with the scientific contribution of the

Foundation

Executive Summary

Sustainable paths for EU increased climate and energy ambition

29 September 2020

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0. Introduction and methodology

Context and objectives of the study

- **Following the Paris Agreement, the European Commission (EC) is considering setting more ambitious decarbonisation targets:**
  - The new von der Leyen Commission announced its **European Green Deal** in December 2019 proposing **more ambitious decarbonisation targets for 2030 (50-55% emissions reduction) and carbon neutrality in 2050**.
  - In the context of the COVID-19 crisis and the resulting economic crisis, the EC proposed in May 2020 an **economic recovery plan** that both repairs the short-term damage of the crisis but also reinforces the green transition strategy of the EU seen as an opportunity to rebound**:**
    - Financial support to Member States **conditional on investments aligned with the Green Deal**
    - Taxes to reimburse mutual debt could include a **carbon border tax**, and more revenues from EU ETS auctions

- **Recent developments make increased decarbonisation ambitions for 2030 both feasible and affordable. Recent years have seen the stars starting to align with regard to:**
  - **Technological progress and cost reductions** in renewables and batteries, and new digital technologies on the supply and demand side providing increased energy efficiency and flexibility potential
  - **National energy policies and regulation** to accelerate decarbonisation: coal phase outs, ICE bans and emissions standards to support the deployment of Electric Vehicles (EVs), actions in favour of a circular economy, etc.
  - **Business initiatives to further support climate action** though digitalisation, deployment of clean technologies and new business models aiming at reducing energy consumption and emissions

In this context, this study offers a fact based analysis to:

i) **assess how more ambitious decarbonisation objectives can be reached in Europe in 2030 and 2050** thanks to cost reduction and recent technological progress both on the supply side and on the demand side,

ii) evaluate the **role of the power sector as a key enabler** of deep decarbonisation and,

iii) estimate the **impact on costs of an increased decarbonisation ambition on an aggregated and sectorial basis.**

The study performs an impact assessment of an EU decarbonisation scenario with a focus on accelerated deployment of clean technologies

- **The study performs an impact assessment of the increased ambition decarbonisation scenario comparing the following scenarios:**
  - **A Reference scenario** aligned with **the EC climate and energy targets and current costs of clean technologies**
  - **A Decarbonisation scenario** aiming for **increased emissions reduction in 2030 and carbon neutrality in 2050,** and taking into account **recent costs reduction in power generation and EVs**
    - A sensitivity analysis of the Reference scenario was also modelled combining the climate targets of the Reference scenario with costs reductions assumed in the Decarbonisation scenario
- **For each sector of the European economy, the study identifies the key enablers (technology, regulation, and business models)** to unlock deep decarbonisation. **A focus is made on the power sector** given its potential to enable faster decarbonisation in other sectors as electrification of end-uses increases.
- **The impact assessment provides a detailed quantitative assessment based on a set of KPIs** of the increased ambition decarbonisation scenario in comparison to the current EC reference scenario.

Scenario assumptions	Reference scenario	Decarbonisation scenario
Power generation costs	Based on IEA WEO cost curves in line with EU REF 2016	Based on lower range of EC PRIMES 2018
Transport costs	Based on EC PRIMES 2018	Assumed Cost parity between EVs and ICEs in 2025
Building and Industry costs		Based on EC PRIMES 2018
Energy policies	EUCO3232.5* in 2030 + EU REF 2016 in 2050	50-55% GHG emission reduction by 2030 + Net zero in 2050

KPIs by sector
Energy consumption
Emission reductions
Energy mix
Evaluation of system costs and necessary investments

Power sector indicators
Power demand and generation
Power capacities (including flexible capacities)
Hourly generation profile in winter and summer
Flexibility of demand and supply

The study leverages a unique modelling approach combining two models to offer both a full economy and granular power sector representation

- **The study fills a gap with existing studies that are either broad in their sectoral coverage but lack a granular and detailed coverage of the power sector, or solely focussed on the power sector and lacking the cross-sectoral perspective.**

- **In order to capture the potential for decarbonisation across the different sectors, the study uses the POLES energy model which covers the full EU economy**
  - The POLES model is a similar model to the PRIMES model and it is commonly used by the JRC of the European Commission and numerous energy market participants, both public and private organizations.

