PSI Center for Nuclear Engineering and Sciences
Center for Energy and Environmental Sciences

Multiple Perspectives on the Role of Nuclear in Energy Scenarios

Insights from the Global, European and Swiss energy systems analyses of PSI Laboratory for Energy Systems Analysis

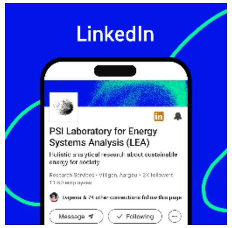
Dr. Evangelos Panos
Nuclear Energy Workshop , 04 April 2024

Laboratory for Energy Systems Analysis (Prof. R. McKenna)

Our **vision** is to be a leading authority for holistic scientific research relating to sustainable energy for society.

Our **mission** is to provide decision support, capacity building, awareness and education for diverse stakeholders.

Our **strategy** is to address global energy challenges with ground-breaking interdisciplinary research.

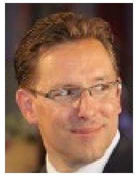


TA

Technology Assessment

Dr. Peter Burgherr

8 Scientists
2 Postdocs
4 PhDs



- Life cycle and sustainability analysis
- MCDA
- Internal / external costs
- Health impacts
- Comparative risk assessment

EE

Energy Economics

Dr. Evangelos Panos

5 Scientists
2 Postdocs
5 PhDs

- Energy technology development
- Scenario analysis
- Policies strategies for sustainable energy systems

RHR

Risk & Human Reliability

Dr. Vinh N. Dang

3 Scientists

- Human Reliability analysis
- Probabilistic safety assessment
- Critical infrastructure and resilience

ESA

Energy Systems Analysis

D-MAVT ETH

Prof. Dr. Russell McKenna

1 Scientist
1 Postdocs
6 PhDs

- Decentralised energy systems
- Energy demand
- Resource assessment
- Sector coupling

Integrated energy-economic systems analysis at PSI

We analyse **energy transition pathways** to identify technologies and policy strategies for sustainable, secure and resilient:

- Energy systems and markets
- Economy and society

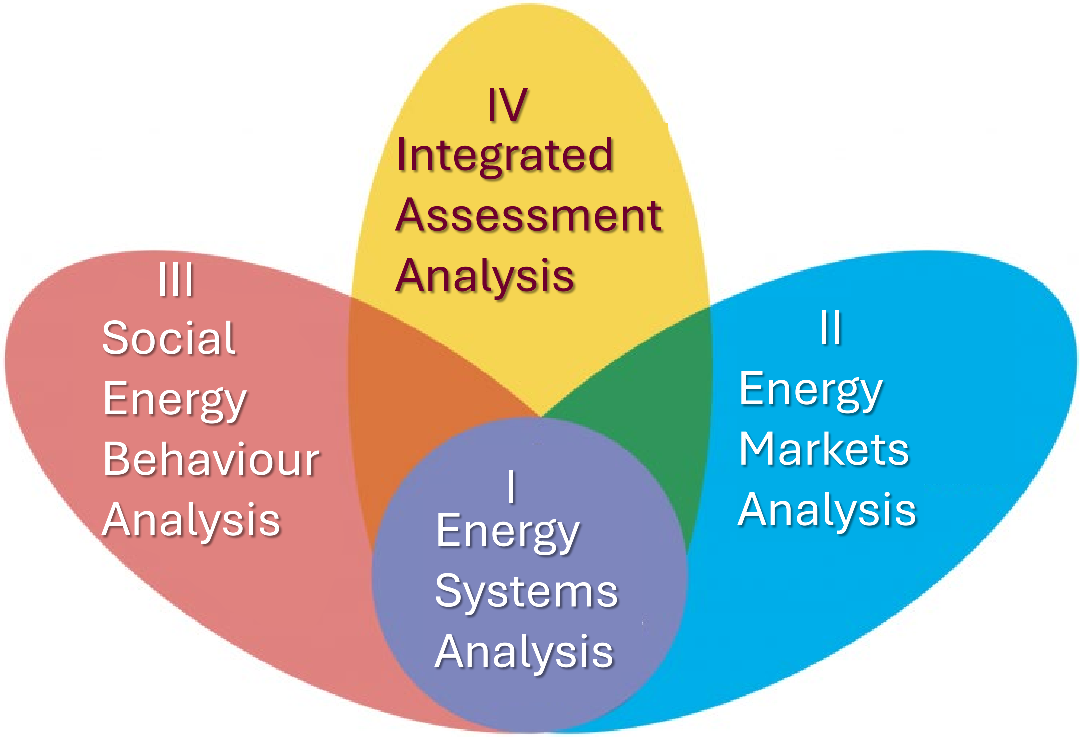
We use:

- **energy-economic models and analyses**
- **scenario techniques**

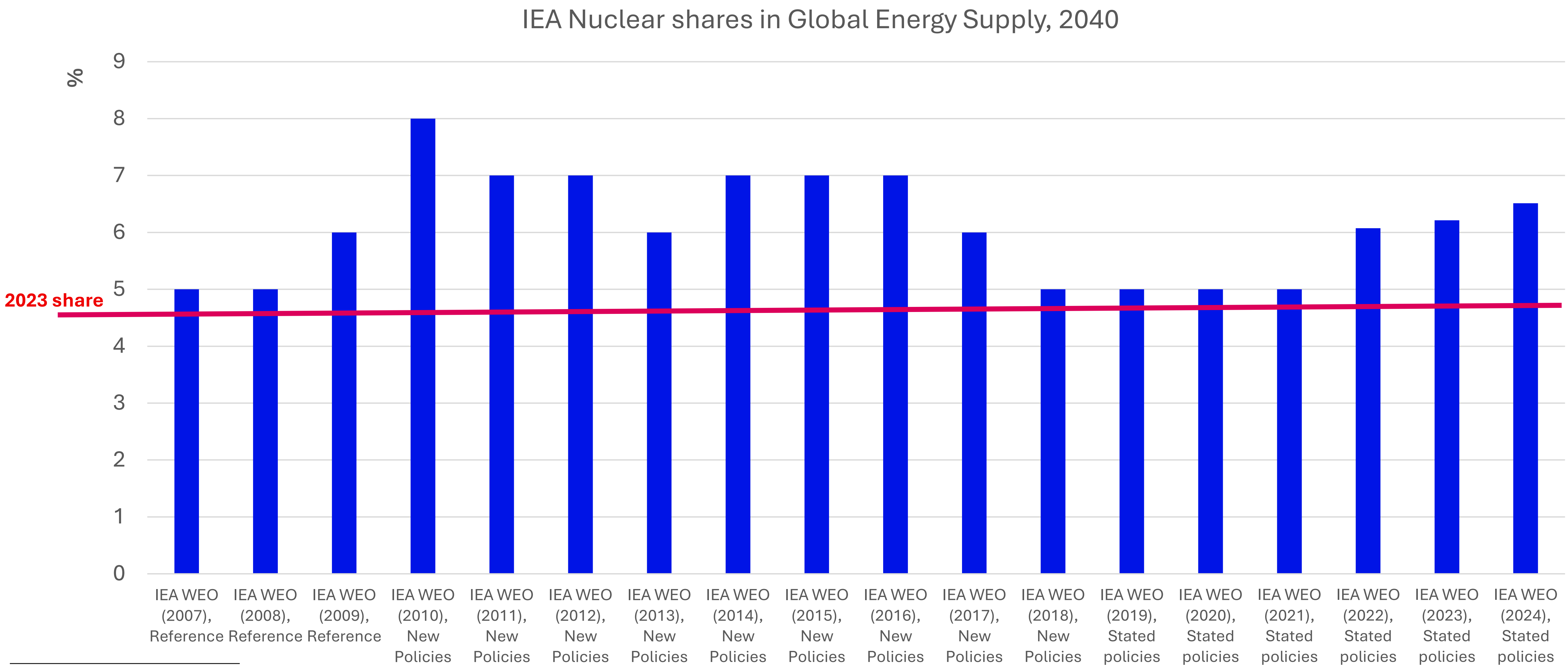
to explore the energy systems transformations

We collaborate with specialists in:

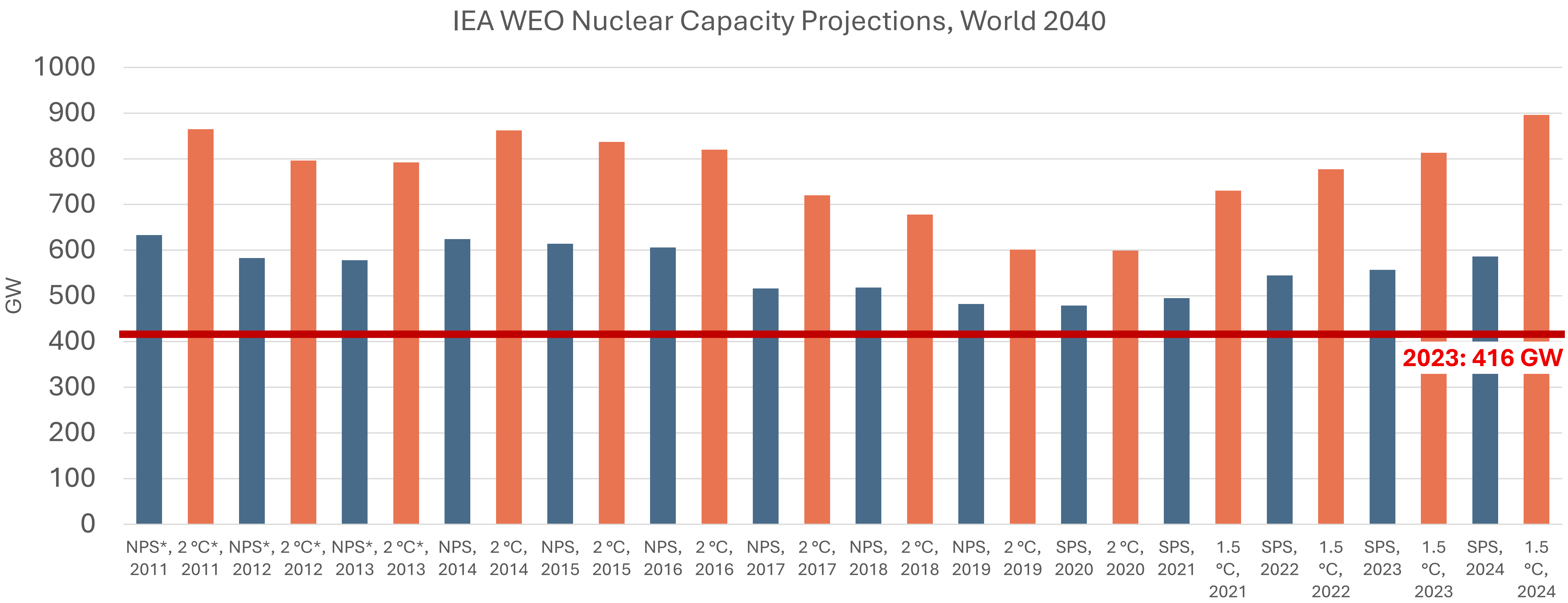
- Grids and sectoral analyses
- Social sciences and macroeconomic analyses



