Modeling carbon neutral pathways for the EU

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EU Policy context

2016-18: Clean Energy for All Europeans package for 2030
- GHG -40%
- RES 32%
- EE 32.5%

2018-19: Clean Planet For All package
- Climate neutrality in the EU by 2050
- –> Zero net CO_2 emissions
- Various pathways

National Energy and Climate Plans (NECPs) end 2019
- Compatible with the RES target
- Short in Energy Efficiency ambition

Current trends
- Coal phase-out, large RES projects
- E-mobility emerging
- Green gas and Hydrogen projects launched

Brussels, 17.9.2020 SWD(2020) 177 final

Stepping up Europe's 2030 climate ambition to 55%

(Climate Target Plan)

Key questions for the model-based analysis

Long term questions:

- Is climate-neutrality by 2050 in the EU viable and sustainable in the long run?
- Is it possible to reach climate-neutrality solely with conventional fuels and technologies?
- If not, what additional elements to promote in addition to conventional policies and technologies?
- Is climate-neutrality affordable?

Mid-term questions:

- Which sectors are affected when increasing the target to 55% in 2030?

PRIMES

Model structure:

- **Modular system:** one module per sector
- **Microeconomic foundation with engineering representations**

Aim:

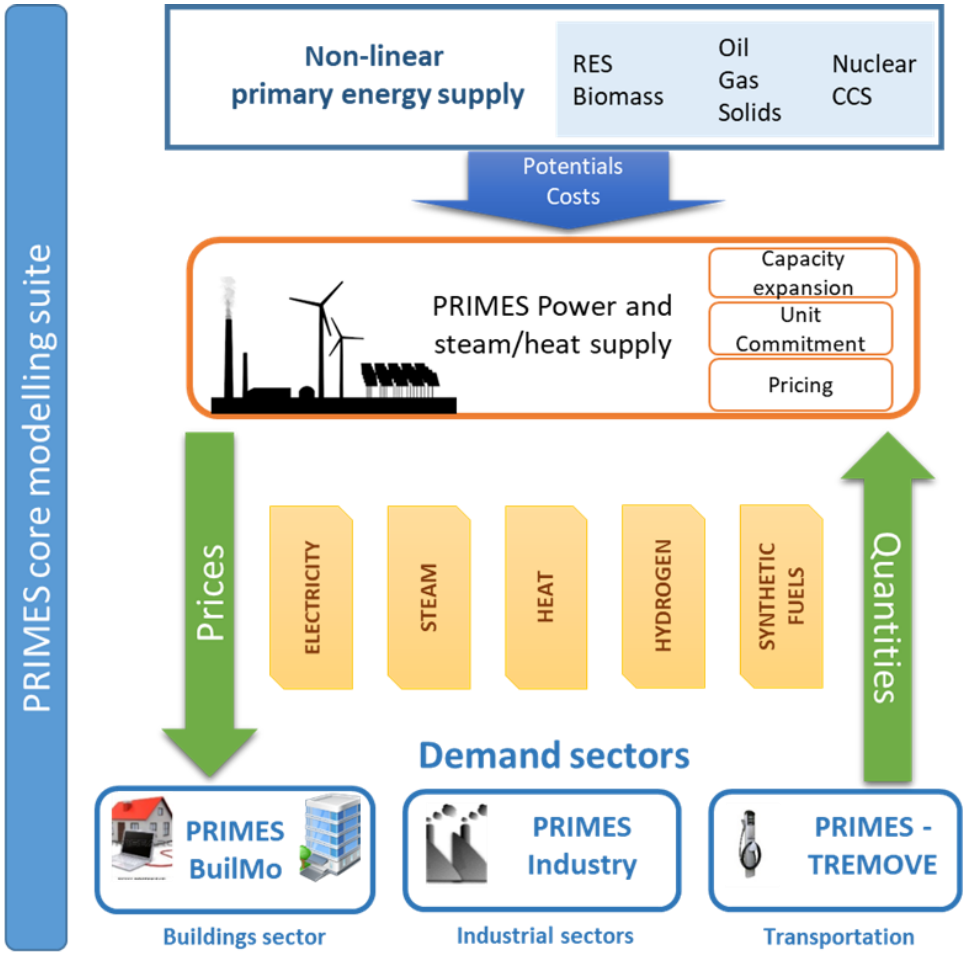
- Simulate structural changes and long-term transitions

Focus:

- **Market-related mechanisms**
- Representation of **policy instruments for market, energy and emissions**, for policy impact assessment

Technology database:

- Energy technology database has a standard format and is open access



Temporal resolution: to 2070, in 5-year time steps
Geographic resolution: 28 EU MS + 10 European non-EU countries
Mathematically: concatenation of mixed-complementarity problems with equilibrium conditions and overall constraints (e.g. carbon constraint with associated shadow carbon value) - EPEC

