GRINS FOUNDATION

WP1: Climate change mitigation and carbon emission reduction – Scenario analysis

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Objectives

- Analysis of the broader implications of policies to addres climate change

✔ Analysis of socio-economic and biophysical impacts of transition towards decarbonization
✔ Development of indicators and databases

Implications of decarbonization

- Identification of the effects of transition pathways on primary energy supply mix and composition of the electricity generation, distributional impacts
- Simulations of future energy demand
- Industry Trend on Decarbonization
- Quantification of marginal CO2 emission factors from European electricity generation

Instruments for decarbonization

- Interventions for landslide risk mitigation and their carbon emissions
- Mobility patterns and carbon emission
- Understanding of drivers of sustainable diets
- Carbon sequestration for different types of crops
- Climate literacy and attitudes toward climate-related issues

Co-benefits of decarbonization

- Co-benefits of climate change policies on reduced air pollution and mortality
- Impacts of reduced air pollution on health and schooling outcomes

Francesco Colelli (UNIVE and CMCC) and Enrica De Cian (UNIVE and CMCC)

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Empirical impacts of climate change on energy systems: from demand to supply

Finanziato dall'Unione europea NextGenerationEU
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Overview

Energy demand

1. identify the causal impact of short- and long-term adaptation
2. project the future long-term impacts on energy demand, along with additional fluctuations from weather shocks

Energy supply

1. identify the potential unavailability of thermal and hydro power generation units due to extreme weather, providing technology-specific responses
2. project impacts on thermal and hydro power generation

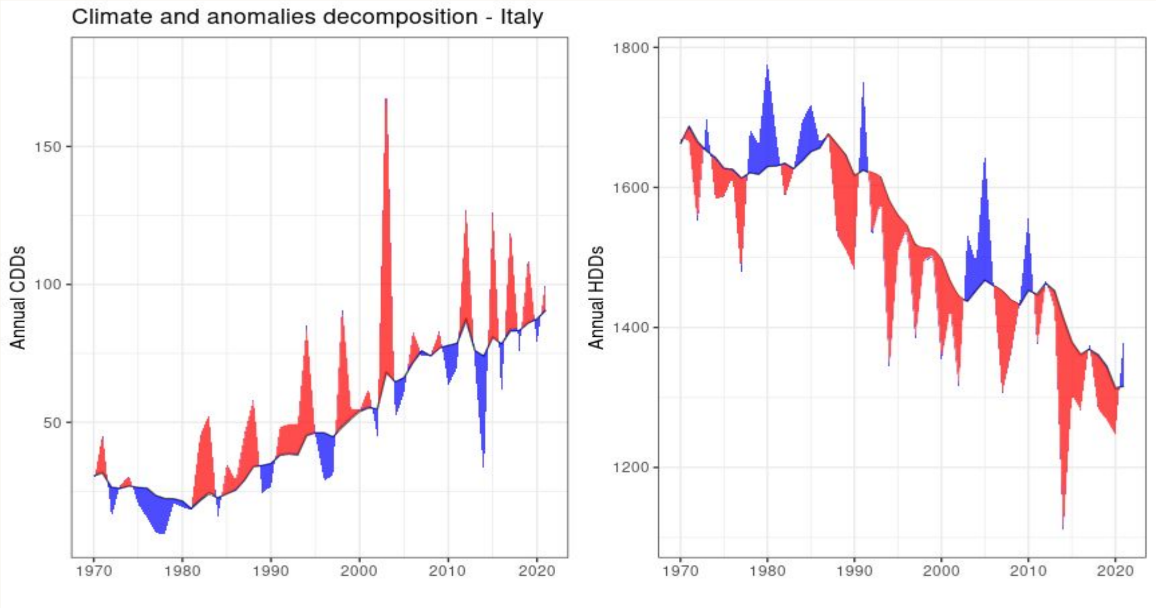
Empirical framework

Climate (c): 10-year moving average of the yearly observed weather (w).

$$c_{i,t} = \mathbb{E}_t w_{i,t} = \ell^{-1} \sum_{s=t-\ell}^{t-1} w_{i,s}$$

Weather anomaly (a): deviation of observed yearly w from c.

$$a_{i,t} = w_{i,t} - c_{i,t}$$



Empirical framework

Electricity and fossil fuel demand is estimated separately for each combination of sector *m* (Residential, Commerical, Industrial, Agricolture and Trasport).

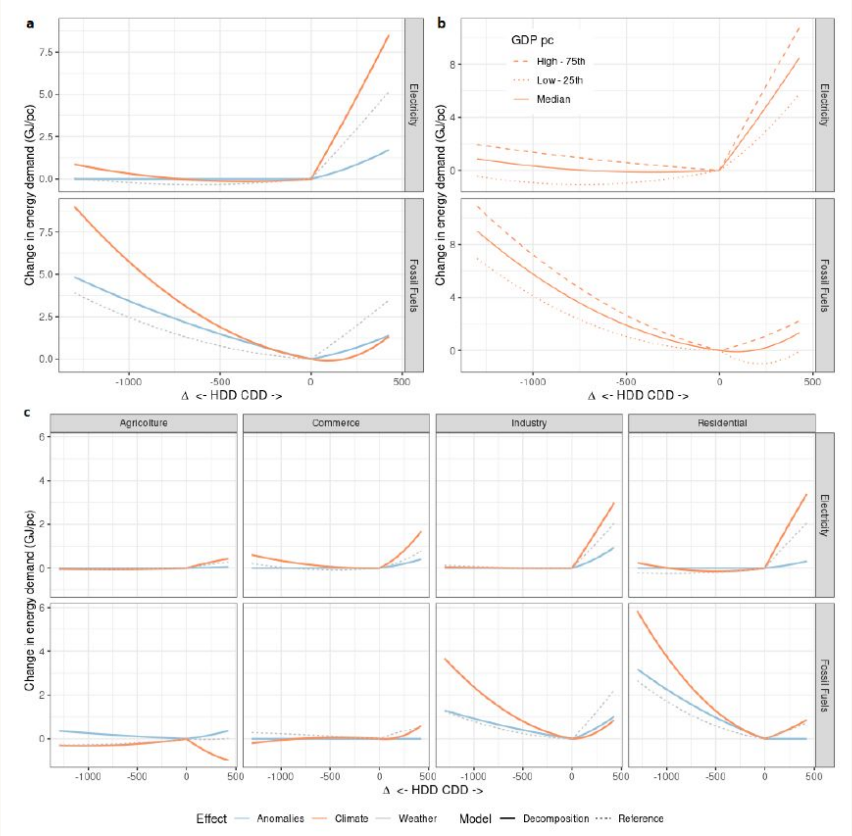
- Uniform effect of climatic DDs and their anomalies

$$q_{i,t} = \gamma_1 cdd^C_{i,t} + \gamma_2 hdd^C_{i,t} + \mathbf{aCDD}^l(\boldsymbol{\eta_1}^l + \boldsymbol{\rho_1}^l cdd^C_{i,t}) + \mathbf{aHDD}^l(\boldsymbol{\eta_2}^l + \boldsymbol{\rho_2}^l hdd^C_{i,t}) + \pi q_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

- Interaction effect of DDs climatic and anomalies with sectoral GDP per capita

$$q_{i,t} = cdd^C_{i,t}(\gamma_1 + \omega_1 y_{i,t}) + hdd^C_{i,t}(\gamma_2 + \omega_2 k_{i,t}) + \mathbf{aCDD}^l(\boldsymbol{\eta_1}^l + \boldsymbol{\rho_1}^l cdd^C_{i,t} + \xi_1 y_{i,t}) + \mathbf{aHDD}^l(\boldsymbol{\eta_2}^l + \boldsymbol{\rho_2}^l hdd^C_{i,t} + \xi_2 y_{i,t})$$
$$+ \pi q_{i,t-1} + \mu_i + \tau_t + \varepsilon_{i,t}$$

Energy demand: results

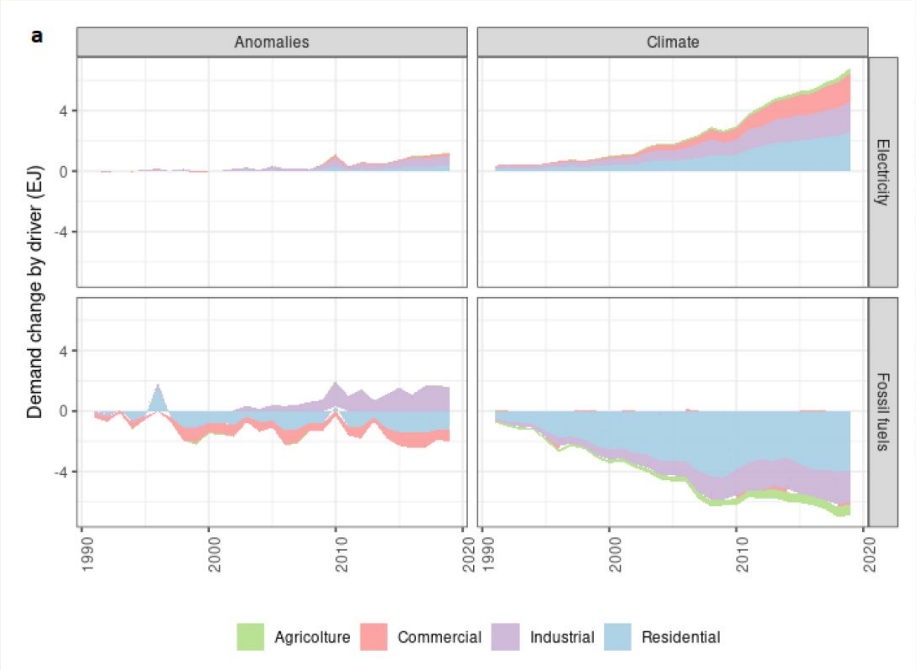


Estimated change on per capita energy demand (GJ/pc).

Differences between the shock of climatic (orange) and weather anomalies (blue) suggest an amplification of energy demand in the long-run (i.e. capital stock accumulation for adaptation).

