Planning in a rollercoaster world: three years of RESILIENT

RESILIENT Final Workshop

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20 November 2026

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Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

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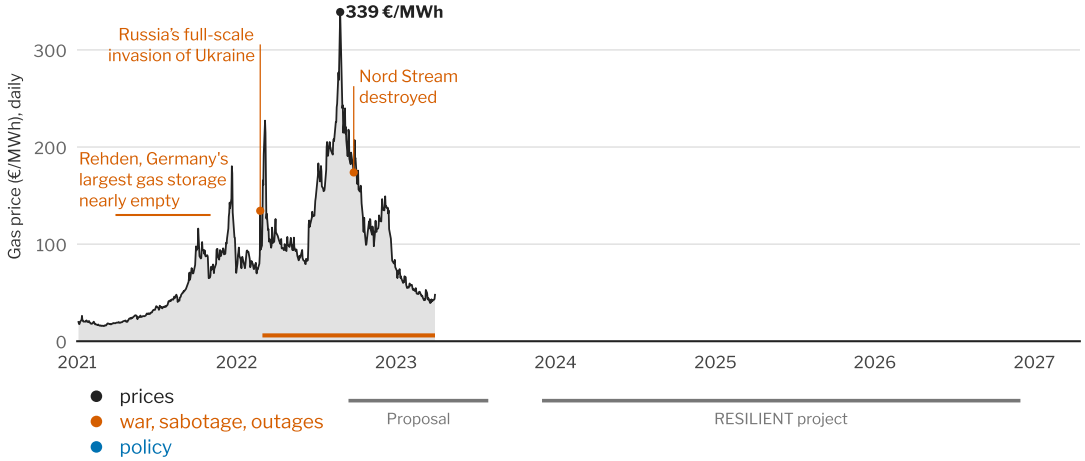
We planned this project in one gas crisis and present it in another



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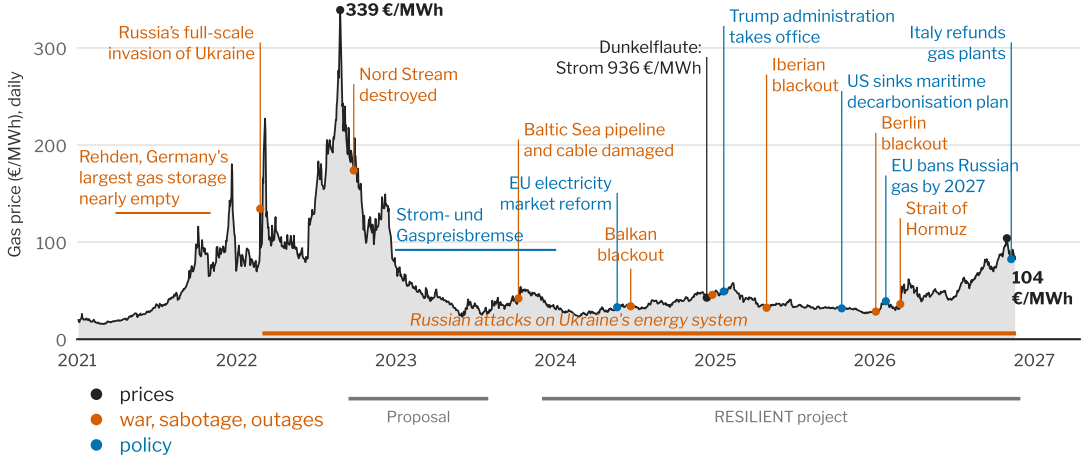
Source: Dutch TTF front-month gas price, daily close: ICE Endex, via Yahoo Finance.