Energy Planning in a Shifting World



IEA WEO series (2007 – 2024)



IEA WEO series (2007 – 2024)

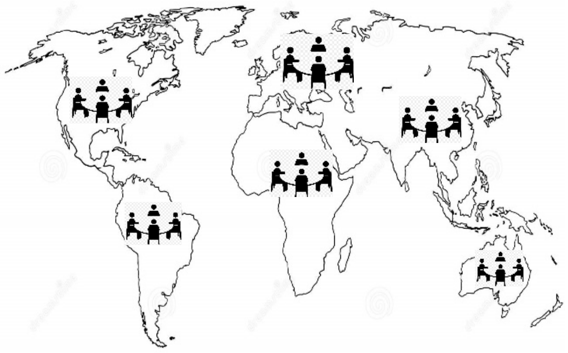
Three Worlds, One Atom:
Diverging Nuclear Features in WEC's Global Visions

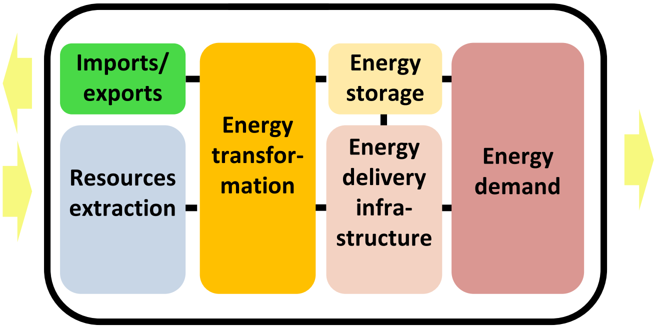
Global Energy Transitions: WEC Scenarios (2013 – 2019)

WEC is a UN-accredited energy body with 3000 members in 90 countries

The World Energy Scenarios are stakeholder-informed scenarios quantified by PSI

- are published every 3 years as flagship reports
- are highlights at the World Energy Congress (4000 delegates)





Definition of storylines in regional stakeholder workshops to identify energy transition challenges

Quantification with the Global Markal Model -GMM energy systems model of PSI

Launch of the report at World Energy Congress

Kober T., Panos, E. et al (2019)

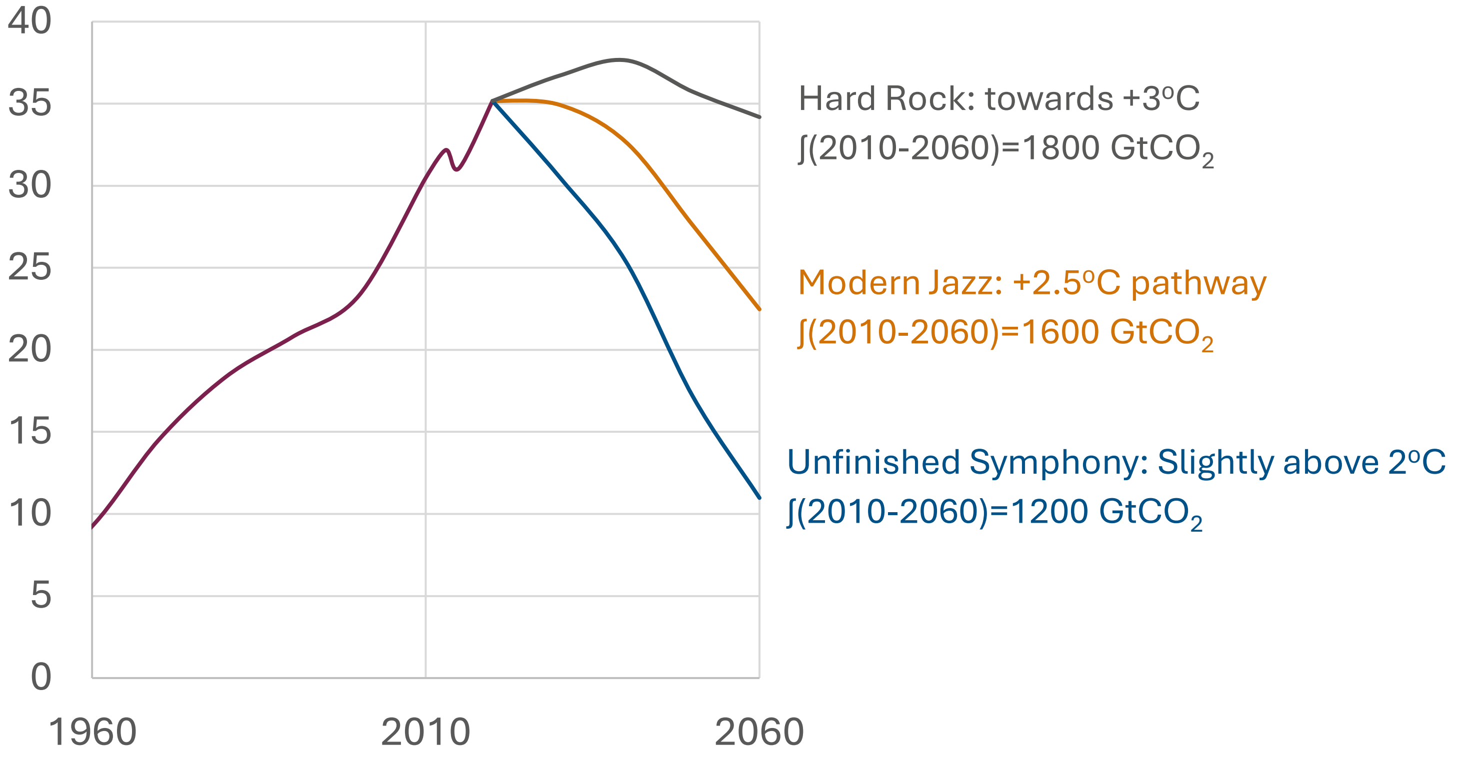
WEC scenarios storylines

Modern Jazz (market oriented)
- Market chooses technologies
- Technology innovation and digitalisation

Unfinished Symphony (regulation oriented)
- Strong policies focusing on sustainability
- Unified climate action

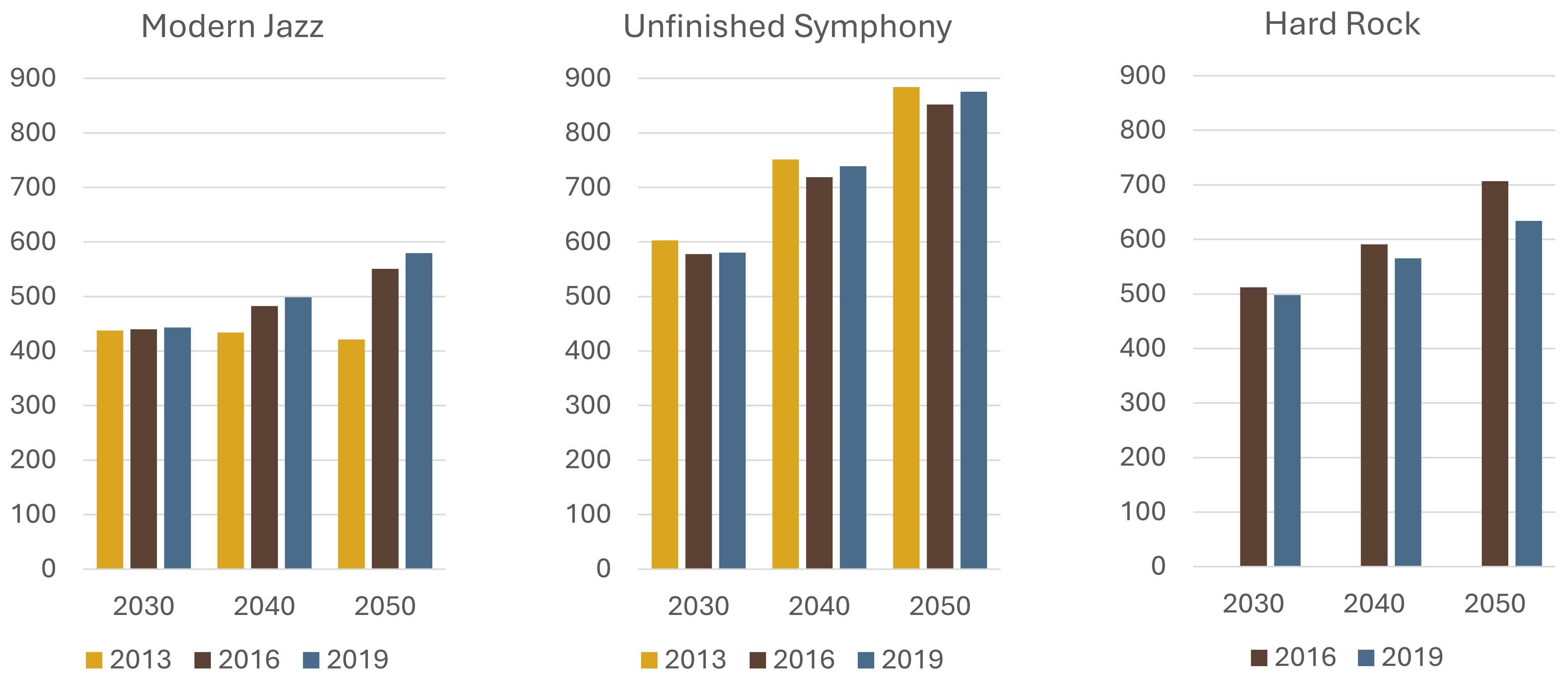
Hard Rock (fragmented policies)
- Low global cooperation
- Focus on energy security