Energy demand: results

Simulated variation in energy demand due to weather anomalies and climatic change in the historical period (1990-2019).



Cumulative additional energy consumption in the 1990-2020 period:

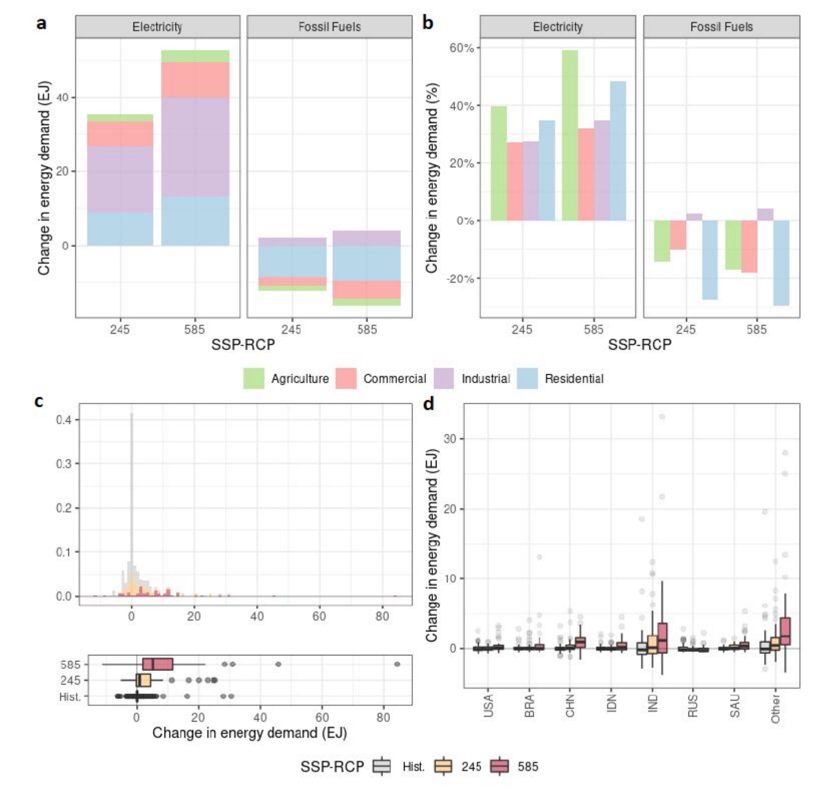
climatic changes

- 74 EJ electricity
- -125 EJ fossil fuels

Idiosyncratic variations in weather

- +10 EJ electricity
- -21 EJ fossil fuels

Energy demand: results



Global projected change in sectoral energy demand due to shifts in the climate around 2050 with respect to the historical climate, by sector and energy carrier.

Distribution of the change in total energy demand due to the effect of historical (grey) and future (orange and red) unexpected anomalies, with respect to the GCM-specific historical climate and average historical weather anomalies.

Energy supply: empirical framework

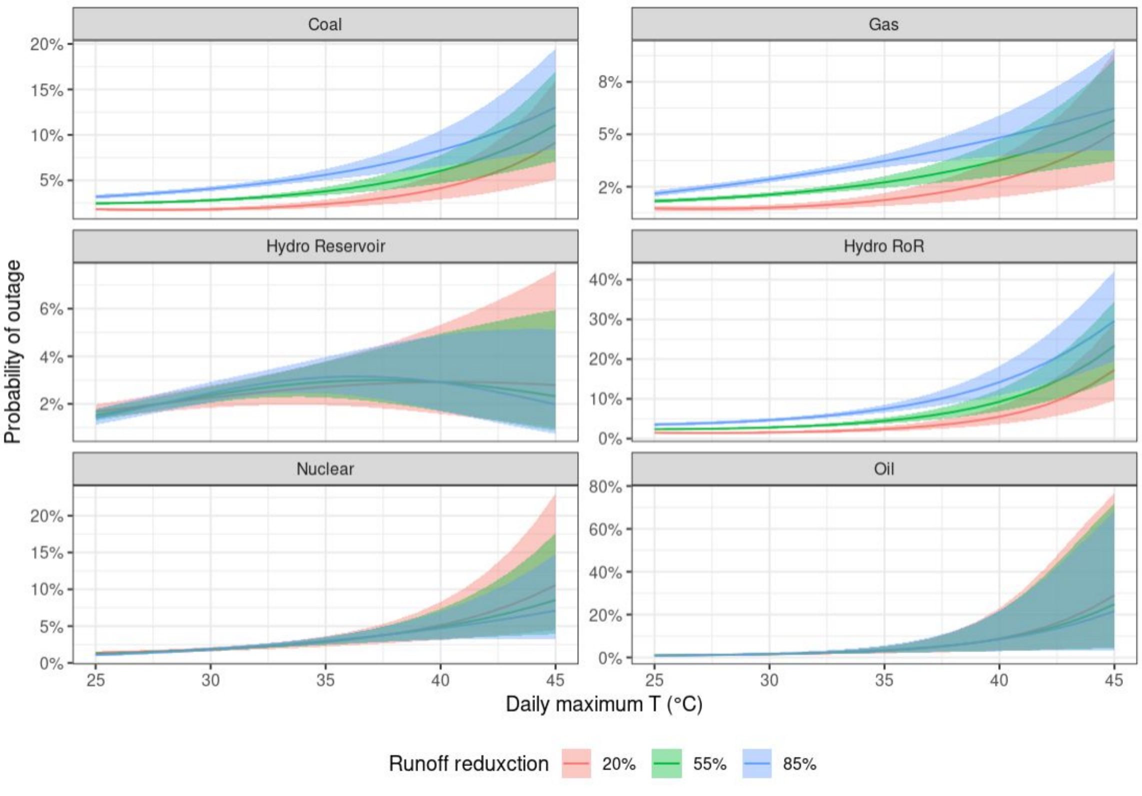
We study the potential unavailability of thermal power generation units due to extreme temperatures by developing a regression model based on outage information collected from 2018 to 2022 in Europe.

The dataset includes information of over 20.000 unexpected outages.

We consider as key dependent variable the occurrence of an outage in each power-plant, and identify the influence of daily maximum temperatures (t) and water runoff anomalies (r):

$$\Lambda(c_{i,t}) = \log\left(\frac{c_{i,t}}{1 - c_{i,t}}\right) = f(t_{i,t}) \cdot k + z(r_{i,t}) \cdot k + \psi k + \mu p + \nu m + \varepsilon$$

Energy supply: results



Estimated response function of outage probability depending on maximum daily temperatures and water runoff anomalies.

Daniele **LEREDE**, Valeria **DI COSMO**
Università degli Studi di Torino, Dipartimento di Economia e Statistica “Cognetti de Martiis”

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Analysis of the long-term effects of the restrictions on trade with Russia on the European energy system

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Outline

- **Introduction** and **aim of the work**
- **Methodology**
- **Scenario analysis**
- **Conclusions** and **perspectives**

Introduction and aim of the work

Within the framework of the European Green Deal to:

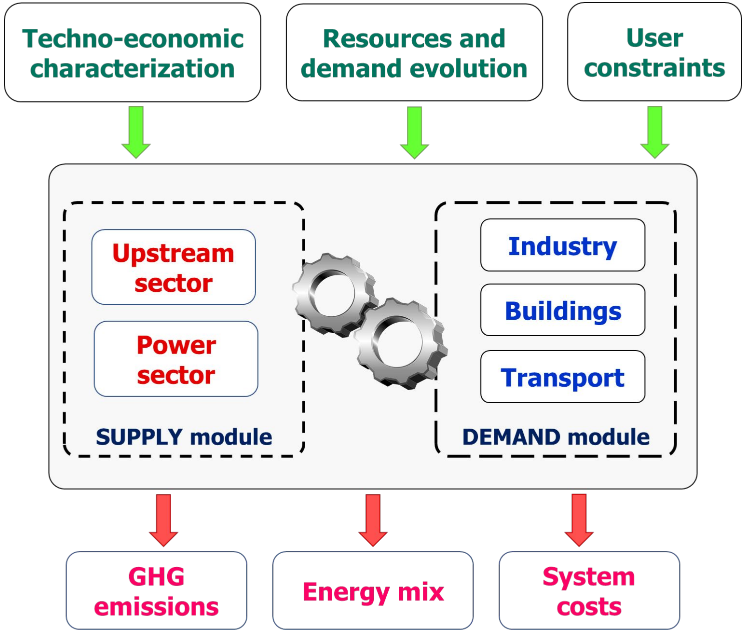
- Become a **carbon-neutral** continent by **2050** through a socially-fair transition
- **Reduce** by at least **55 % greenhouse gases emissions by 2030** with respect to 1990 levels

and following Russia's invasion of Ukraine, the European Commission is implementing its **REPowerEU Plan** to **save energy**, **produce clean energy** and **diversify energy supplies**

The **aim of this work** is to study the impact of **changing patterns in European energy supply** on **energy-intensive sectors** in **Net-Zero Emissions scenarios** up to **2050**

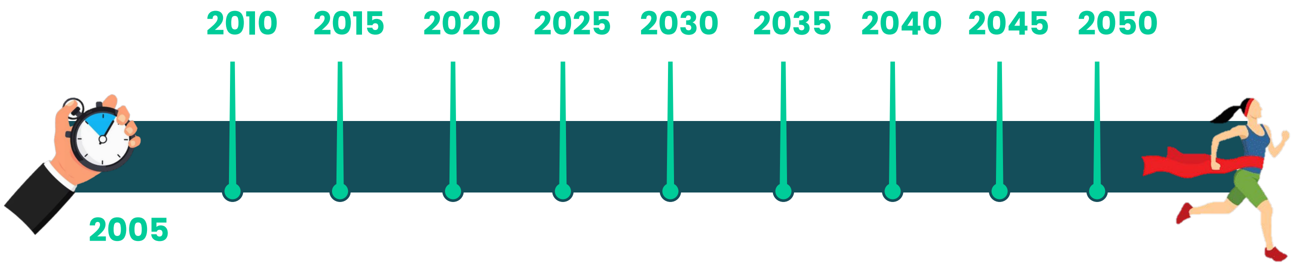
Energy system optimization models (ESOMs) provide tools to:

- **Optimize** energy **supply and demand** to **satisfy specific end-use demands** according to a **minimum cost paradigm**
- Analyze the **role of innovative technologies**
- Assess the **feasibility** of **energy and climate policies** in **different scenarios**
- Analyze the impact of policy constraints on **energy-intensive supply and demand sectors**



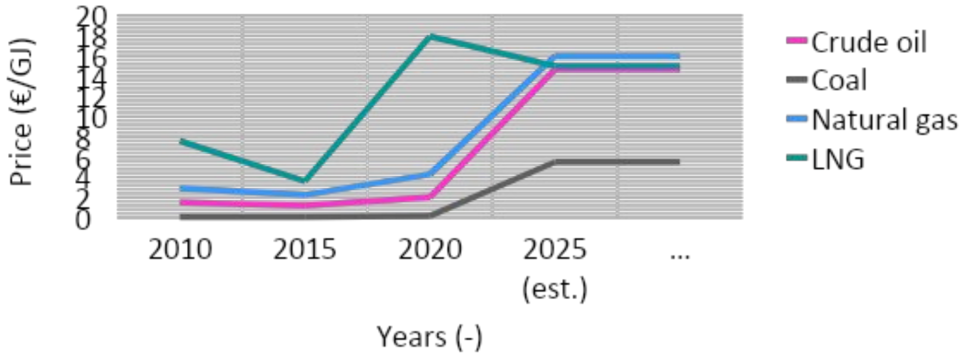
TEMOA-Europe is the **first-of-a-kind open-database** and **open-software ESOM** for **OECD Europe**

TEMOA-Europe inputs include a **database of > 1000 technologies** to build the **optimal energy system** over a **long time scale**



Main features of the analyzed scenarios

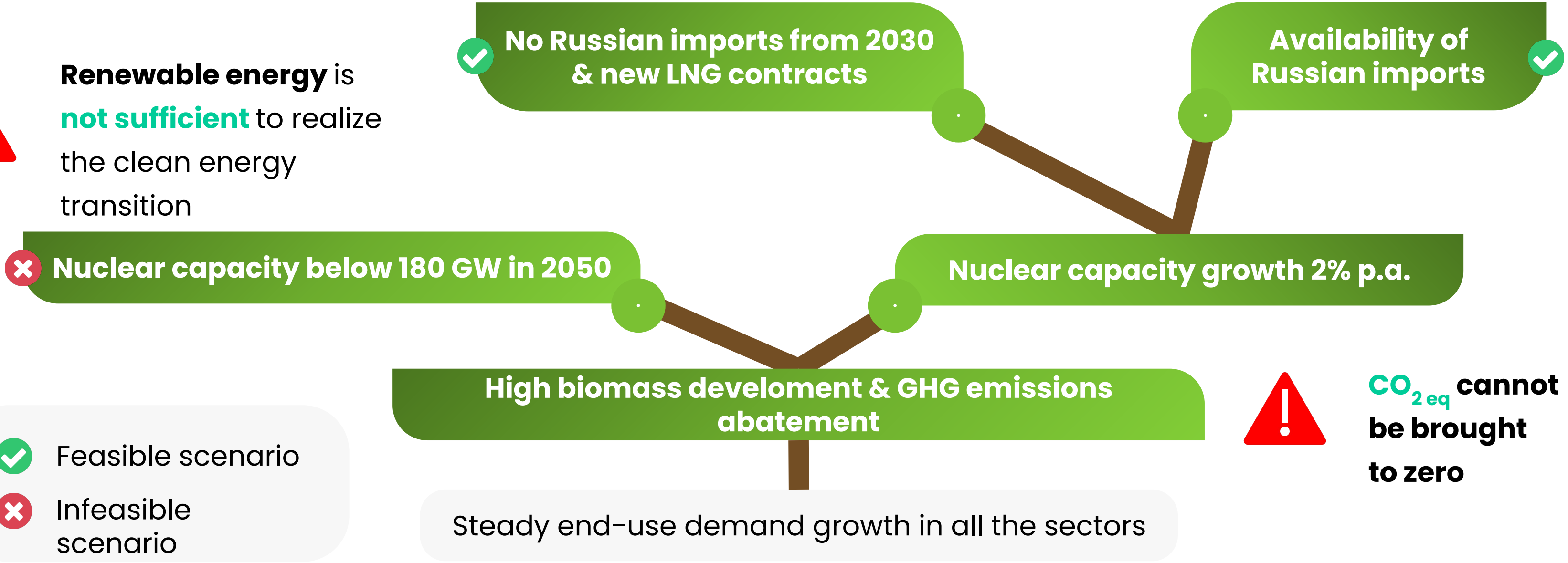
- **GHG emissions reduction: Fit for 55 by 2030** & **Net-Zero Emissions (NZE) by 2050**
- **Input prices for imported fossil fuels:** elaborated from World Bank data and kept **stable** at post-Ukraine invasion levels



- **Main decarbonization alternatives: renewables** and **nuclear**, **hydrogen**, **carbon capture, storage and utilization**, **afforestation**

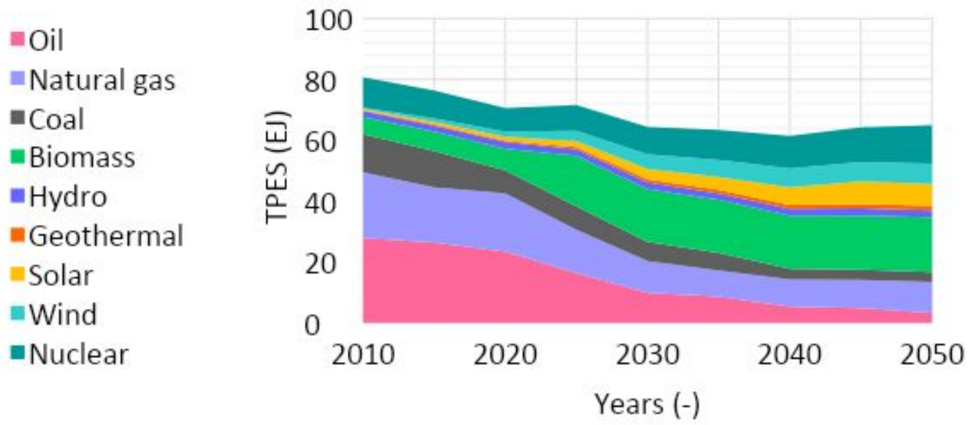
Scenario tree

Renewable energy is **not sufficient** to realize the clean energy transition



$CO_{2\,eq}$ **cannot be brought to zero**

- ✓ Feasible scenario
- ✗ Infeasible scenario

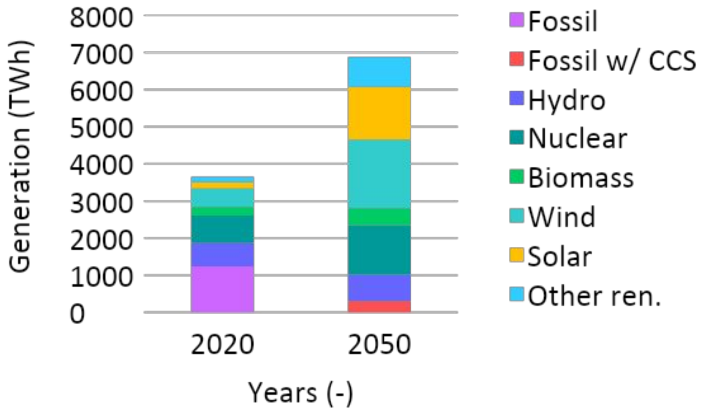


Results - Total primary energy supply:

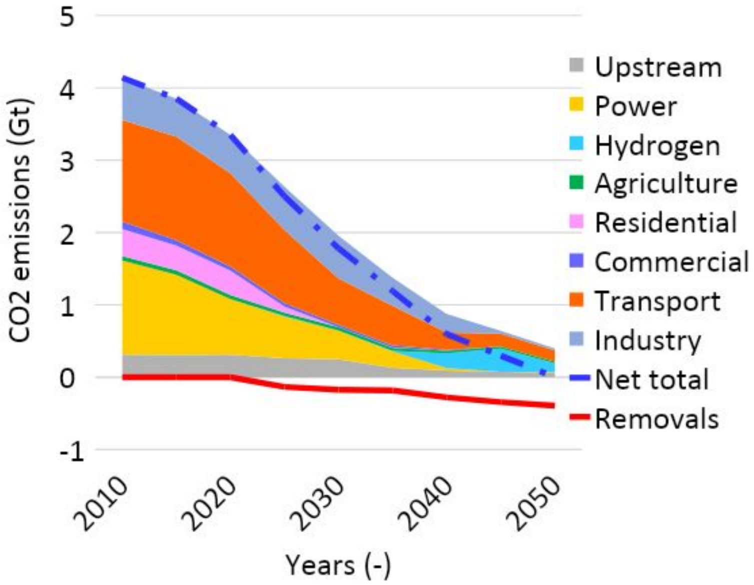
- The **peak in fossil demand** should be reached in the **before 2025**
- **Biomass** gains a large role by 2050

Results – Electricity generation mix:

- Abating emissions requires **strong electrification of end-uses** (+ 80% current levels)
- Development of **CCS** in power sector **not crucial**

