Cost-optimal vs. policy-driven scenarios for a decarbonised European energy system

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Policy Response Mechanism

Core Working Groups → **Electrification**

Question 1 → European Commission Directorate-General for Energy

How does the implementation of the updated National Energy and Climate Plans compare to the **cost optimal approach** at a European level?

Question 2 ↓

entsoe

What are the offshore grid investment needs to meet the **EU's 2030 targets**?

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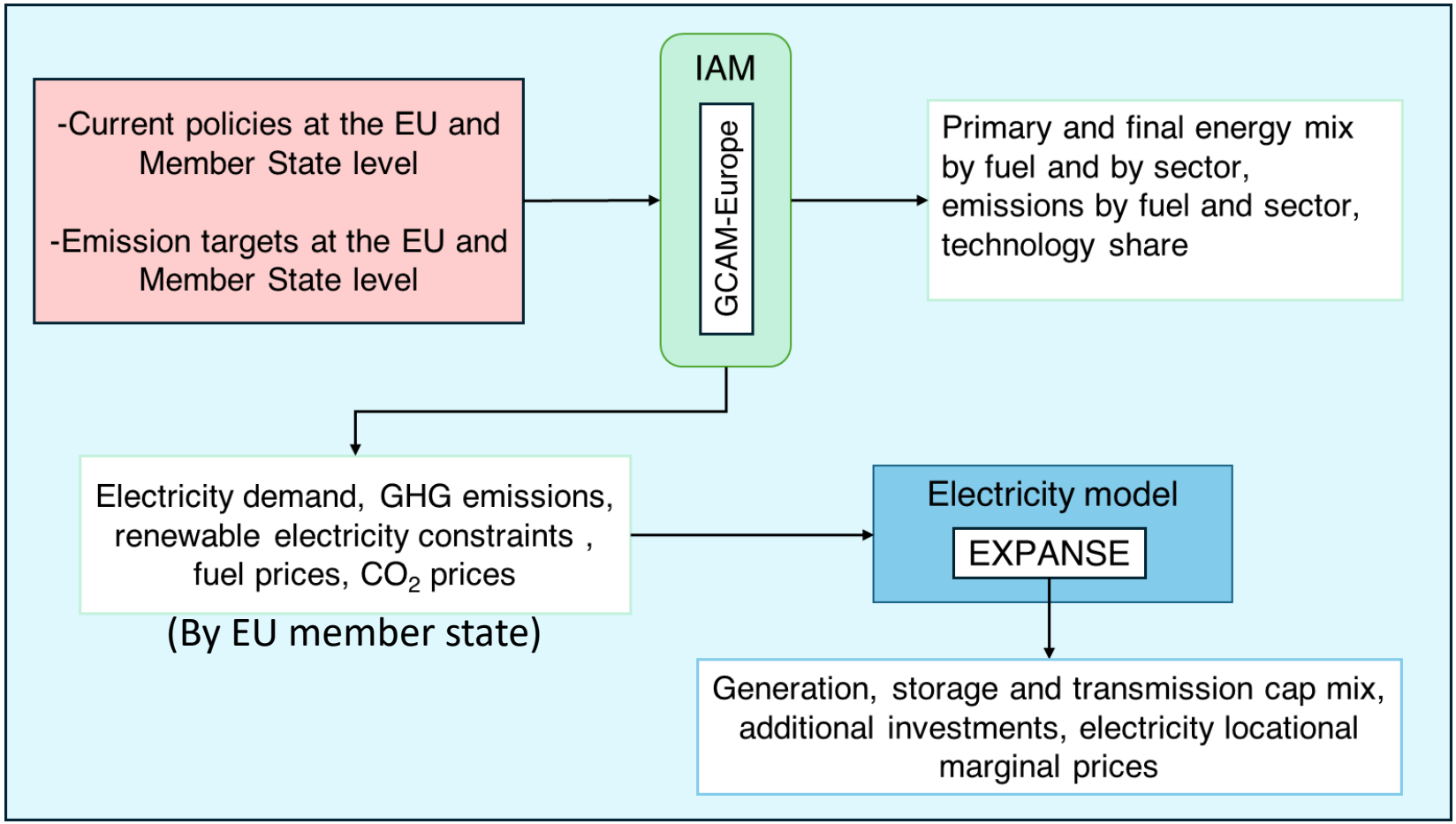

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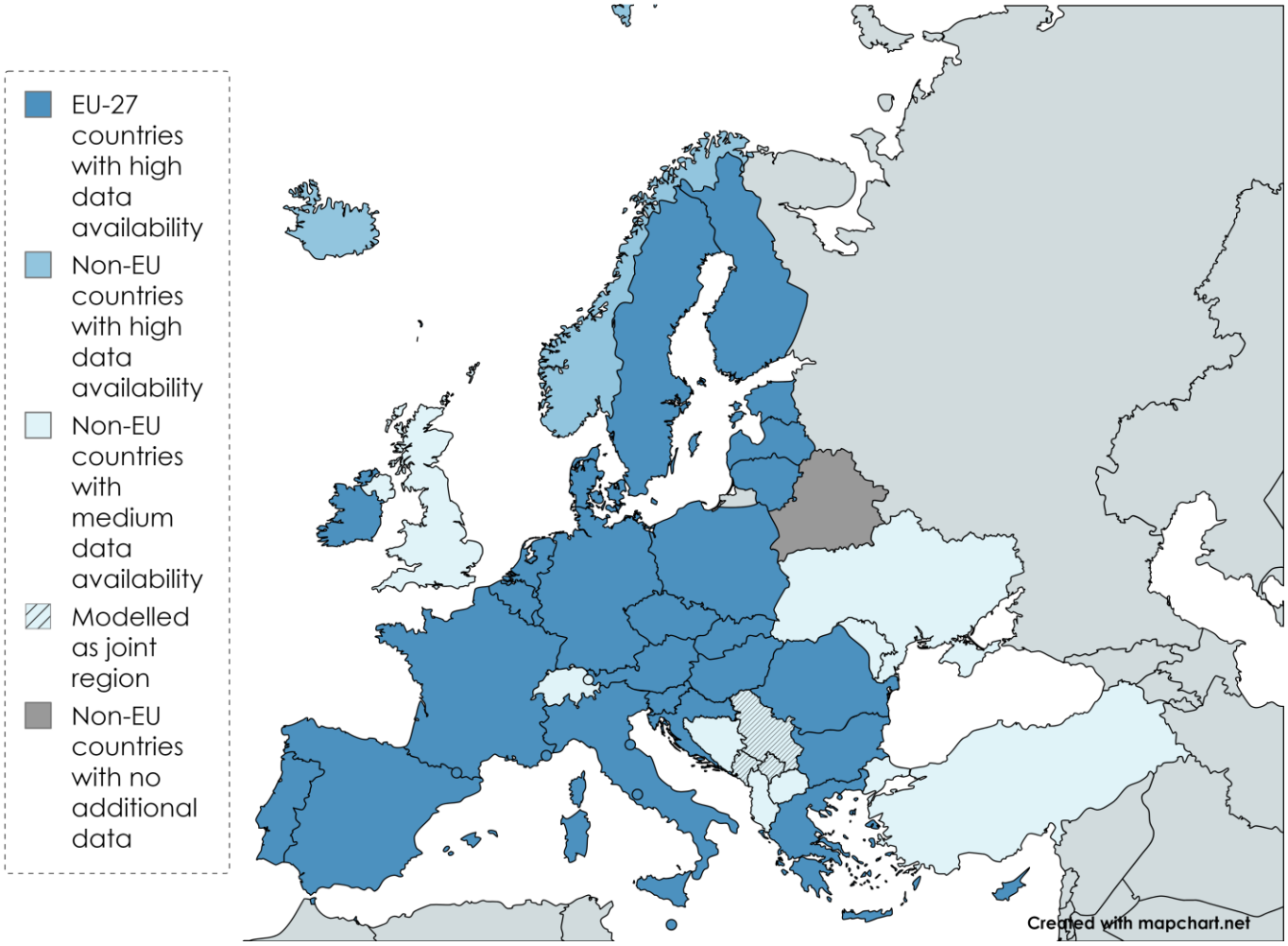
Methodology: GCAM-Europe