WEC Results: CO_2 emissions from fuel combustion ($GtCO_2$/yr.)



Kober T., Panos, E. et al (2019)

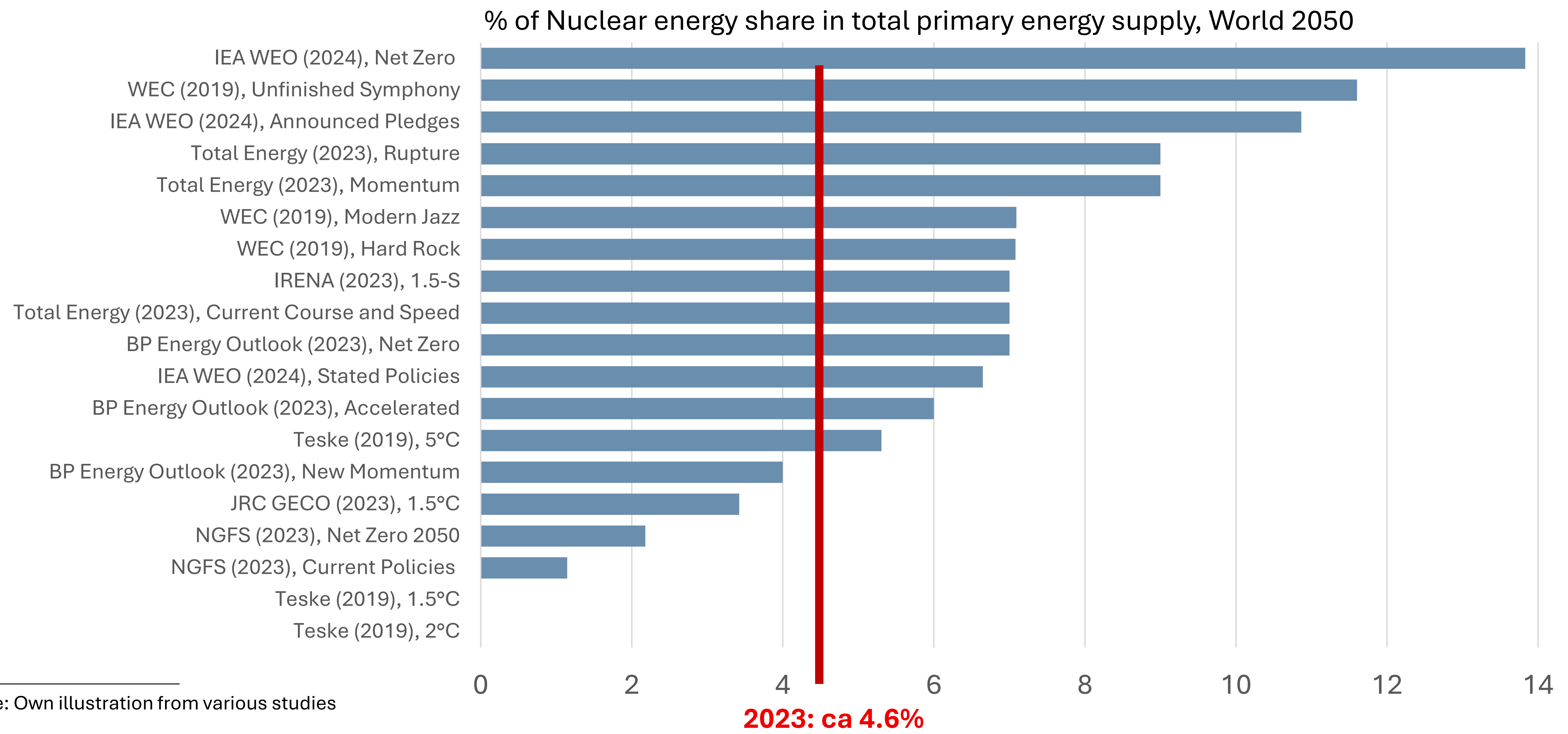
Global installed nuclear capacity in WEC scenarios series (GW/yr.)



In 2050, across all scenarios and years of the study:
EU31: 83 – 93 GW , USA: 100 – 120 GW, China: 138 – 283 GW , India: 50 – 129 GW

WEC scenarios reports (2013-2019)

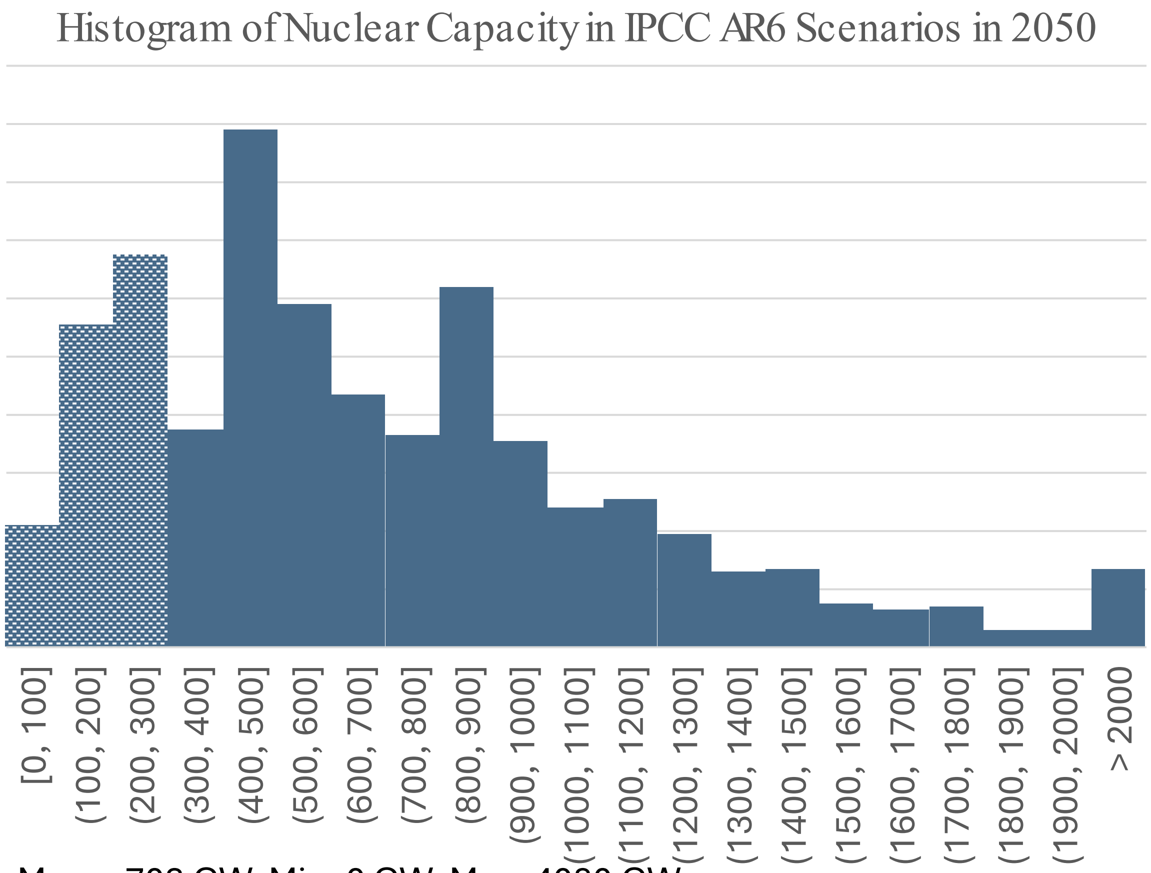
Stakeholder views are more cautious when it comes to nuclear deployment than normative model-based scenarios