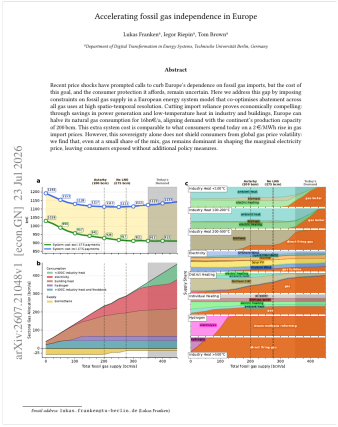
We planned this project in one gas crisis and present it in another



Source: Dutch TTF front-month gas price, daily close: ICE Endex, via Yahoo Finance.

Research questions addressed in RESILIENT

- **Gas price shocks**
- Industrial decarbonisation
- Weather extremes
- Biomass and e-fuels
- Trade and geopolitics
- Price formation
- Infrastructure attacks, outages, and energy self-sufficiency



Accelerating fossil gas independence in Europe

Lukas Franken*, Jeger Riepin*, Tom Brown*

*Department of Digital Transformation in Energy Systems, Technische Universität Berlin, Germany

Abstract

Recent price shocks have prompted calls to curb Europe's dependence on fossil gas imports, but the cost of this goal, and the consumer protection it affords, remain uncertain. Here we address this gap by imposing constraints on fossil gas supply in a European energy system model that co-optimises abatement across all gas uses at high spatio-temporal resolution. Cutting import reliance proves economically compelling: through savings in power generation and low-temperature heat in industry and buildings, Europe can halve its natural gas consumption for 10bn€/a, aligning demand with the continent's production capacity of 200 bcm. This extra system cost is comparable to what consumers spend today on a 2 €/MWh rise in gas import prices. However, this sovereignty alone does not shield consumers from global gas price volatility: we find that, even at a small share of the mix, gas remains dominant in shaping the marginal electricity price, leaving consumers exposed without additional policy measures.

arXiv:2607.21048v1 [econ.GN] 23 Jul 2026

Email address: lukas.franken@tu-berlin.de (Lukas Franken)

arXiv, 2026 Research | Panel

Research questions addressed in RESILIENT

- Gas price shocks
- **Industrial decarbonisation**
- Weather extremes
- Biomass and e-fuels
- Trade and geopolitics
- Price formation
- Infrastructure attacks, outages, and energy self-sufficiency


ENVIRONMENTAL RESEARCH LETTERS

LETTER • OPEN ACCESS

The role of projects of common interest in reaching Europe's energy policy targets

Bobby Xiong*, Tom Brown and Iegor Riepin

Published 3 February 2026 • © 2026 The Author(s). Published by IOP Publishing Ltd

Environmental Research Letters, Volume 21, Number 3

Citation Bobby Xiong et al 2026 Environ. Res. Lett. 21 034011

DOI 10.1088/1748-9326/ae3846

PDF ePub

Authors Figures Tables References Open science

Article information

Abstract

The European Union aims to achieve climate-neutrality by 2050, with interim 2030 targets including 55% greenhouse gas emissions reduction compared to 1990 levels, 10 Mt of domestic green hydrogen production, and 50 Mt of domestic CO_2 injection capacity annually. To support these targets, projects of common and mutual interest (PCI-PMI)—large infrastructure projects for electricity, hydrogen and CO_2 transport, and storage—have been identified by the European Commission. This study focuses on PCI-PMI projects related to hydrogen and carbon value chains, assessing their long-term system value and the impact of pipeline delays and shifting policy targets using the sector-coupled energy system model PyPSA-Eur. Our study shows that PCI-PMI projects enable a more cost-effective transition to a net-zero energy system compared to scenarios without any pipeline expansion. Hydrogen pipelines help distribute affordable green hydrogen from renewable-rich regions in the north and southwest to high-demand areas in central Europe, while