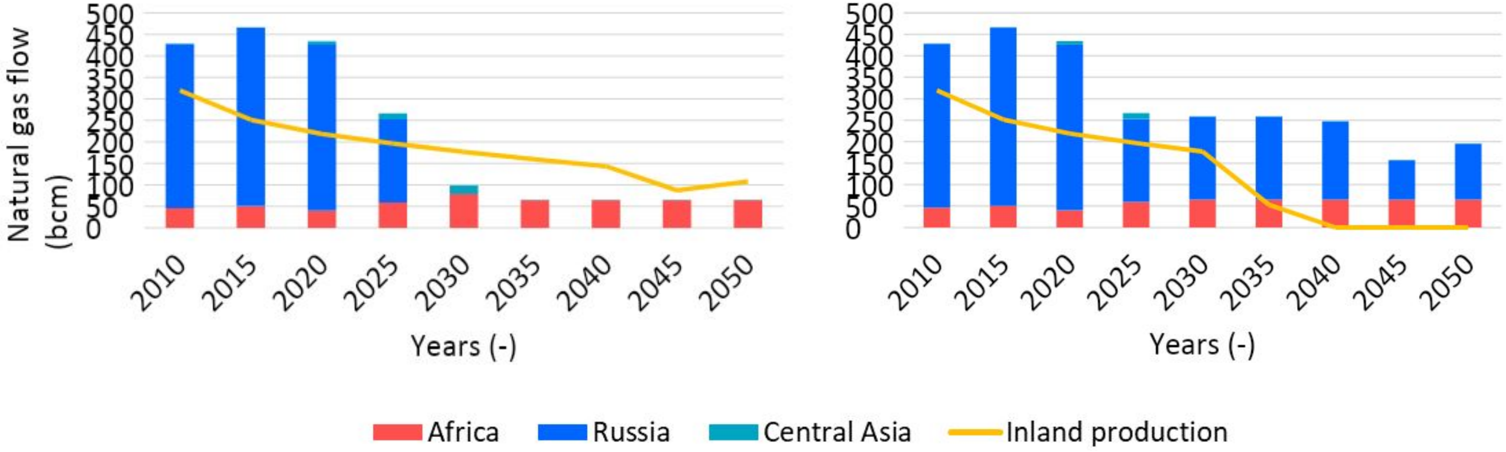


Results – CO_2 emissions



- **Industrial decarbonization** is helped by the **adoption of CCS** in the **cement subsector**
- **Biofuels** are fundamental for the **industrial** and the **aviation** sectors
- CO_2 emissions from **hydrogen production with coal and gas w/ CCS** are non-negligible by 2050
- **Afforestation** contributes to remove **0.4 Gt CO_2** per year by 2050

Long-term effects of the restrictions on Russian natural gas imports



- The **absence of Russian gas imports** **does not allow the shutdown of inland gas fields** while the **recent LNG supply contracts put in place are sufficient to contrast that setback**

Conclusions and policy implications

- **TEMOA-Europe** is not able to compute **NZE by 2050 trajectories for $CO_{2\,eq}$** (CO_2 alone can be brought to net-zero) even if relying on a database of more than 1000 technologies
- Abating emissions is possible only considering a **strong support from nuclear energy and renewables**, especially **biomass** which **can directly substitute fossil fuels in a wide range of applications**
- The **absence of Russian fossil imports** represents a **temporary setback** and **should not have relevant impacts on the decarbonization of the European energy system**

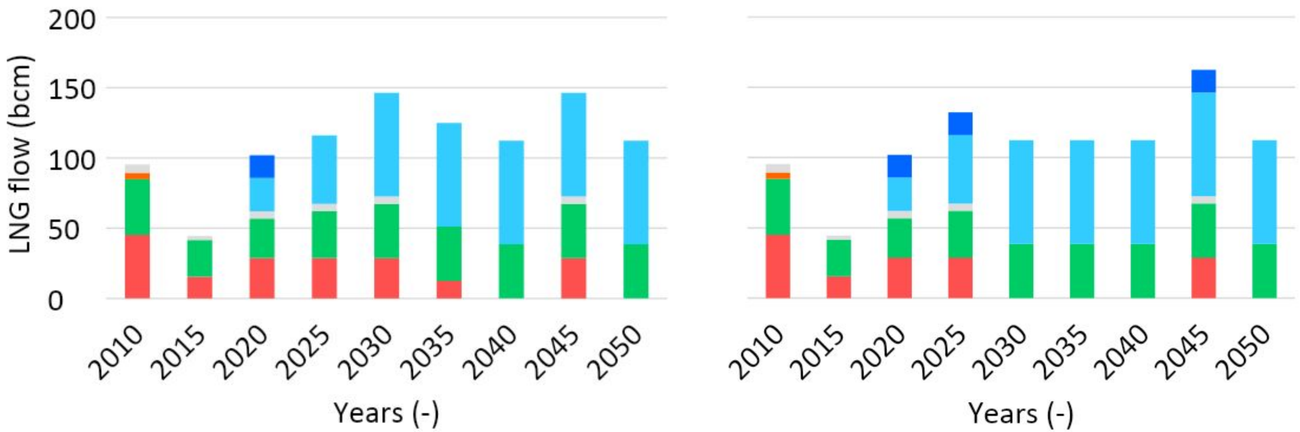
Future insights

- Review of the **biofuel production chain** due to the expected large role of biomass as from the outcomes of this work

- Deep review of all the **European policies** related to the realization of the **EU Green Deal** to produce more detailed scenarios (e.g. concerning **hydrogen**)

- **Endogenous implementation** of **price-elastic demands** and **technology learning curves**

Long-term effects of the restrictions on Russian natural gas imports



- Russia has a marginal role in LNG supply

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WP1: Decarbonising hard-to-abate sectors

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01 Decarbonising Fuels

02 Decarbonising Industries

03 Carbon Offsetting

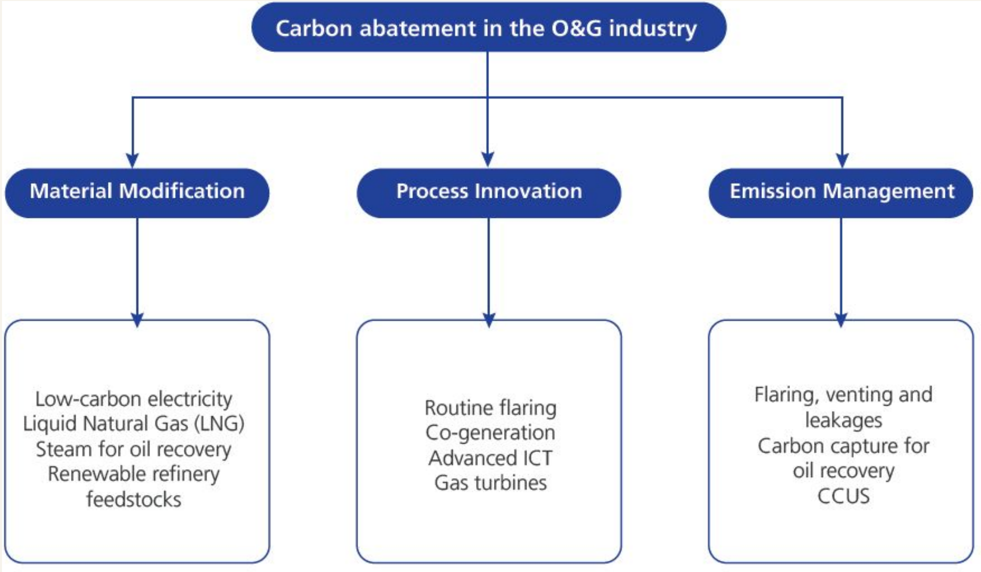
01 Decarbonising Fuels

Decarbonizing fuels

Oil & Gas

In the oil & gas (O&G) sector, the direct and indirect impacts of refining, transport, flaring, extraction and use mean the industry contributes 15% of global emissions.

For direct emissions, there are three main approaches to decarbonization for heavy industries: material modification, process innovation and emission management.



Decarbonizing fuels

Oil & Gas

The most efficient methodology is typically selected based on assessment of **carbon dioxide savings weighed against costs**:

- **Material modification** includes integrating renewables, process innovation covers co-generation while emissions management also incorporates reducing leaks
- **Leak detection** and repair is amongst the most efficient approaches to abatement and has the potential to reduce emissions by 85%
- **Process innovations** center on eliminating routine flaring, encouraging co-generation, improving the energy efficiency of oil & gas plants by utilizing the power of advanced Information and Communication Technologies (ICT) and promoting enhanced energy recovery from gas turbines.

Decarbonizing fuels

Oil & Gas Climate Initiative

OIL AND GAS CLIMATE INITIATIVE

The Oil & Gas Climate Initiative, which represents about 33% of global production, has set ambitious abatement targets.

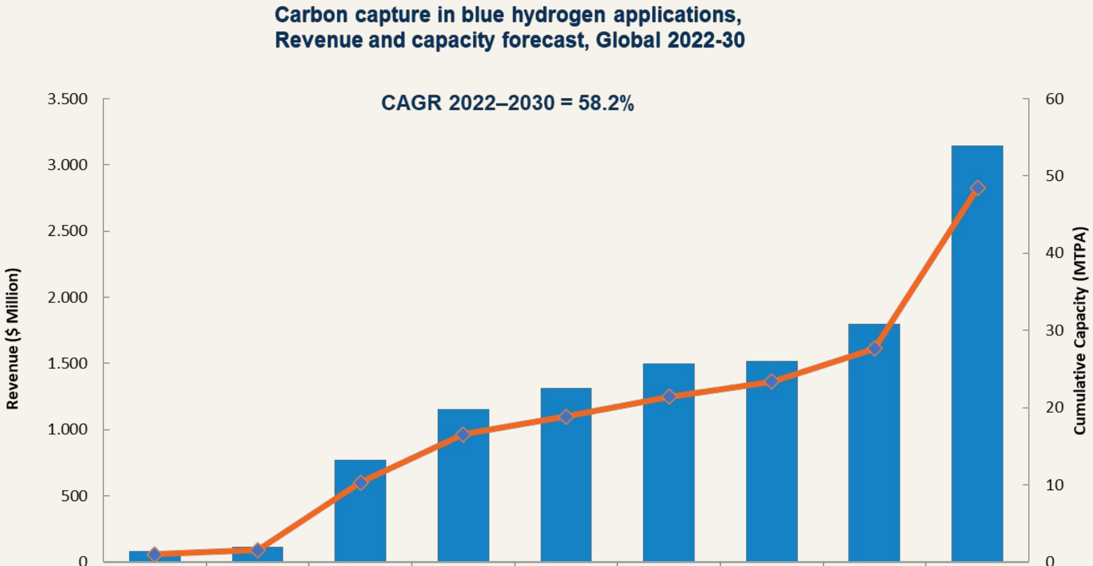
Its members are investing $6.5 billion in low carbon technology Research & Development (R&D) with initiatives aimed at reducing the average methane intensity of upstream oil & gas operations to less than 0.25% by 2025 from a baseline of 0.32%.