PRIMES typical inputs and outputs

Input	*Process*	*Output*
GDP and economic growth per sector (many sectors) –GEM-E3 World energy supply outlook – world prices of fossil fuels – PROMETHEUS (or POLES) Taxes and subsidies Interest rates, risk premiums, etc. Environmental policies and constraints Technical and economic characteristics of future energy technologies Energy consumption habits, parameters about comfort, rational use of energy and savings, energy efficiency potential Parameters of supply curves for primary energy, potential of sites for new plants especially regarding power generation sites, renewables potential per source type, etc.	**PRIMES model** **(PRice-Induced Market Equilibrium System)** **Performs iterations of demand and supply through explicitly calculated prices**	• Detailed energy balances (EUROSTAT format) • Detailed demand projections by sector including end-use services, equipment and energy savings • Detailed balance for electricity and steam/heat, including generation by power plants, storage and system operation • Production of fuels (conventional and new, including biomass feedstock) • Investment in all sectors, demand and supply, technology developments, vintages • Transport activity, modes/means and vehicles • Association of energy use and activities • Energy costs, prices and investment expenses per sector and overall • CO2 Emissions from energy combustion and industrial processes • Emissions of atmospheric pollutants • Policy Assessment Indicators (e.g. imports, RES shares, etc.)

Model coverage

PRIMES power and heat

- Capacity expansion, Unit Commitment, Pricing module
- Power, heat and steam production
  - CHP, boilers, industrial plants, etc
- Database includes over 13000 power plants
- Detailed representation of RES including water depth and closeness to shore for off-shore wind
- Represents policies in detail including different types of RES support, facilitation policies,
- Different market design and cross border options can be studied with the model

PRIMES-BuiMo

- Very detailed segmentation of households and dwelling types (270 building types);
- RES, fossil and P2X fuels
- 28 heating and cooling technologies
- Dynamic programming modelling of renovation strategies
- Representation of several non-market barriers, hidden costs and idiosyncratic behaviors
- Detailed portrayal of policies specific comprising economic policies and measures (i.e. taxes-subsidies, white certificates), regulatory instruments (i.e. efficiency standards, eco-design standards) as well as research and development measures
- 5 income classes

PRIMES Industry

- 10 industrial sectors
  - further split in 31 sub-sectors and in total 234 energy uses
  - distinct sectors for primary and secondary (recycling) production
- 22 different fuels, including "new" fuel carriers (hydrogen, biofuels)
- process emissions included
- CCS option is included for all process emissions
- Detailed portrayal of policies specific comprising economic policies and measures (i.e. taxes-subsidies, white certificates), regulatory instruments (i.e. efficiency standards, BAT) as well as research and development measures

PRIMES-TREMOVE

- All transport modes: passenger, freight (also maritime and aviation)
- All fuel types: fossil, biofuels, P2X
- Re-fueling and recharging infrastructure is represented in a stylized manner and its influence on choices
- Transport-related choices with consideration of heterogeneity of agents
- Large number of policies portrayed: CO_2 standards, blending rates and/or mandates by mode and fuel
- *PRIMES biomass: verifies the sustainability criteria and computes prices for biofuels*

Overview of PRIMES modelling approach

What PRIMES can do

- The distinctive feature of PRIMES is the combination of micro-economic foundations with engineering at a fairly high level of detail, compatible with a long-term time scale and sectorial detail of available statistics for Europe
- Designed to provide long term energy system projections and system restructuring up to 2070, both in the demand and the supply sides. Projections include detailed energy balances, structure of demand by sector, structure of power system and other fuel supplies, investment and technology uptake, costs per sector, overall costs, consumer prices and certificate prices (incl. ETS) where applicable, emissions, overall system costs and investment.
- Impact assessment of specific energy and environment policies, applied at Member State or EU level, including
  - Price signals, such as taxation, subsidies, ETS
  - Technology promoting policies
  - Standards
  - Infrastructure
  - RES supporting policies
  - Efficiency promoting policies
  - Environmental policies
- The linked model system PRIMES and CAPRI (EuroCARE), GAINS (IIASA) and GLOBIOM (IIASA) (for non-CO2 gases, air quality, biomass resources and land use) cover all GHGs.

What PRIMES cannot do

- Cannot produce short-term forecasts as it is not an econometric model (so projections are not statistically based on past observations, which in PRIMES are only used for parameter calibration).
- It is a partial equilibrium model, not performing closed-loop energy-economy equilibrium analysis, unless linked with a macroeconomic model such as GEM-E3.
- PRIMES lacks spatial information at a subnational level and so lacks details about distribution and transport infrastructure and flows that depend on spatial information (except electricity and gas flows over a country-to-country based grid infrastructure, which is represented in PRIMES).
- PRIMES considers infrastructure exogenously in all sectors. Also PRIMES considers learning by doing exogenously (except for the Biomass module), but varies assumptions across scenarios to represent “enabling conditions”.
- PRIMES is an empirical numerical model with emphasis on sectoral and country specific detail; it has a very large size and so some compromises were necessary to limit computer time at reasonable levels. In this sense, although rich in technology representation, the modules of PRIMES are far more aggregated than pure engineering models.