- **The study then provides a deep dive on the power sector through a detailed European power market model with an hourly definition and a granular geographic coverage**
  - Granular modelling of the power sector decarbonisation (hourly resolution) accounting for deep penetration of RES, batteries, demand response and digitalisation
  - Impact assessment of the Decarbonisation scenario on networks using outputs from the European power market model and a literature review of the incremental network costs due to RES integration, and costs savings associated with demand side flexibility

Whole economy

Enerdata POLES

Multi-sector and energy annual equilibrium model

- Annual power demand
- Emission from power sector

Power sector focus

CL modelling

- In depth review of power sector recent transformations
- Hourly dispatch model of power sector

1. Increased decarbonisation is possible in 2030 and 2050 thanks to recent technology and policy developments

Increased ambition in 2030 of up to 55% GHG reduction is achievable, affordable and necessary to achieve net zero in 2050

In line with recent announcements of the "Green Deal" of the European commission and the climate objectives supported by the EU recovery plan, this study demonstrates that increasing the GHG emission reduction by 2030 to up to 55% is:

- **Achievable** thanks to the combination of:
  - **Recent technological advances** in RES and batteries for electric vehicles enabling faster decarbonisation
  - **Electrification in the transport and building sectors** through electric vehicles and heat pumps
  - **Business initiatives** deploying innovative solutions in particular to develop flexibility and leveraging clean technologies and digital solutions that unlock additional GHG emission reduction potential
  - **New national and local energy policies and regulations** including coal phase-out, ICE bans and tighter emission limits – that support deeper ambition for decarbonisation

- **Affordable** thanks to the **recent cost reductions** for clean technologies and **business models leveraging digitalisation** enabling **the large scale deployment of flexibility on both the supply side and demand side** :
  - Reaching close to 55% GHG reduction in 2030 could be achieved at a slightly lower cost for consumers than the previously agreed 2030 target thanks to the rapid decline in costs of RES as well as flexibility resources
  - Impact on affordability / competitiveness can be reduced via redistributive policies and public support, in particular the Just Transition Mechanism implemented as part of the EU Green Deal and Recovery Plan to support the energy transition by providing economic and social support

