10th International Conference on Smart Energy Systems
10-11 September 2024
#SESAAU2024

BIDIRECTIONAL SOFT-LINKING OF OPEN-SOURCE ENERGY MODELS TO EVALUATE THE FEASIBILITY OF TRANSITION PATHWAYS TO CARBON NEUTRALITY IN THE POWER SECTOR

Mr. Nikos Kleanthis, Dr. Vassilis Stavrakas,
Prof. Dr. Alexandros Flamos

Outline

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Outline

Introduction (1/3)

Amendment of the Greek **National Energy and Climate Plan** (NECP)

Increased ambition, including high **variable renewable energy** (VRE) capacity targets in the **power sector**

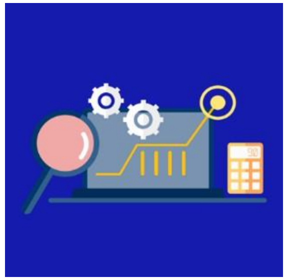
How can **carbon neutrality** in the power sector be achieved while transitioning to a **flexible**, VRE-based future instead of continuing to rely on natural gas?

Need for modelling support to provide feasible decarbonisation pathways

RQ part of the Horizon IAM COMPACT & ENCLUDE Energy Citizens for Inclusive Decarbonization projects:

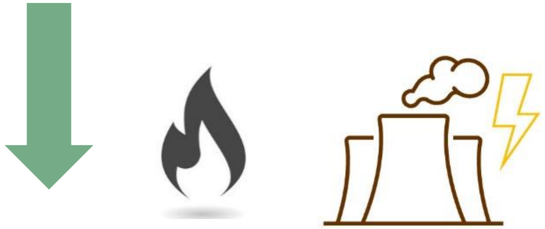
"What are the capacity and flexibility requirements for a carbon neutral power sector?"

Introduction (2/3)

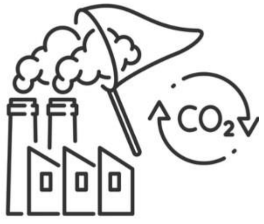


Modelling tools capable of capturing VRE variability to analyse **flexibility issues** and provide relevant solutions.

……..we **soft-link** two **open-source** tools (OSeMOSYS + Flextool) to provide insights regarding three alternative cost-optimal decarbonisation pathways by 2050 in the power sector.



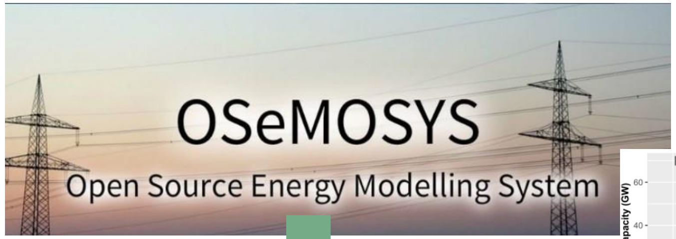
- ❑ Future role of natural gas and hydrogen,
- ❑ Integration of VRE with energy storage,
- ❑ Potential use of carbon capture and storage (CCS), etc.

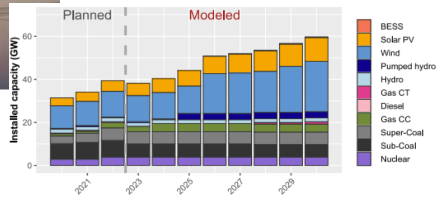


Introduction (3/3)

Why these tools? **Open-source, well documented, transparency, scalability, fast learning curve, replicability**

Capacity Expansion Model (CEM)



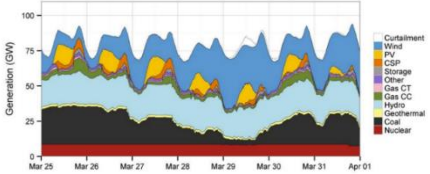


Delivery of Long Term Decarbonization pathways

Production Cost Model (PCM)

IRENA International Renewable Energy Agency

FlexTool



Delivery of ST dispatch to identify flexibility issues e.g. loss of load, curtailment

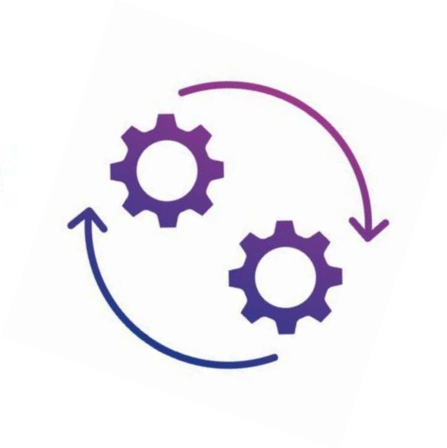
Outline

Methods (1/2)

Coupling of two models .....

OSeMOSYS-GR
Linear Optimization Energy Planning Model

Newly developed Capacity Expansion Model for the Greek power sector



FlexTool

Adjusted based on the power sector design provided by OSeMOSYS-GR

... to develop a **bidirectional** soft-linking approach!

Methods (2/2)

OSeMOSYS-GR
Linear Optimization Energy Planning Model

Long-term scenario analysis

→

IRENA
International Renewable Energy Agency
FlexTool
(Dispatch mode)

Short-term assessment of flexibility: identification of issues

↓

IRENA
International Renewable Energy Agency
FlexTool
(Investment mode)

Short-term assessment of flexibility: Solving issues

→

OSeMOSYS-GR
Linear Optimization Energy Planning Model

Refined (No loss of load, low curtailment) long-term scenario analysis

Outline

1. Introduction
2. Methods
3. Application to the power sector in Greece
4. Results
5. Conclusions and policy implications

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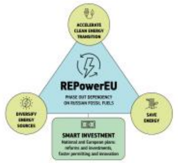
Application to the power sector in Greece (1/4)

- Limited capacity for interconnections
- Heavy reliance on NG for electricity production
- Significant VRE potential

European Green Deal (2019) → **NECP (2019)** →

➢ Terminating **domestic lignite mining** & lignite-fired electricity generation by **2028**



National Climate Law (2022)
REPowerEU (2022)
} → **Revised draft NECP (2023)** → **Revised final NECP (June 2024)**

➢ Decarbonisation of power sector by **2040**

➢ Focus on VRE (69 GW in 2050)

↓

After 2022 & **energy crisis**, the government has been reconsidering the role of natural gas

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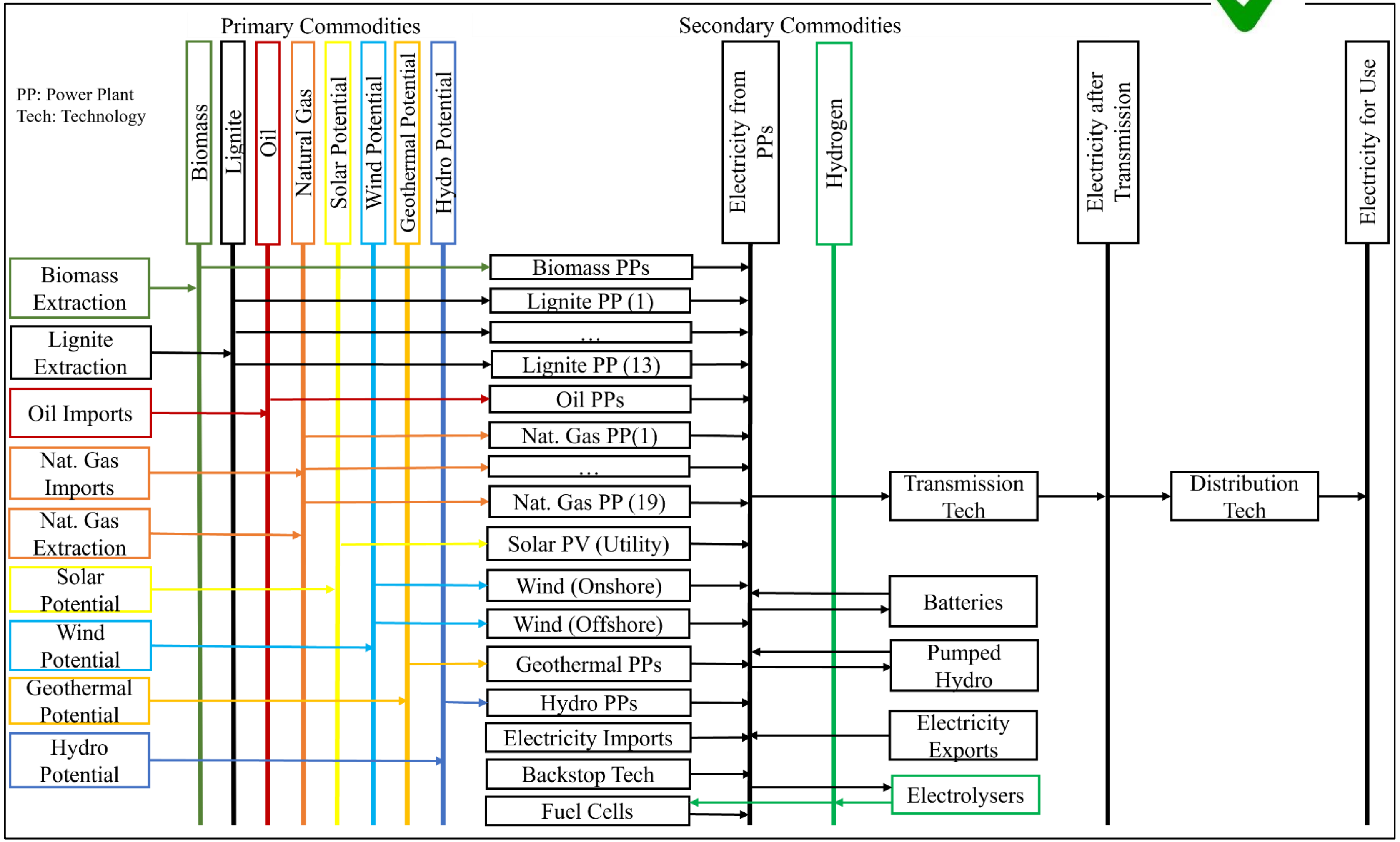
Reference Power System

Application to the power sector in Greece (2/4)

OSeMOSYS-GR Linear Optimization Energy Planning Model

IRENA International Renewable Energy Agency FlexTool

- **Fossil-fired power plants:** lignite, natural gas, and oil.
- **RES:** hydro, wind onshore & offshore, solar PV, biomass & geothermal.
- **Electricity & hydroelectric storage:** battery & pumped hydro.
- **Hydrogen production & consumption:** electrolysers & fuel cells.
- **Interconnections** with neighbouring countries.
- **Transmission** & **distribution** losses.