- Newly developed (in DIAMOND project): European version with all countries separated and higher sectoral detail (upon data availability)
- Mostly based on Eurostat to align with EU policy paradigm
- Within global modelling context
- Fully open-source

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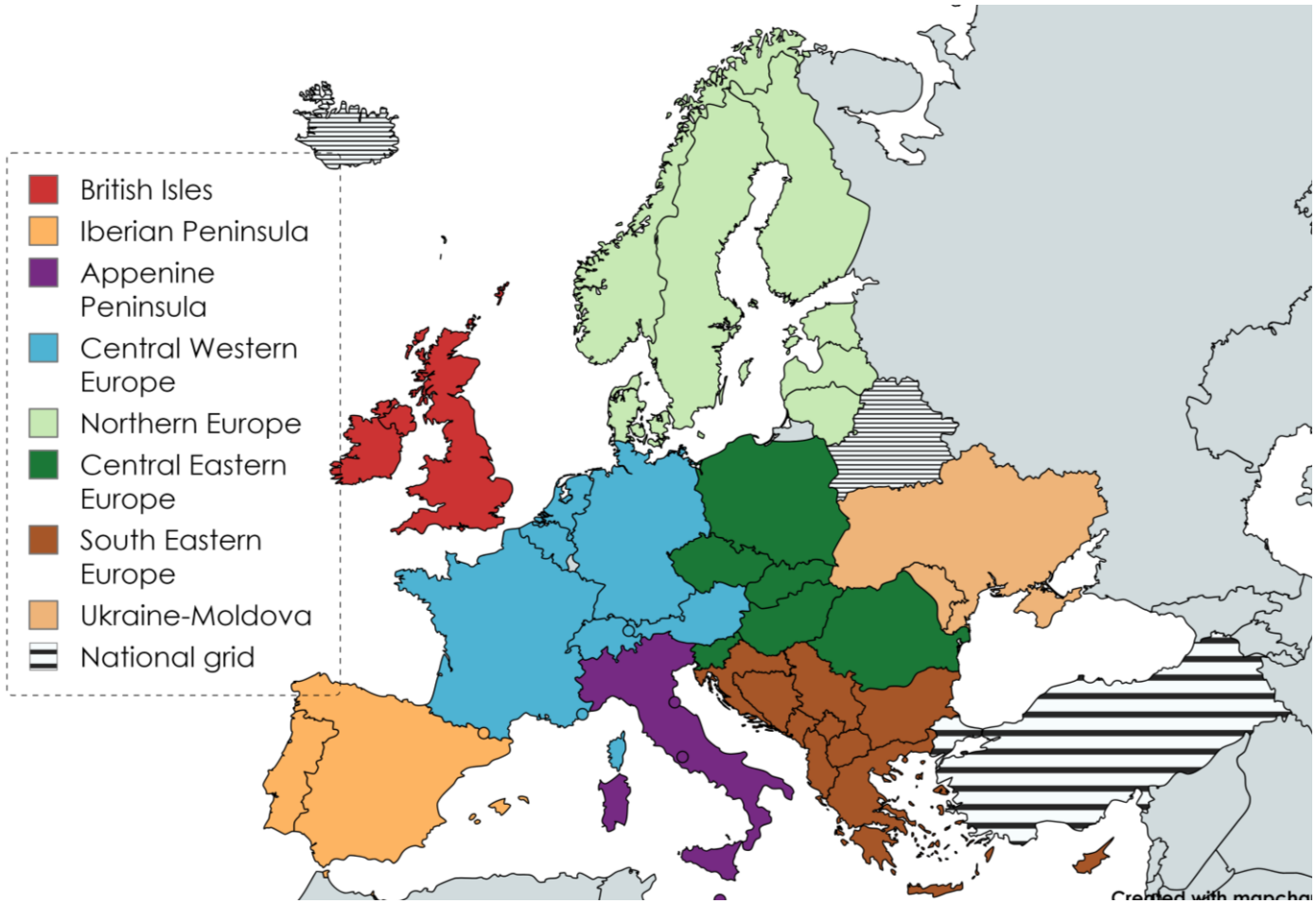
- Interconnected electricity grid based on grid regions, load segments (base, intermediate, sub-peak and peak), and inter-segment storage
- Segments based on openTEPES (IIT) representation of ENTSO-E "National trends" scenario
- Working at 5-year periods, hence complemented with EXPANSE for detailed electricity system consequences



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		Scenario			
		FF55_POLICY	*FF55_FREE*	*NECP_POLICY*	*NECP_FREE*
Policy representation (up to 2030)	Energy taxation (electricity, gas, fuels; kept constant at observed 2024 levels), coal phase-out agendas				
	Energy efficiency and Renewable energy targets				
	Explicit EU-wide policies (ETS, vehicle emission standards)				
	Economy-wide carbon cap covering all CO2 emissions		Caps equal to fossil CO_2 in FF55_POLICY		Caps equal to fossil CO_2 in NECP_POLICY
Post-2030 carbon cap constraining net CO_2 linearly towards zero in 2050 (assuming unchanged LULUCF emissions/removals)					

Color legend:

Member-state specific implementation	Aggregated EU-wide implementation

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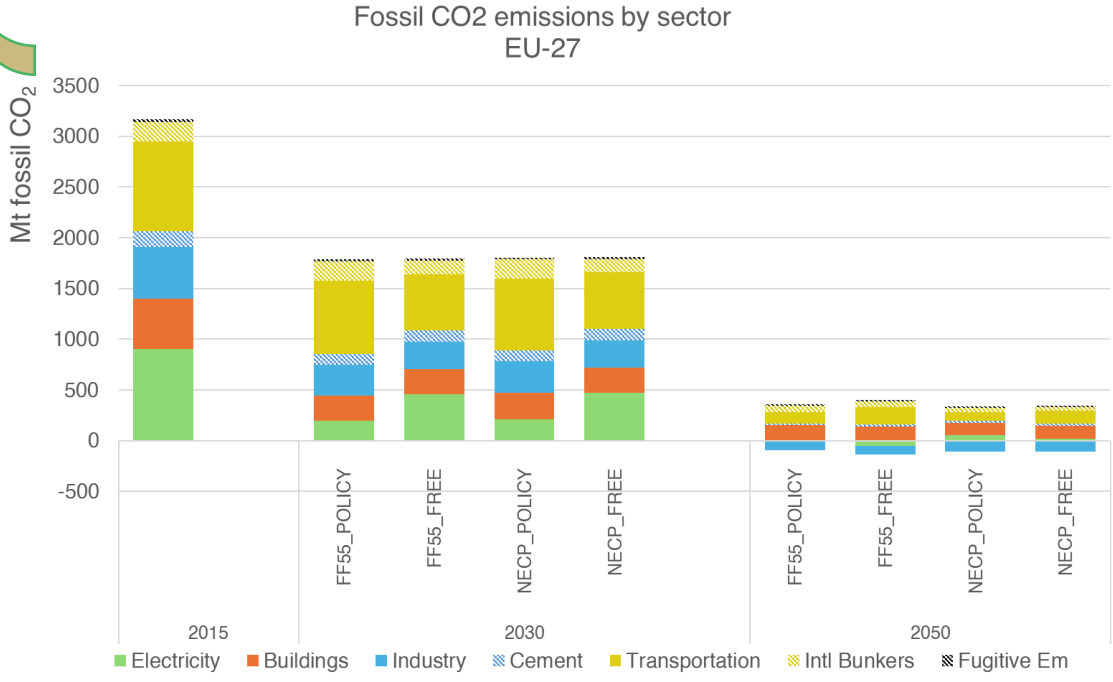
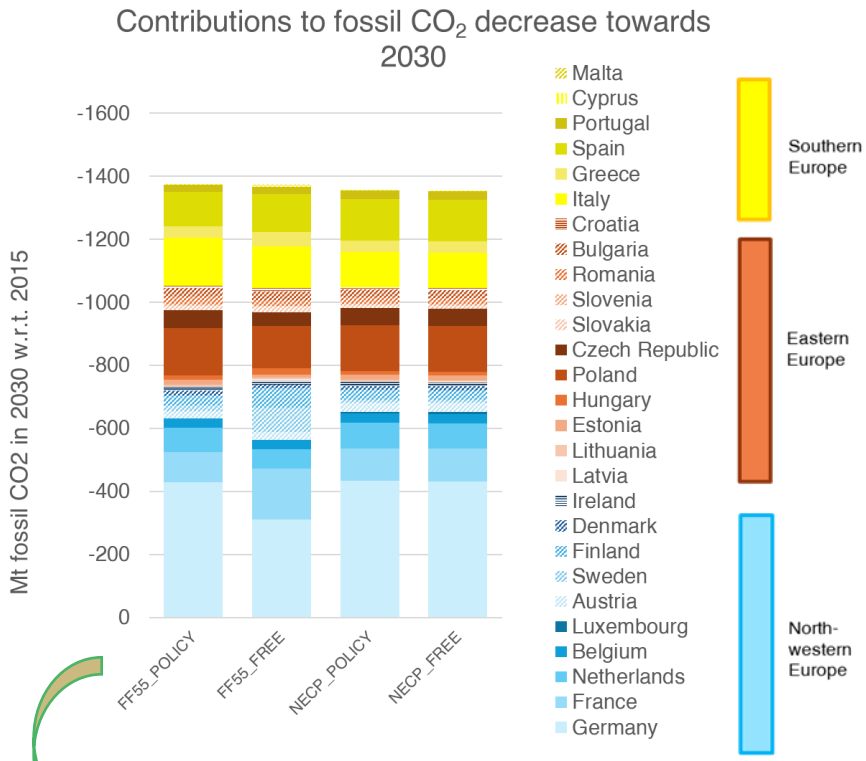
Modelling results (GCAM-Europe): Emissions

-All scenarios reach the FF55 emissions target (-55% vs. 1990)
-Minor differences between POLICY and FREE variants:
- **POLICY**: extra constraints (renewables, efficiency, carbon pricing) → more cuts in electricity sector
- **FREE**: relatively higher reductions in transport

-By 2050, emissions in all scenarios reduced by ~94%





Geographical split of emission reductions similar in each scenario (roughly reflecting current emission shares), except for **FF55_FREE** which allocates significantly more reductions to Scandinavian countries & France.