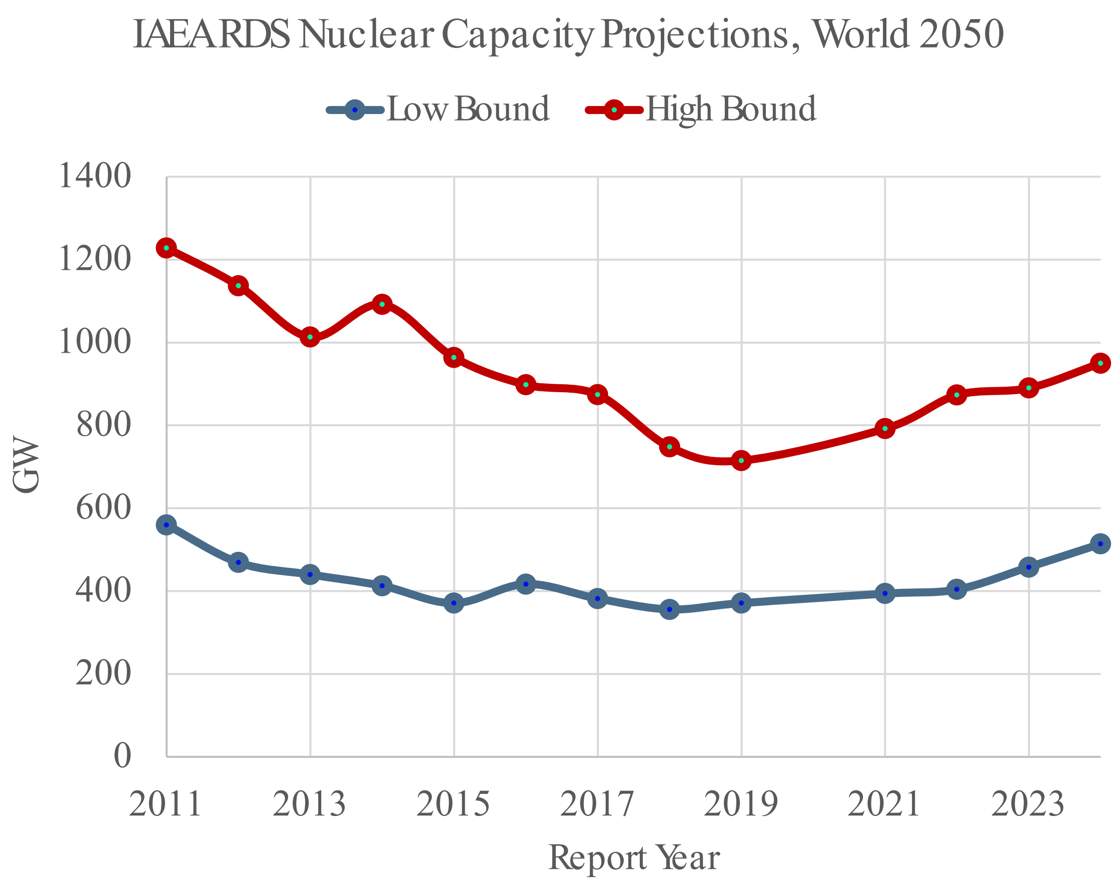
Source: Own illustration from various studies

Energy Futures in a World of Uncertainty: Where does Nuclear Stand?

IPCC AR6 vs IAEA reports: global nuclear capacity in 2050



Mean: 703 GW, Min: 0 GW, Max: 4080 GW
%scenarios with lower capacity in 2050 than today: 28%
%scenarios with higher capacity in 2050 than IAEA2024: 24%



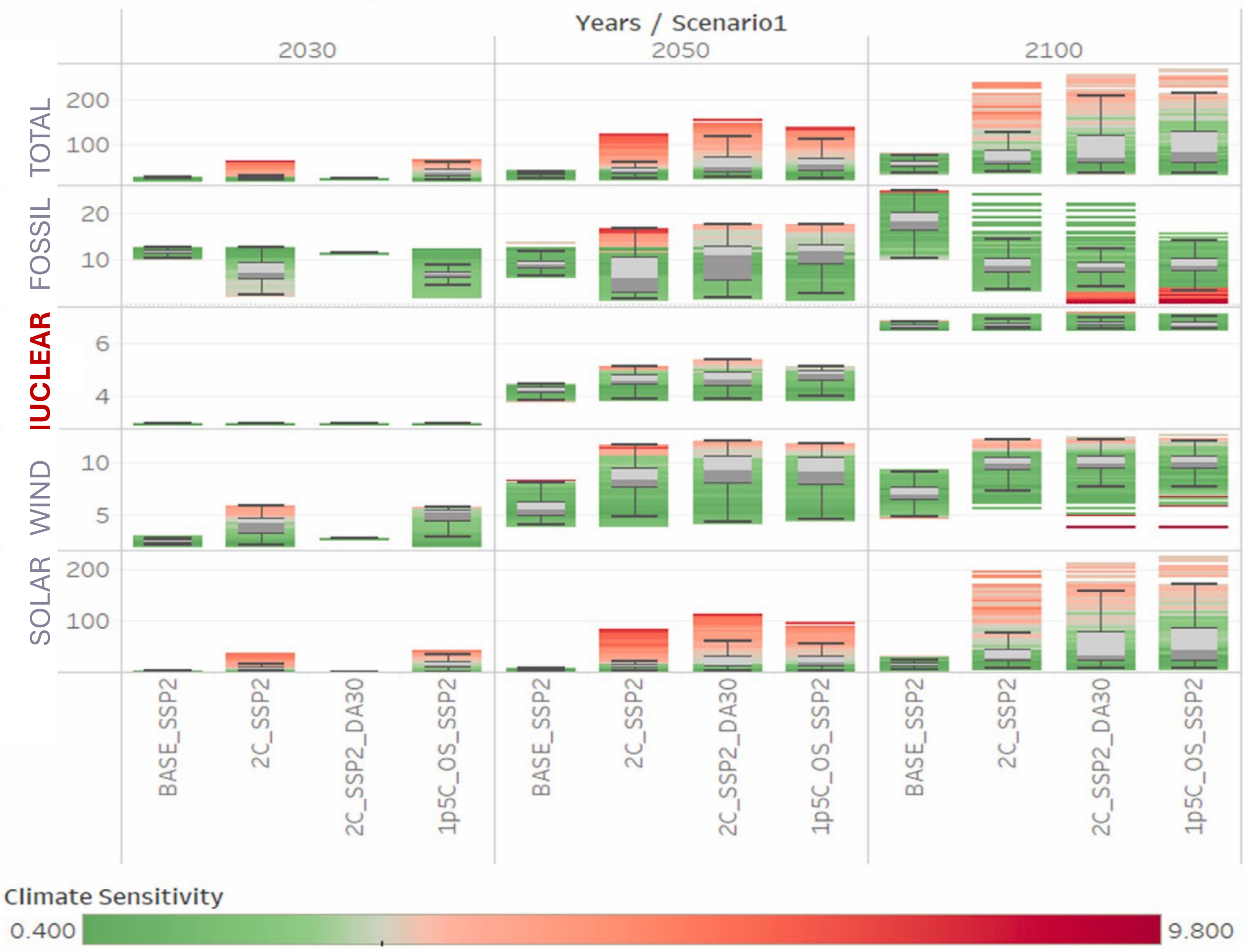
IPCC AR6 scenario database

IAEA RDS (2024)

Nuclear uptake in the context of climate change uncertainty
(doing nothing, achieving 2°C, aiming for 1.5°C)

- ETSAP-TIAM integrated assesment model
- Four scenario families, 1000 scenarios each
- Uncertainties to consider:
  - Technology costs & discount rates
  - Renewable energy sources
  - Economic/Demographic growth
  - Demand elasticities
  - Climate sensitivity

ELECTRICITY SUPPLY (PWh)



Panos E., et al. (2023a)