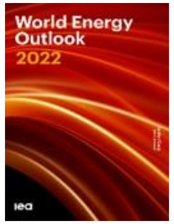
Application to the power sector in Greece (3/4)

- Electricity demand, natural gas price, and ETS CO_2 emission allowance **prices**.
- **Data** concerning the **fossil-fired power plants**, such as capacities, minimum stable generation, efficiencies, minimum uptimes/ downtimes, their availabilities considering planned commissioning and de-commissioning of generating capacity.

Renewables.ninja

- **Technological data**, e.g., capital costs, fixed and variable O&M costs, efficiencies, capacity factors.

EU Reference Scenario 2020



World Energy Outlook 2022

- **Residual capacities** of existing electricity generation technologies.

entsoe Transparency Platform

- **Import capacity** from interconnections.

Ten-year development plan of the Greek IPTO

Application to the power sector in Greece (4/4)

For all the scenarios

- **Carbon neutrality** should be achieved by **2040**
- **Phase out** of **lignite** by **2028**

❑ Neutrality 1

2020 — 2024 → 2040 → 2050

- 2024: **Starting year**
- **Higher rate of capacity expansion** of **VRE**, **electricity storage**, and **fuel cells**
- **Phase out** of **natural gas before** the milestone year
- 2040: **Milestone year**

❑ Neutrality 2

2020 — 2024 → 2035 → 2050

- 2024: **Starting year**
- **Lower rate of capacity expansion** of **VRE**, **electricity storage**, and **fuel cells**
- 2035: **Natural gas** & **biomass** plants retrofitted with **CCS**

❑ Neutrality 3

2020 — 2024 → 2035 → 2050

- 2024: **Starting year**
- **Higher rate of capacity expansion** of **VRE**, **electricity storage**, but **fuel cells** at a **lower rate**
- 2035: **Natural gas** plants switch to **hydrogen**

Outline

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OSeMOSYS-GR
Linear Optimization Energy Planning Model

Results (1/15)

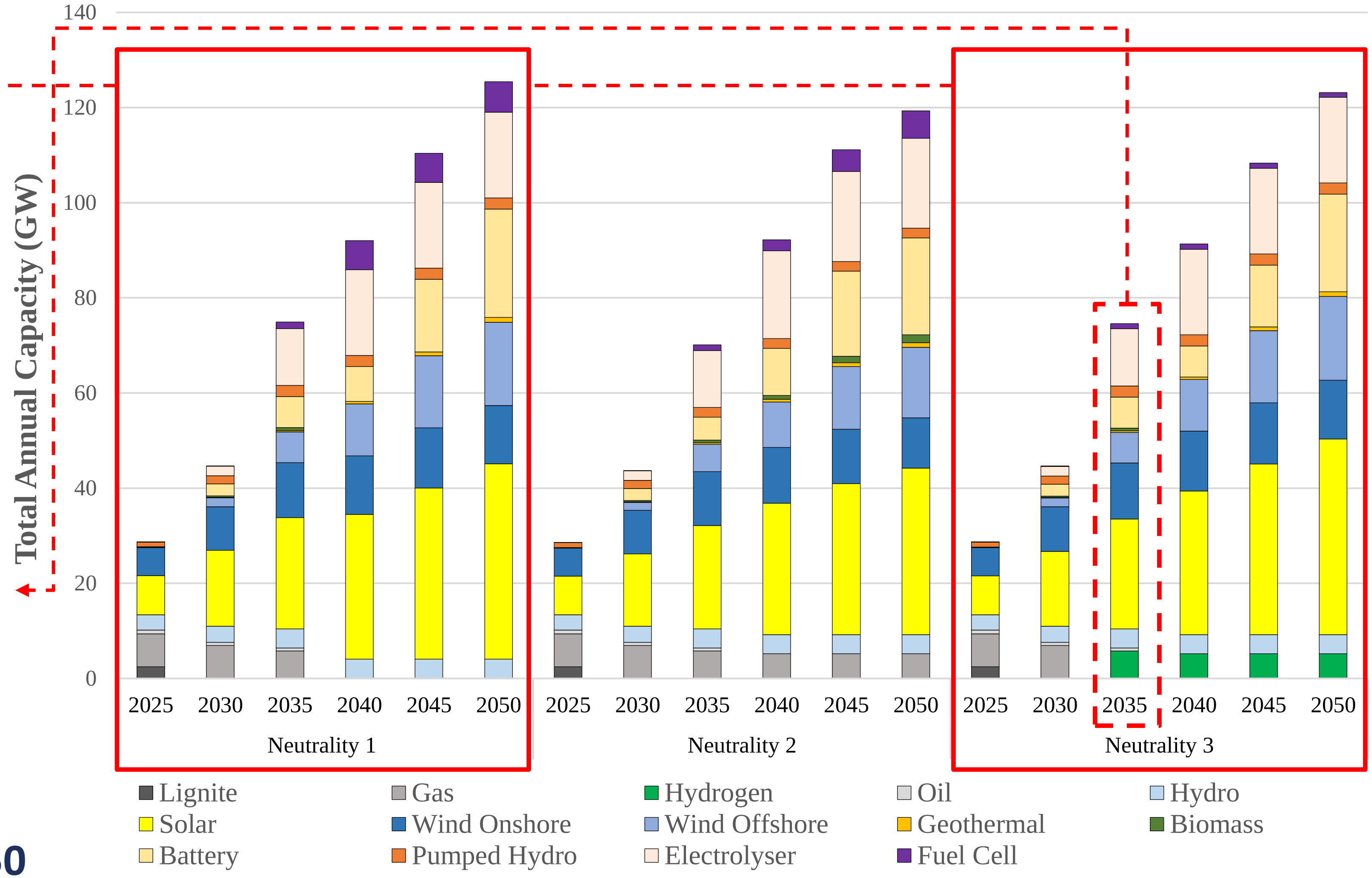
2030: ~27 GW VRE
2040: ~54 GW VRE
2050: ~**71 GW** VRE

NECP target: **69.5 GW**

Neutrality 1 and **Neutrality 3** scenarios …

… **result** in the **achievement** of the **national VRE capacity targets** by **2050**

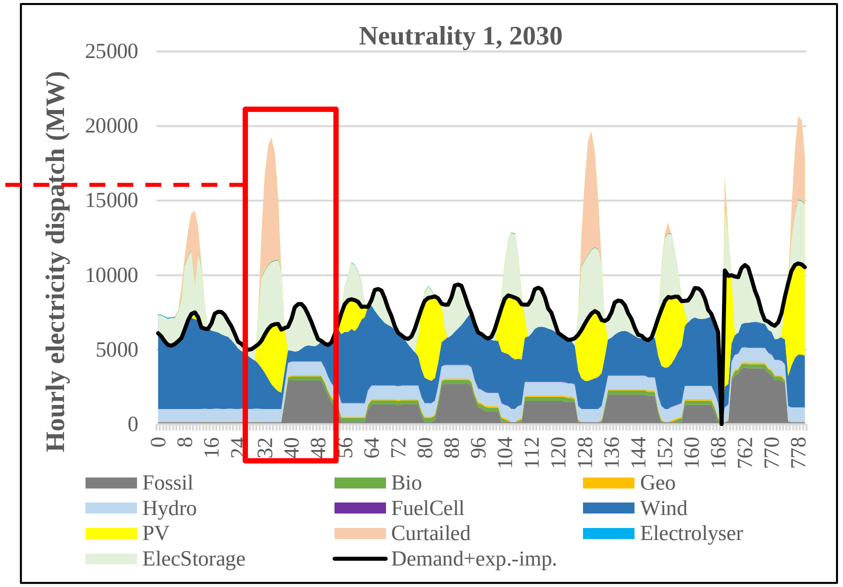
Long-term capacity planning prior to flexibility assessment

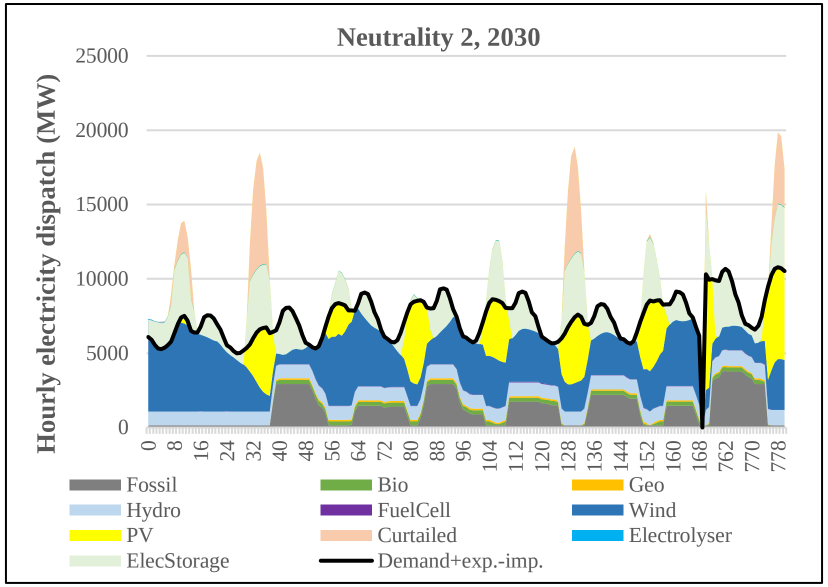


FlexTool **Flexibility assessment for 2030**

Results (2/15)

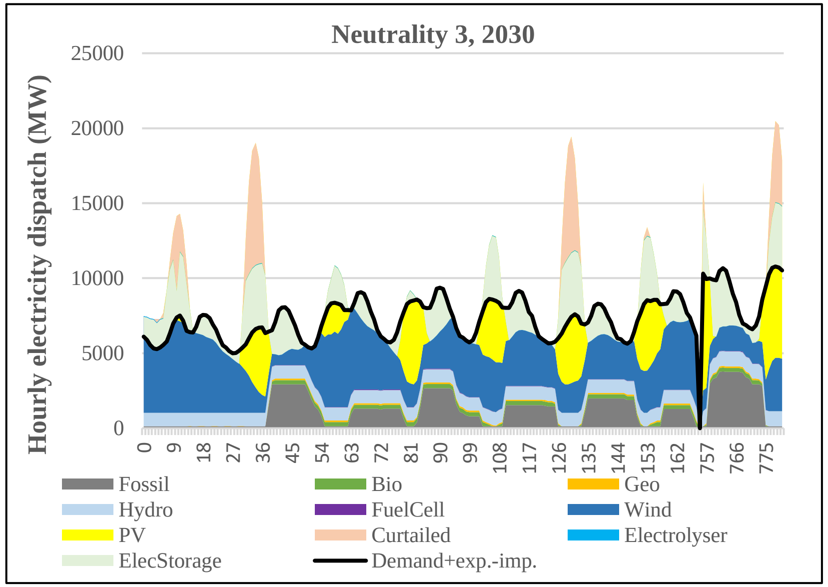
Daily dispatch





The flexibility assessment results are **similar** in **2030** since the decarbonisation pathways do not significantly differ by then.

