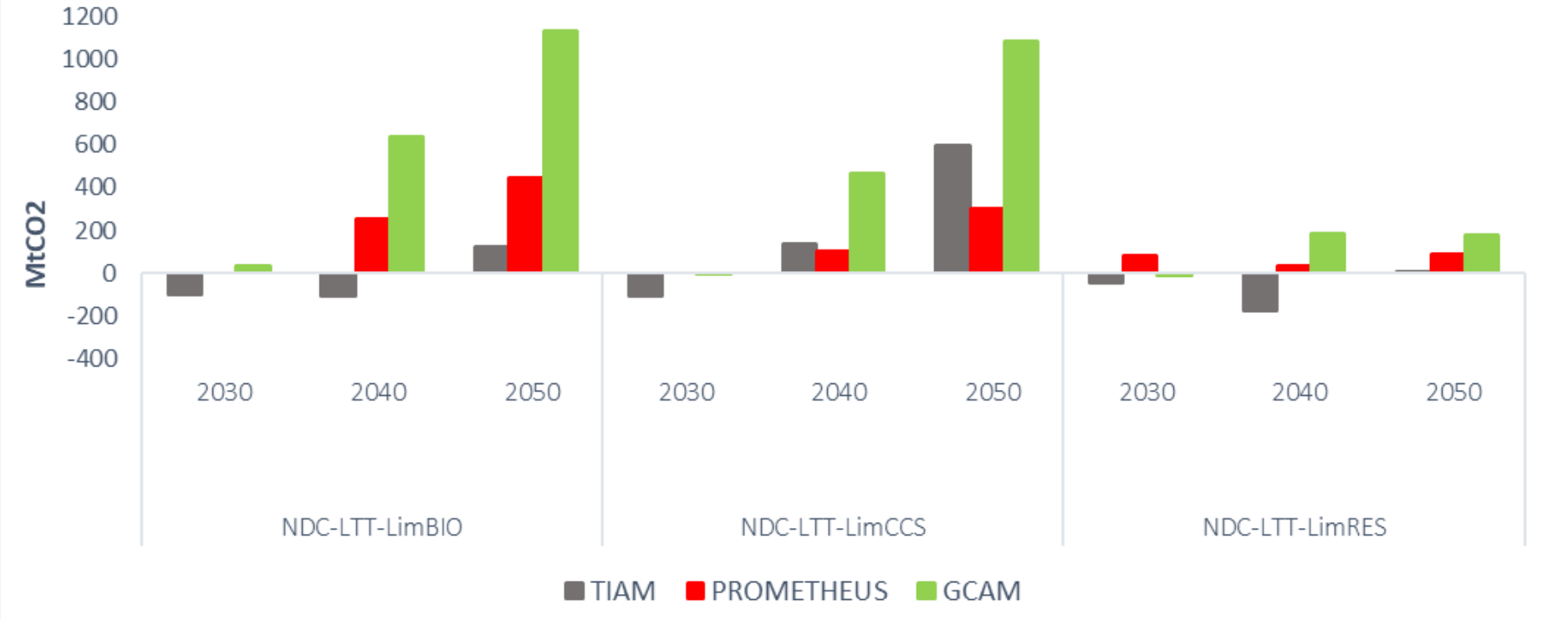


Figure 2. *Differences in EU CO2 emissions between alternative scenarios with the baseline scenario in 2030-2050. Source: GCAM, PROMETHEUS, and TIAM.*

The long-term impact of cleantech constraints on EU transport

NDC-LTT-LimRES

- Battery costs higher -> EV adoption slows
- **2040-2050:** without cheap RES and batteries, electrification stalls
- Oil demand in transport stays higher than baseline (especially in freight & aviation)
- Gas would play a transitional role
- **Risk**: EU imports more oil and gas -> weaker energy security

NDC-LTT-LimBIO

- 2040-2050: no large-scale biofuels for aviation/shipping
- Heavy reliance on synthetic fuels (hydrogen based) -> but very costly
- For road transport- faster push to EVs because liquid biofuels are unavailable

NDC-LTT-LimCCS

- **2030**: Not much immediate effect
- **2040-2050:**
- Without CCS, hard to abate sectors face higher residual emissions
- More reliance on direct electrification (EVs) but sectors like aviation get stuck with higher emissions