Environmental Research Letters, 2026


Fraunhofer ISI

TECHNISCHE UNIVERSITÄT BERLIN

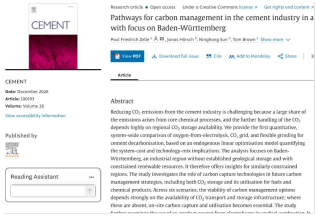
PyPSA

Sprintsitzung CO_2-Infrastruktur

Diskussion PyPSA-Eur Modellierung | 30.06.2026 | Wissenschaftspark Gelsenkirchen

Bobby Xiong, Khaled Al-Dabbas, Tobias Fleiter

Case study NRW, 2026 Poster


CEMENT

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Pathways for carbon management in the cement industry in a with focus on Baden-Württemberg

Paul Friedrich Zeile*, Jonas Hörsch*, Hongkong Sun*, Tom Brown*, Show more

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Article

CEMENT

Date: December 2026

Article: 100319

Volume: Volume 26

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Reading Assistant

Abstract

Reducing CO_2 emissions from the cement industry is challenging because a large share of the emissions arises from core chemical processes, and the further handling of the CO_2 depends highly on regional CO_2 storage availability. We provide the first quantitative, system-wide comparison of oxygen-from-electrolysis, CO_2 grid, and flexible grinding for cement decarbonisation, based on an endogenous linear optimisation model quantifying the system-cost and technology-mix implications. The analysis focuses on Baden-Württemberg, an industrial region without established geological storage and with constrained renewable resources. It therefore offers insights for similarly constrained regions. The study investigates the role of carbon capture technologies in future carbon management strategies, including both CO_2 storage and its utilisation for fuels and chemical products. Across six scenarios, the stability of carbon management options depends strongly on the availability of CO_2 transport and storage infrastructure; where these are absent, on-site carbon capture and utilisation becomes essential. The study

CEMENT, 2026 Research II Poster

Research questions addressed in RESILIENT

- Gas price shocks
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- Biomass and e-fuels
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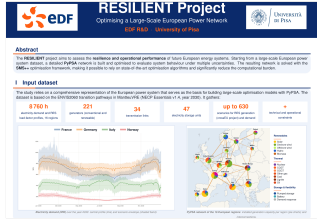
- Infrastructure attacks, outages, and energy self-sufficiency



Applied Energy, 2026



EDF and University of Pisa, 2026 **Poster**

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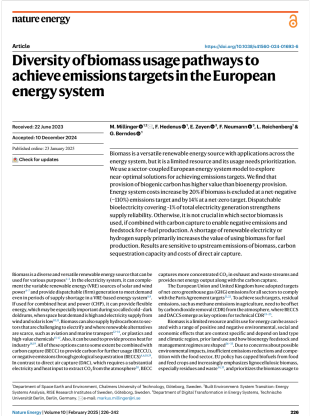

nature energy

Article

https://doi.org/10.1038/s41560-024-01683-6

Diversity of biomass usage pathways to achieve emissions targets in the European energy system

Received: 22 June 2023

Accepted: 10 December 2024

Published online: 23 January 2025

Check for updates

M. Millinger[1,2], F. Hedenus[3], E. Zeyen[4], F. Neumann[4], L. Reichenberg[3] & O. Berndes[3]

Biomass is a versatile renewable energy source with applications across the energy system, but it is a limited resource and its usage needs prioritization. We use a sector-coupled European energy system model to explore near-optimal solutions for achieving emissions targets. We find that provision of biogenic carbon has higher value than bioenergy provision. Energy system costs increase by 20% if biomass is excluded at a net-negative (−110%) emissions target and by 14% at a net-zero target. Dispatchable bioelectricity covering ~1% of total electricity generation strengthens supply reliability. Otherwise, it is not crucial in which sector biomass is used, if combined with carbon capture to enable negative emissions and feedstock for e-fuel production. A shortage of renewable electricity or hydrogen supply primarily increases the value of using biomass for fuel production. Results are sensitive to upstream emissions of biomass, carbon sequestration capacity and costs of direct air capture.