Scenario	Peak net load (MW)	Curtailment (% of VRE gen.)	Loss of load (% of annual demand)
“Neutrality 1”	8,182	8.9	0
“Neutrality 2”	8,195	7.7	0
“Neutrality 3”	8,176	8.7	0

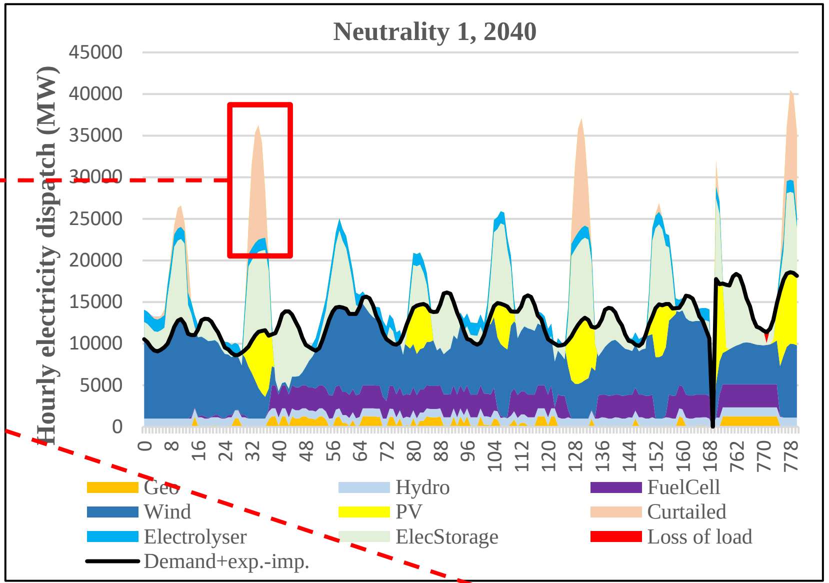


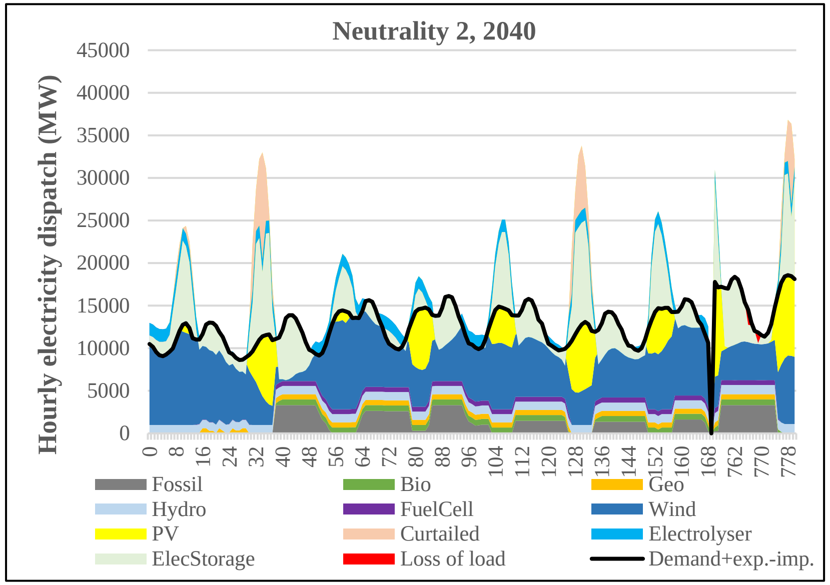
FlexTool **Flexibility assessment for 2040**

Results (3/15)

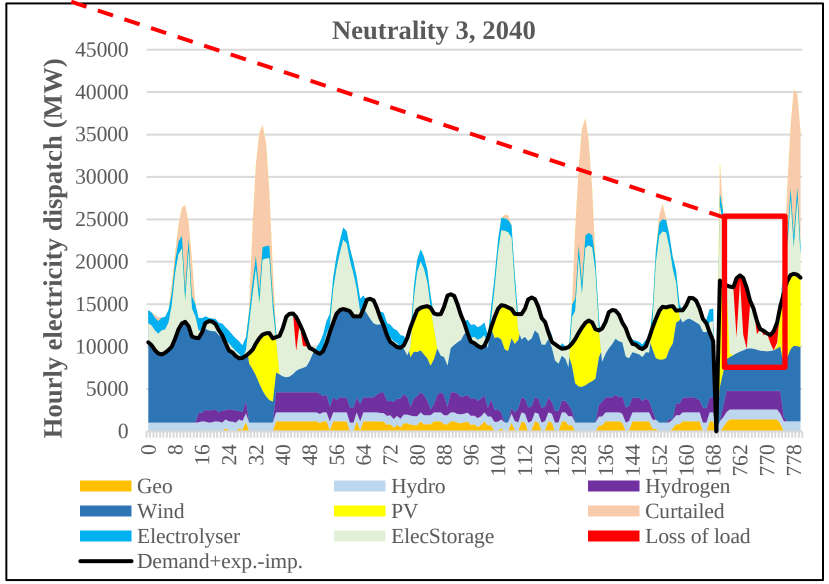
Curtailment

Losses of load are mainly detected in "***Neutrality 3***".





Scenario	Peak net load (MW)	Curtailment (% of VRE gen.)	Loss of load (% of annual demand)
"Neutrality 1"	12,635	6.9	0.08
"Neutrality 2"	13,117	4.1	0.13
"Neutrality 3"	12,555	9.3	1.42



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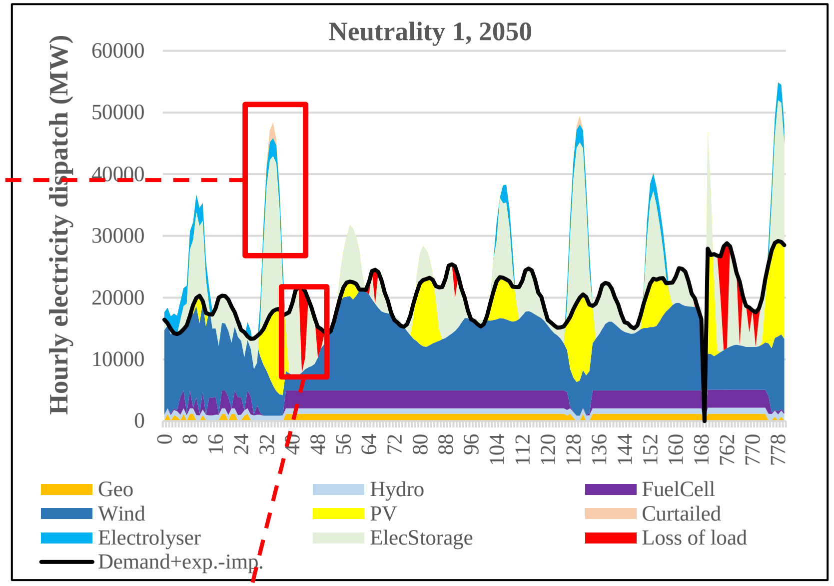
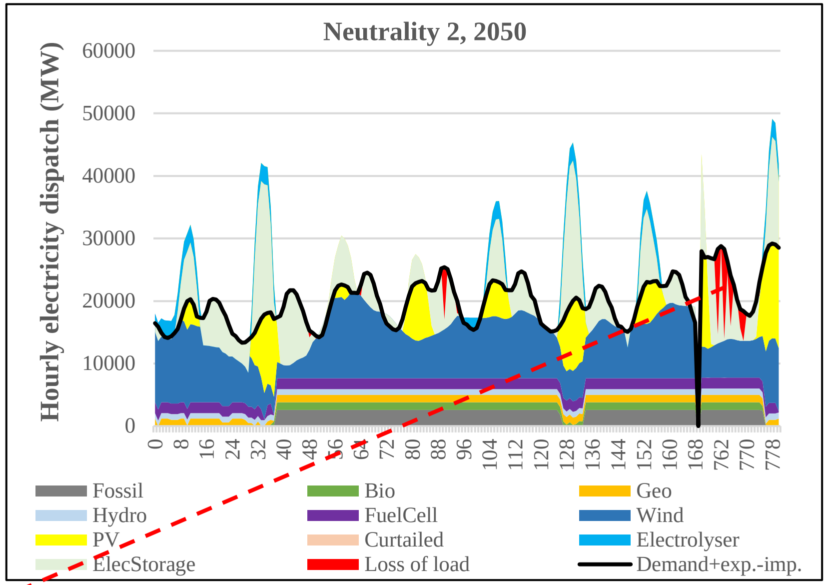
FlexTool

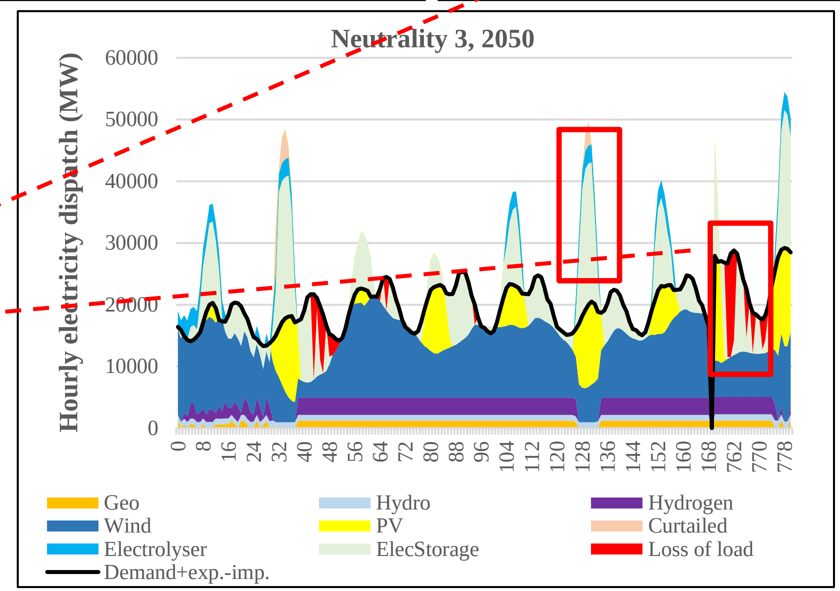
Flexibility assessment for 2050

Results (4/15)

- Curtailment is reduced towards **2050** due to the increased capacity of electricity storage and electrolysers.
- Losses of load are noticeable in all three scenarios.