Options for decarbonisation

"NO-REGRET" OPTIONS

Energy efficiency improvement in buildings, equipment and vehicles.

Enhanced **renewables** in power generation

- Large-scale investment in variable renewables
- Reliable integration of renewables (grids, market integration, storage systems, demand response)

Electrification of transport and heating where cost-efficient, e.g.:

- Private transport in urban environments
- Heat pumps in heating

Produce sustainably and use advanced (second-generation) **biofuels**.

Extension in **Long Term Operation** (LTO) of the existing nuclear fleet where possible and **geological storage of CO_2** where acceptable.

DISRUPTIVE CHANGES

Reduce energy demand in all sectors beyond conventional energy savings, e.g. circular economy, sharing of vehicles, secondary materials production via recycling.

Changes in **the way users use energy**, e.g. high electrification in industry and transport, direct use of distributed hydrogen and the way energy is distributed (grid and storage for hydrogen, liquified hydrogen or GHG-free methane) etc.

Changes in the **production and nature of energy commodities**, e.g.:

- mix hydrogen and biogas in gas distribution
- replace fossil gas by carbon-neutral methane
- replace fossil liquids by carbon-neutral fuels

Capturing CO_2 from air or biomass for re-use (**synthetic hydrocarbons**) or underground storage (**carbon sinks**).

Capturing CO_2 from fossil fuels combustion or industrial processes and use to produce materials (**sequestering carbon dioxide**).

PRIMES modelling to explore contrasted strategies

Max Efficiency & Circular Economy	Maximum Electrification	Hydrogen as an end-use carrier	GHG-neutral fuels (gaseous, liquids)
Pros • Non expensive • No pressure in the energy supply potential **Cons** • Depends on investment by individuals • Potential uncertain • Unclear appropriate policy signals • Low demand discourages investment in the supply side	**Pros** • Efficient and convenient • Modest growth of demand for electricity **Cons** • Cannot fully electrify industry and transport • Lack of competition among carriers • High seasonal and daily variability, high balancing costs	**Pros** • H2 can be a universal carrier • Chemical storage of electricity • Less electricity intensive than e-fuels **Cons** • Infrastructure changes • Uncertain future costs of H2 and fuel cells • Public acceptance	**Pros** • Existing infrastructure and way of consuming energy • Chemical storage of electricity • Competition among carriers **Cons** • Carbon neutral CO_2 feedstock (DAC, biogenic) • Uncertain future costs of e-fuels • Vast increase of total power generation

Demand side modelling challenges

Circular economy

- What is the potential for decreasing energy demand through circularity?
  - Recycling and modularity
  - Primary and secondary production of metals
  - Literature still under development

Energy efficiency

- Examine the potential of increasing the efficiency of the transport system (e.g. car sharing, improved scheduling)
  - Heat recovery capabilities in industry
  - Deep renovation strategies in buildings

Buildings

- Representation of non-market barriers, idiosyncratic behaviors: Detailed segmentation of households and dwelling types
- Long payback periods of renovation investments: Nested choice of other energy equipment, depending on the choice for heating and insulation

Industry

- Decarbonize process emissions
- Direct use of carbon-free hydrogen in industrial uses; Upper limit to the electrification of industrial uses
- 1-3 investment cycles till 2050
- High segmentation of industrial sectors, energy uses, technologies, Dynamic and intertemporal modelling of capital vintages, technology and fuel choice

Transport

- Decarbonisation of long-distance mobility
- Inclusion of novel technologies (electric aircrafts, hydrogen vessels, electric trucks)
- Inclusion of new energy carriers (hydrogen, e-fuels, advanced biofuels)
- New trends: sharing