Biomass is a diverse and versatile renewable energy source that can be used for various purposes[1–3]. In the electricity system, it can complement the variable renewable energy (VRE) sources of solar and wind power[4–6] and provide dispatchable (firm) generation to meet demand even in periods of supply shortage in a VRE-based energy system[7–9]. If used for combined heat and power (CHP), it can provide flexible energy, which may be especially important during so-called cold-dark-still periods (periods with low solar irradiation, low wind speeds and cold) in Europe[10–12]. Biomass can also be supplied to the transport sector, a sector that are challenging to electrify and where renewable alternatives are scarce, such as aviation and maritime transport[13–15], or plastics and high-value chemicals[16–18]. Also, it can be used to provide process heat for industry[19–21]. All of these options can to some extent be combined with carbon capture (BECCS) to provide carbon for further usage (BECCU), or to enable negative emissions (BECCS) by storing the carbon[22–24]. In contrast to direct air capture (DAC), which requires a substantial electricity and heat input to extract CO_2 from the atmosphere[25], BECC captures more concentrated CO_2 in exhaust and waste streams and provides net energy output along with the carbon capture.

The European Union and United Kingdom have adopted targets of net-zero greenhouse gas (GHG) emissions for all sectors to comply with the Paris Agreement targets[26,27]. To achieve such targets, residual emissions, such as methane emissions in agriculture, need to be offset by carbon dioxide removal (CDR) from the atmosphere, where BECCS and DAC are the most scalable options available[28–30].

Biomass is a limited resource and its use for energy can be associated with a range of positive and negative environmental, social and economic effects that are context-specific and depend on land type and climatic regions, prior land use and how bioenergy feedstock and management regimes are shaped[31–33]. Due to concerns about possible environmental impacts, insufficient emissions reductions and competition with food production[34–36], the European Union has moved away and from crop- and food crop-based energy emphasizes lignocellulosic biomass, especially residues and waste[37,38], and prioritizes the biomass usage to

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Nature Energy | Volume 10 | February 2025 | 226–242

226

Nature Energy, 2025 **Research** **Poster**



arXiv

Physics > Physics and Society

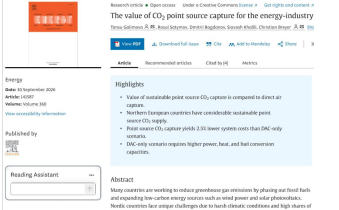
[Submitted on 13 Apr 2026]

E-biofuels reduce the cost of achieving emissions targets in hard-to-electrify sectors

Yunlong Zhang, Markus Millinger, Fredrik Hedenus, Karin Pettersson, Tom Brown

Renewable liquid fuels are essential for achieving emissions targets for hard-to-electrify sectors such as aviation and shipping. While biofuels and synthetic e-fuels have been well-studied, e-biofuels, produced by adding renewable hydrogen to biomass conversion to better utilise the biogenic carbon, remain understudied and lack a clear role in EU fuel regulations. In this paper, using a sector-coupled European energy system model, we find that e-biofuels are cost-effective to meet stringent emissions targets if biomass availability is limited and fossil fuels are ineligible, either due to limited carbon dioxide sequestration capacity or to high renewable fuel mandates. By directly increasing utilisation of biogenic carbon instead of synthesising fuels based on captured CO_2, there are savings from fuel production and carbon capture that reduce total system costs by up to 2.7% and liquid fuel costs by more than 10%. Our results highlight the role of e-biofuels as a potential hedge against uncertainty in biomass, hydrogen, and carbon storage availability, as well as evolving policy implementation.

arXiv, 2026 **Poster**



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The value of CO_2 point source capture for the energy-industry

Tymu Gallimore, Raoul Sotyrnes, Dmitrii Bogdanov, Siavash Khalili, Christian Breyer

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Energy

Date: 30 September 2026

Article: 141587

Volume: Volume 360

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Highlights

- Value of sustainable point source CO_2 capture is compared to direct air capture.
- Northern European countries have considerable sustainable point source CO_2 supply.
- Point source CO_2 capture yields 2.5% lower system costs than DAC-only scenarios.
- DAC-only scenario requires higher power, heat, and fuel conversion capacities.