Leak detection and repair is amongst the most efficient approaches to abatement and has the potential to reduce emissions by 85%

Hydrogen

Blue hydrogen

Overall, alternative fuel use in heavy industries remains limited but implementing CCUS for hydrogen production offers a way in which to decarbonize.



	2022	2023	2024	2025	2026	2027	2028	2029	2030
Revenue ($ M)	80,3	113,9	770,6	1155,7	1315,9	1498,4	1517,8	1796,7	3147,9
Annual Capacity	1,0	1,5	10,3	16,5	18,8	21,4	23,4	27,6	48,4

"Blue" hydrogen is produced from fossil fuels such as oil, gas and coal principally via steam methane reforming or autothermal reforming and uses CCUS to capture CO2 produced

Hydrogen

Green hydrogen

Implementing widespread green hydrogen production processes means:

- **removing 830 million tons** of annual CO_2 emissions globally which stem from the use of fossil fuels to produce H_2;
- **greater and accelerated efforts** from stakeholders across the value chain

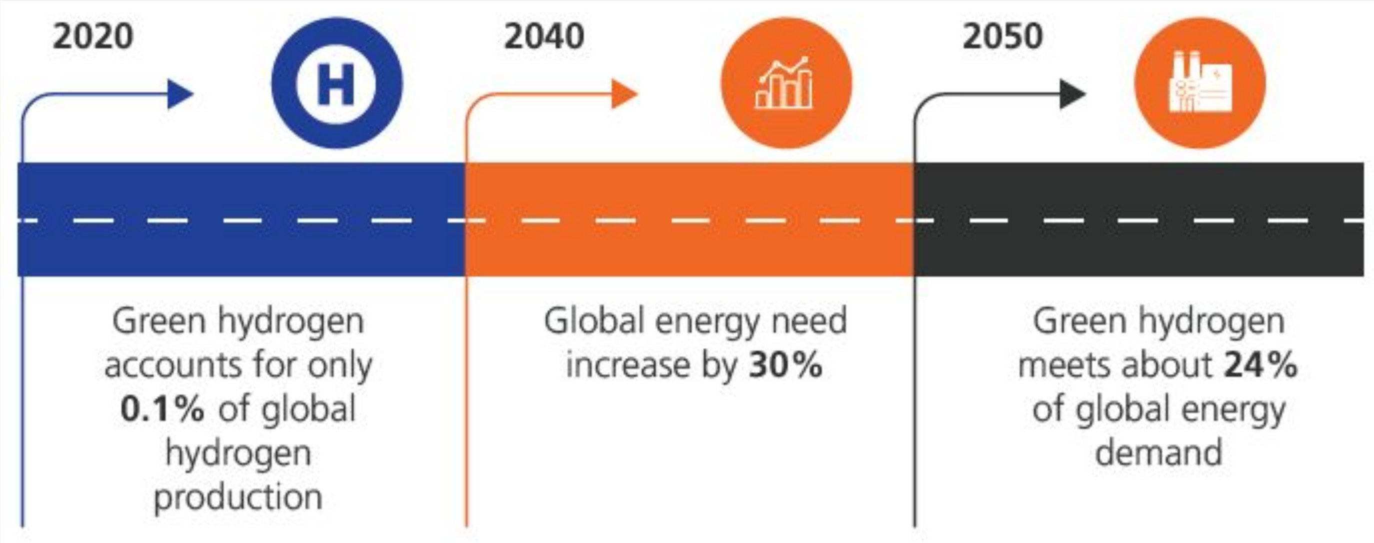
To produce more than 18 megatons (Mt) of green hydrogen annually by 2030, an investment of more than **100 billion dollars** is required but only $20b is currently committed to infrastructure development.

Hydrogen

Green hydrogen

Today, green hydrogen accounts for only 0.1% of global production but has the potential to meet 24% of global energy demand through $160b of financing

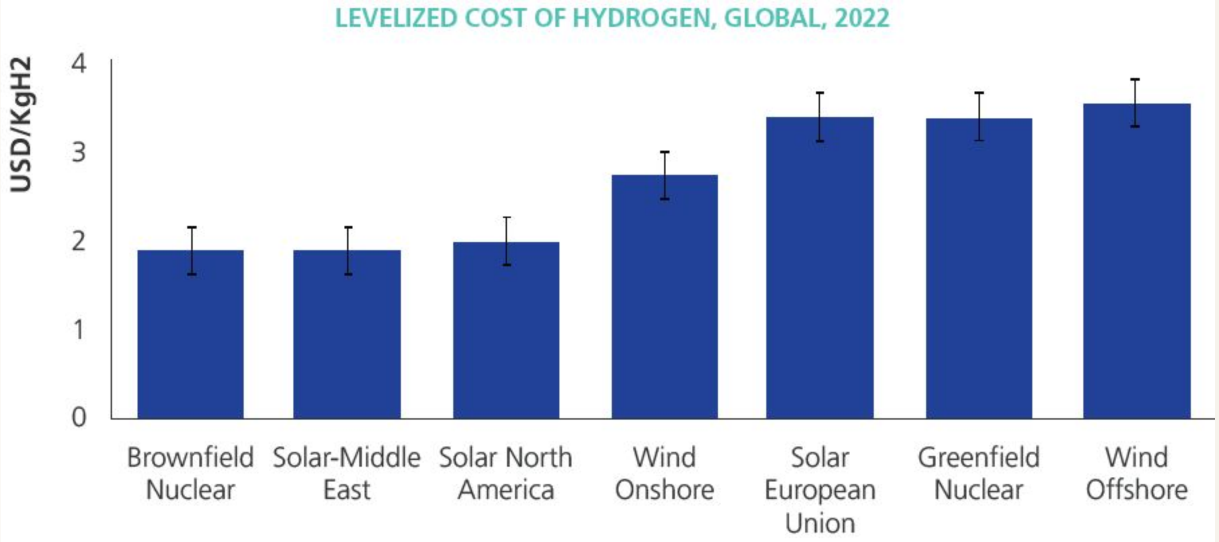
Green hydrogen roadmap global 2020-2050



Hydrogen

Cost comparison

The graph depicts the levelized cost of hydrogen production for various electricity generation technologies.

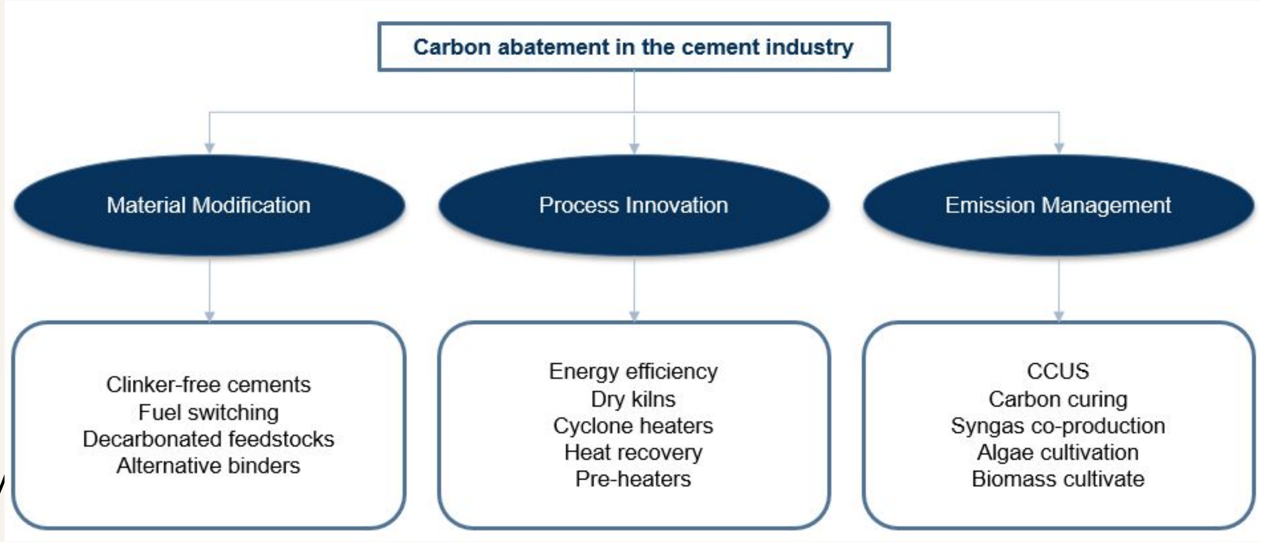


While newly built nuclear plants are already cost-competitive with offshore wind and solar power, facilities which operate over time will offer the lowest-cost hydrogen production solutions via electrolysis. As a point of comparison, H2 production through SMR at gas prices of $100 per MWh does not compare favorably.

02 Decarbonising Industries

Cement

The cement industry is estimated to release about **1 kg of carbon dioxide for every 1kg of cement** that is produced. The average CO2 emissions per ton has decreased by 18% since the 1990s, mainly due to improvements in the efficiency of production plants and by switching to waste materials for energy generation need, but the **average CO2 per ton still contributes about 6% of global emissions** With the demand for buildings and infrastructure set to rise due to rapid urbanization across the globe, the need for sustainable construction techniques is gathering pace.



Cement

Unlike other industries, the release of carbon dioxide in the cement sector is largely attributed to the chemical reactions.

During the manufacturing process itself and notably in the conversion of limestone ($CaCO_3$) into calcium oxide (CaO) which is the primary precursor to cement CO_2 is emitted.

It is chemically impossible to transform $CaCO_3$ into CaO and then into cement clinker without emitting CO_2.