Supply side challenges

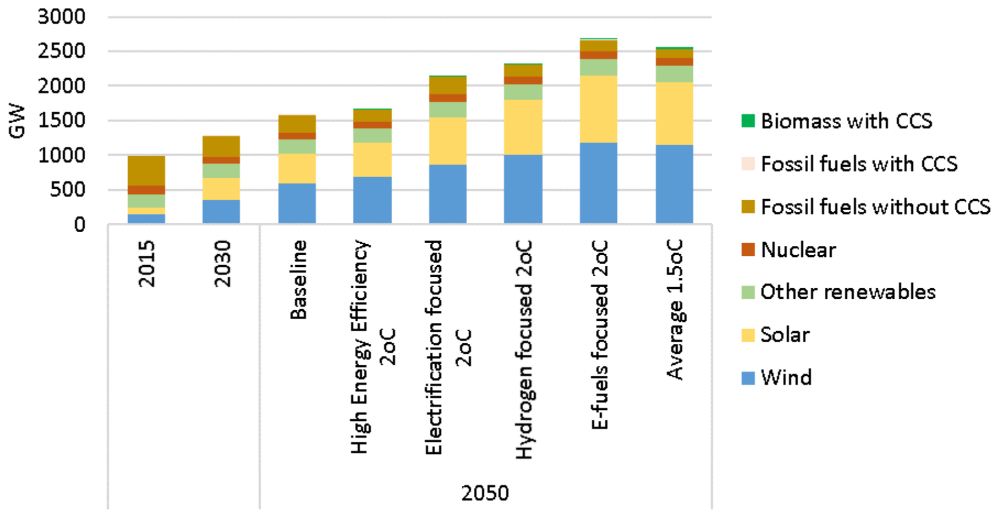
Power and Heat

- Demand for flexibility because of extreme RES (85%)
- Differentiated unit commitment from capacity expansion
- Integrated simulation over the European interconnected system using flow-based allocation
- Synergies with the industrial sector
- Simultaneous simulation of electricity, distributed heat and industrial steam (boilers, CHP, district heating)

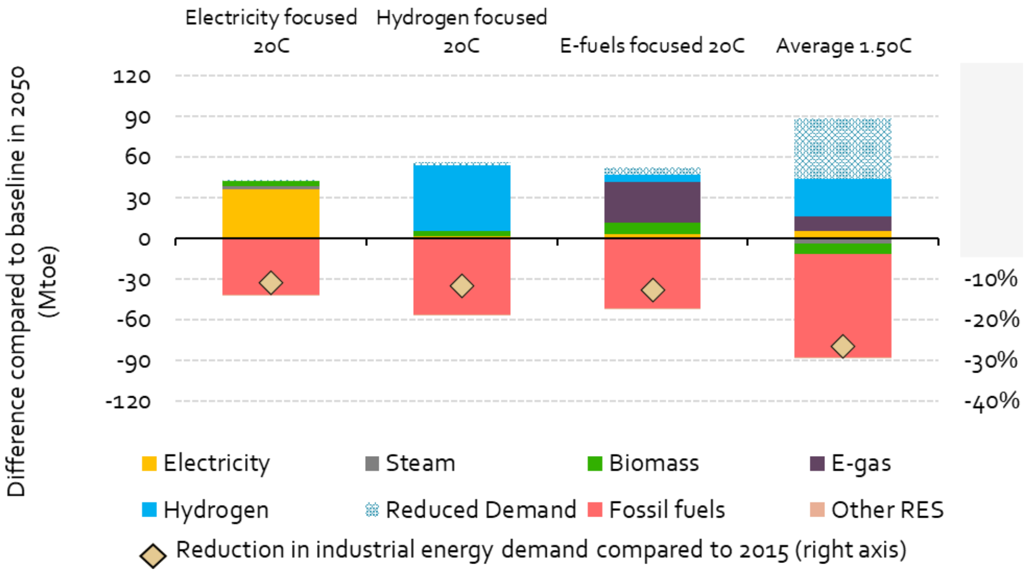
Production of new fuels and storage

- Multiple storage options (batteries, pumping, hydrogen, e-gas)
- Co-production of multiple products: location of production and consumption, infrastructure