Adaptability of the built environment

NDC-LTT-LimRES

- **2030**: electricity prices rise, slowing heat pump adoption
- **2040-2050:**
- Slower electrification of heating -> households and firms hold on to gas boilers longer
- District heating may rely more on fossil backup when RES are constrained
- By 2050, buildings still decarbonize , but later and with more gas in the mix -> higher costs, higher lock-in risks

NDC-LTT-LimBIO

2030: Small impact (biomass is niche in buildings already)

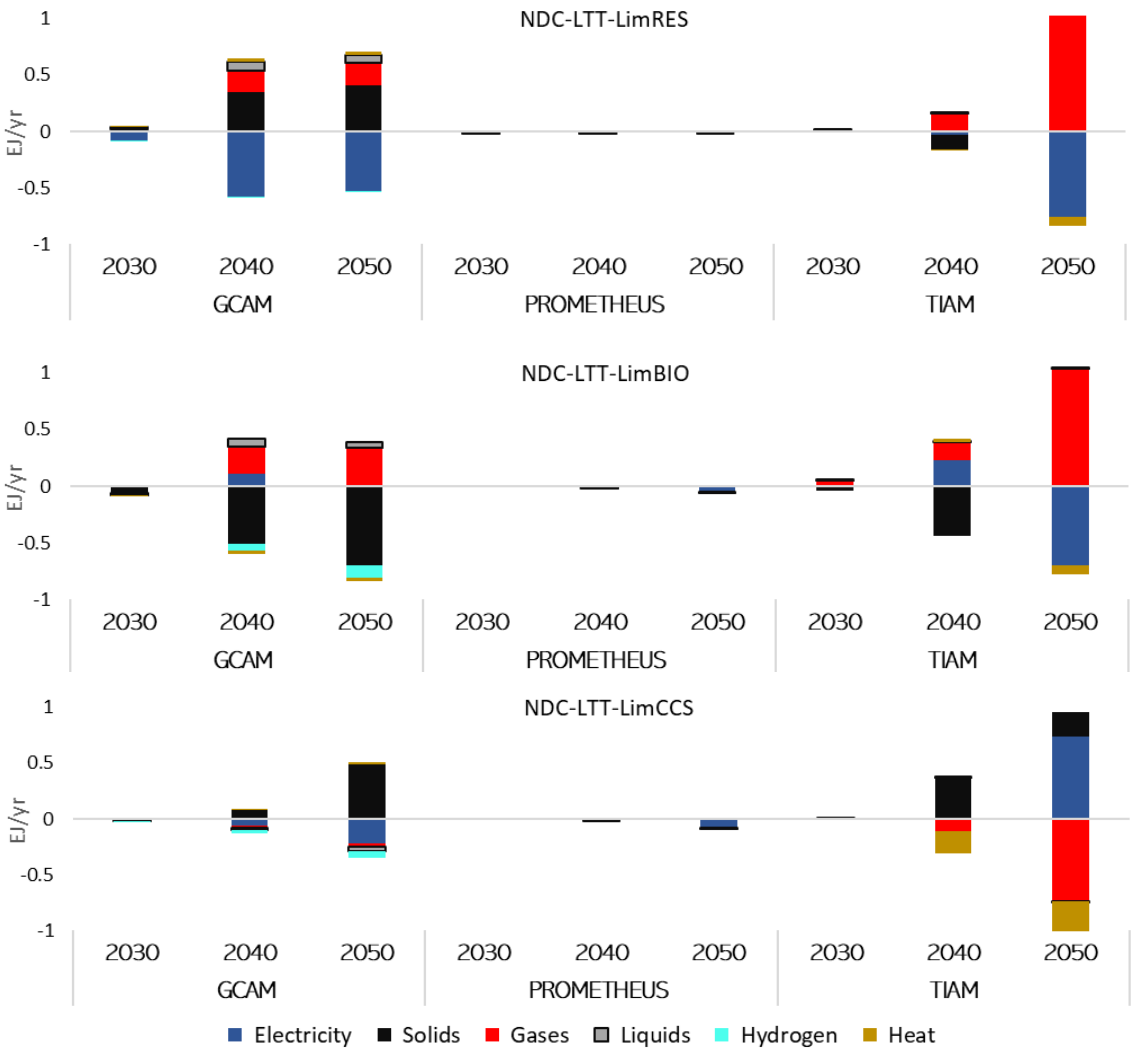
2040-2050:

- No biomass for heating (pellets, stoves, small boilers)
- This means heavier reliance on heat pumps & electricity
- In regions with slower electrification (e.g. Eastern EU), gas boilers persist longer ->higher emissions

NDC-LTT-LimCCS

- CCS is less relevant for buildings directly (since emissions are diffuse)
- Indirect effect: district heating from waste/biomass with CCS disappears -> less negative emissions
- 2050: buildings may still decarbonize but residual emissions elsewhere must be balanced -> stronger pressure on buildings for deeper efficiency cuts

Prospects of EU industrial decarbonisation under technology limitations



- **Limited RES & batteries**: Constraints on RES and storage capacity increase electricity costs and reduce supply reliability, slowing down the electrification—thus, delaying the transition to green hydrogen and low-emission industrial heat

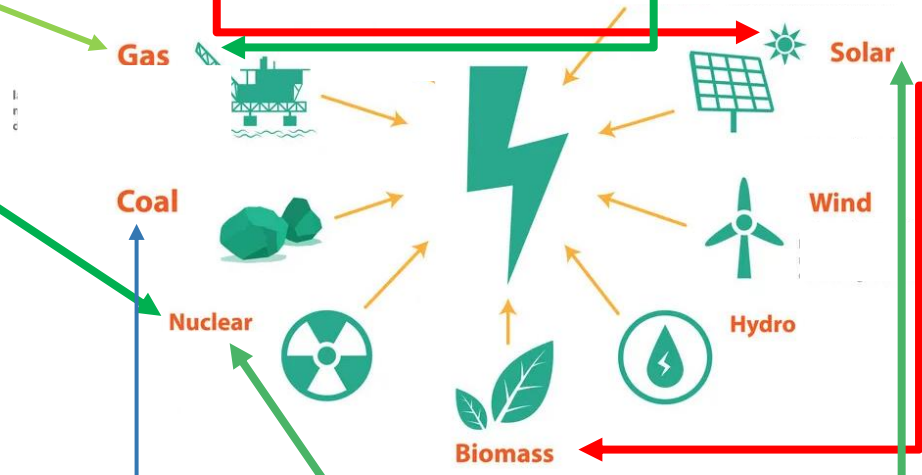
- **Biomass constraints**: biomass provides both a renewable feedstock and a source of industrial heat. Restricting its availability limits the substitution of fossil fuels and eliminates the potential for CDR to offset residual industrial emissions. This results in higher reliance on imported gas and higher system costs.

- **CCS constraints**: in energy intensive industries, CCS is the only available option to address process emissions. A cap on CCS deployment prevents deep emission cuts, locking in residual CO2 and raising dependence on carbon-intensive production routes

Resilience of a crippled EU power sector

NDC-LTT-LimRES

NDC-LTT-LimBIO



NDC-LTT-LimRES

Other dispatchable clean options (nuclear, hydro) expand; near-term gas acts as bridge fuel

NDC-LTT-LimBIO

Limits BECCS—
Weaker potential for negative emissions

NDC-LTT-LimCCS

NDC-LTT-LimCCS

the EU push even harder on the clean technologies that don't need CCS

Conclusions

- Europe's path to climate neutrality remains highly dependent on a limited set of technologies, each playing a distinct role in decarbonisation
- Technology constraints pose measurable risks to achieving EU's 2030 and 2050 climate goals, leading to higher emissions, system costs, and fossil fuel imports
- Among the scenarios tested, limiting biomass and carbon capture produces the largest emission increases (up to 1.1GtCO2 by 2050), due to the constraints in CDR and CCS. RES and battery constraints have smaller but still significant long-term impacts.

Sectoral impacts are <u>asymmetric</u>:

- ***Power sector*** compensates via nuclear and gas, raising costs and import dependency
- ***Industry*** faces persistent process emissions without CCS and biomass feedstocks
- ***Transport*** remains tied to fossil fuels without efficient biofuels or electrification capacity
- ***Buildings*** sector can only decarbonize if clean electricity is cheap and widely available. Any constraint on RES or biomass slows down the shift to clean heating, keeps gas boilers in use and raises costs for households.

Thank you!

For further questions you are welcome to send them at:

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