Scenario	Peak net load (MW)	Curtailment (% of VRE gen.)	Loss of load (% of annual demand)
"Neutrality 1"	21,073	0.3	2.81
"Neutrality 2"	22,086	0	1.59
"Neutrality 3"	20,947	0.8	3.17

Results (5/15)

Insights from the flexibility assessment (dispatch mode): Additional **flexibility and capacity** is required after **2030** to prevent **loss of load**.

Considering the above ➔ FlexTool was used in **investment mode** to cover the arisen flexibility issues.

"Neutrality-Flex" scenarios	Peak net load (MW)	Curtailment (% of VRE gen.)	Loss of load (% of annual demand)
"Neutrality 1-2050"	20,114	1	0
"Neutrality 2-2050"	21,324	0.2	0
"Neutrality 3-2050"	19,873	1	0

Investment mode: The **VRE** and **storage capacity** additions eliminate loss of load and significantly decrease peak net load (~1GW across all scenarios) in 2050.

A **second round of runs** incorporating the flexibility insights in terms of additional investments ("*Neutrality-Flex*" scenarios) is performed using **OSeMOSYS-GR**.

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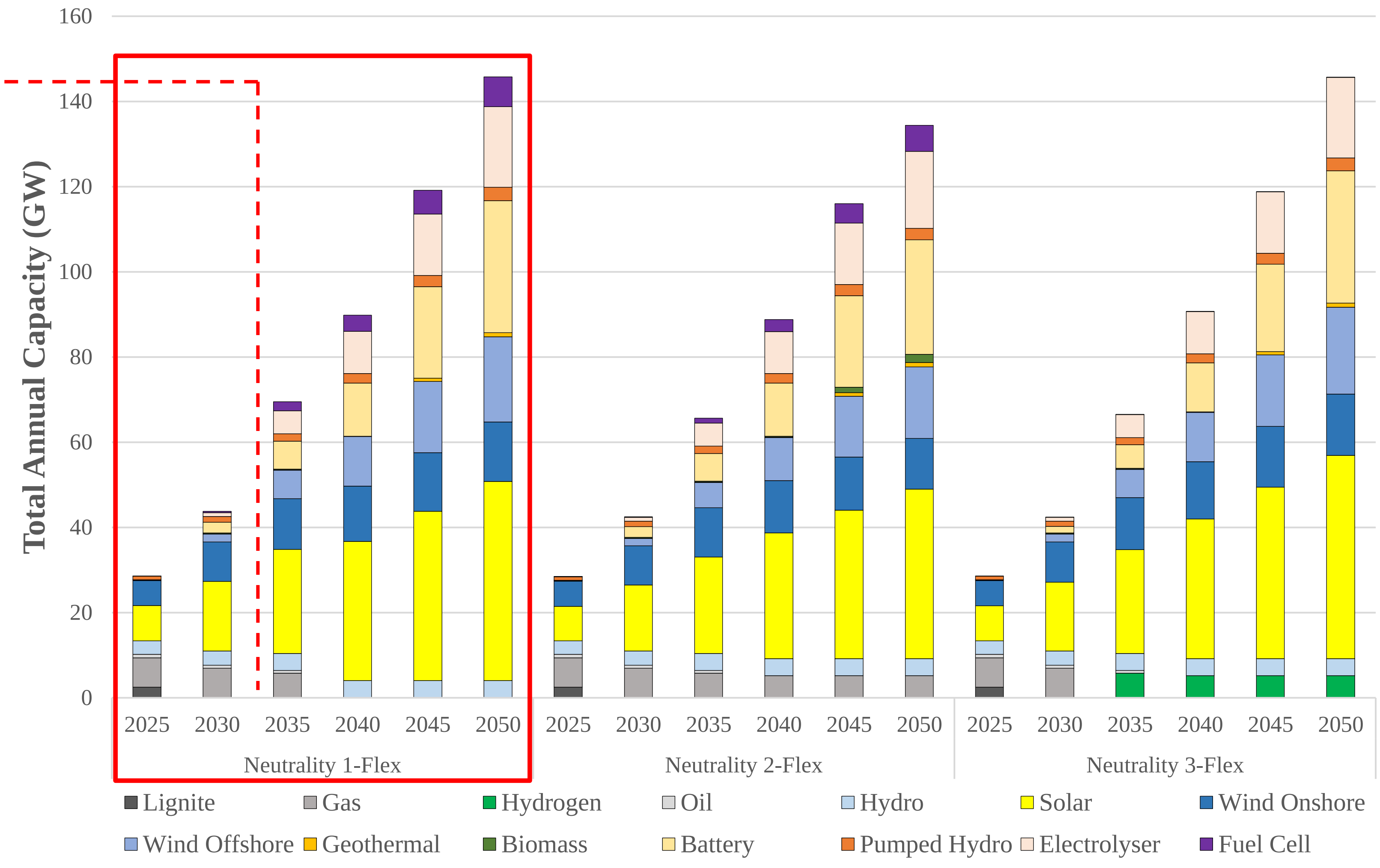
Results (6/15)

Neutrality 1-Flex scenario allows the phaseout of natural gas by **2033**.

Long-term capacity planning after flexibility assessment



Results (7/15)

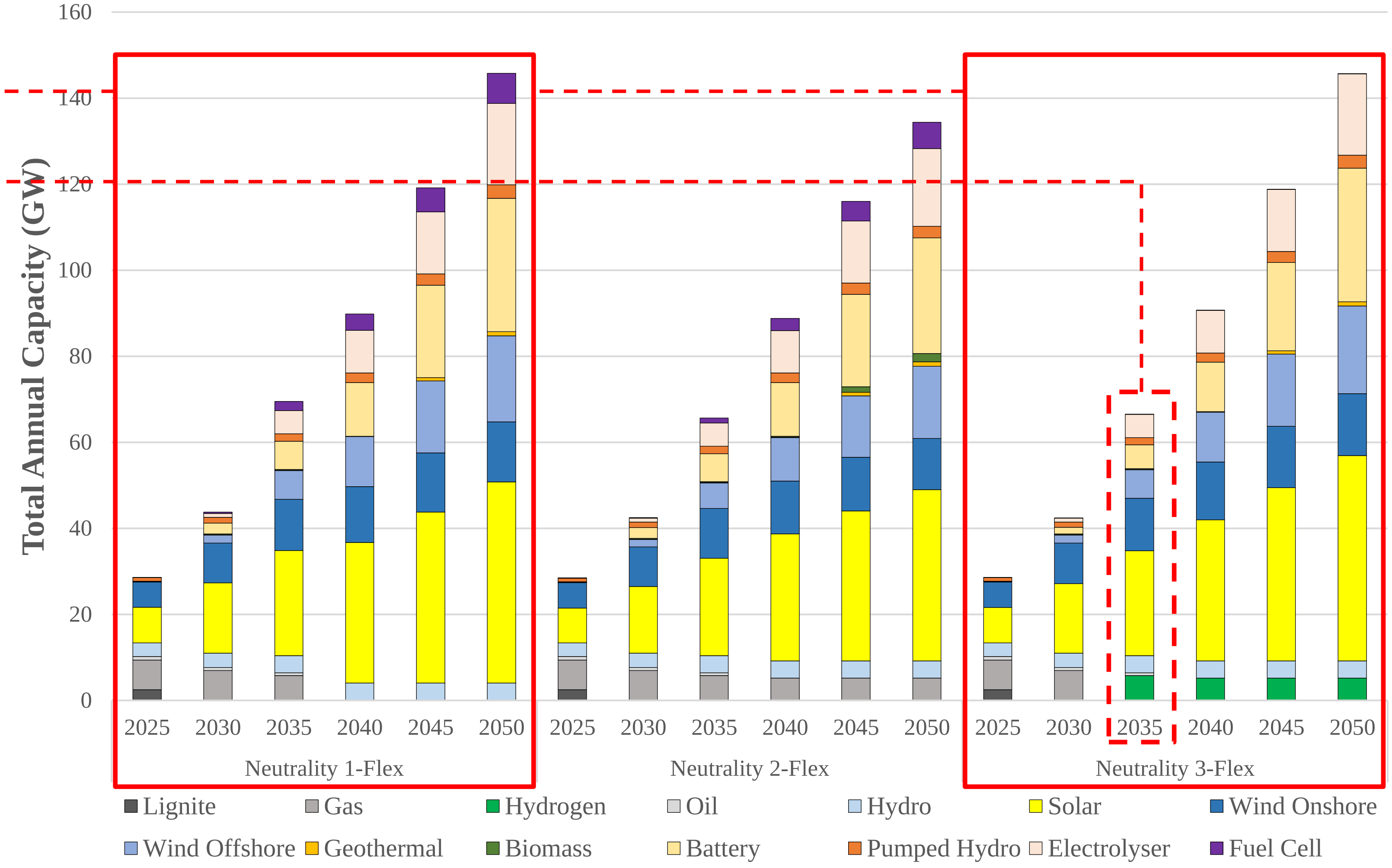
2030: ~27 GW VRE
2040: ~57-58 GW VRE
2050: **~81-82.5 GW** VRE

NECP target: 69.5 GW

Neutrality 1-Flex and **Neutrality 3-Flex** scenarios ...