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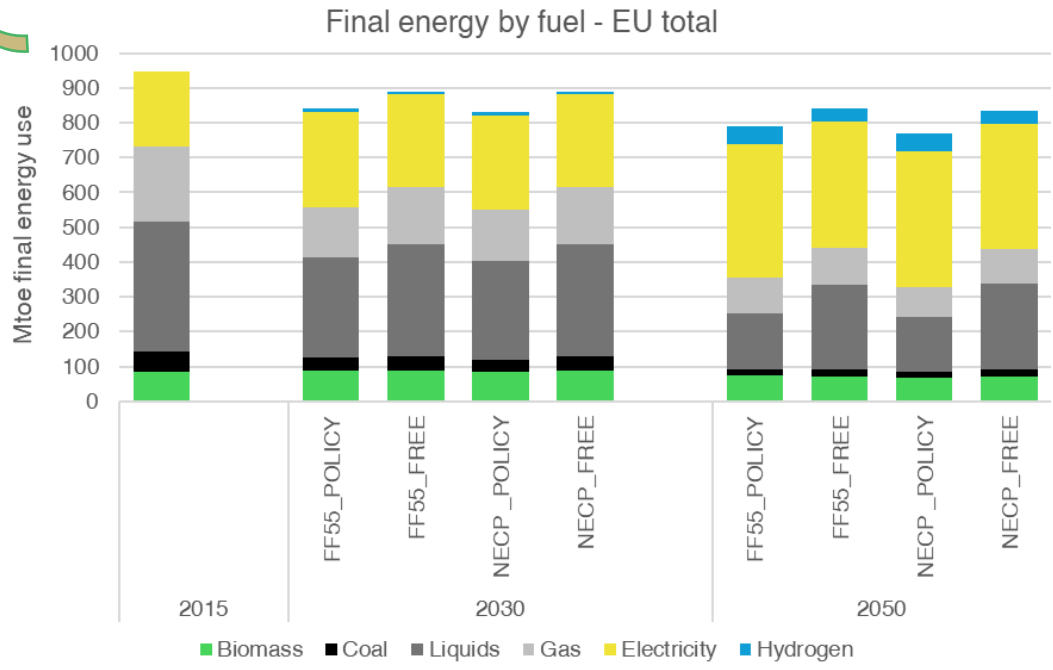
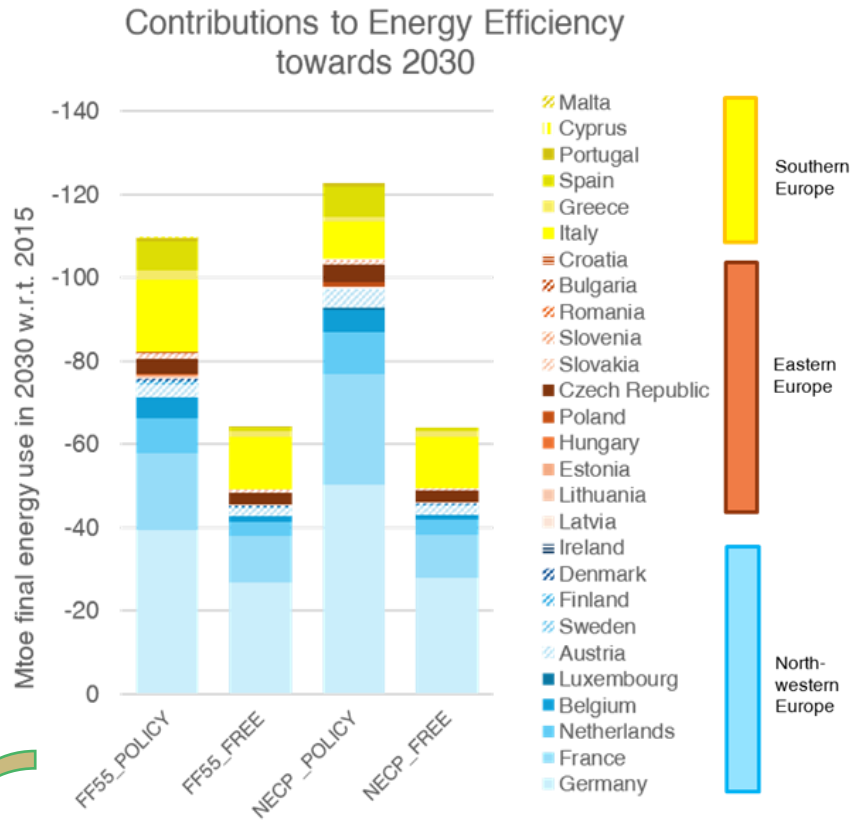
Modelling results (GCAM-Europe): Energy efficiency

- Most reductions in gas and liquids consumption due to energy efficiency (mostly towards 2030), electrification and hydrogenisation (mostly towards 2050)
- Compared to **POLICY** scenarios, **FREE** scenarios reflect significantly less energy savings, with the major difference in liquid energy consumption.





POLICY: Model allocates less energy savings to north-western Europe than NECPs, partly compensated by more savings in Italy (*FF55_POLICY* relative to *NECP_POLICY*)
FREE: Little geographic difference in the geographical allocation of limited efficiency gains

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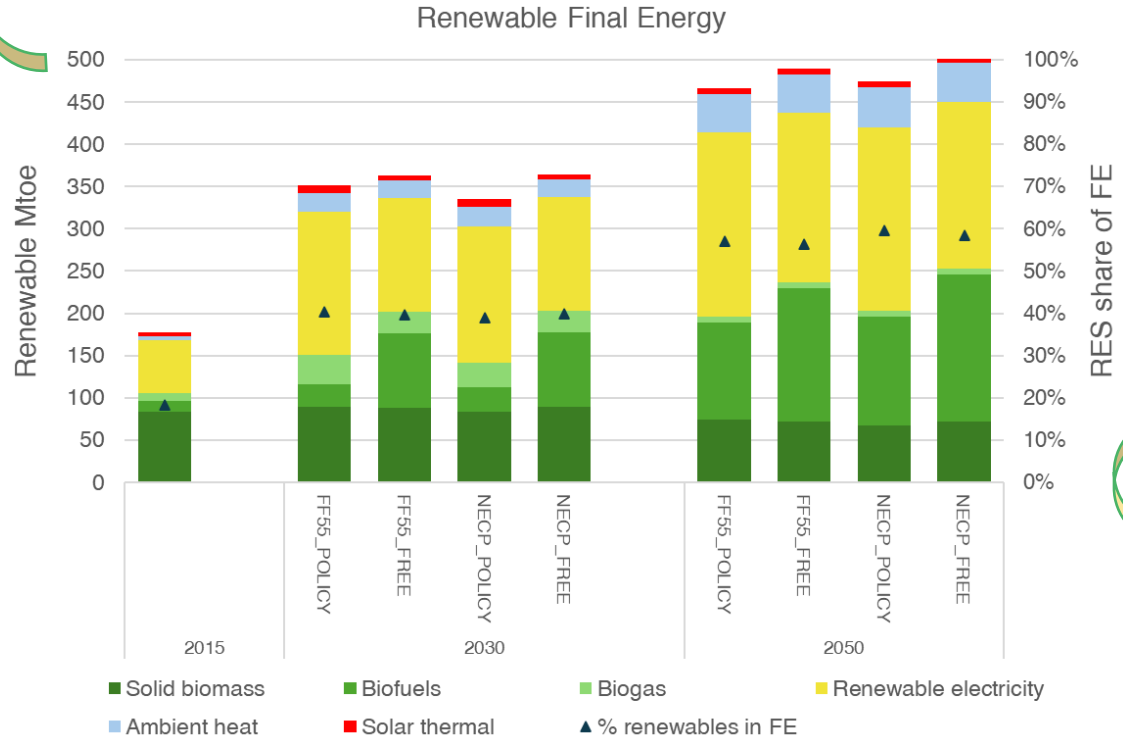
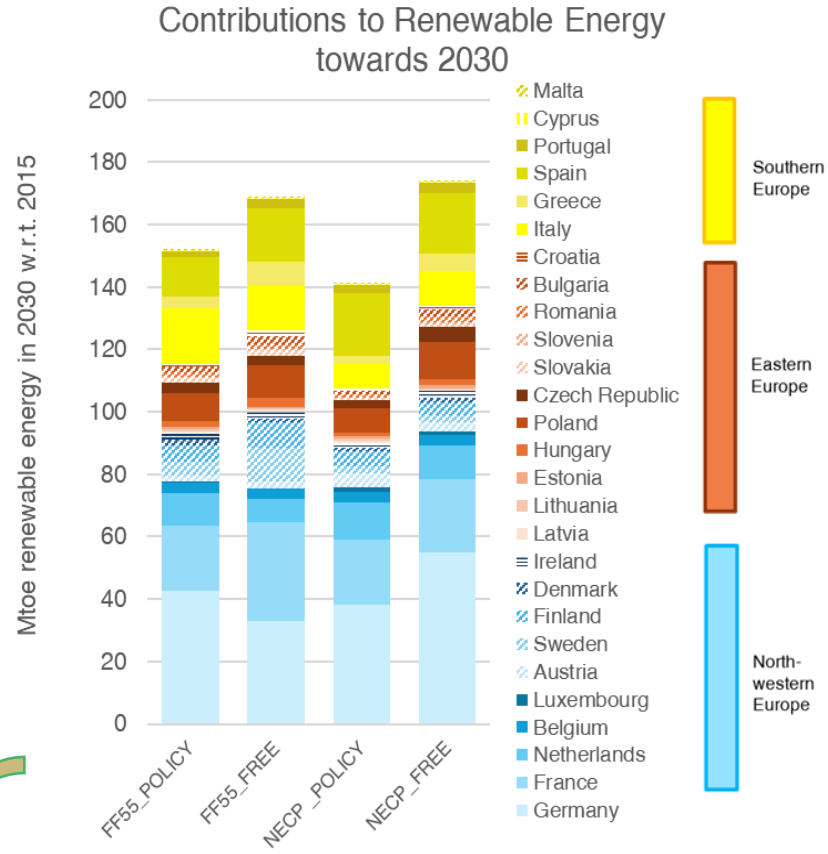
Modelling results (GCAM-Europe): Renewable energy