Reading Assistant

Abstract

Many countries are working to reduce greenhouse gas emissions by phasing out fossil fuels and expanding low-carbon energy sources such as wind power and solar photovoltaics. Nordic countries face unique challenges due to harsh climatic conditions and high shares of

Energy, 2026 **Poster**

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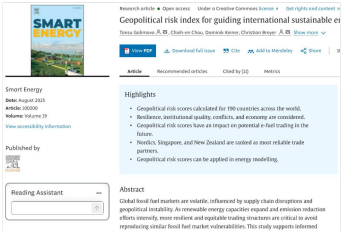
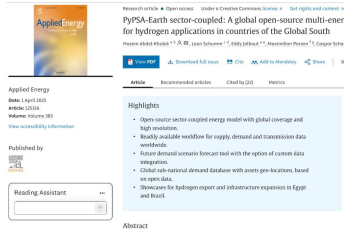


Smart Energy, 2025



Applied Energy, 2025

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Energy Economics 147 (2025) 108463

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/eneeco

Price formation without fuel costs: The interaction of demand elasticity with storage bidding

Tom Brown, Fabian Neumann, Iegor Riepin

Department of Digital Transformation in Energy Systems, Institute of Energy Technology, Technische Universität Berlin, Fakultät TK, Einsteinufer 25 (TA 8), 10587 Berlin, Germany

ARTICLE INFO

ABSTRACT

Energy Economics, 2025

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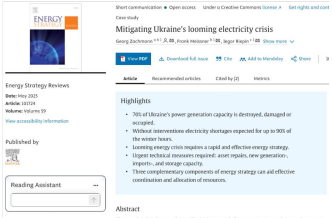


Energy Strategy Reviews, 2025



Working paper, 2026 **Research I**



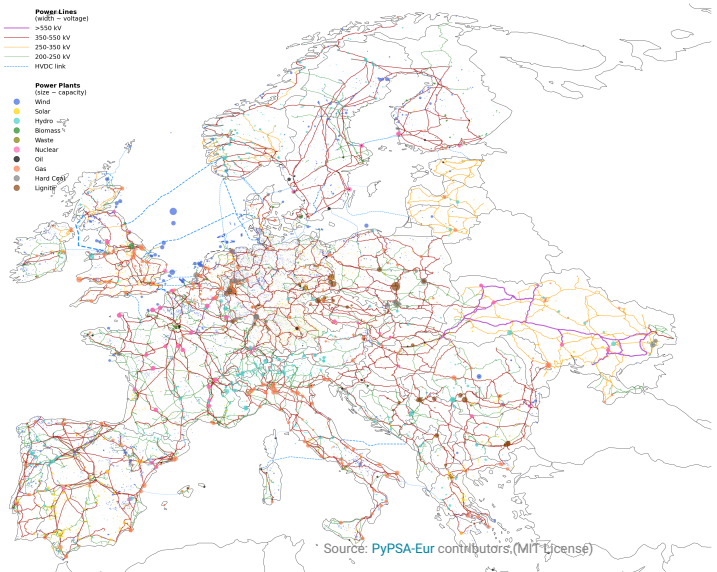
Scientific Data, 2025

In 2022 we extended PyPSA-Eur to Ukraine and Moldova

In 2022, our group extended **PyPSA-Eur** to cover **Ukraine and Moldova** — to support work on Ukraine's energy crisis caused by the Russian full-scale invasion.