... overshoot the NECP target by 11.5-13.0 GW

Long-term capacity planning after flexibility assessment



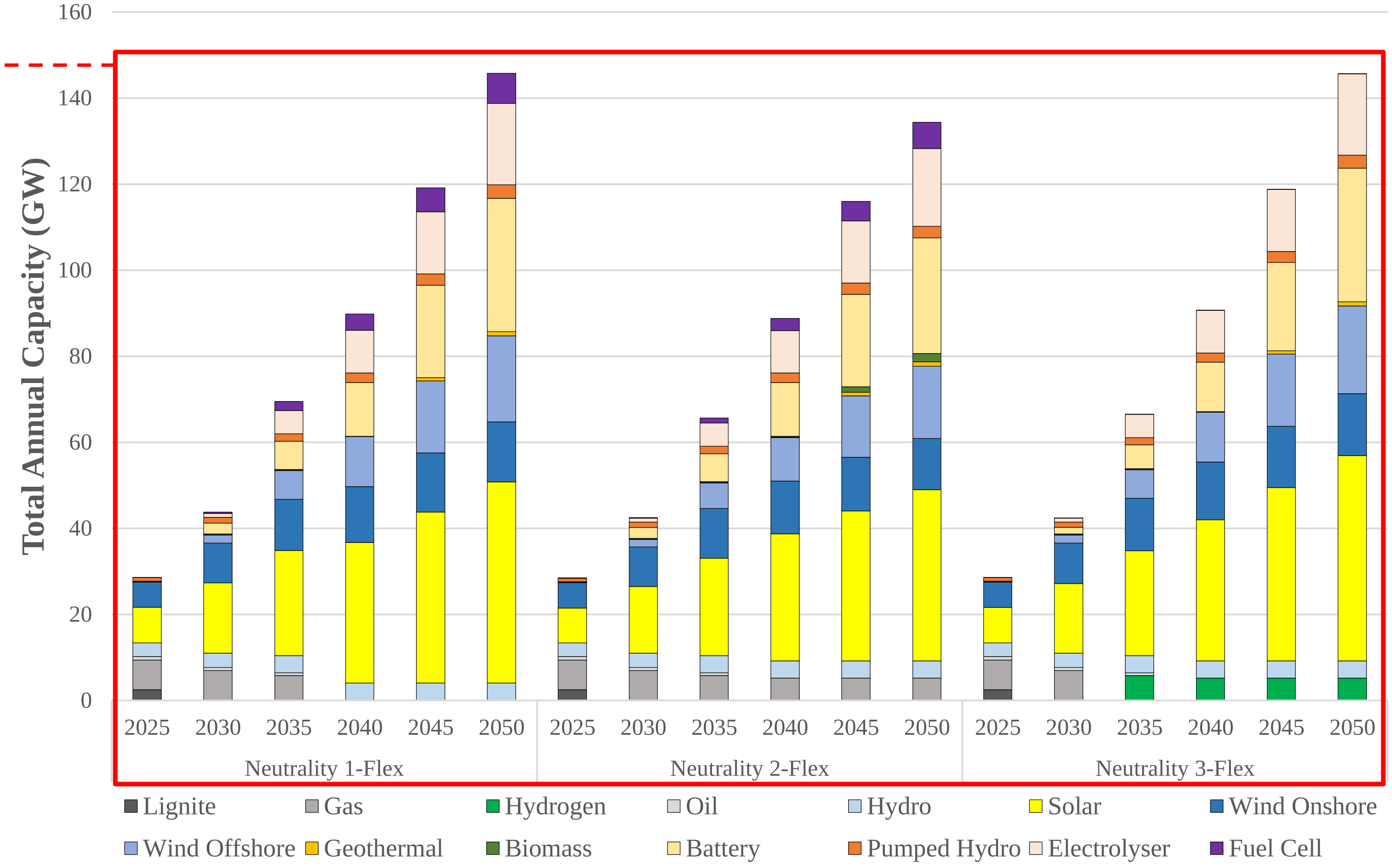
Results (8/15)

Battery & **pumped storage** capacity grows to **29.5-34.1 GW** by **2050**

Electrolyser capacity grows to **18.1-18.9 GW** by **2050**

Total capacity of **flexibility solutions** amounts to **47.6-53 GW** by **2050**

Long-term capacity planning after flexibility assessment



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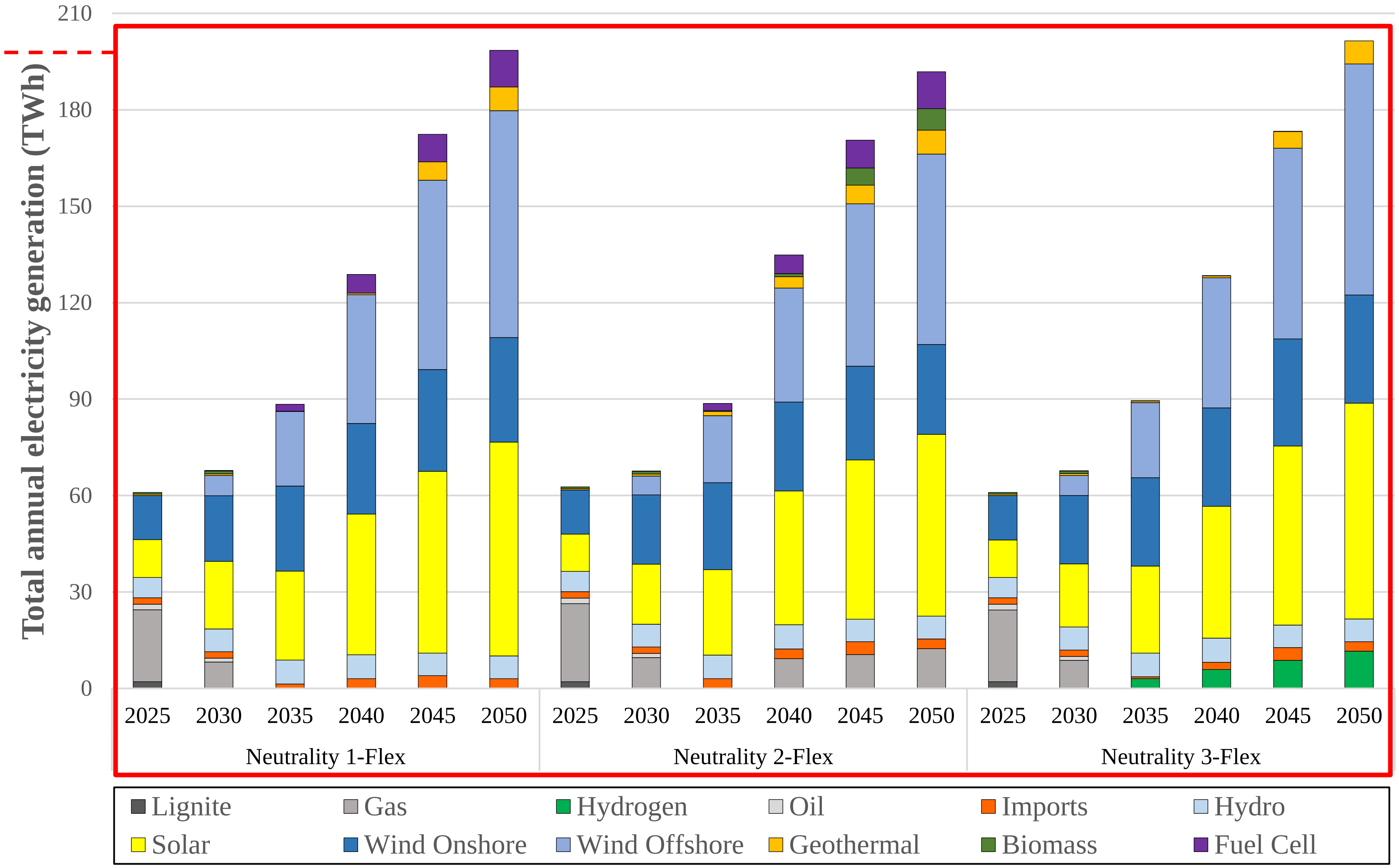
OSeMOSYS-GR Linear Optimization Energy Planning Model

Results (9/15)

2030: ~81-83% of total annual power generation from RES and hydrogen

NECP target: **81.5%**

Long-term capacity planning after flexibility assessment



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OSeMOSYS-GR
Linear Optimization Energy Planning Model

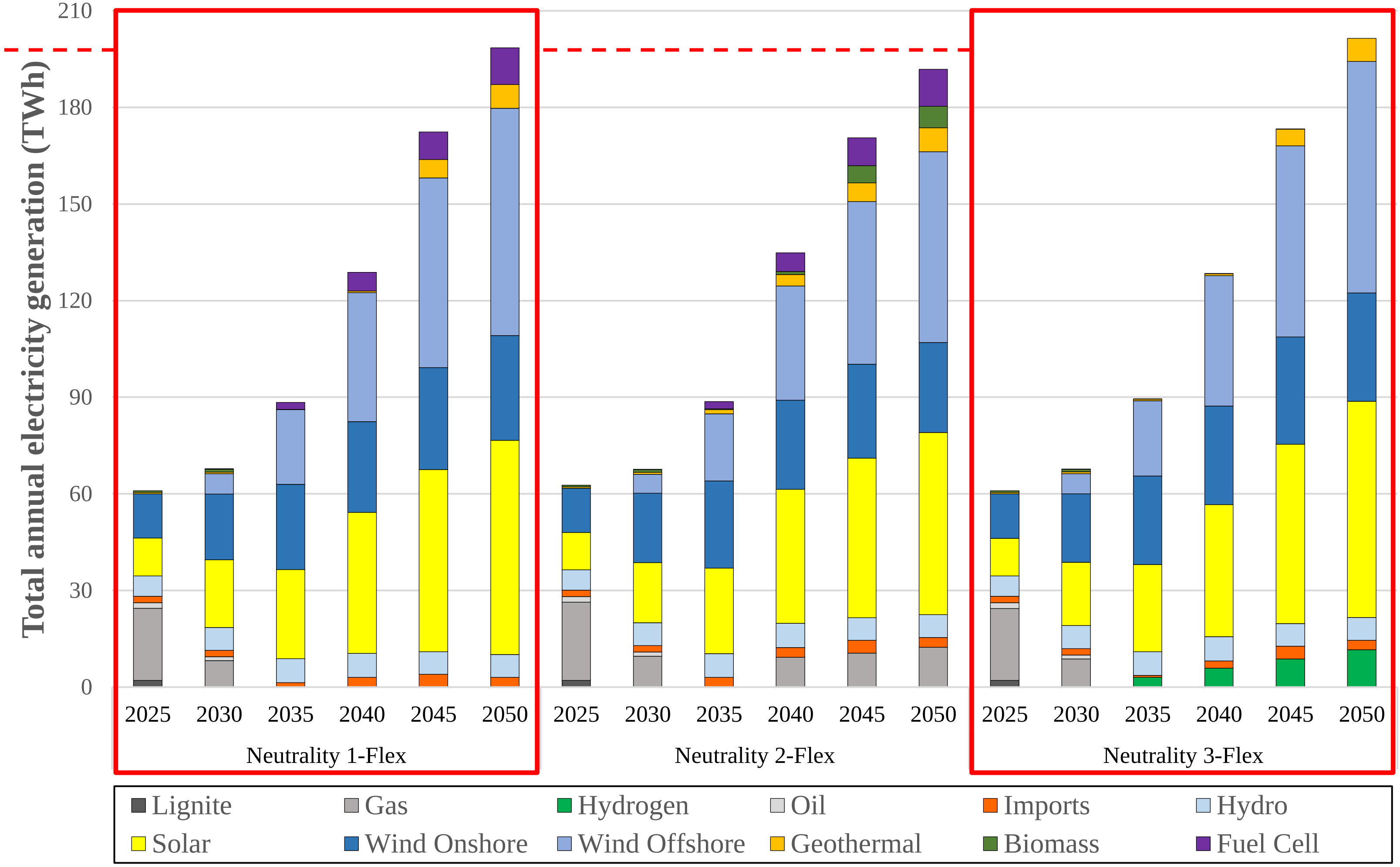
Results (10/15)