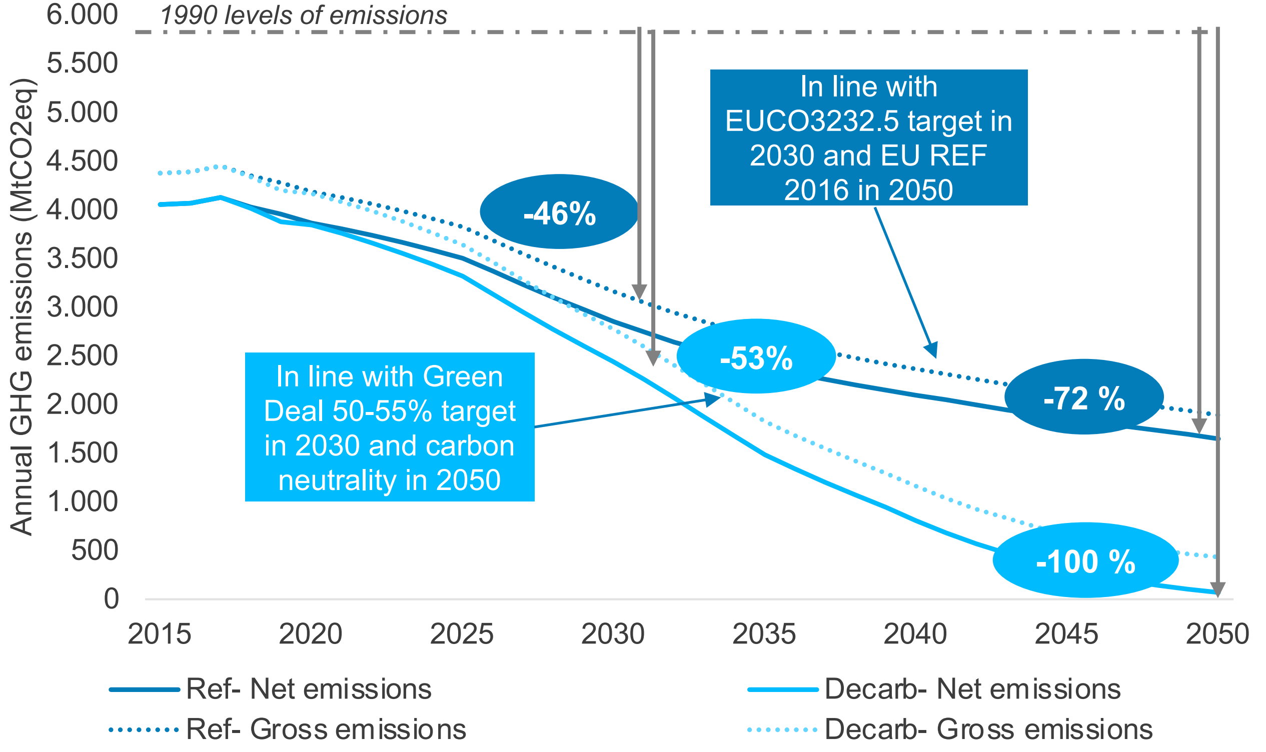
- **Necessary to meet 2050 carbon neutral objective** as current scenarios rely on hypothetical acceleration of the effort post 2030 and unproven technologies:
  - In order to achieve net zero ambitions in 2050, electrification of end uses via sector coupling and an increased effort in the transport, industrial and buildings sector are necessary.
  - Nevertheless thanks to recent costs reductions in clean technologies, total cost for consumers is similar to previously anticipated costs with lower ambitions.

2. Electrification of end uses and energy efficiency are necessary for a full decarbonisation

Increasing the target GHG emission reduction close to 55% in 2030 is possible and necessary to achieve net zero emissions in 2050