Carbon captured can be reused in the manufacturing process or for other purposes and has the potential to reduce emissions by up to 95% to 99%

Steel

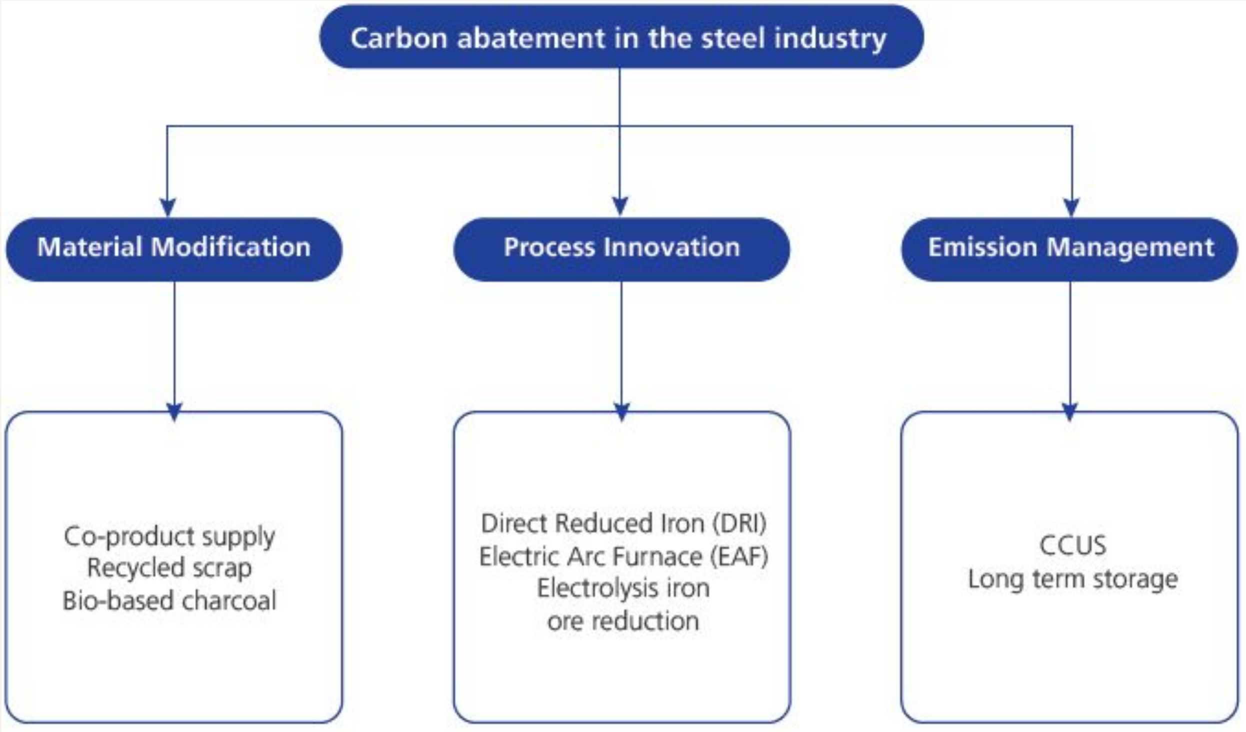
In the steel industry, decarbonization has not received any focused investment and the space still contributes between 7% and 9% of global emissions

Material modification includes leveraging co-products, process innovation covers direct reduced iron while emissions management also incorporates CCUS

Electrolysis for iron ore reduction is gaining R&D interest for the long term

Steel

By reusing steel in the form of scrap, the industry can drastically **reduce its carbon footprint up to 100%** across its product life cycle. However, the availability of scrap is limited owing to the inherently long life of steel products.

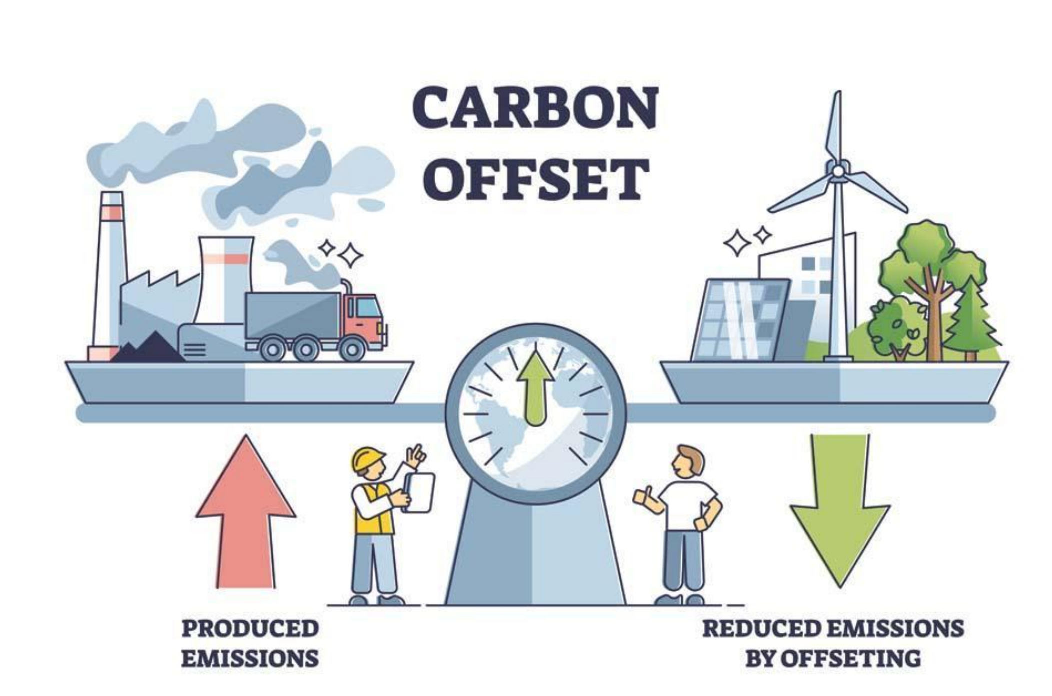


Energy consumption in the steel industry has already witnessed a 61% drop in the last 50 years. Although there is still room for improving the efficiency of production processes, the potential for achieving further significant emission reductions is limited to 15% to 20%.

03 Carbon Offsetting

Offsetting

Only if other approaches to decarbonization fail or are temporarily unavailable, offsetting offers market participants another way in which to reduce their footprints.



Carbon offsetting forms part of a broader approach to emissions management in heavy industries which is supported by emerging digital solutions

Offsetting is limited not only to production activities but also plays a key role in aviation

Implications for Banks

- Banks will need to **provide finance the rollout capital**-intensive cutting-edge material modification, process innovation and emission management solutions
- In the meantime**, banks are supporting innovation in heavy industries** through a combination of direct and conventional commercial lending to start-up clients and indirect investments through dedicated vehicles.
- Projects proliferating, technology improving – notably in respect of electrolyzers – and public sector support continuing (in the form of direct investment in the EU, via the Commission's Hy2Use scheme and the **European Hydrogen Bank**, and in the US, through **hydrogen-dedicated tax credits** stemming from the Infrastructure Investment and Jobs Act and **Inflation Reduction Act**), determine, for investors, the role to assess which opportunities are bankable and which pose significant risk.

GRAZIE PER L'ATTENZIONE

anna.monticelli@intesasanpaolo.com

GRINS spoke 6 meeting, Padova, 20-21 November 2023

RFF CMCC European Institute on Economics and the Environment

GRINS FOUNDATION

Fit-For-55 and beyond: European power system transition and its social impacts

Alice Di Bella, Paola Rocchi

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Framework and research question

Framework

2020 European Green Deal: two steps for practical implementation

- European Climate Law: legally binding target of climate neutrality by 2050
- Fit-For-55 (FF55) package: various policy instruments designed to reduce EU's greenhouse gas emissions by 55% by 2030 with respect to 1990

Research question

Analyse the transition pathway for the European energy system, focusing on the technical feasibility and social implications of the policy framework

- within the FF55 package and achieving climate neutrality
- with a particular focus on the Italian case

Literature review and aim

Literature review

Studies that assess possible pathways for the EU to achieve a carbon-neutral energy system by 2050 (energy models): Löffler et al. 2019, Victoria et al. 2020, Seck et al. 2022

- Lacking social aspects and implications on households and firms

Studies that assess macroeconomic and implications of FF55 (GEM)

- Not grounded on technical assessment of the transition pathway for the European energy system (Orecchia et al. 2023)

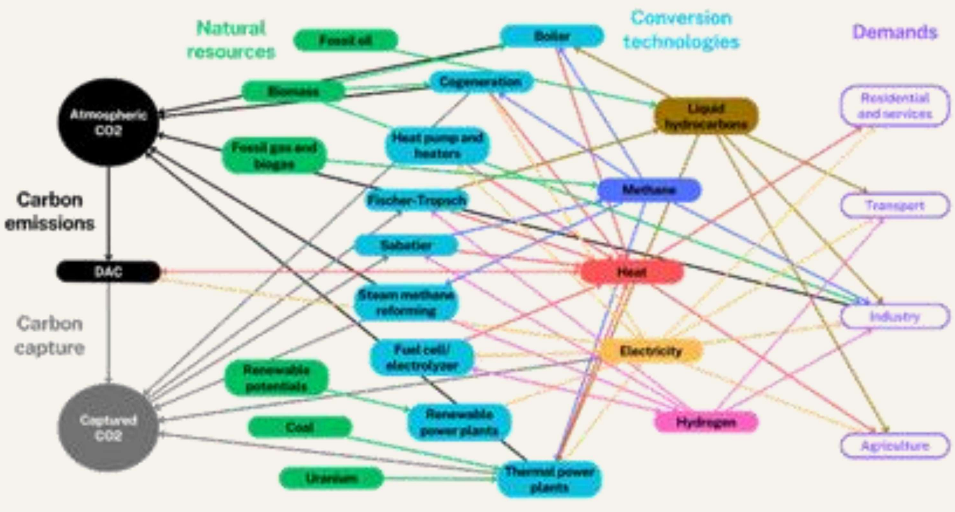
Aim

Linking the 2 approaches (EC. 2020), adding distributive considerations or a broader time perspective