POWER GENERATION

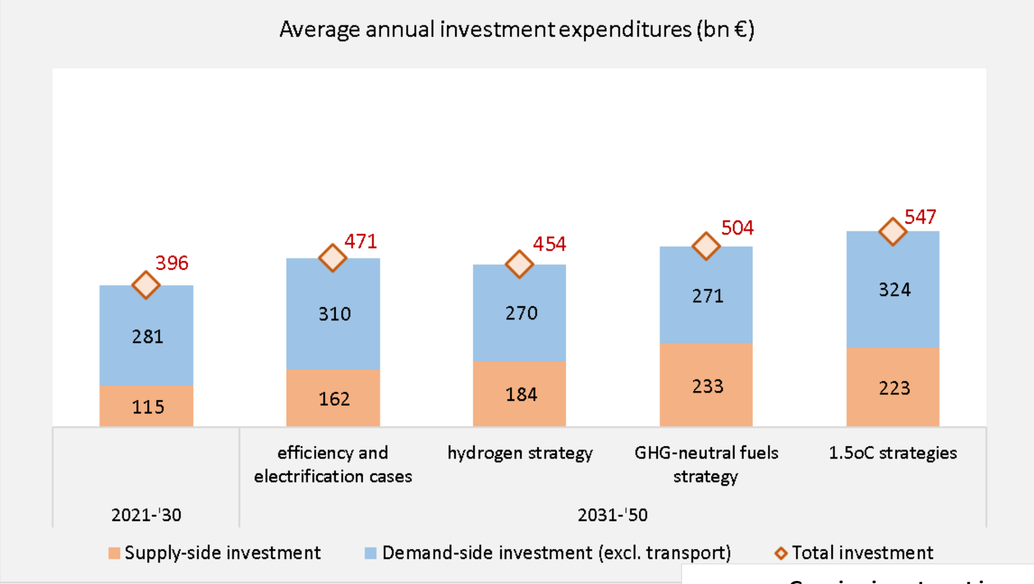


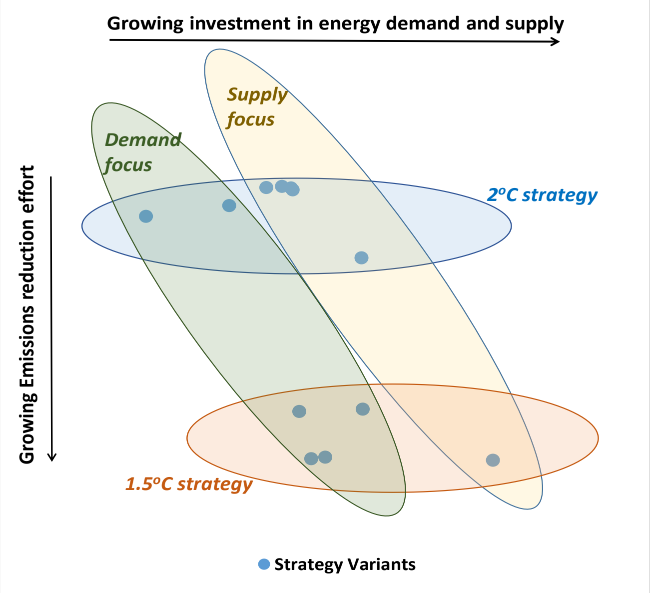
INDUSTRY



Energy system costs and investment

- The long-term strategy needs increasing investment (in both energy demand and supply sectors) but reduces energy purchasing expenditures
- The fastest growing part of investment concerns individuals and firms as end-users of energy.
- Investment in infrastructure is the fastest growing part of investment in energy supply sectors
- Average costs of electricity are similar in all strategy variants, as the decreasing capital costs of RES and chemical storage offset diseconomies of scale.
- The learning-by-doing dynamics of today's low TRL technologies are of crucial importance for the costs of the supply focused scenarios.
- The transition is particularly capital-intensive, both in demand and energy supply sectors.
- The scenarios focusing on reducing the demand for energy services require lower total investment expenditures compared to the supply-focusing scenarios.
- As expected, the 1.5°C variants are more costly than the 2°C ones.



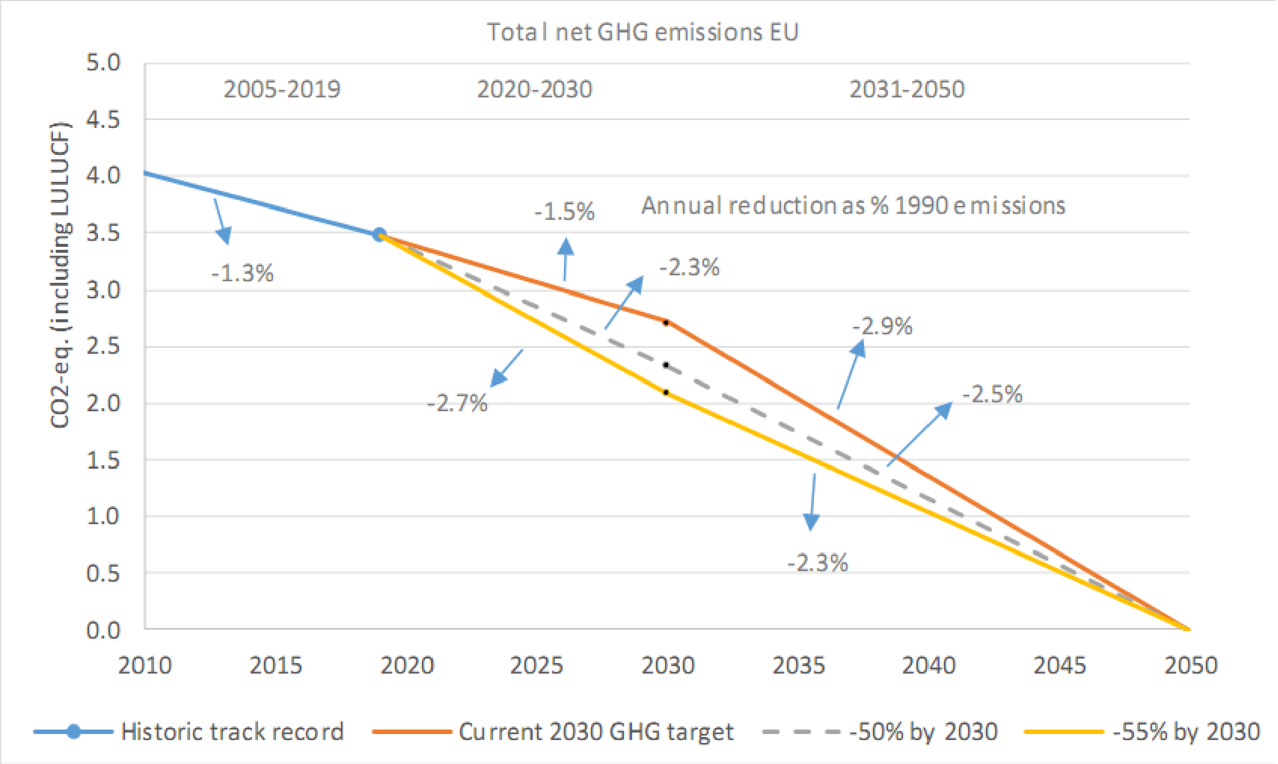


Increasing the EU 2030 target(s)