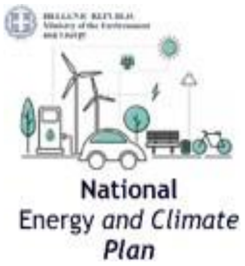
Long-term capacity planning after flexibility assessment

Neutrality 1-Flex and **Neutrality 3-Flex** scenarios

2050: ~98.5% of total annual power generation from RES and hydrogen

NECP target: **98.3%**





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Linear Optimization Energy Planning Model

Results (11/15)

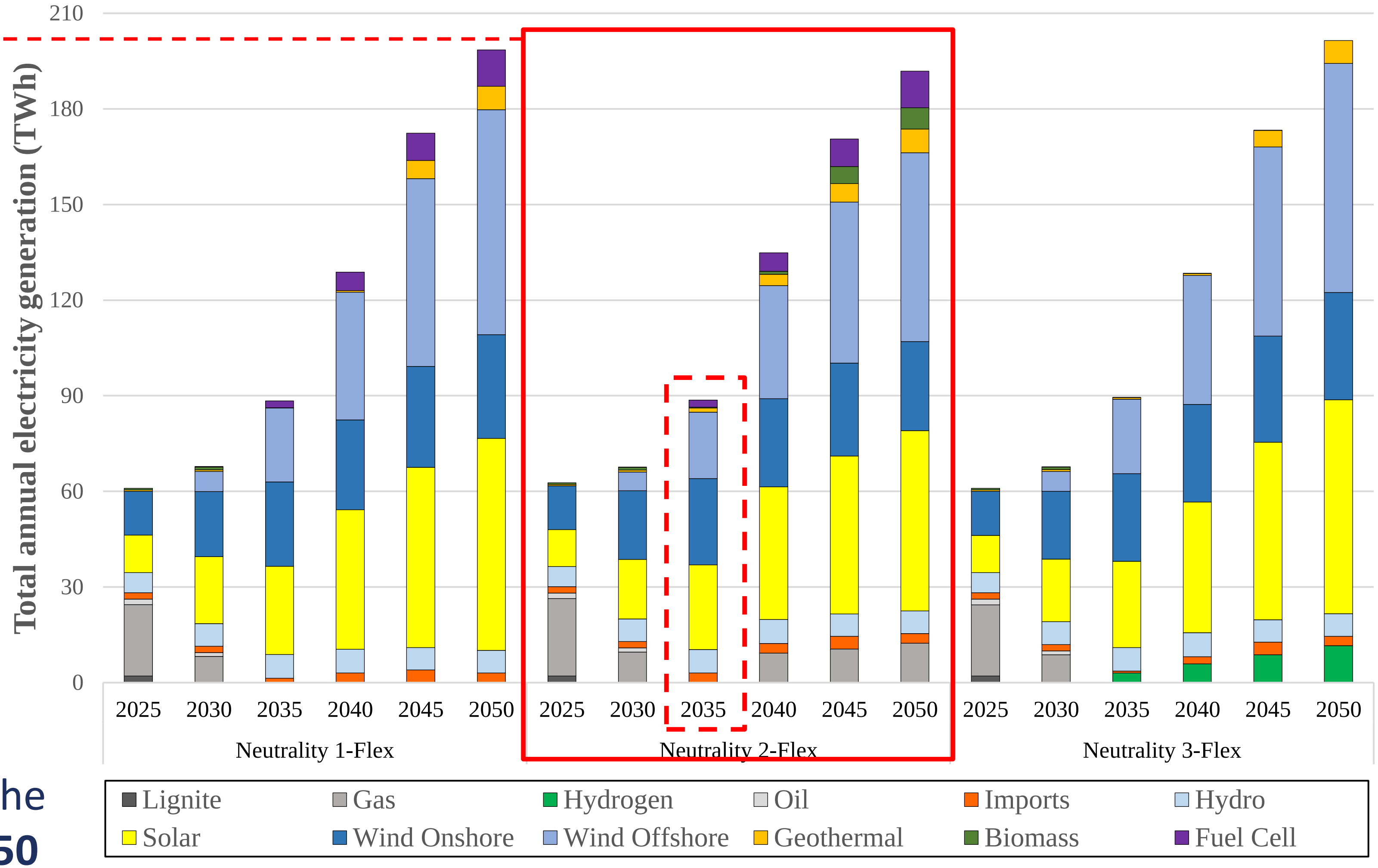
Neutrality 2-Flex scenario …

2050: ~92% of total annual power generation from RES and hydrogen

NECP target: **98.3%**

… **cannot result** in the **achievement** of the **national RES penetration targets** by **2050**

Long-term capacity planning after flexibility assessment



Results (12/15)

Flexibility solutions provided by Flextool investment mode → Feasible system sizing

Electricity generation (TWh)	2030	2035	2040	2045	2050
"Neutrality 1"	78.8	106	131	159.8	177.9
"Neutrality 1-Flex"	67.8	88.4	128.8	172.4	198.5
"Neutrality 2"	76.6	105.1	135	159.4	174.5
"Neutrality 2-Flex"	67.7	88.6	134.9	170.6	191.8
"Neutrality 3"	78.7	103	131.1	160.1	178.7
"Neutrality 3-Flex"	67.7	89.5	128.4	173.2	201.4

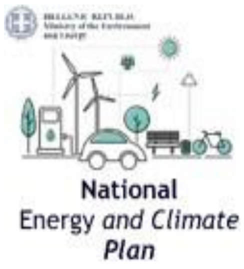
Curtailment reduction → 2040

Loss of load reduction → 2050

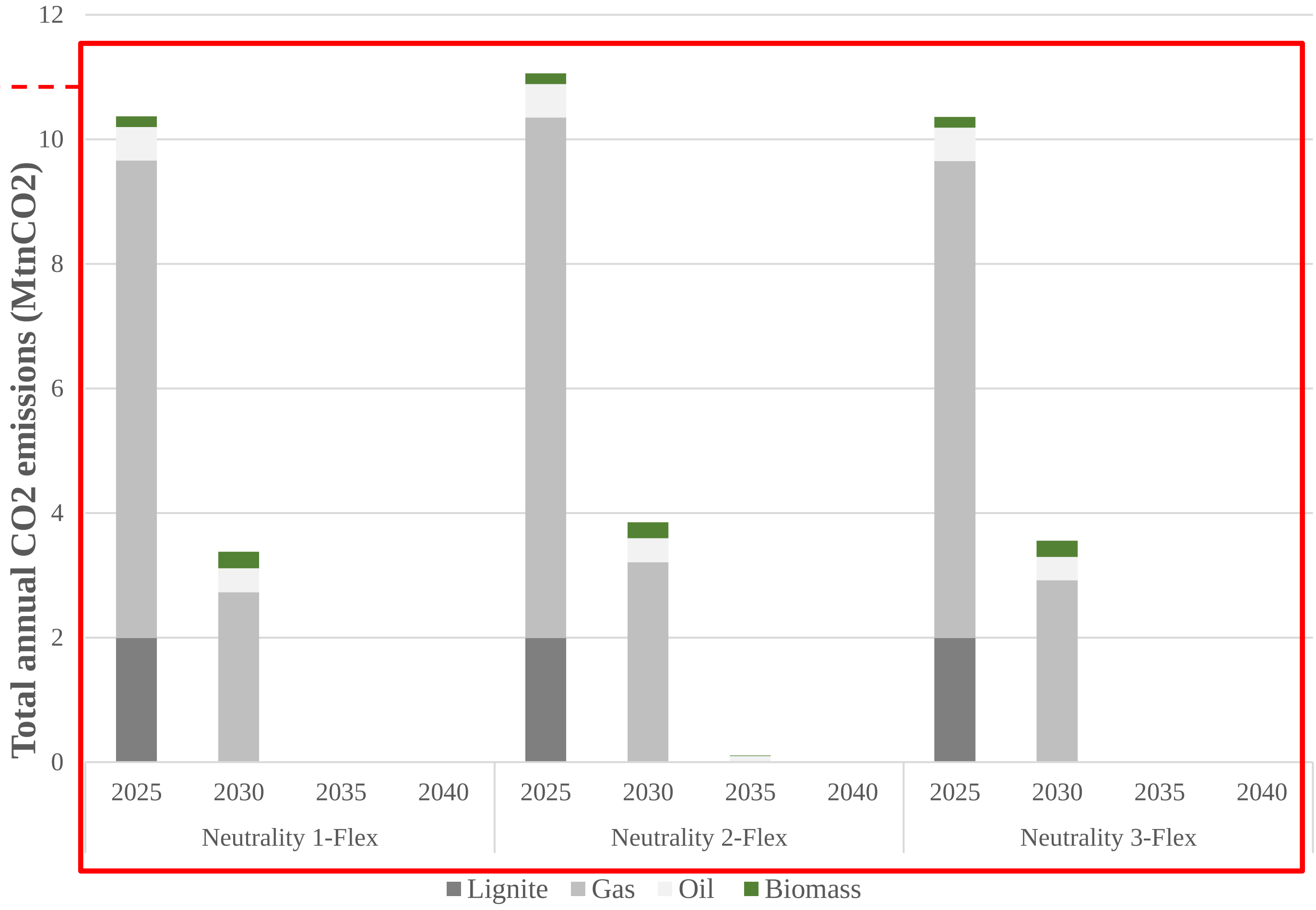
Results (13/15)

The CO2 emission reduction by **2030** compared to the 2005 levels is **93.4-94.2%** in the "*Neutrality-Flex*" scenarios.