Probability distributions of global nuclear electricity (PWh) in 2050

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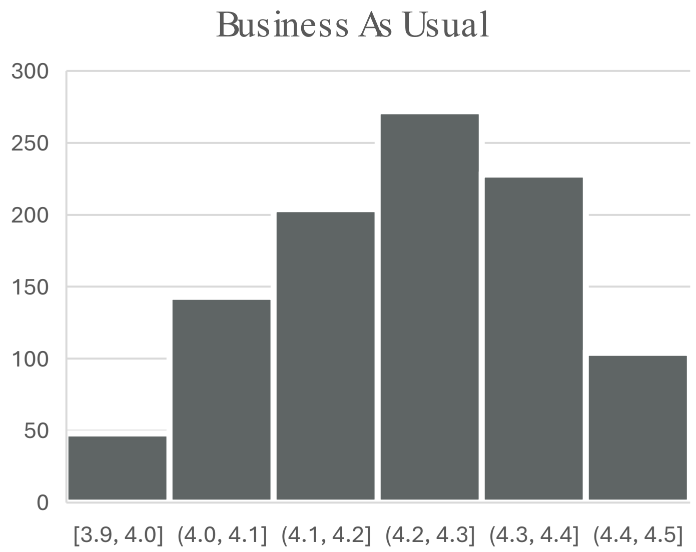
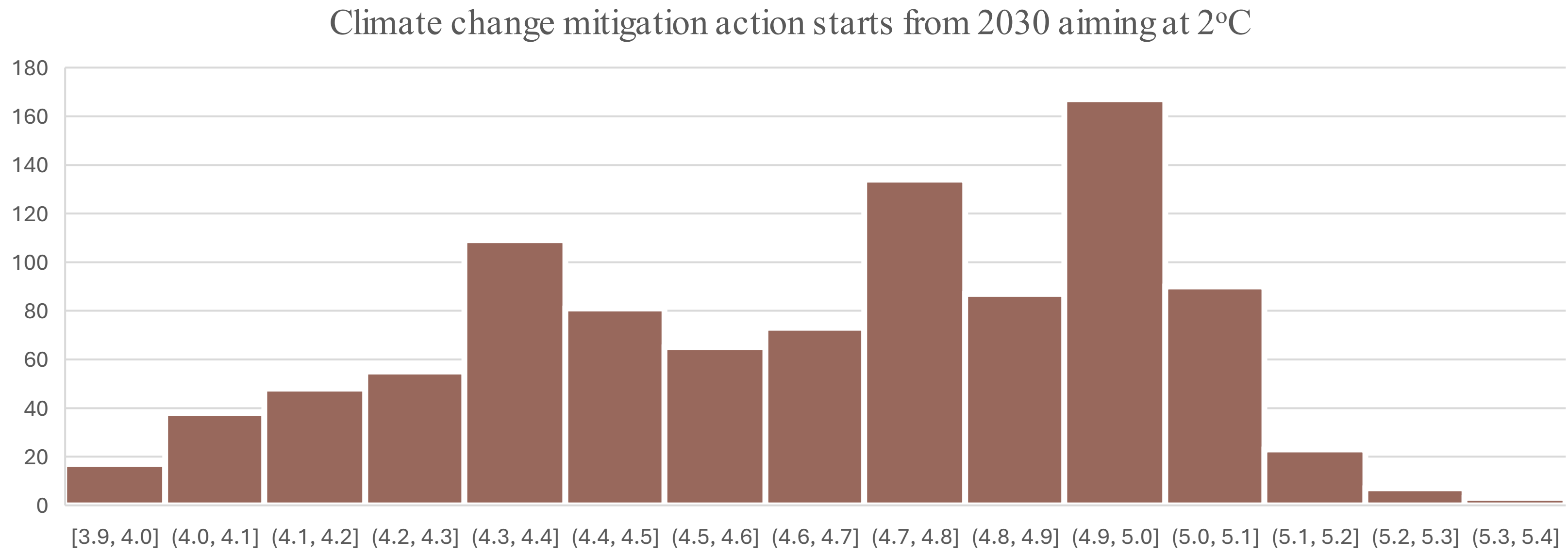
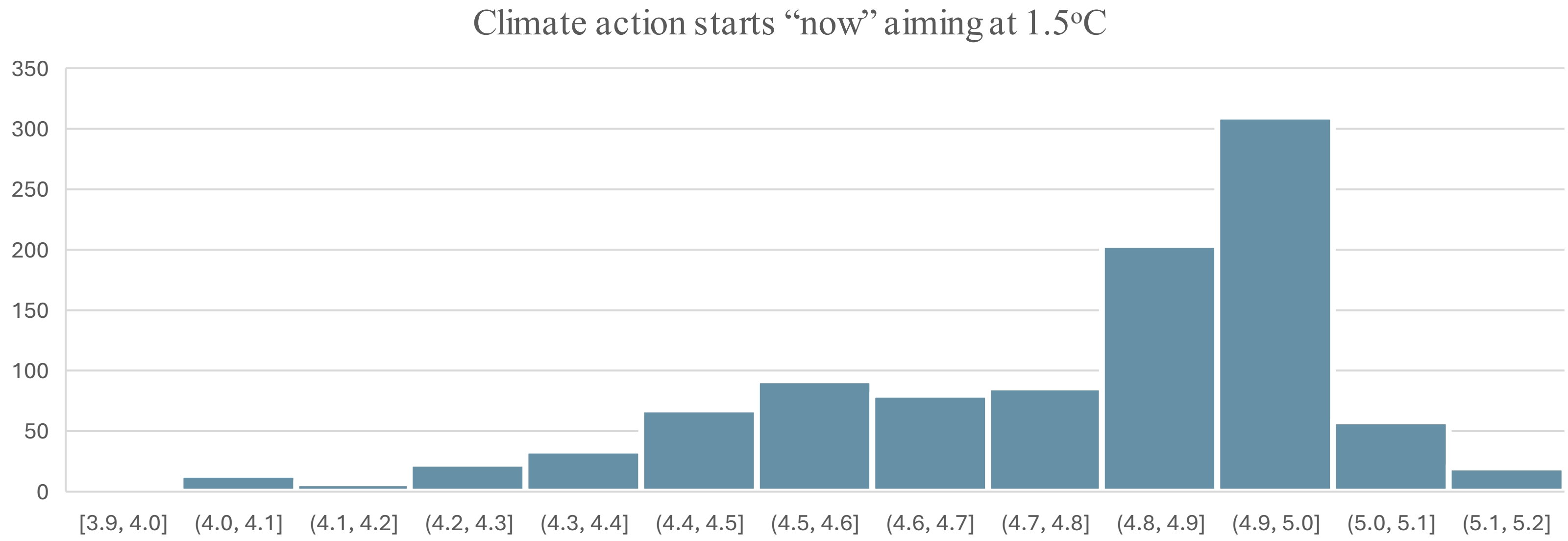


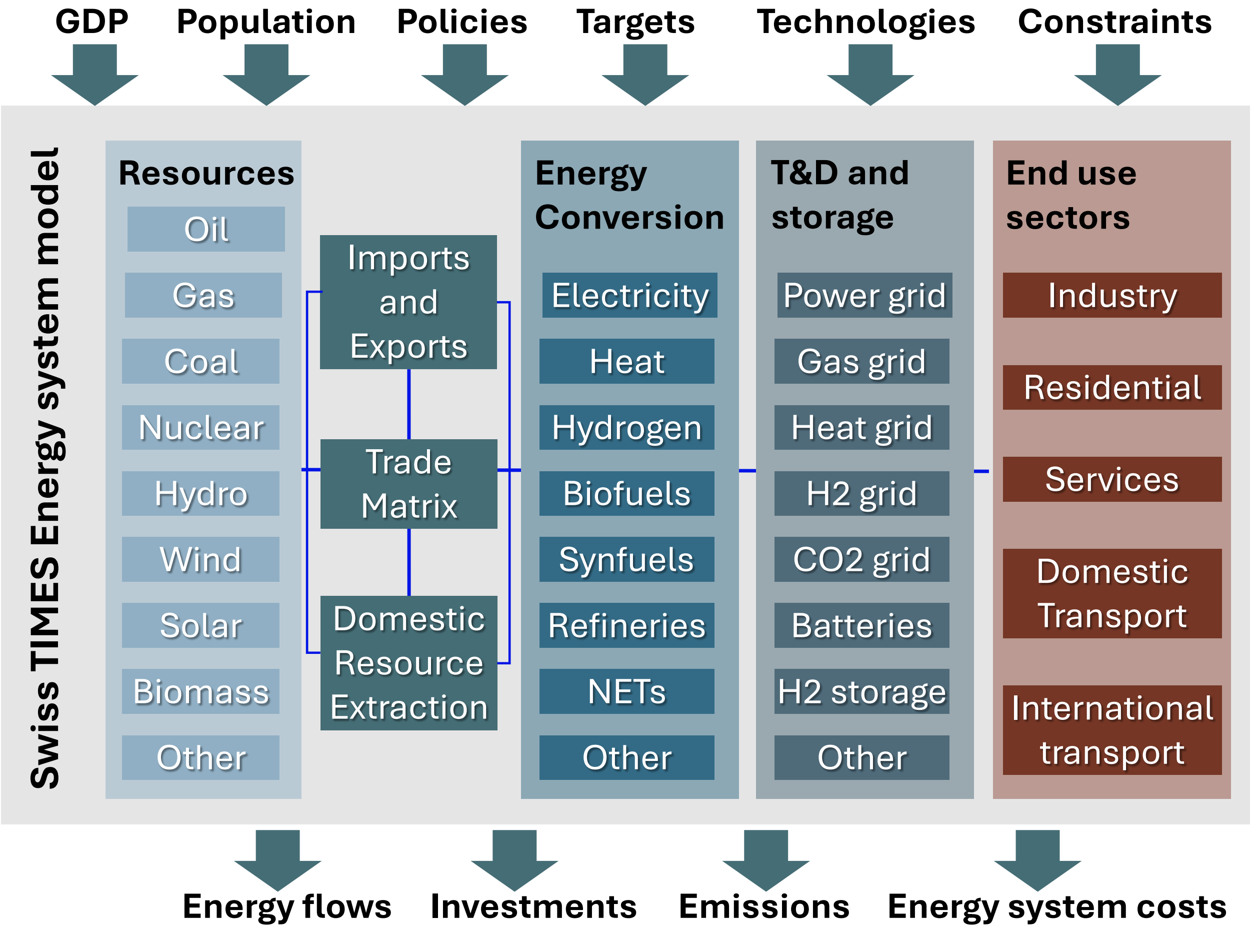


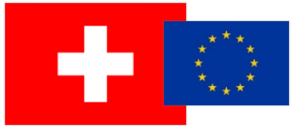


Panos E., et al. (2023a)