-All scenarios close to the RES share target (42.5%), overall strong increase in heat pumps towards 2030 and 2050.

- **POLICY**: accelerates electrification (renewable electricity + heat pumps) → Role of energy efficiency policies
- **FREE:** close to 2030 RES targets but leans heavily on biofuels as a substitute for fossil liquids (role of BECCS bonification)





POLICY: Model allocates more renewable energy to eastern Europe & Italy than NECPs, partly compensated by less RES in Spain (*FF55_POLICY* relative to *NECP_POLICY*)
FREE: Model allocating (*FF55_FREE*) much more renewables to Scandinavia and France and less to Germany and Netherlands.

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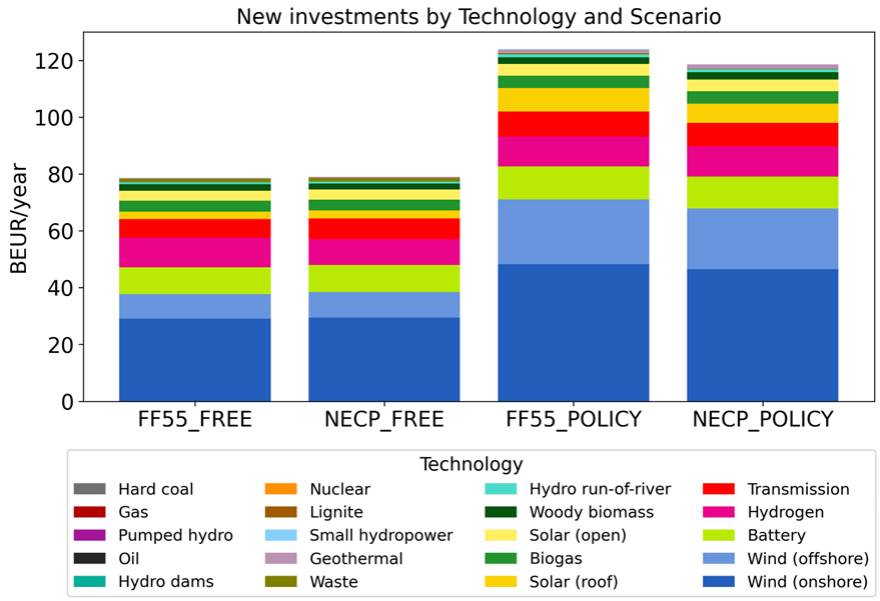
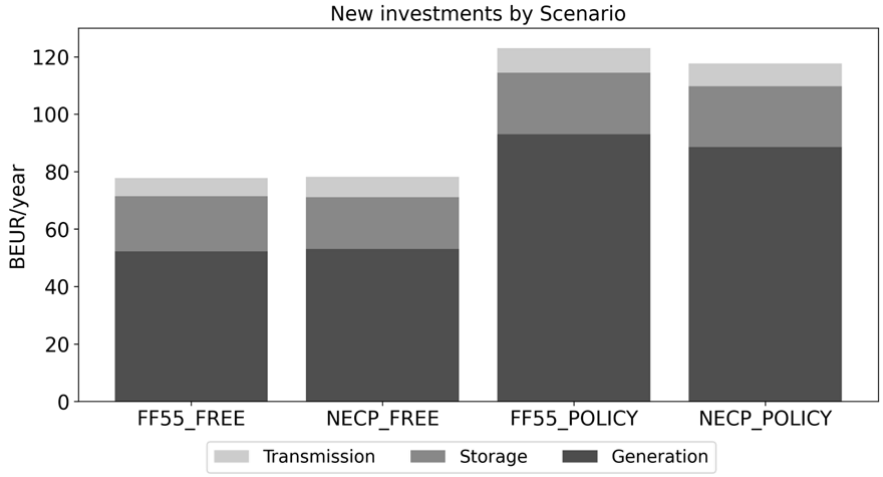
Modelling results (EXPANSE): Investments





- **FF55_POLICY**: highest investments driven by stringent EU-wide carbon pricing & renewable targets. Capital-intensive deployment of new generation capacity dominates.
- **NECP_POLICY:** substantial but lower investments; higher energy efficiency (see GCAM-Europe outcomes) & less electricity compared to EU-wide approach.
- **FREE scenarios:** significantly less investments in electricity system due to higher focus on renewable (bio-)liquids.
- **Investment composition:** Generation is the cost driver, storage grows with system inflexibility, and transmission costs higher in national policy pathways where cross-border efficiency is limited.