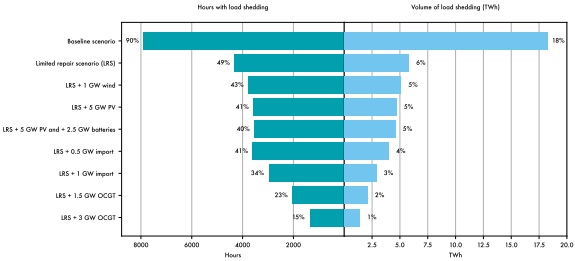
Several research groups have built upon this data extension:

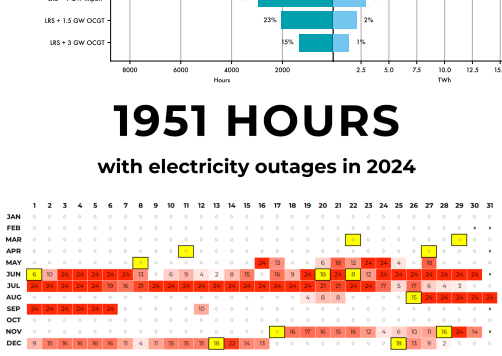
- Green Deal Ukraine
- Sotnyk et al., 2024
- Zachmann et al., 2025
- Tröndle et al., 2024
- Oxford EPG report

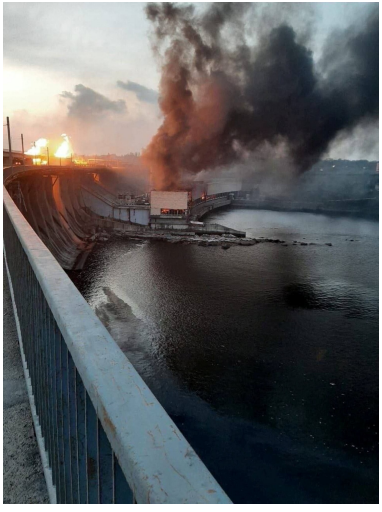


Source: PyPSA-Eur contributors (MIT License)

Ukraine: what an electricity system under attack needs first







Source: Photo: Reuters (Denys Shmyhal); top: Zachmann, Meißner, Riepin (2025); bottom: dixigroup.org

number of hours of outages

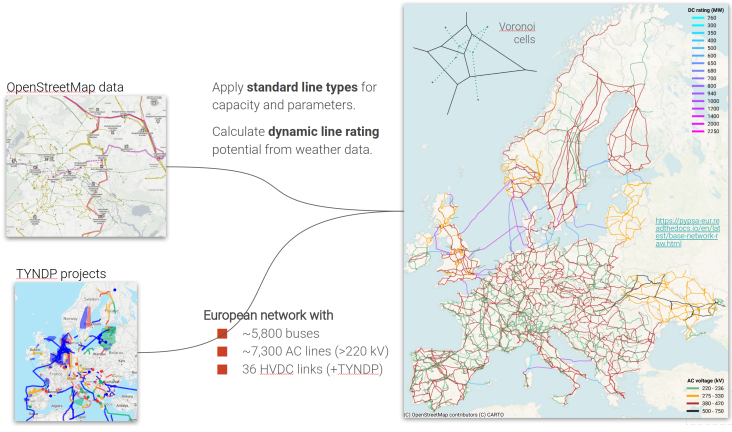
massive attacks on energy infrastructure