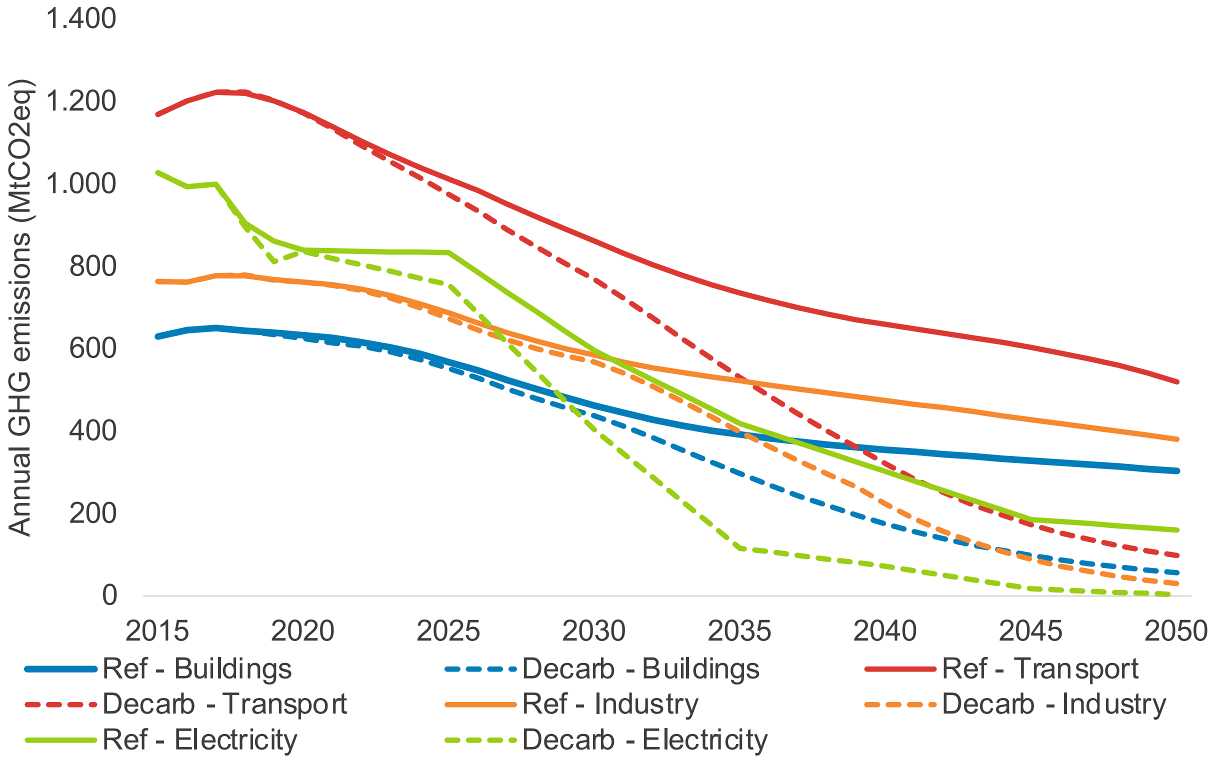
- **Achieving close to 55% emissions reduction in 2030 is feasible** in the Decarbonisation scenario thanks to the faster decarbonisation already initiated in the transport (-11% in 2030 vs Reference scenario) and electricity (-32% in 2030 vs Reference scenario) sectors in particular.
- Increasing ambitions in 2030 has become **a cost effective approach to achieve net zero in 2050 as the costs of clean technologies have declined** and this allows to reduce the uncertainties associated with the backloading of emission reductions.
- A contribution of all sectors is necessary to achieve carbon neutrality in 2050 and can be achieved through **sector coupling and electrification of end uses**.