The Quiet Giant: Nuclear Power in the EU’s Climate Agenda

The Swiss-EU TIMES modelling framework of PSI





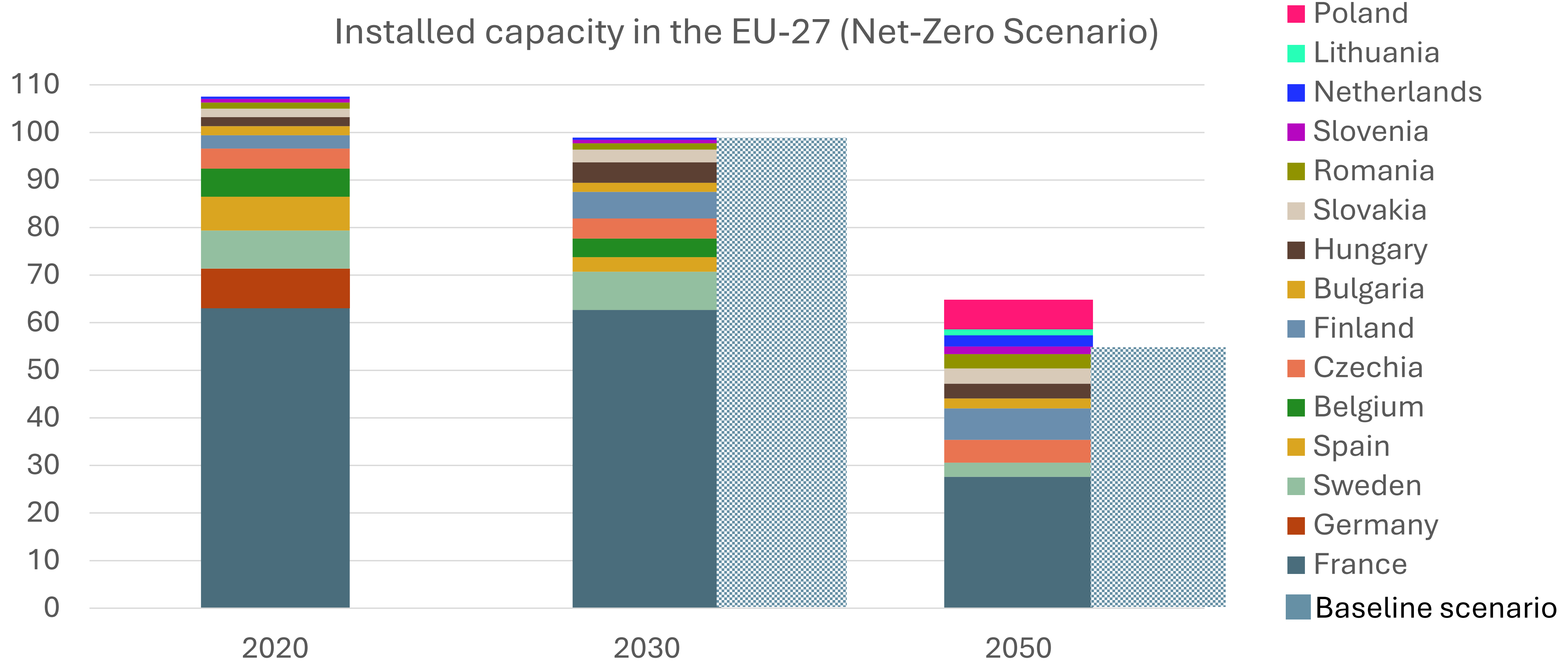
- Full energy system representation
- Multi-carrier and multi-sectoral model
- Long horizon pathways (2020 – 2050+)
- Ageing structure of technologies
- Endogenous expansion of grids
- Flexibility and demand management
- Endogenous extensions of nuclear reactors

40+ peer-reviewed publications with STEM

Scenarios definition

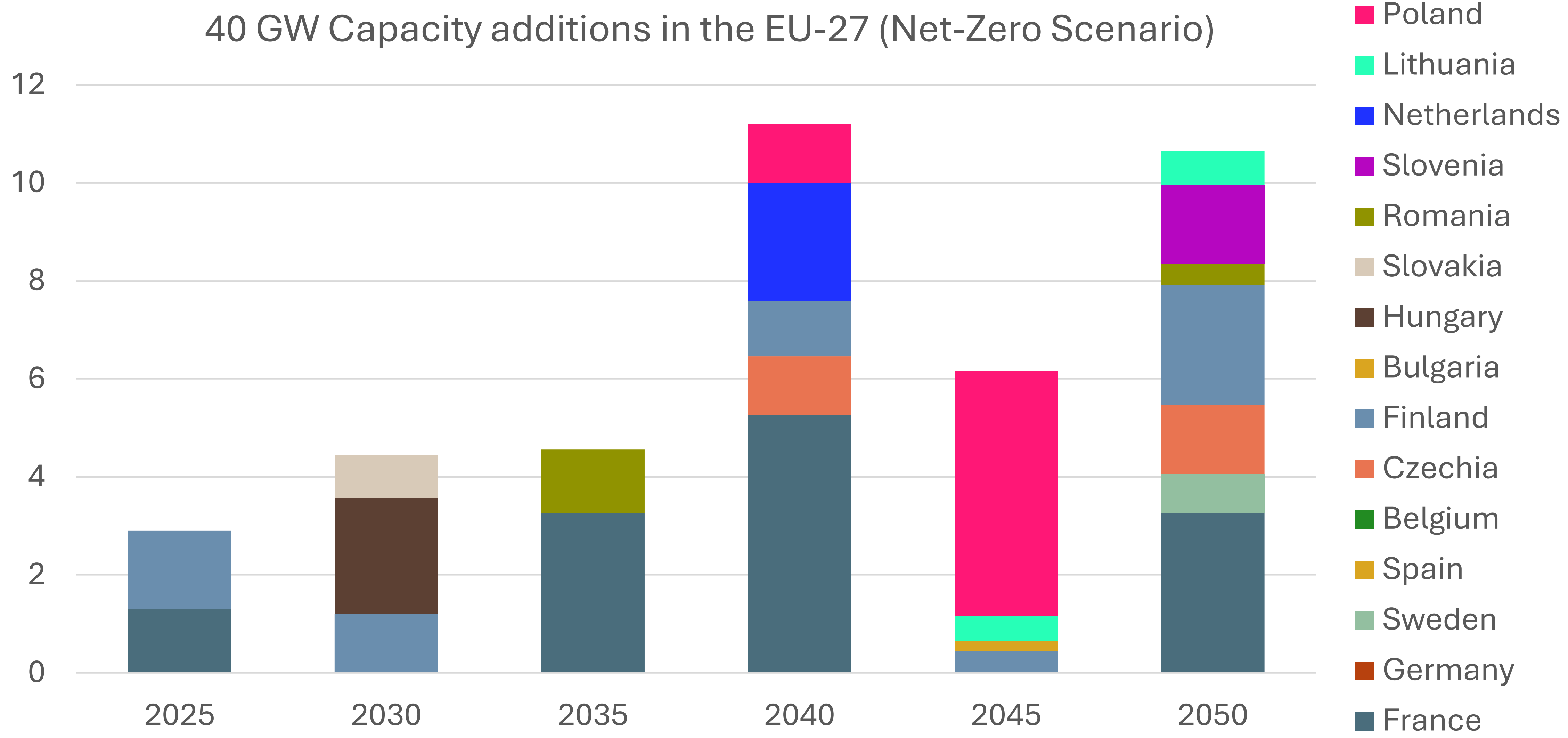
Scenario	EU-27
Baseline (policies in the legislation until 1.1.2024)	• EED energy efficiency (EU2023/1791) • EPBD buildings performance standards (EU2018/844) • ETS (all revisions up to EU2023/959) • EU RED III renewable targets (up to EU2023/2413) • GHG effort sharing (up to EU2023/857) • Vehicle emissions standards (EU2019/631, EU2023/851) • Heavy vehicle emissions standards (EU2019/1242) • Coal phase out 2030 in DE, DK,FI,GR,HU,IE,IT,NL,PT,SI,SK,ES • Intra-EEA aviation in EU-ETS • NTC electricity capacities as in ENTSO-E TYNDP 2022 plan • Reduction of nuclear share in France • New nuclear plants those under construction/advanced planning
Net-Zero Scenario	• GHG emissions from 1990: -55% in 2030, -90% in 2040 • Net-Zero GHG emissions in 2050 at the EU-level • Individual net-zero GHG emissions targets of the member states • GHG emissions reduction scope as in the EU Climate Law - includes LULUCF and 50% of the international transport • Refuel aviation SAF mandates • EU-ETS-2 from 2030 (although incl. in 2023 revision of EU-ETS) • New nuclear power as per optimizer

Net-Zero vs Baseline: +10 GW of nuclear capacity in 2050



Panos E., et al. (2025)

Who invests in the EU in new nuclear capacity?



Panos E., et al. (2025)

Democracy, Decarbonisation and the Atom:
Switzerland’s Path to Net-Zero

Timeline of Swiss Nuclear Power – 60 years of Referendums

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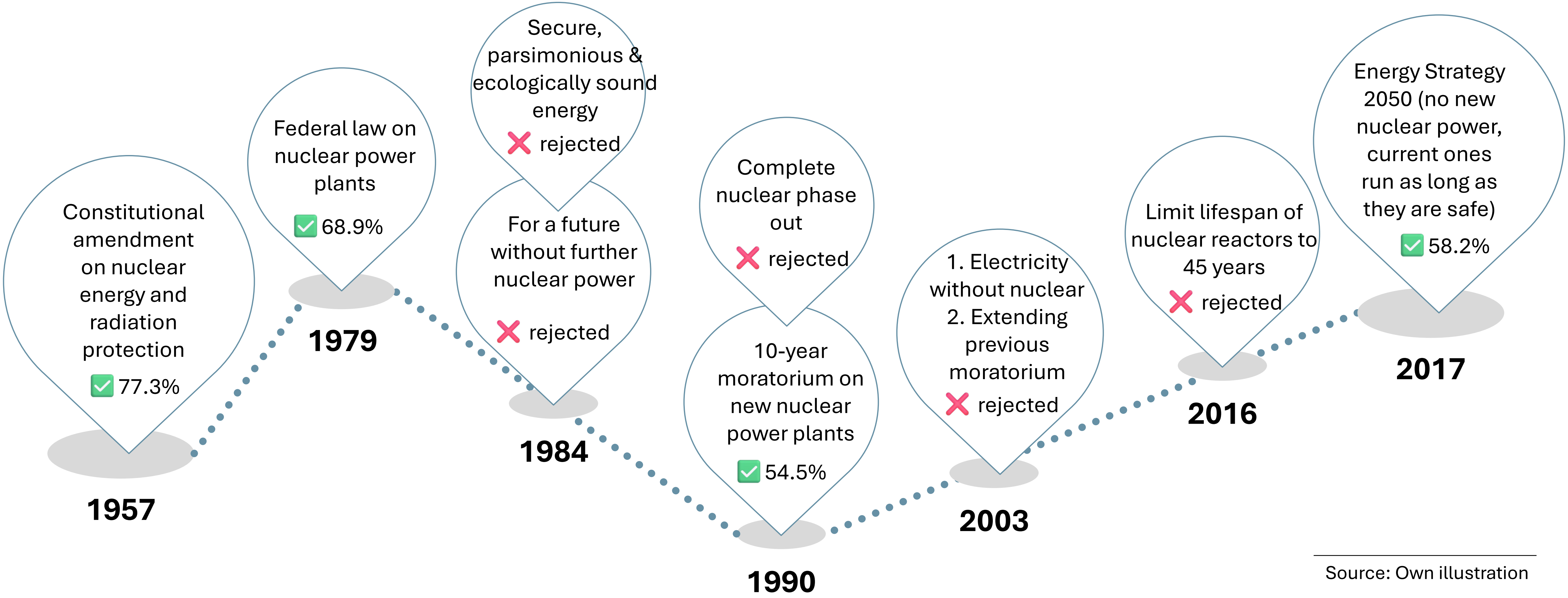