USAID

dixigroup

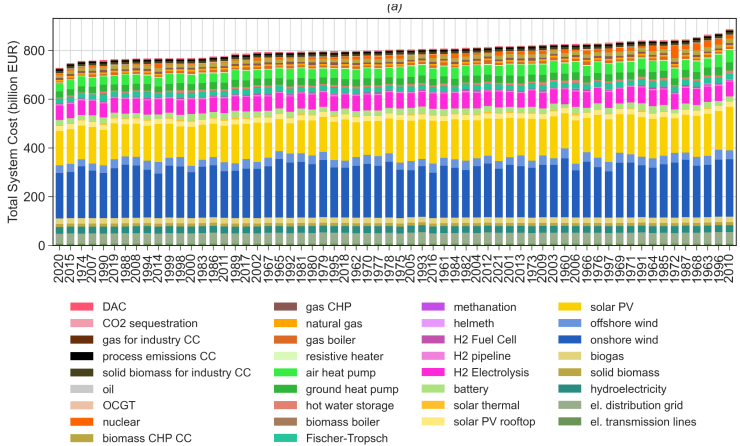
Energy Map

Europe's transmission grid from OpenStreetMap data



PyPSA-Eur PR: #1079 Introducing OpenStreetMap high-voltage grid to PyPSA-Eur (merged August 2024)
PyPSA-Eur PR: #1740 Implementation of voltage levels 110kV-220kV using osm-raw (merged August 2025)
grid-builder: github.com/PyPSA/grid-builder (build the grid for any country from the latest OSM data)
Paper: Xiong et al. (2025). Modelling the high-voltage grid using open data for Europe and beyond. Sci. Data

Multiple weather years in one optimisation problem



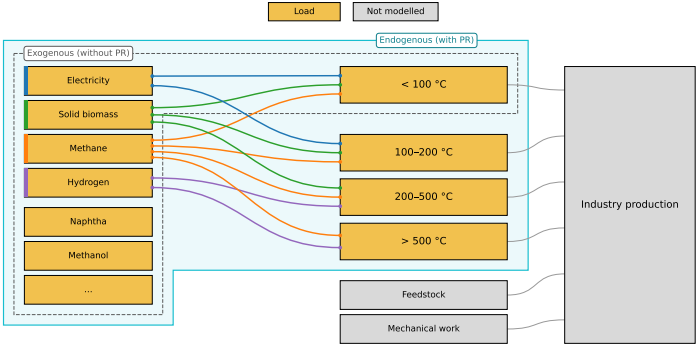
The cost-optimal system depends on the weather year it is designed for. PyPSA-Eur can now optimise one system against **several weather years at once**.

PyPSA-Eur PR: #1613 Multiple weather years in one optimisation problem (merged April 2025)

Paper: Gøtske et al. (2024). Designing a sector-coupled European energy system robust to 60 years of historical weather data. Nat. Commun.

Industrial process heat by temperature band

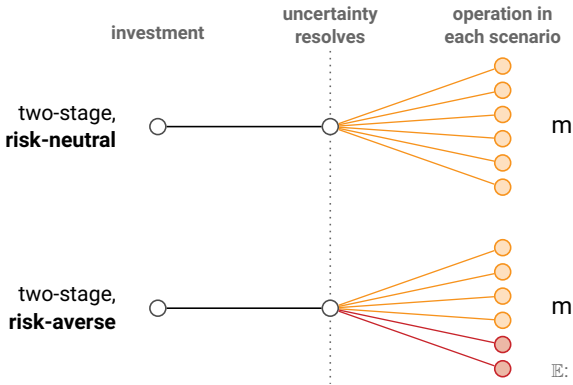
- Before: industrial heat was a **fixed demand** with fixed fuels
- Now: demand is split into **temperature bands**, by industry branch
- The model **chooses the supply**: heat pumps, electric boilers, biomass, methane, hydrogen



PyPSA-Eur PR: #1943 Endogenous Industry Heat (merged November 2026)

Paper: Franken et al. (2026). Accelerating fossil gas independence in Europe. arXiv

Stochastic and risk-averse optimisation, released with PyPSA v1.0



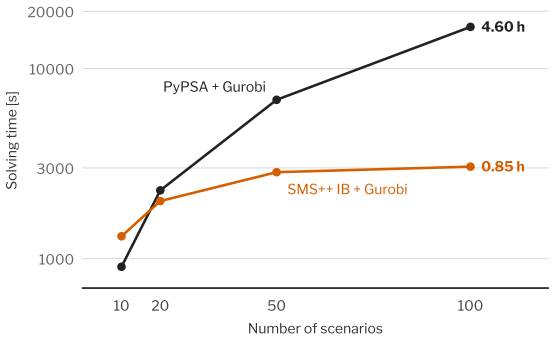
$$\min \ \text{CAPEX} + \mathbb{E}[\text{OPEX}]$$

$$\min \ \text{CAPEX} + (1-\omega)\,\mathbb{E}[\text{OPEX}] + \omega\,\text{CVaR}_{\alpha}[\text{OPEX}]$$