Net and gross GHG emissions (MtCO2eq), Reference vs. Decarbonisation scenarios



Source: Enerdata and CL

Gross GHG emissions (MtCO2eq) per sector, Reference vs. Decarbonisation scenarios



Notes: 1) Difference between gross and net emissions is the Land Use, Land and-use change and forestry (LULUCF) activities
2) 1990 levels of emissions exclude LULUCF (to avoid complexity of accounting) and include international aviation. With LULUCF, emissions reduction in the Decarbonisation scenario would be 54% (and 48% in the Reference scenario).

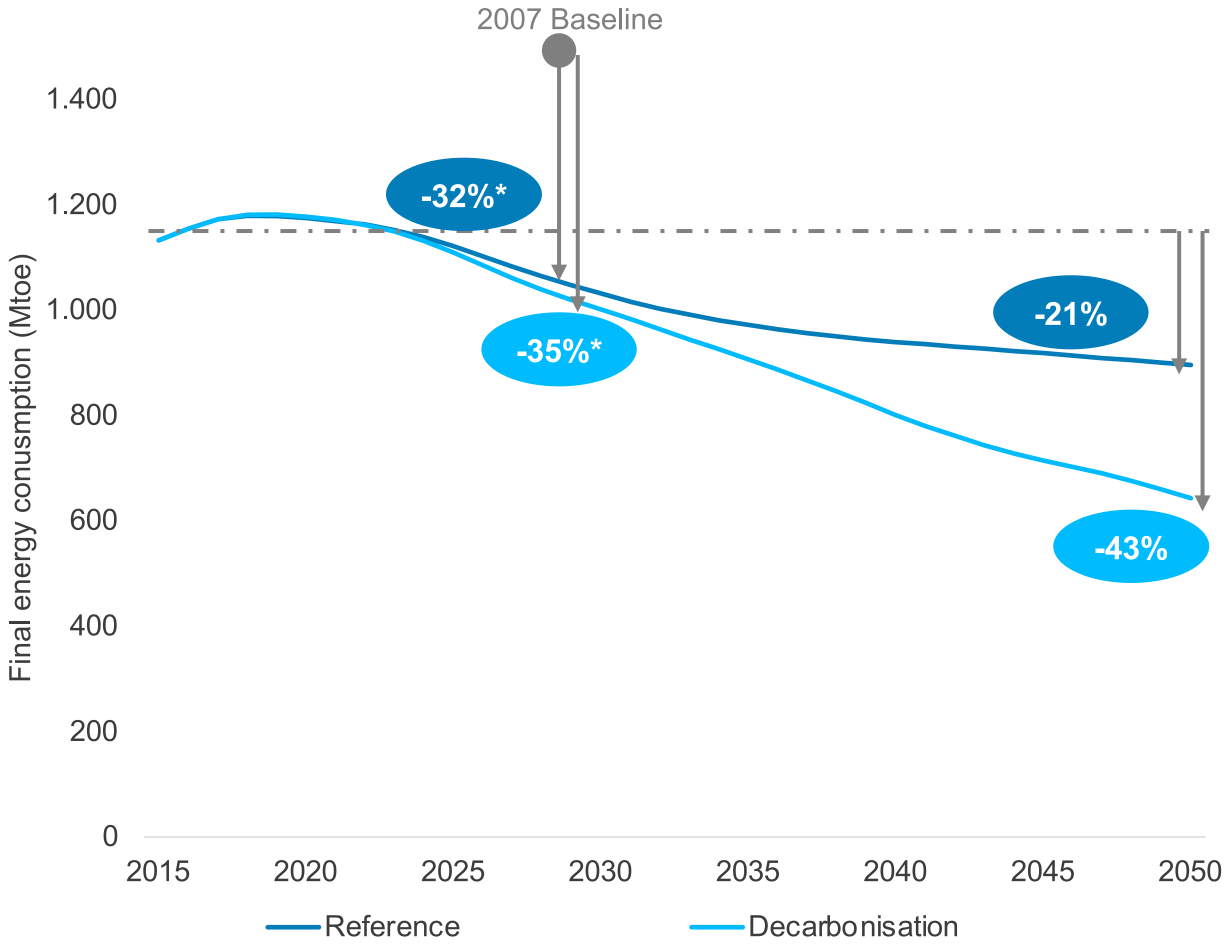
To achieve the ambition of net zero emissions in 2050, significant gains on energy efficiency are needed

- **Additional energy efficiency gains can be achieved in 2030 in the Decarbonisation scenario** (35% energy efficiency rate vs 32% in the Reference scenario) thanks in particular to the higher uptake of EVs.

- **In order to achieve carbon neutrality in 2050, energy efficiency gains must double** (final energy demand in the Decarbonisation scenario reduces by 43% in 2050 compared to 2015 while only 21% reduction is achieved in the Reference scenario).

- **This effort will be borne by all sectors by 2050 in the Decarbonisation scenario**:
  - **Significant efficiency gains are achieved in the transport sector** (67% reduction in energy consumption between 2015 and 2050) thanks to the large scale deployment of electric vehicles.
  - **In the buildings sector**, 41% energy efficiency gains are achieved in 2050 thanks to **the increased electrification of the sector via Heat Pumps** from renovation of existing buildings and new buildings.
  - **In the industry sector, energy intensity** measured in koe/€ **decreases by 45% between 2015 and 2050** thanks mostly to the reuse and recycle measures, the use of hydrogen as industrial feedstock in the chemical industry, and the electrification of steel processes (electric arc furnaces).