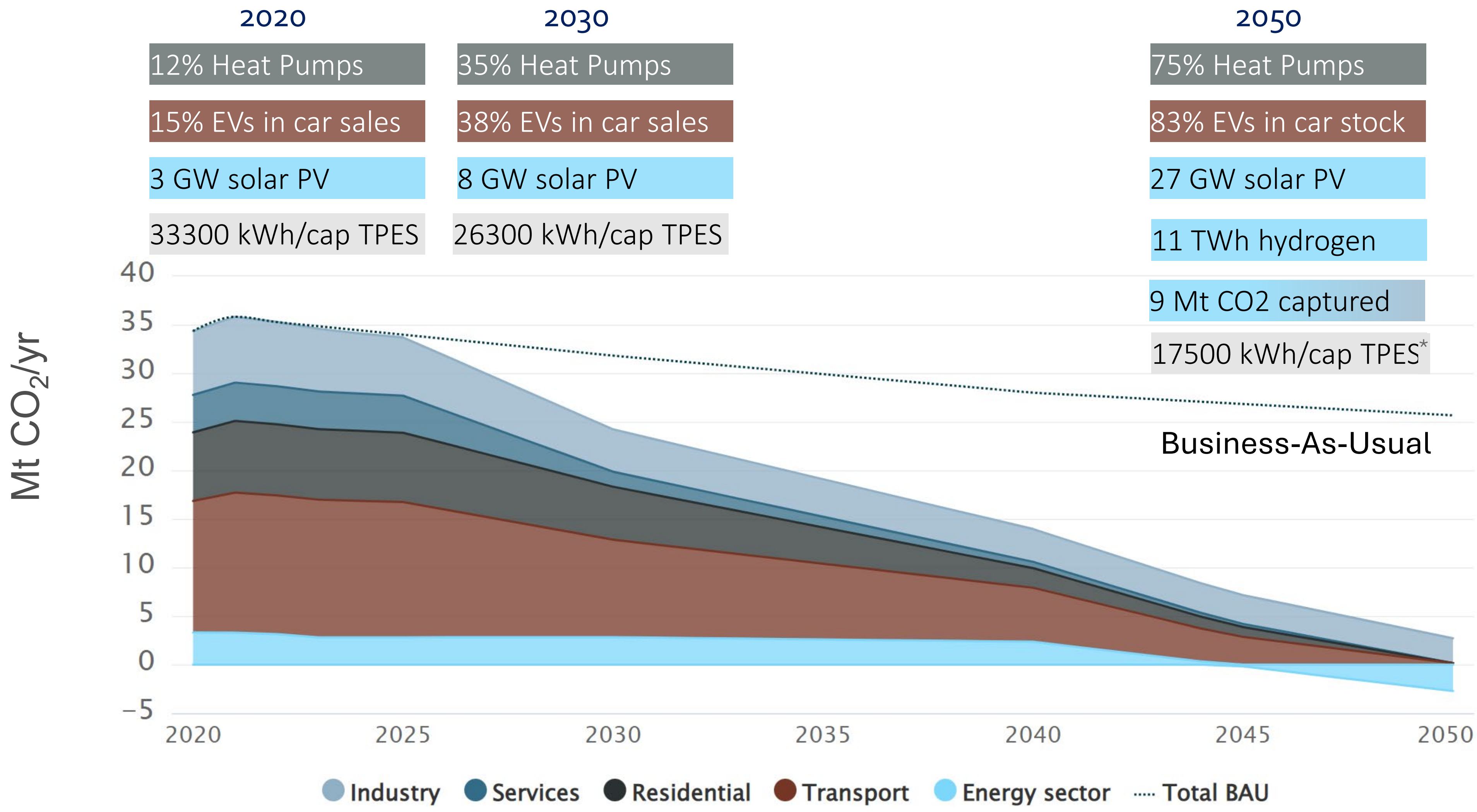
Source: Own illustration

Persistent Public Ambivalence: never fully embraced or fully rejected nuclear power

Pivotal decisions on shaping nuclear energy in Switzerland: the 10yrs moratorium in 1990) and the Energy Strategy in 2017

Forthcoming referendum on «Blackout Initiative» to lift nuclear investment ban in 2025

A cost-optimal pathway to a climate neutral energy system



NPV @2.5%:
97 billion CHF
or 12% of GDP_{2023}

Panos E., et al. (2023b)

*TPES - Total Primary Energy Supply

In view of the net-zero challenge, and security of energy supply concerns has the nuclear opinion in Switzerland changed ?

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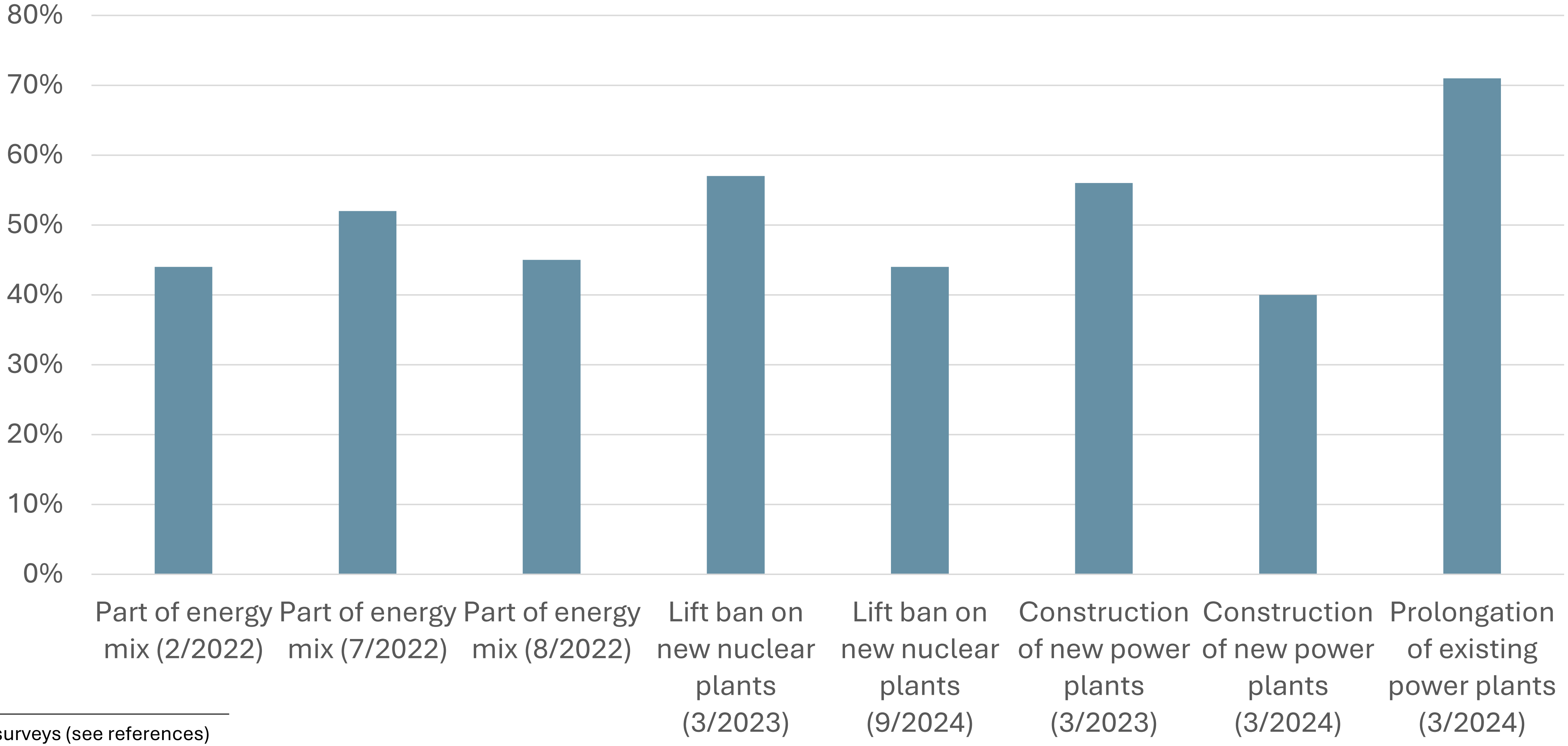
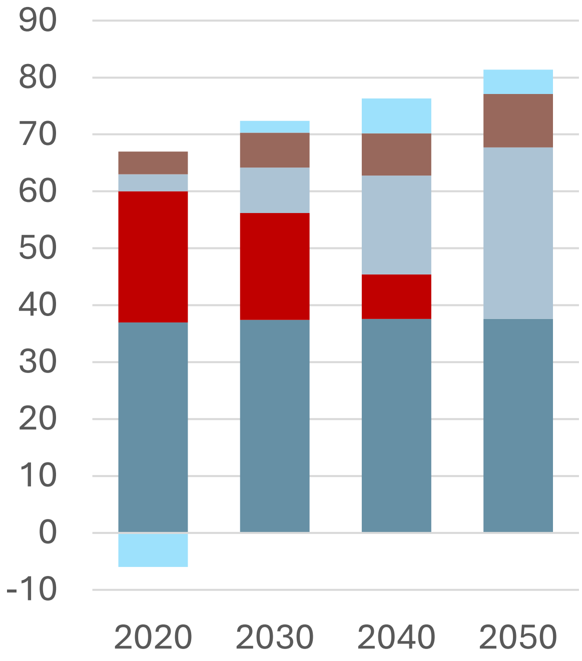