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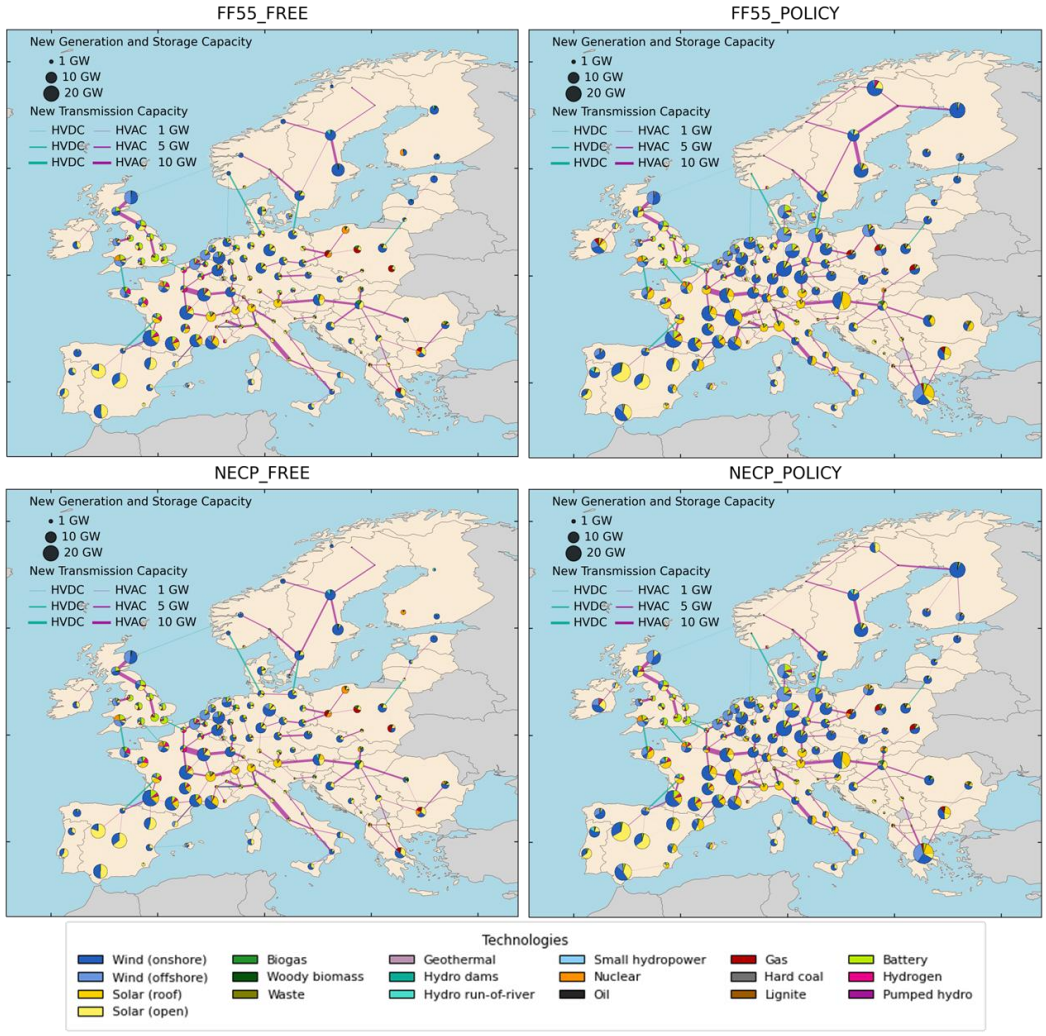
Modelling results (EXPANSE): New installed capacities



- **POLICY** (right panels): : More nodes with new capacity additions across Europe → deployment is more spatially distributed.
- **FREE** (left panels): Fewer nodes, with capacity concentrated in resource-rich regions → reflects a cost-optimal allocation.
- Massive build-out of **wind** (North Sea, Central & Eastern) and **solar** PV (South)
- **Batteries** & hydrogen key for storage, esp. in West & North Europe
- **Grid expansion** (HVAC/HVDC) crucial to link renewable hubs (North Sea, Iberia, Nordics) with demand centres in Central & Western Europe (Germany, Benelux, N. Italy, France, UK)

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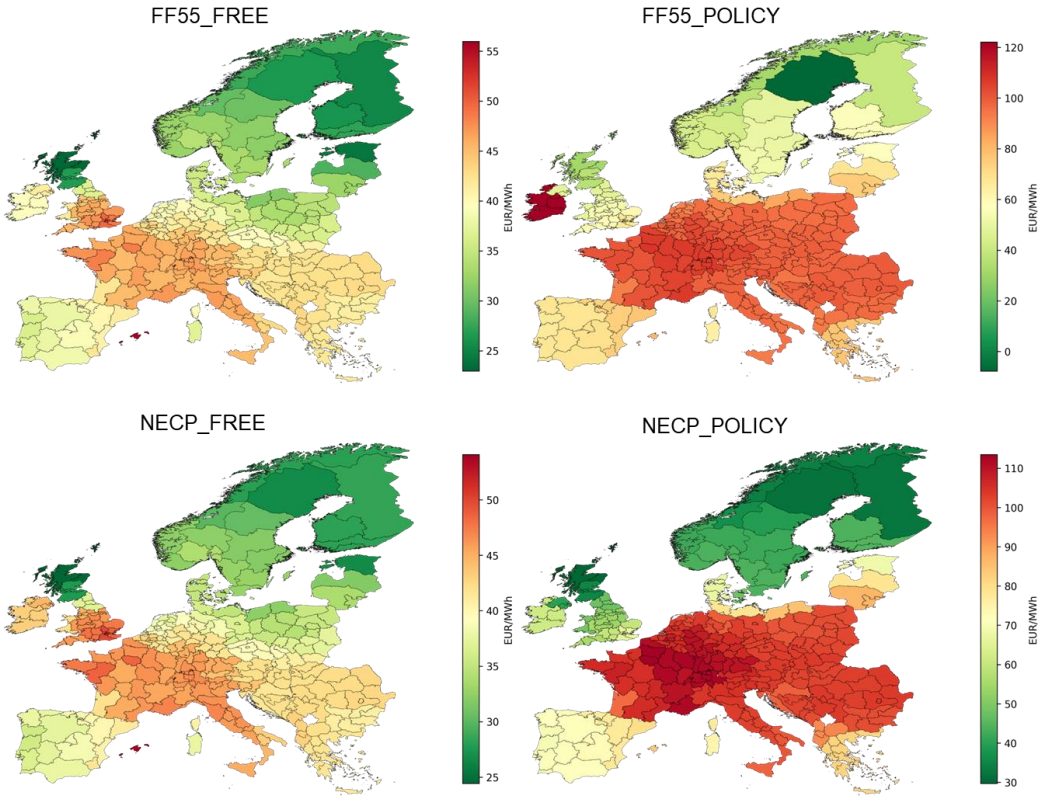
Modelling results (EXPANSE): Electricity prices



- **POLICY (**right panel**):** higher & more uneven LMP due to CO_2 price; greater price spikes in Central & Southern Europe, where reliance on dispatchable fossil plants is higher.
- **FREE**: Lower and more uniform prices across regions → better alignment of renewable resources and demand;
- Lower LMPs in Northern Europe due to RES abundance
- Geographic disparities in electricity affordability; highlights the value of flexibility and interconnection in mitigating high LMPs

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- **Emissions**: Current EU and national policies can deliver 2030 targets, and the geographical split is relatively close to a cost-optimal approach, but the sectoral split differs significantly, putting more weight on mitigation in electricity and less in transport.
- **Cost-optimal scenarios** can, in principle, achieve comparable decarbonisation outcomes at lower system costs and electricity prices, but real-world energy transitions rarely align with idealised optimisation outcomes due to political, institutional, and socioeconomic constraints (more biofuels and CCS, and less reduction in consumption).
- **Energy efficiency** gains are not cost-optimal but policy-driven; binding measures and funding instruments are essential to lock in demand reductions. However, reducing final demand has strong co-benefits, such as also illustrated during the 2022 energy crisis.
- **Wind, solar, and storage** must scale rapidly; EU-level planning should balance concentrated vs. distributed investments across Member States.
- **Grid congestion and underinvestment** could undermine decarbonisation; NECP-driven disparities in investments in renewable electricity need to be compensated by appropriate investments in transmission grid capacity to meet goals and avoid electricity price disparities.