The -40% GHG in 2030 is insufficient for climate neutrality by 2050

A -55% GHG in 2030 is recommended

- Investors and policy makers need a strong signal to act strongly in next 10-15 years to develop the infrastructure to achieve carbon neutrality
- Avoid lock-in effects driven by lower target
- System integration perspective: power generation needs to reduce emissions first in order to allow for other changes
- Stronger target allows for revision of key legislation to provide strong signals:
  - ETS - scope and MSR
  - Renewables
  - Energy Efficiency
  - Transport sector policy



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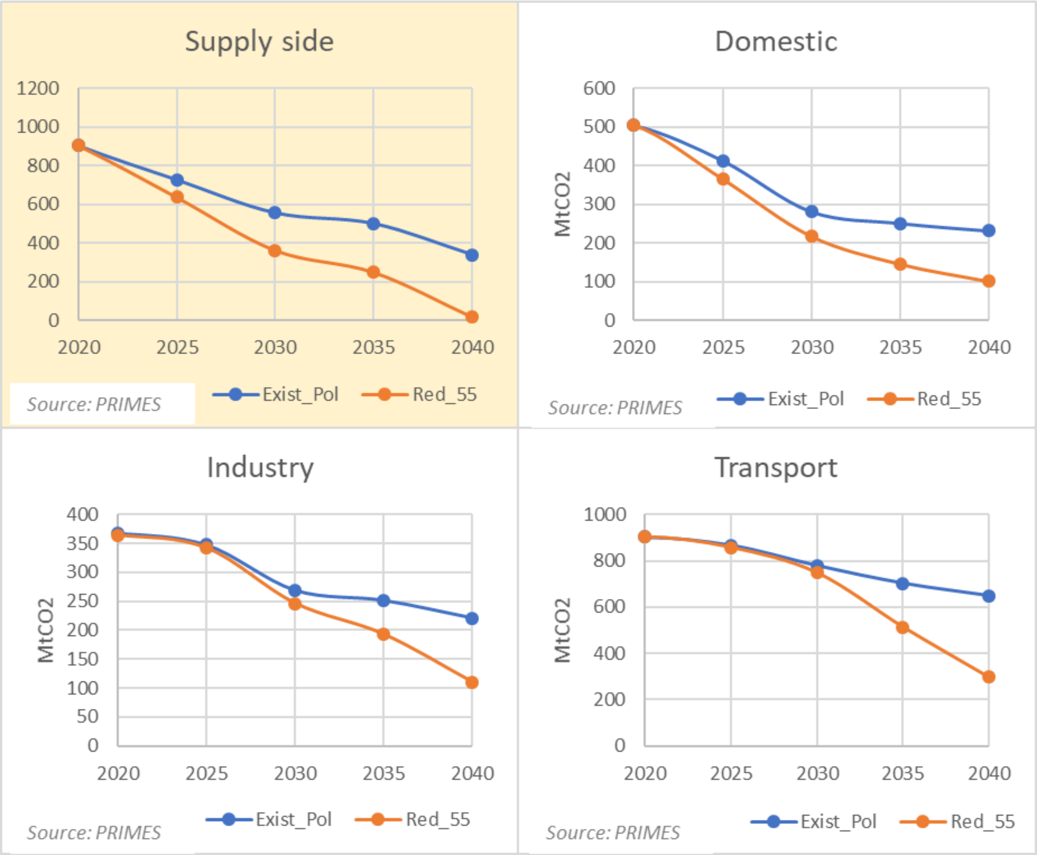
Moving to 55%: Emission pathways by sector

Moving to 55% implies an acceleration of emission reductions particularly in the energy system

- Supply side already progressing rapidly towards decarbonisation:
  - Coal-phase out
  - Cost reduction of renewable technologies
- Buildings:
  - Technologies are known
  - Market and non-market barriers are limiting factors
- Industry:
  - Long lead times and investment cycles
  - Avoiding lock-ins
- Transport
  - Infrastructure requirements
  - Technological developments required