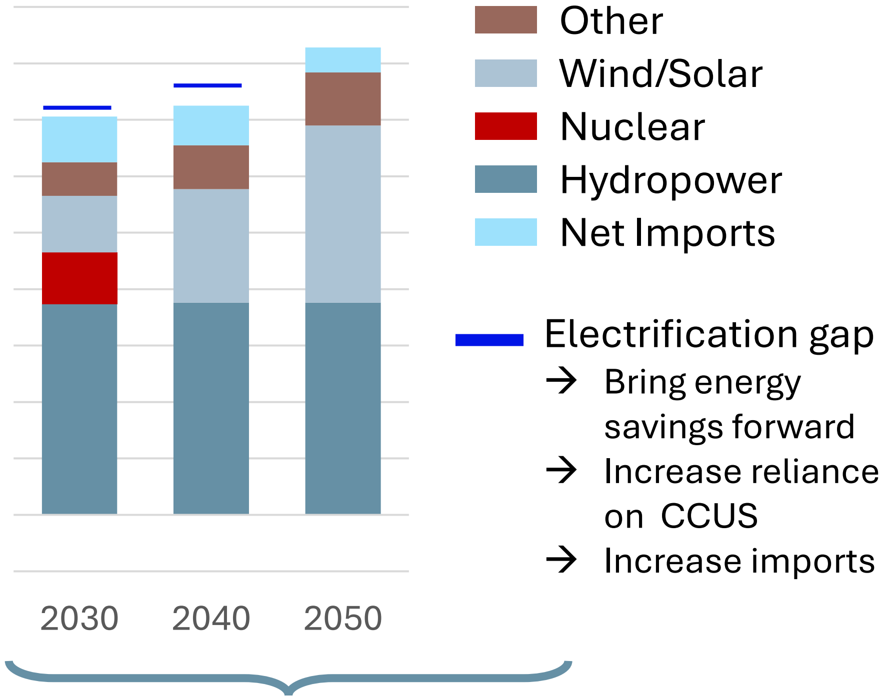
Several surveys (see references) between 2/2022 – 9/2024)

A net-zero system needs all domestic options

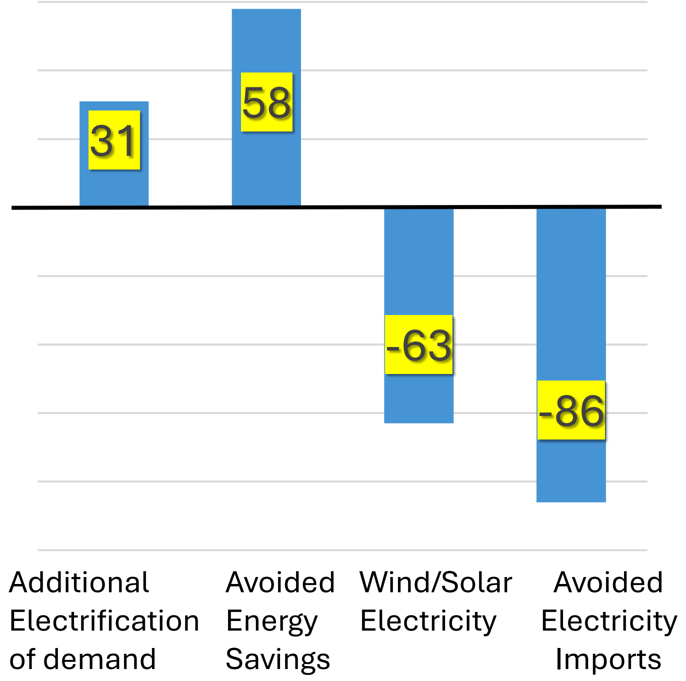
Electricity supply TWh/yr. (60 yrs lifetime for nuclear)



Electricity supply TWh/yr. (50 yrs lifetime for nuclear)



Cumulative (2030-2050) impacts of 10yrs nuclear life extension in TWh/yr.



NPV from the cost optimal pathway: + 11 billion CHF

This cost difference is the system value of nuclear 10yrs lifetime extension

Panos E., et al. (2023b)

Overall key take aways

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- Nuclear futures are shaped as much by societal and political consensus as by technical models, costs
- Stakeholder-informed scenarios suggest a cautious optimism rather than a deterministic nuclear expansion
  - Many scenarios in the past have had nuclear capacity extensions not materialised
- Despite uncertainty, nuclear remains a “quite giant”
- In the EU, new nuclear investment is targeted and politically / geopolitically contingent
- Switzerland shows a unique path for nuclear, based on direct democracy, despite persistent ambivalence
- Lifetime extension of existing reactors: low-regret, high-impact action to bridge toward net-zero goals
- Nuclear investments need clear and early policy signals – if bans are lifted without strong government support, they will create nervousness and uncertainty in the market, also affecting renewable energy deployment

What is coming in PSI energy economic modelling 2025 - 2027:

Socio-economics of energy transition

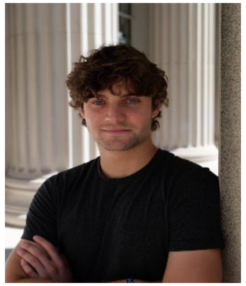
Scalable energy system analysis

Markets and energy infrastructures

Nuclear technology holistic analysis

Ongoing PhD: Holistic energy systems analysis of nuclear energy in a Swiss context

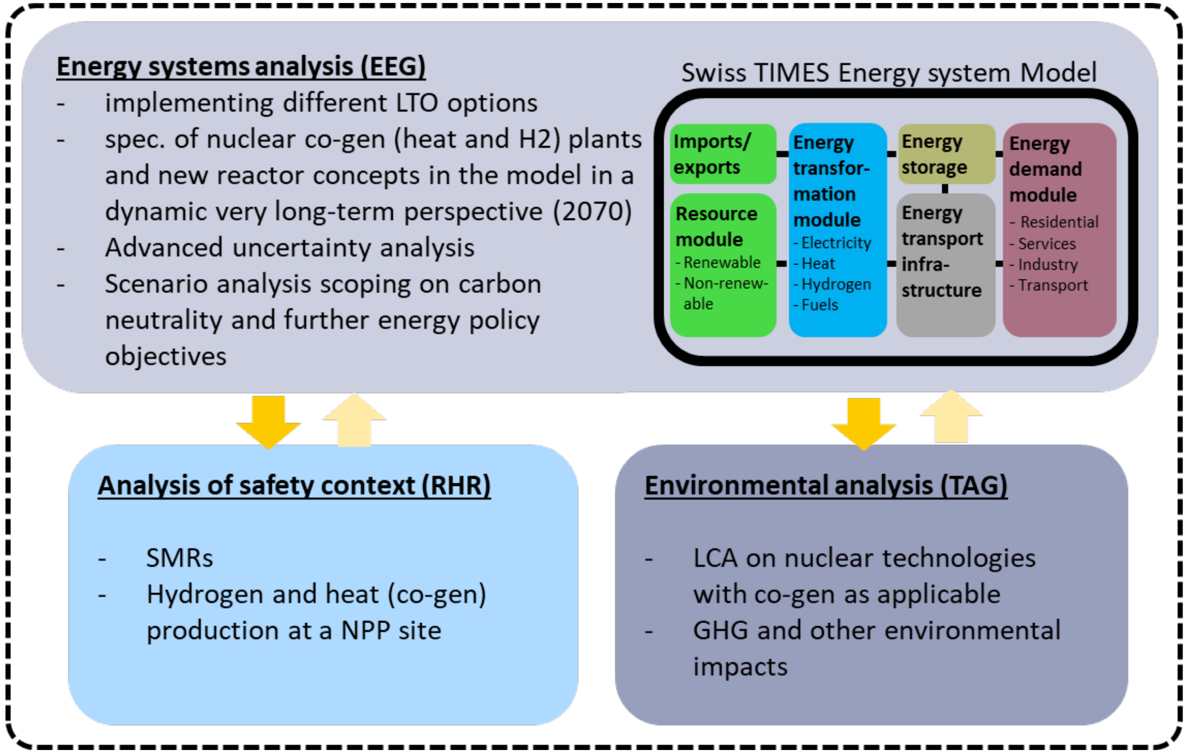
What are the short-term and long-term benefits/risks of nuclear power implementation in Switzerland? Can nuclear play a role in the country's Energy Transition?



Lucas Javier Fernandez de Losada
MSc Nuclear Engineering (EPFL/ETH)

- **Energy-Economic Systems Analysis** on the role of nuclear in electricity and new energy markets
- **Life Cycle Assessment** of new nuclear builds to quantify GHG emissions and other environmental impacts
- **Multi-Criteria Decision Analysis** to weigh trade-offs and benefits in energy system, environment and economy that nuclear technologies may bring

Specification of nuclear technology of major interest →



→ System config. under different scenarios
→ Nuclear tech. deployment and investments
→ Environmental and safety implications

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Thank you!

My thanks go to:

- Tom Kober (FHNW)
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- Lucas Javier Fernandez de Losada (PSI)
- Russell McKennan (ETH/PSI)

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