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Thank you!

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Scenarios	**FF55**: EU-wide targets	**NECP**: Member State targets
POLICY: Policies/targets to 2030, then linear interpolation to net zero	**FF55_POLICY** *EU-wide targets for 2030 in line with Fit-For-F55 are applied for renewables (42.5% of final energy) and energy efficiency (11.7% reduction in final energy w.r.t. 2020) and net-zero for 2050*	**NECP_POLICY** *EU-ETS (1 and 2), vehicle emission standards, country-specific coal phase-out strategies, renewable energy (% share of final energy) and energy efficiency as a maximum final energy use targets defined in country-specific NECPs.*
FREE: Cost-optimal pathways (models must achieve FF55/NECP and net zero emissions levels by 2030 and 2050)	**FF55_FREE** *Same level of CO_2 emissions mitigation in the EU as in the FF55_POLICY scenario through emissions constraints without considering the current climate policies, allowing the models to select the cost-optimal pathway for reducing emissions.*	**NECP_FREE** *Same level of CO_2 emissions mitigation in Member States as in the NECP_POLICY scenario through emissions constraints without considering the current climate policies, allowing the models to select the cost-optimal pathway for reducing emissions.*

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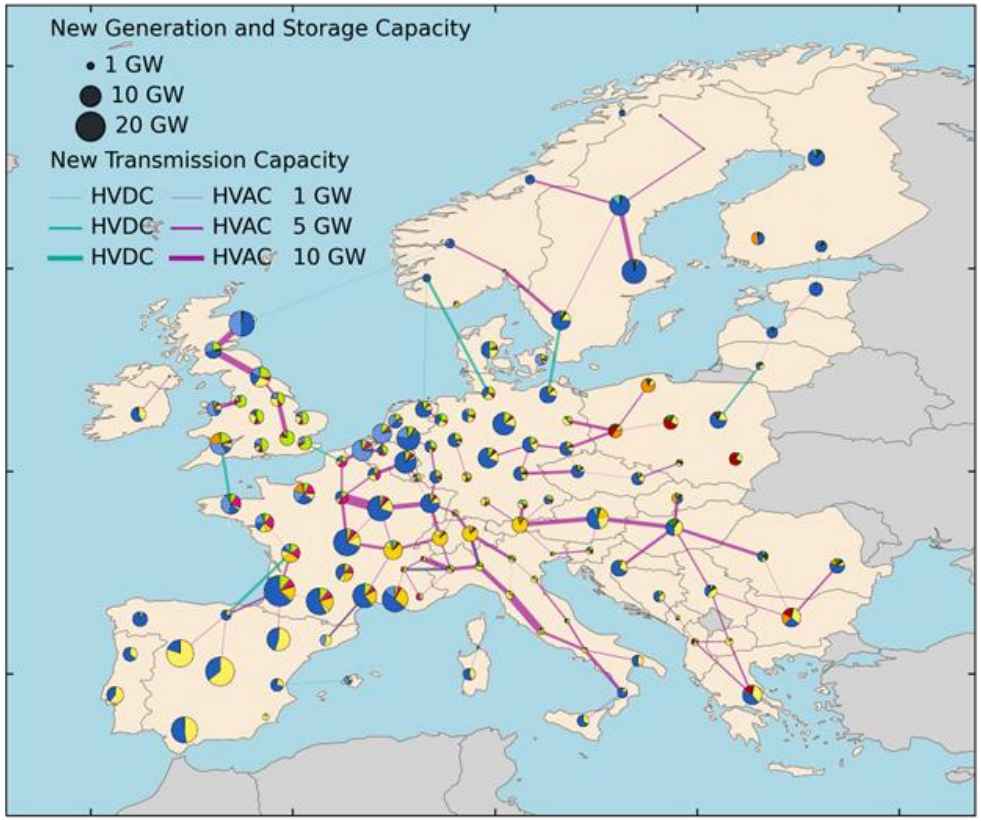
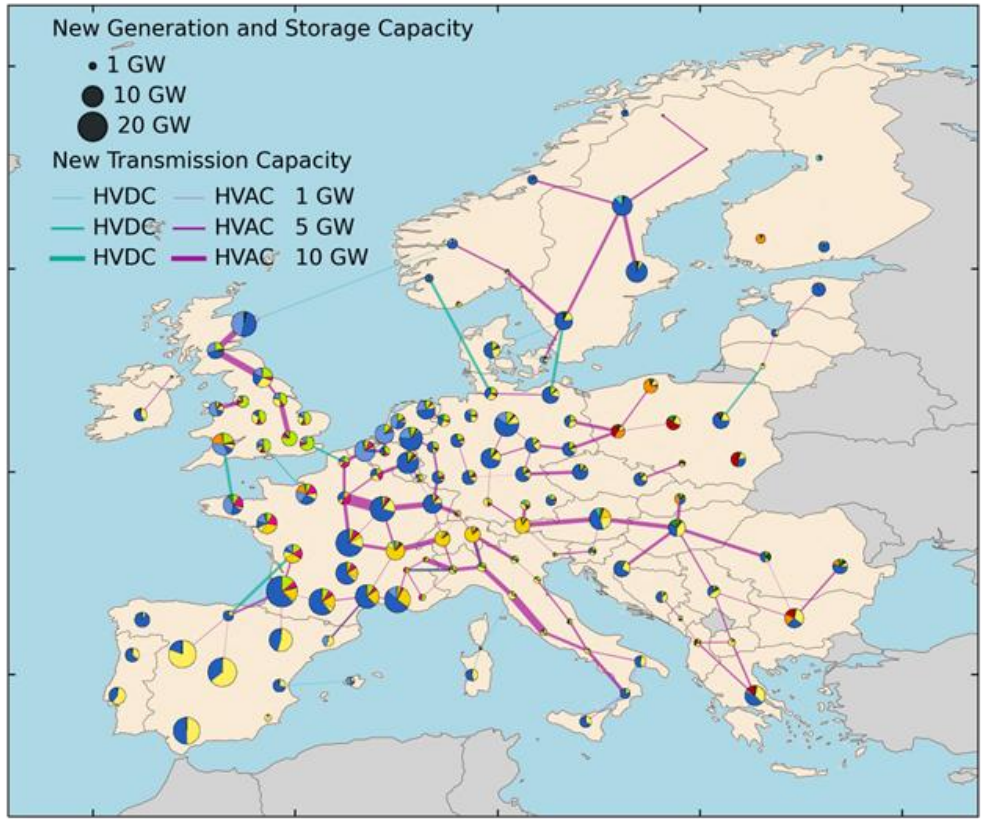
New capacity (FREE scenarios)