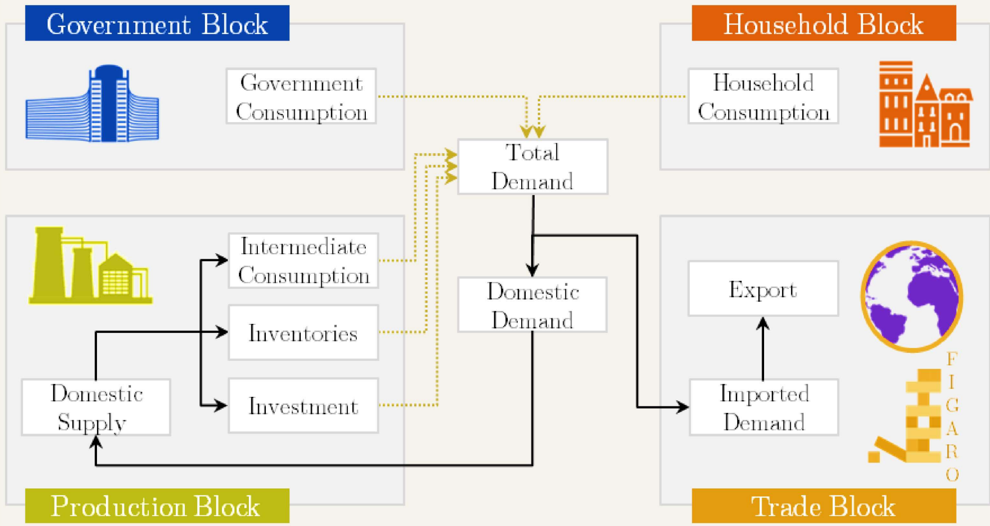
Proposal

Link Energy System Optimization Model for the European Union ESOPUS and the general equilibrium model FIDELIO

ESOPUS

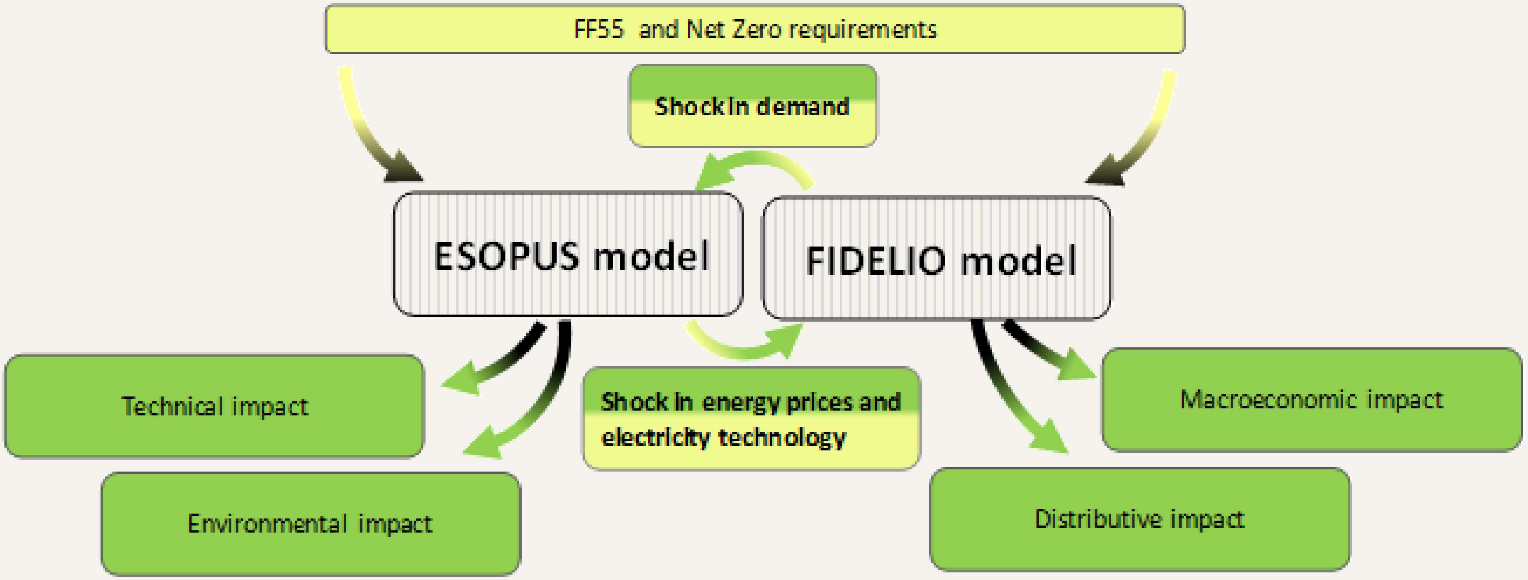


FIDELIO



Proposal

Link Energy System Optimization Model for the European Union ESOPUS and the general equilibrium model FIDELIO



Interim report

Focus

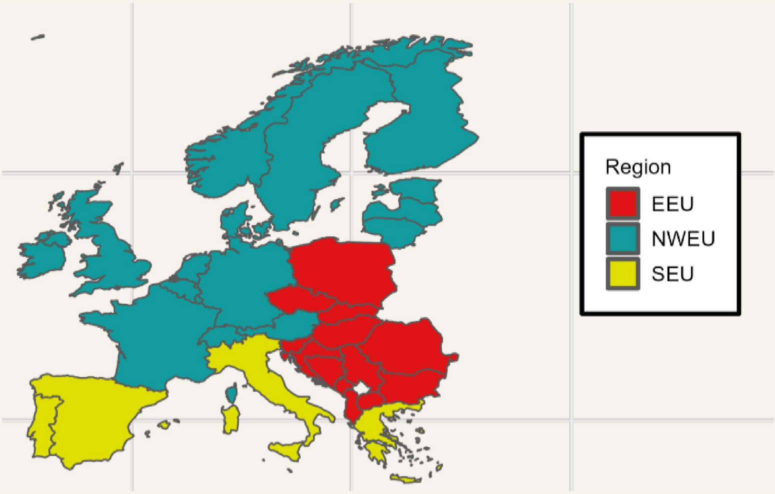
This interim report focuses on the implications of emissions reduction requirements for the European power sector

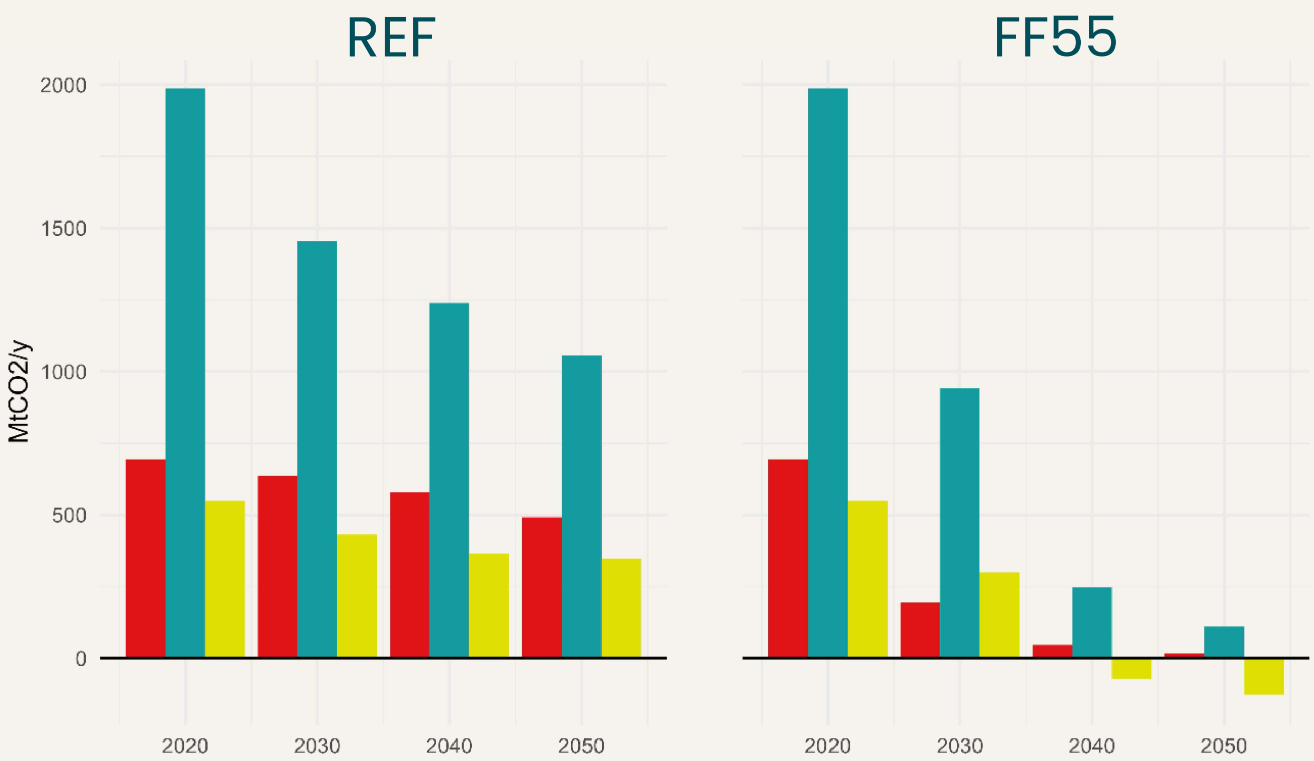
- Key contributor to EU GHG reduction
- Empowering transition in other sectors