NECP target: **89.7%**



CO2 emissions

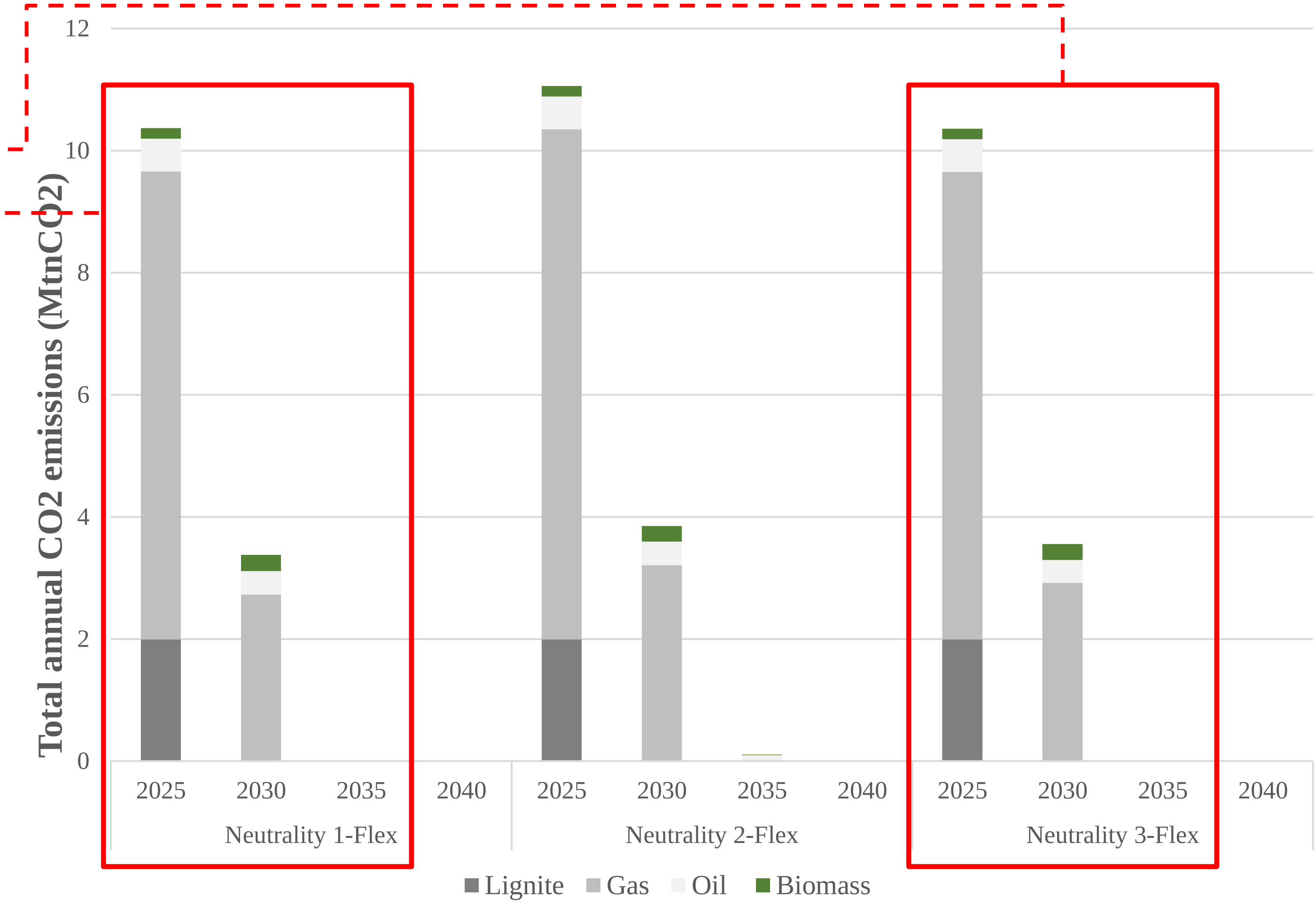


Results (14/15)

Neutrality 1-Flex and **Neutrality 3-Flex** scenarios ...

... **result** in the **achievement** of the **carbon neutrality target** by **2035**, **five years earlier** than the **NECP target (2040).**

CO_2 emissions



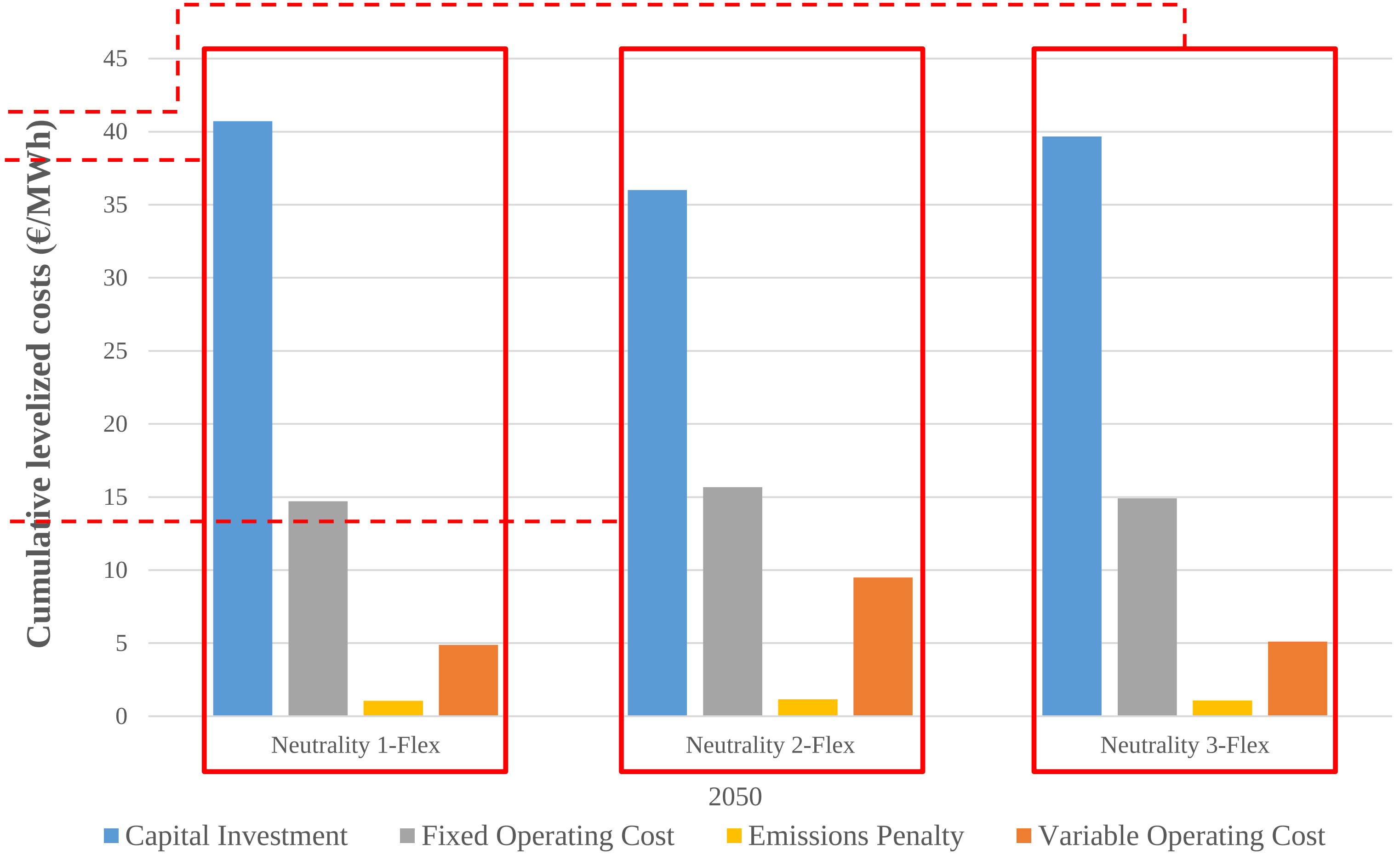
Results (15/15)

Neutrality 1-Flex and Neutrality 3-Flex: larger capital investment requirements (**40.7** and **39.7 €/MWh**) due to higher adoption rate of VRE and storage

Neutrality 2-Flex: higher variable operating cost expenditures (**9.5 €/MWh**) due to continuation of gas-fired electricity generation

All scenarios: similar total levelized cost **(60.8-62.3 €/MWh)**

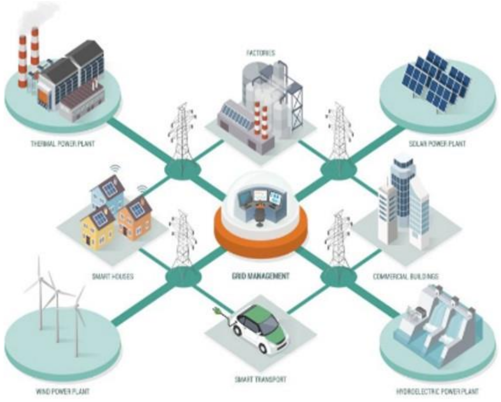
Costs



Outline

We see that ….(1/3)

…..exploring long-term decarbonisation pathways should **combine long-term capacity planning** with **short-term operational assessment** to provide feasible solutions



We see that ….(2/3)

…..there is path dependency on natural gas in Greece **at least until 2033**, which could either result in a **lock-in effect** or lead to **stranded assets (…risk that investments in new NG power plants may not be profitable)**

……switching to **hydrogen** can be an alternative for newly built natural gas power plants to avoid becoming stranded assets.

We see that ….(3/3)

……switching to **hydrogen** can be an alternative for newly built natural gas power plants to avoid becoming stranded assets.

……gas power plants that can switch to hydrogen could be prioritised in terms of fossil-fuel investments.

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Publication

Bidirectional soft-linking of a Capacity Expansion Model with a Production Cost Model to evaluate the feasibility of transition pathways to carbon neutrality in the power sector

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Energy system modelling
Flexibility assessment
OSeMOSYS
Production Cost Models

ABSTRACT

Energy system models have supported well-informed decision-making processes in Europe over the past few decades. However, the vision of climate neutrality requires an additional level of detail that comes with designing an energy system based on intermittent renewables; many models that have already been applied to explore decarbonisation pathways, though, lack the necessary time resolution to capture the integration of variable renewable energy, or are not open source, raising concerns of transparency and scientific reproducibility. In this article, we address this gap by introducing a bidirectional soft-linking approach between two open-source tools- the Capacity Expansion Model, OSeMOSYS, and the Production Cost Model, FlexTool- to generate long-term scenarios and evaluate their short-term feasibility. More specifically, our approach allows the optimisation of power sector investments over a 30-year period and its hourly operation at different snapshots, thus evaluating the integration of variable renewable energy more accurately. To test our approach, we apply it to the power sector in Greece, to study the capacity and flexibility requirements of the transition to carbon neutrality and the economic impacts of reducing reliance on gas. Our results provide insight into the conditions under which emission and electricity capacity and generation targets can be attained. Modelling outcomes demonstrate that there is a path dependency on natural gas in Greece at least until 2033, while there is potential to achieve carbon neutrality much earlier than 2040 if significant investments in renewable energy materialise. Finally, cost comparisons reveal that switching to hydrogen could be, not only an effective solution for new gas plants to avoid becoming stranded assets, but also the most economically efficient alternative for a green transition in the power sector.