FF55_FREE



NECP_FREE

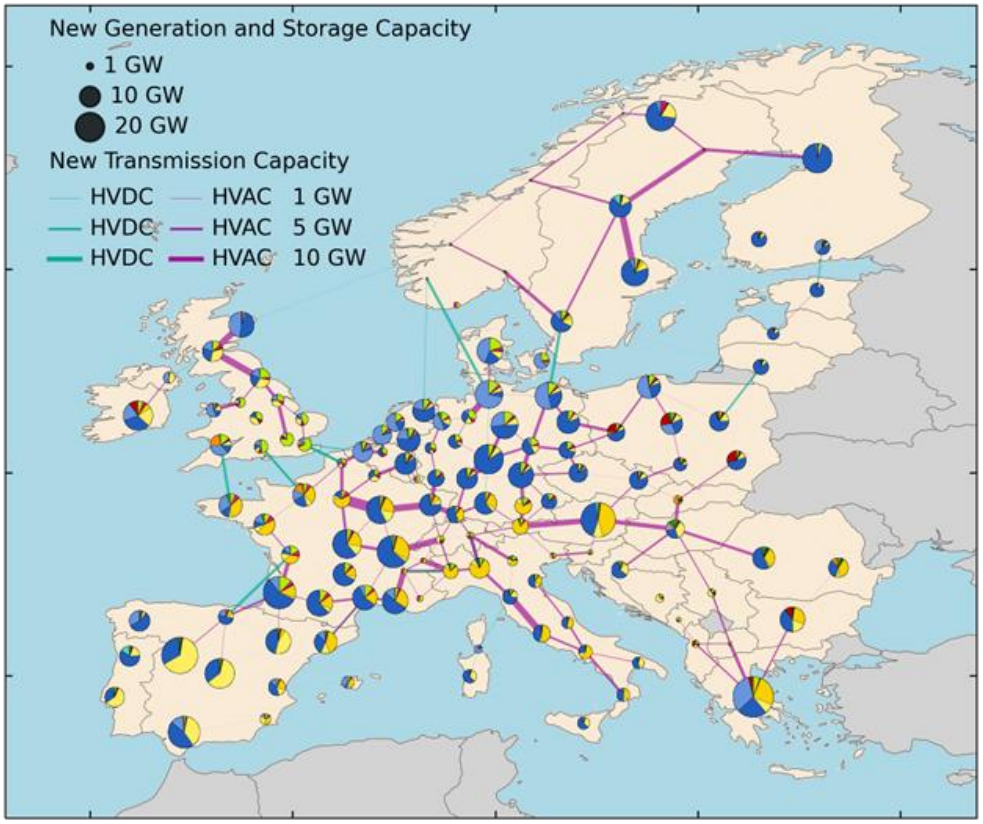


Technologies

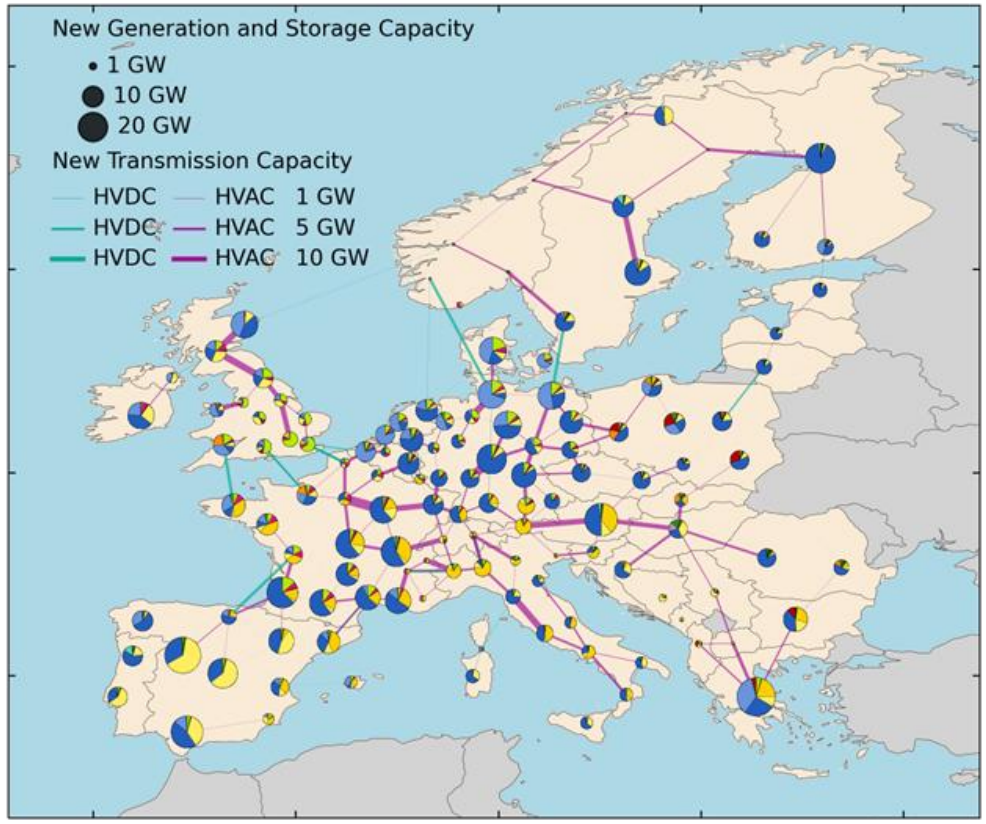
Wind (onshore)	Biogas	Geothermal	Small hydropower	Gas	Battery
Wind (offshore)	Woody biomass	Hydro dams	Nuclear	Hard coal	Hydrogen
Solar (roof)	Waste	Hydro run-of-river	Oil	Lignite	Pumped hydro
Solar (open)					

New capacity (POLICY scenarios)

FF55_POLICY



NECP_POLICY



Technologies

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- Wind (offshore)
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- Woody biomass
- Waste
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- Hydro dams
- Hydro run-of-river
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- Oil
- Gas
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- Lignite
- Battery
- Hydrogen
- Pumped hydro