Scenarios

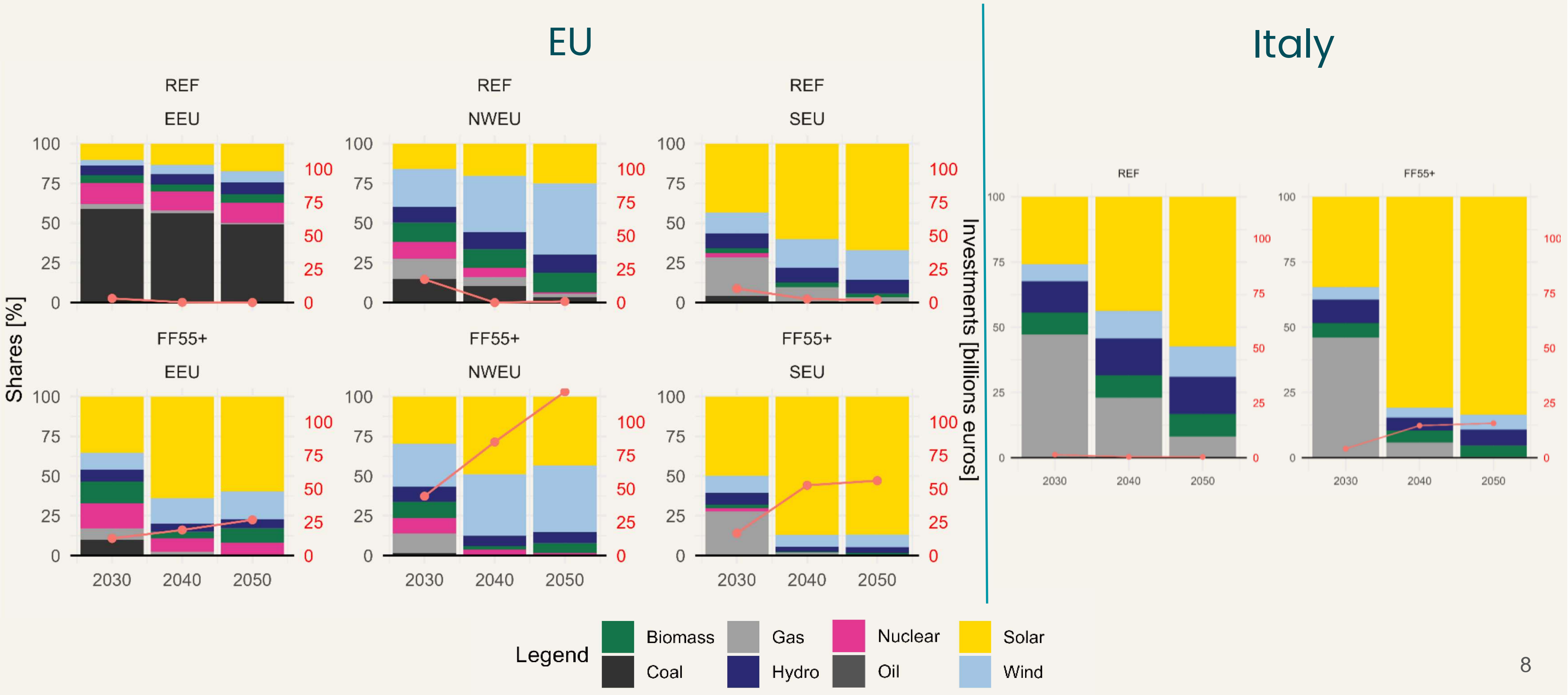
	REF	FF55+		
ESOPUS	No climate policy for the energy sector	FF55 in 2030 , Net Zero CO2 emissions in 2050		
FIDELIO		FF55+_no_red	FF55+_hous_red	FF55+_mix_red
		FF55+, no revenues redistribution	FF55+, revenues to households	FF55+, revenues to households/government

Results (1): CO_2 emissions



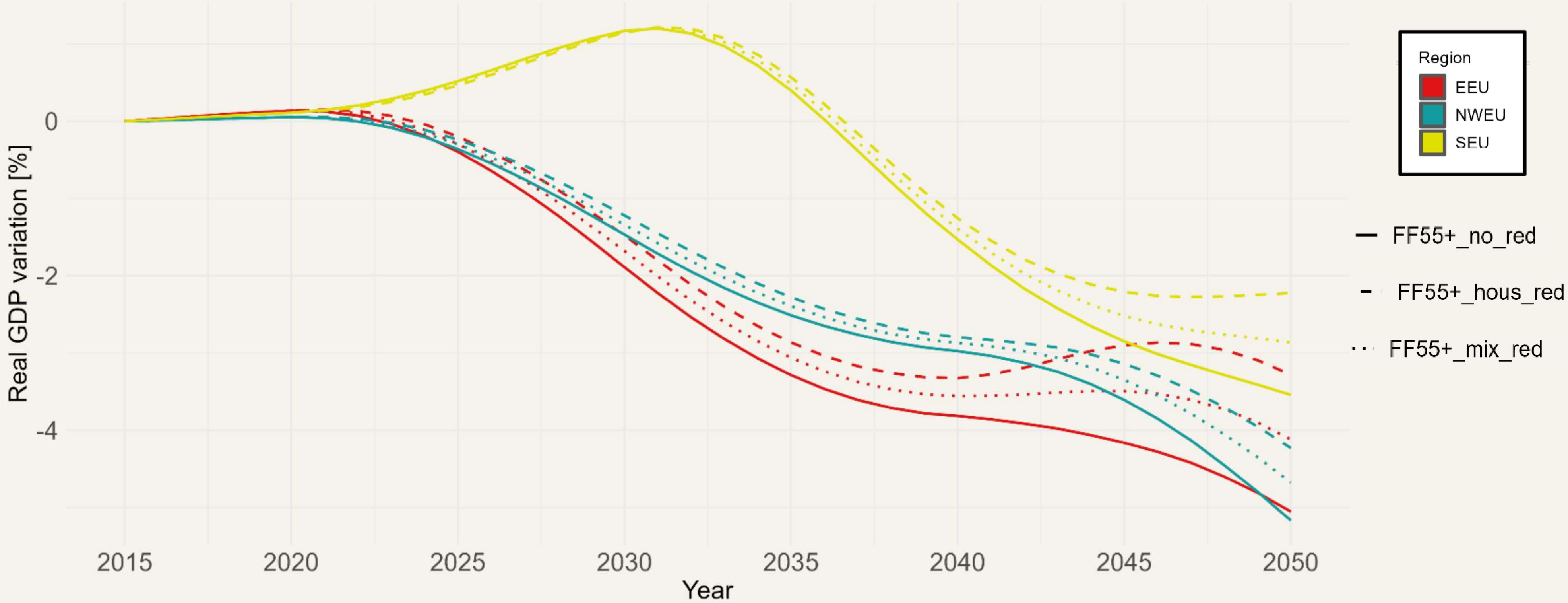


Results (2): power generation by technology



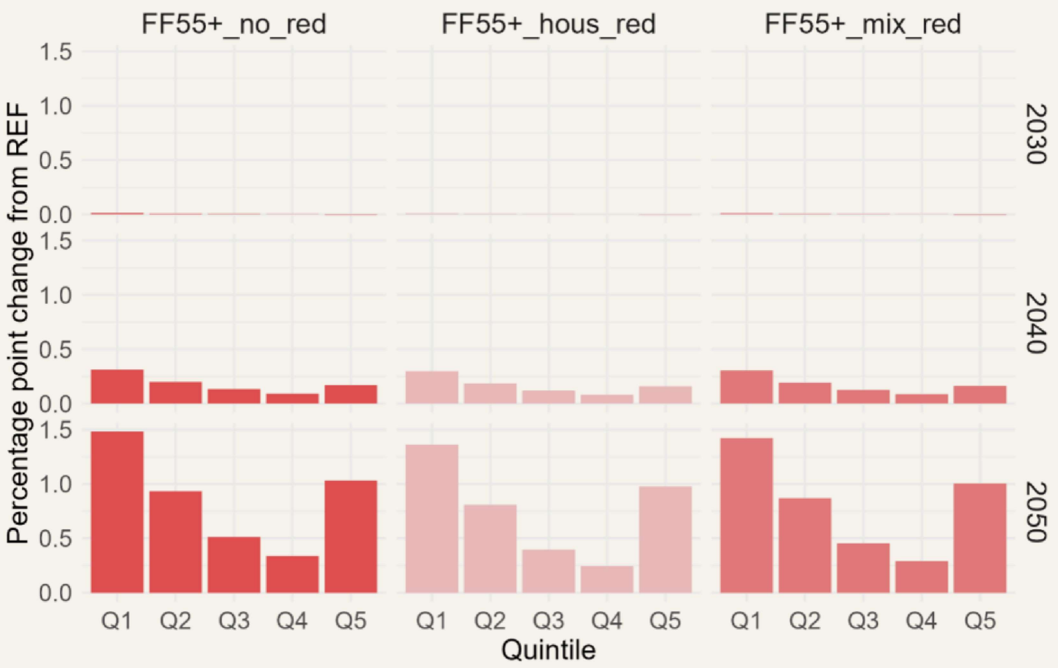
Results (3): macroeconomic impact

Real GDP deviation from the REF scenario



Results (4): impact by quintile, Italy

Electricity share pp change



Consumer surplus loss (hous_red)

As % of income

	2030	2040	2050
Q1	0.45	3.11	7.37
Q2	0.42	2.90	6.84
Q3	0.36	2.51	5.86
Q4	0.32	2.20	5.10
Q5	0.27	1.80	4.10

Conclusions

Policy implications

Europe

- Positive trajectory towards FF55 intermediate step of a 55% emissions abatement even without explicit policy instruments
- Achieving emissions reduction targets for 2040 will require steadfast policy support and a focus on advancing relevant technologies
- Significant variations among European countries: addressing regional disparities is key to achieving an equitable transition

Conclusions

Policy implications

Italy

- Solar generation pivotal to achieve policy targets in the electricity sector
- 2030: ongoing technical transformation in line with the FF55 framework
- Pushing photovoltaics installation can increase the investments needed into the transition by 2040 and 2050: negative impact on GDP
- Stronger impact on lower-income households: the design of the policy's redistribution mechanism is pivotal in mitigating adverse effects

Conclusions

Caveat

- None of the 2 models addresses the aspect of political feasibility. Political choices made at the Union level might meet different resistances in different Member States. More vulnerable countries might need specific incentives and tailored instruments to boost co-benefits from the energy decarbonization

Next steps

- More comprehensive understanding of the complex relationships among the different policies of the FF55 package and the broader targets for other economic sectors and agents
- Improve the iterative linkage between our models for a more precise evaluations of policy impacts

Thanks for the attention!! Questions?