Moving to 55%: power generation

Increase in electricity demand

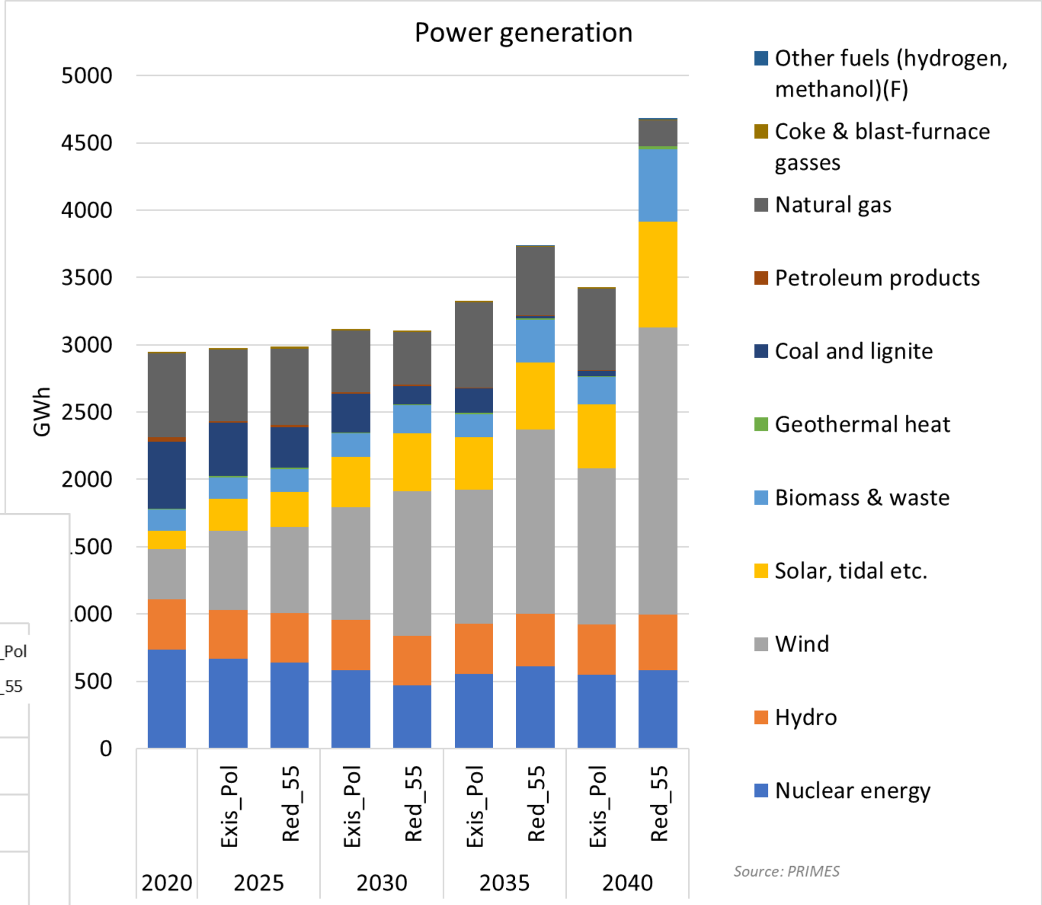
- Electricity is fundamental – heat pumps and e-mobility electrify demand

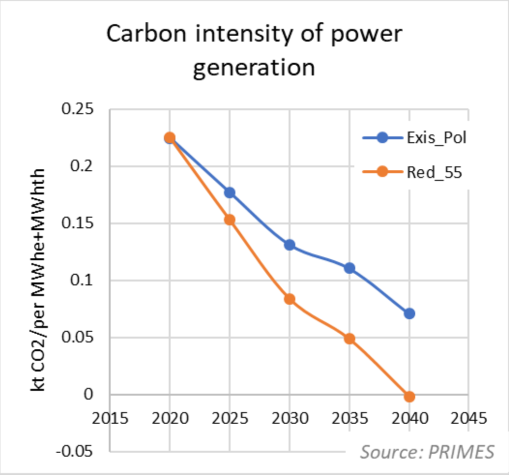
In the long-term e-fuels decarbonize demand further and ensure storage

Generation relies on RES, with wind and solar increasing impressively

Prices signals and regulatory infrastructure needs to allow speeding up of emission reductic

Carbon neutrality would be reached by 2040





Moving to 55%: buildings

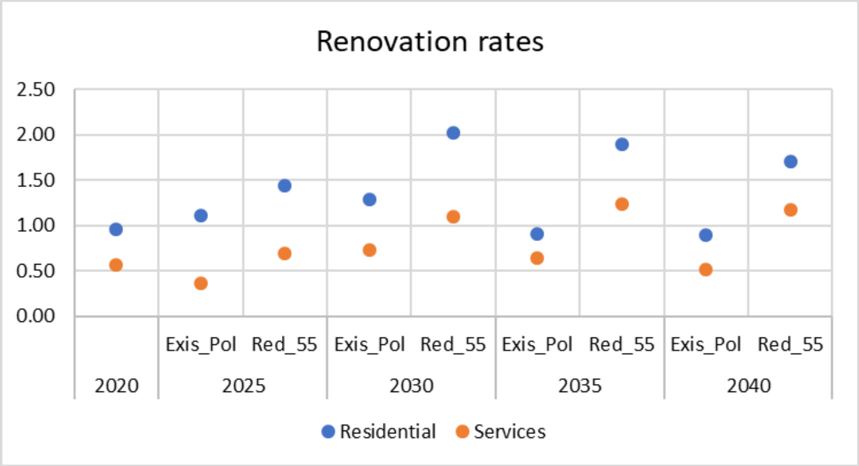
Rates of renovation of old buildings will have to increase considerably from 1% to almost 2% renovation per annum