$\mathbb{E}$: expected value over scenarios
ω: weight on the worst outcomes
CVaR_{α}: mean cost of the worst $(1-\alpha)$ share

PyPSA PR: #1154 New Optimization Module & Stochastic Networks (merged August 2025)
PyPSA PR: #1345 Add risk-averse optimization (merged September 2025)
Case study: EDF R&D and University of Pisa. Optimising a large-scale European power network (poster)

Solving it at scale, with the University of Pisa



- PyPSA now talks to **SMS++**, a framework for **decomposition**
- Same optimal solution; solving time grows slower with increasing problem size
- Small subproblems make large models tractable also without commercial solvers

PyPSA PR: #1558 Smspp optimization (in review)
SMS++ development: gitlab.com/smspp/smspp-project
🏆 Enrico Calandrini (University of Pisa) wins second place at the PEREGRINE PIPS-IPM++ Hackathon for integrating PIPS-IPM++ into SMS++

Two workshops planned, seven held in 2025


Stuttgart, TransnetBW, January


Groningen, Gasunie, February


Berlin, four German TSOs, May


Berlin, TU Berlin, May


Copenhagen, DTU, June

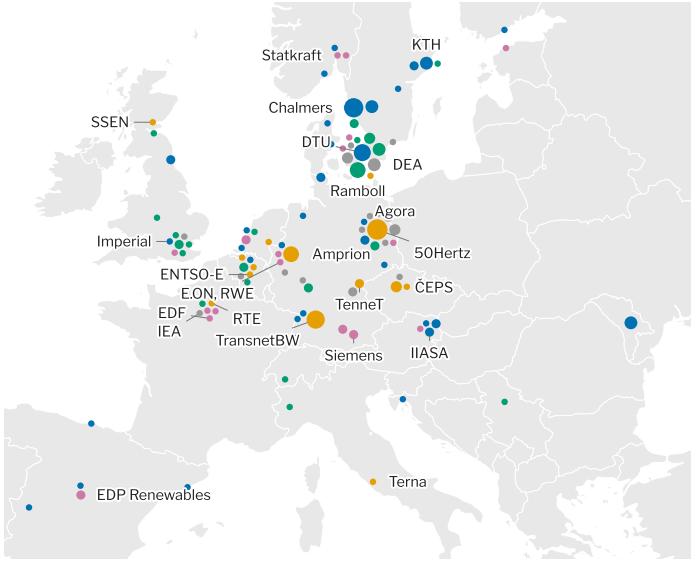

Gothenburg, RISE, November

210

participants in 2025

- **67** Universities and research institutes
- **38** TSOs
- **44** Utilities and industry
- **37** Consultancies
- **24** Public sector, NGOs, other

All training material is public: resilient-project.github.io



Where participants came from

- Universities and research institutes
- TSOs
- Utilities and industry
- Consultancies
- Public sector, NGOs, other

participants per organisation

1 5 10

Source: Anonymised registration list of the 2025 workshops; organisations placed at their head offices.

Open tools and models as a basis for public decisions

Network operators

NGOs, universities & international organisations

Regulators



The RESILIENT team



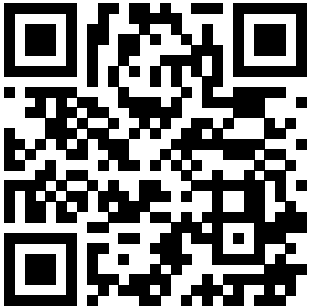
Source: Consortium meeting in Pisa, May 2025. Photo: RESILIENT team

One question for you, and where to find our work



In a few words: what is the biggest threat to resilience in your field of work?

Join at slido.com with **#2205 286**



All papers, code, data and training material from RESILIENT

resilient-project.github.io