ENCLUDE
Energy Citizens for Inclusive Decarbonization

IAM COMPACT

At high impact scientific journal

Status:
Under minor revision

Next steps & Further research (1/2)

Manias et al. (2024). Report on the decarbonization potential of energy citizenship at the national and the EU levels: Deliverable 5.4 Energy Citizens for Inclusive Decarbonization (ENCLUDE). Zenodo. https://doi.org/10.5281/zenodo.12686859


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ENCLUDE - Energy Citizens for Inclusive Decarbonization

Published July 8, 2024 | Version v1 | Project deliverable | Open

Report on the decarbonization potential of energy citizenship at the national and the EU levels: Deliverable 5.4 Energy Citizens for Inclusive Decarbonization (ENCLUDE)

Manias, Nikos[1]; van den Berg, Nicole J.[2]; Kleanthis, Nikos[1]; Fotopoulos, Dimitris[1]; Stavrakas, Vassilis[1]; van Vuuren, Detlef P.[2]; Flamos, Alexandros[1]

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2. Utrecht University, Heidelberglaan 8, 3584 CS Utrecht, The Netherlands

Efforts to address the contemporary climate and energy-related challenges towards a green, inclusive, and fair transition by 2050, require the empowerment and engagement of citizens and other societal actors, as has been duly acknowledged within the recent European Union's strategic and legislative frameworks. Citizens are anticipated to expand their role as self-consumers and contributors within energy communities, actively shaping alterations in the energy landscape, impacting both demand and supply.

ENCLUDE
Energy Citizens for Inclusive Decarbonization

Citizen preference-led energy system planning alternatives under various future-world evolutions: Coupling transformative scenario design with energy system modelling towards 100% renewable-based energy systems

Nikos Kleanthis, Vassilis Stavrakas*, Alexandros Flamos

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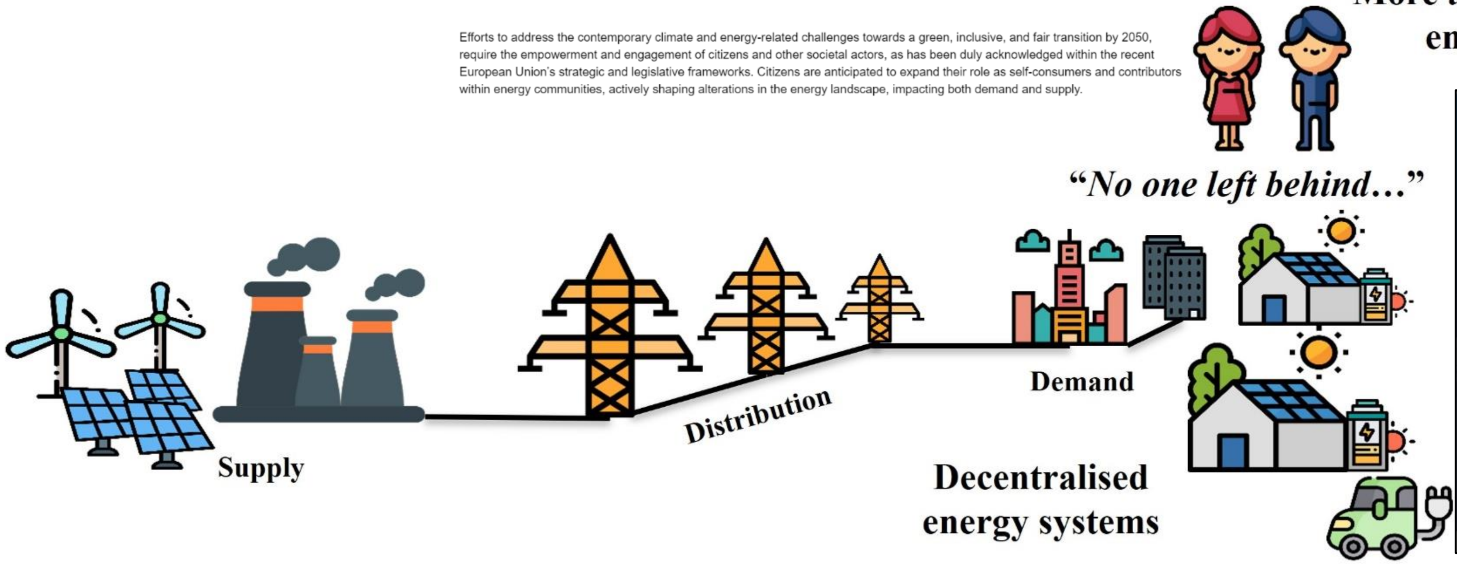
More active role of end-users



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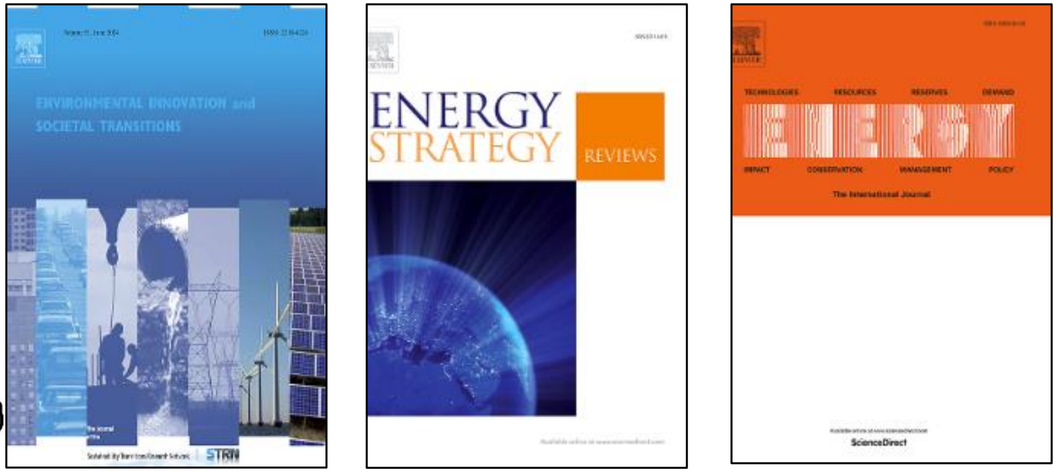

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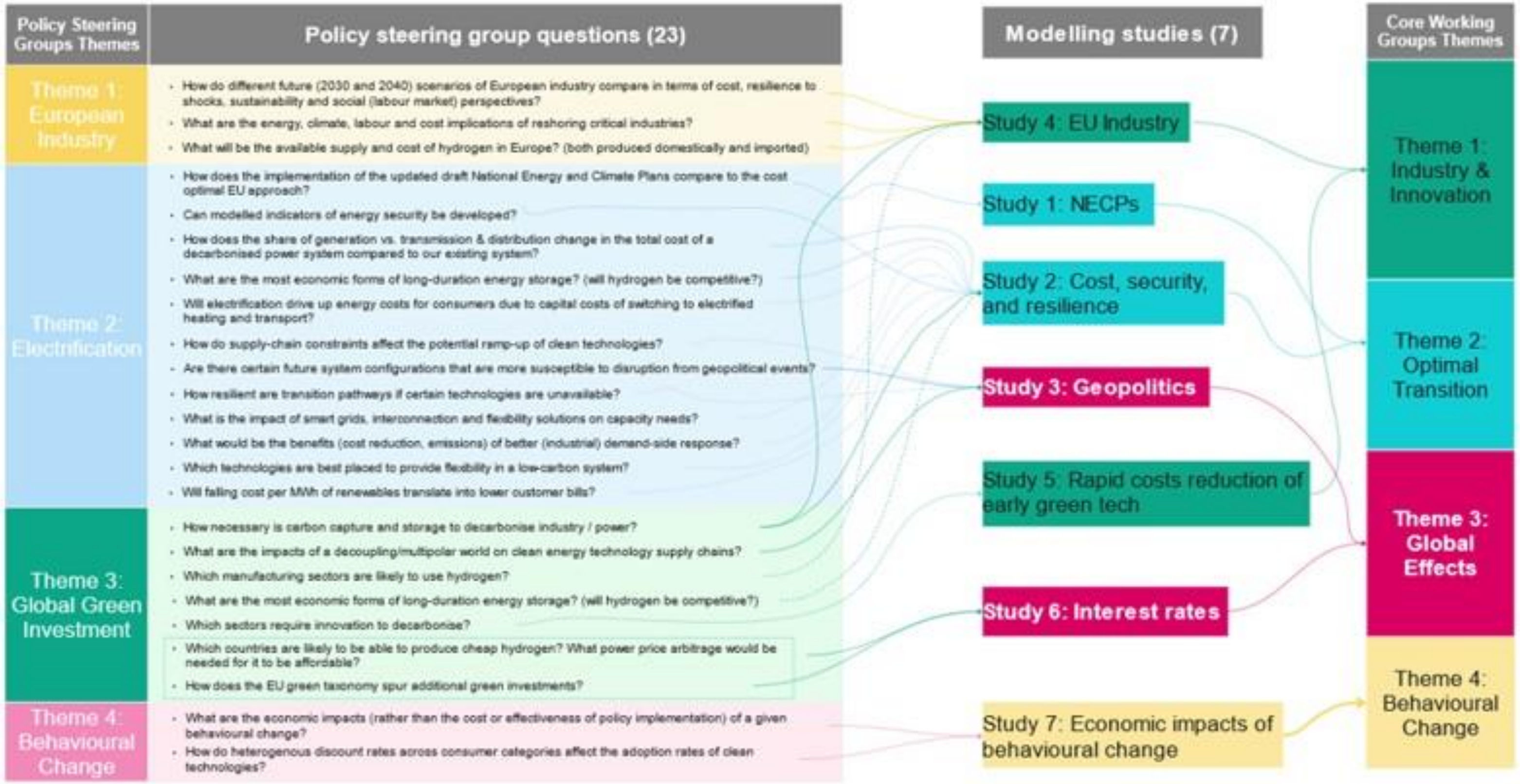
Next steps & Further research (2/2)



How do interest rates of different energy technologies influence decarbonisation pathways?

Contact us!

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ANY QUESTIONS?

Mr. Nikos Kleanthis, Dr. Vassilis Stavrakas,
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