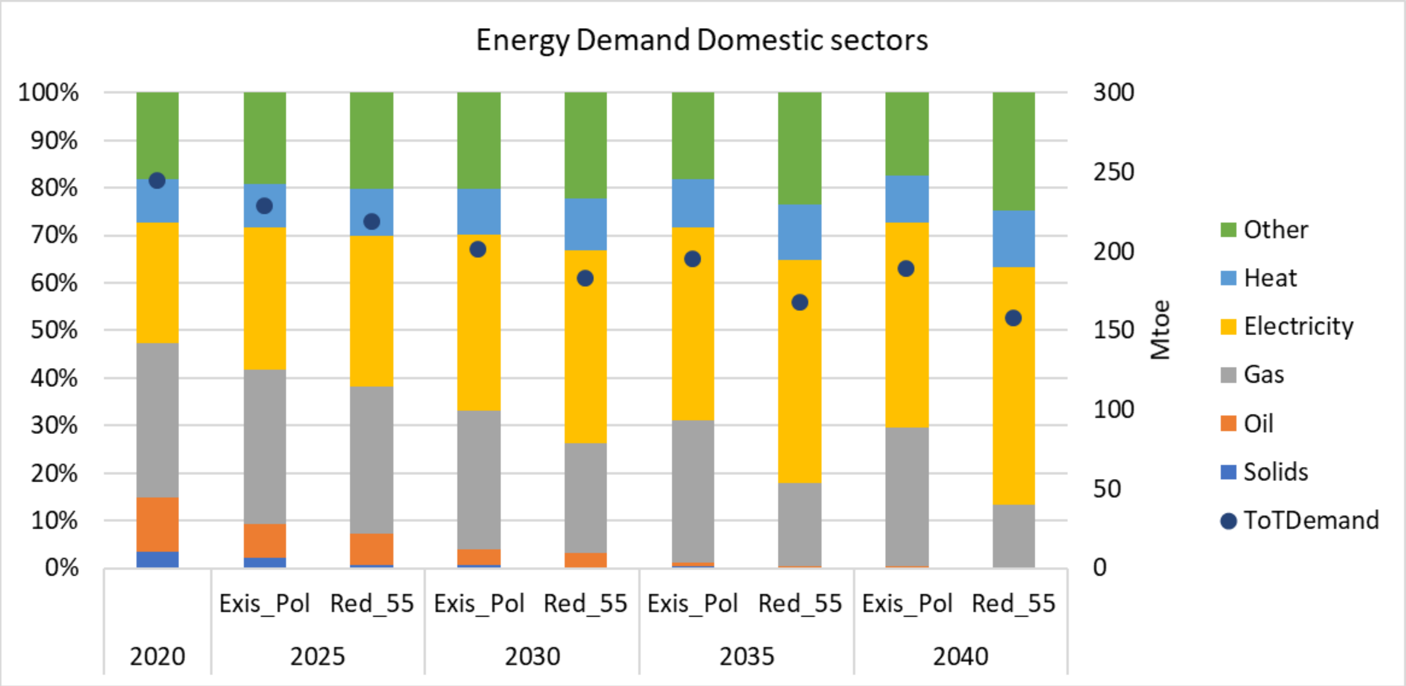
Also to shift from light to deep energy-related renovation

The renovation strategies submitted by the MS must be enhanced

Emission reductions are driven by:
- Renovation
- Fuel-switching: to electricity and direct RES

Policies to reduce market and non-market barriers need to be put in place





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Concluding remarks

- Climate neutrality in the EU by 2050 is feasible without excessive cost burden.
- However, cost estimations are uncertain as depending on the potential of learning and massive industrial production of new technologies.
- There should be no doubt about the no-regret options of the strategy, namely energy efficiency, renewables, electrification and advanced biofuels where cost-effective. The 2030 EU climate and energy is consistent with the LTS.
- Disruptive changes are necessary to reach climate neutrality. They may imply changes in the energy production, distribution and consumption paradigm.
- The choice of a single strategy for disruptive changes is not yet mature. Actions are necessary to resolve the technology, as investment requires long-term visibility.
- The next decade is of utmost importance for infrastructure, industrial development of immature technologies and the power sector restructuring: moving to 55% is a good sign for regulatory certainty
- Addressing concerns related to investment by individuals and firms with poor fund raising capabilities constitutes a new policy priority.