Final energy demand (Mtoe), Reference vs. Decarbonisation scenarios



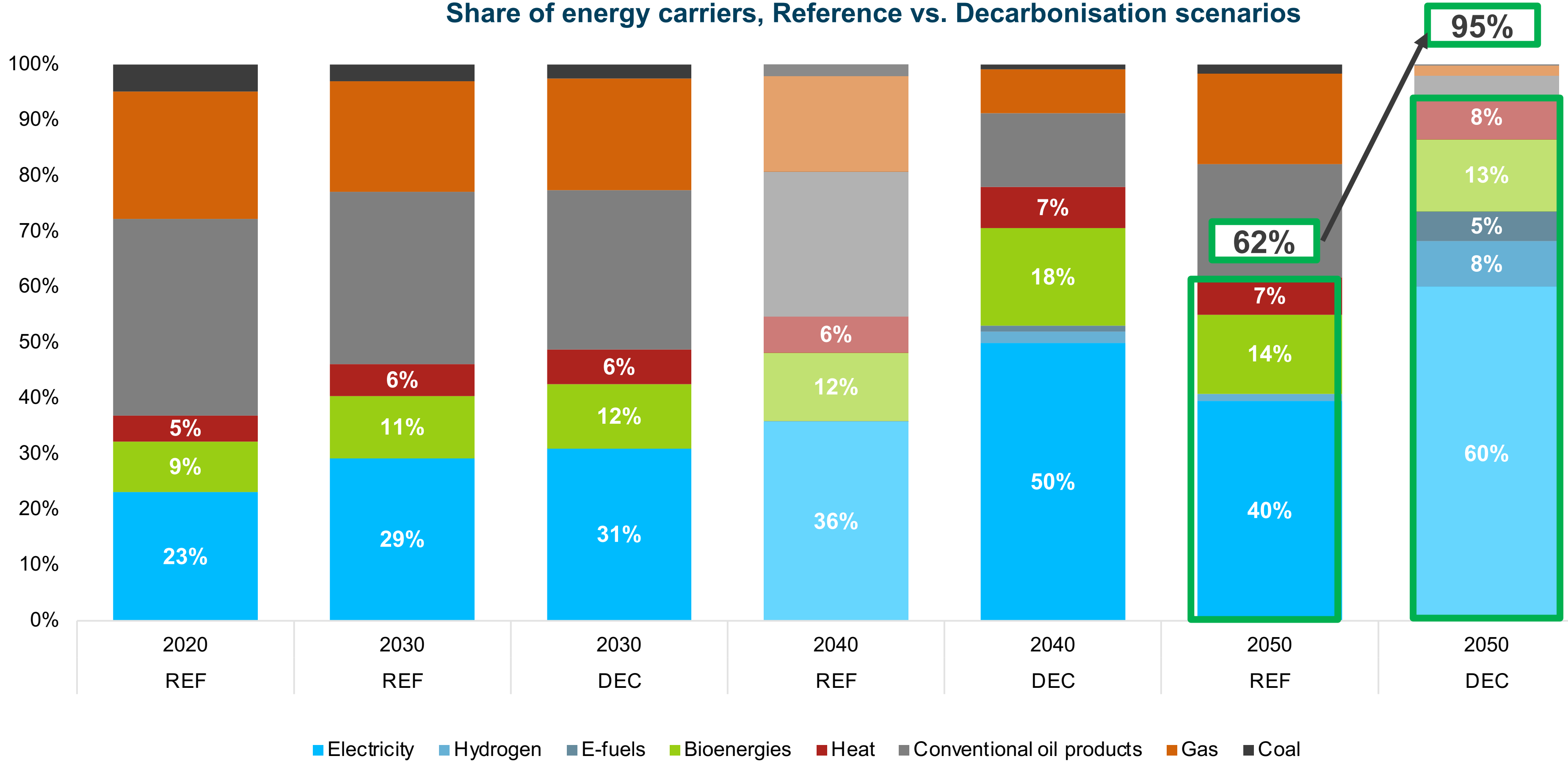
Source: Enerdata and CL

Note: Final energy demand in POLES represented on the figure includes non-energy uses. For the comparison with the 2007 EC Baseline, we add international flights and remove non-energy uses to calculate the energy efficiency targets in 2030 on the same perimeter as the European Commission's.

Electrification of end uses increases significantly in the Decarbonisation scenario to achieve net zero emissions in 2050

- With a significant increase in direct electrification rate from 40% in the Reference scenario in 2050 to **60% electrification in the Decarbonisation scenario**, **electricity emerges as the critical energy vector to achieve net zero ambitions in 2050**.
- The inclusion of **hydrogen** (from electricity, either green from RES or blue from nuclear) **as a new energy vector** (in particular as feedstock for the industry) **along with bioenergies** contributes to a 33pp increase in low carbon share in 2050 in the Decarbonisation scenario compared to the Reference scenario.
- Gas either renewable or non-renewable remains used in the industry sector for heat applications, and in the buildings sector.

Share of energy carriers, Reference vs. Decarbonisation scenarios



+33pp low carbon share to achieve net zero in 2050

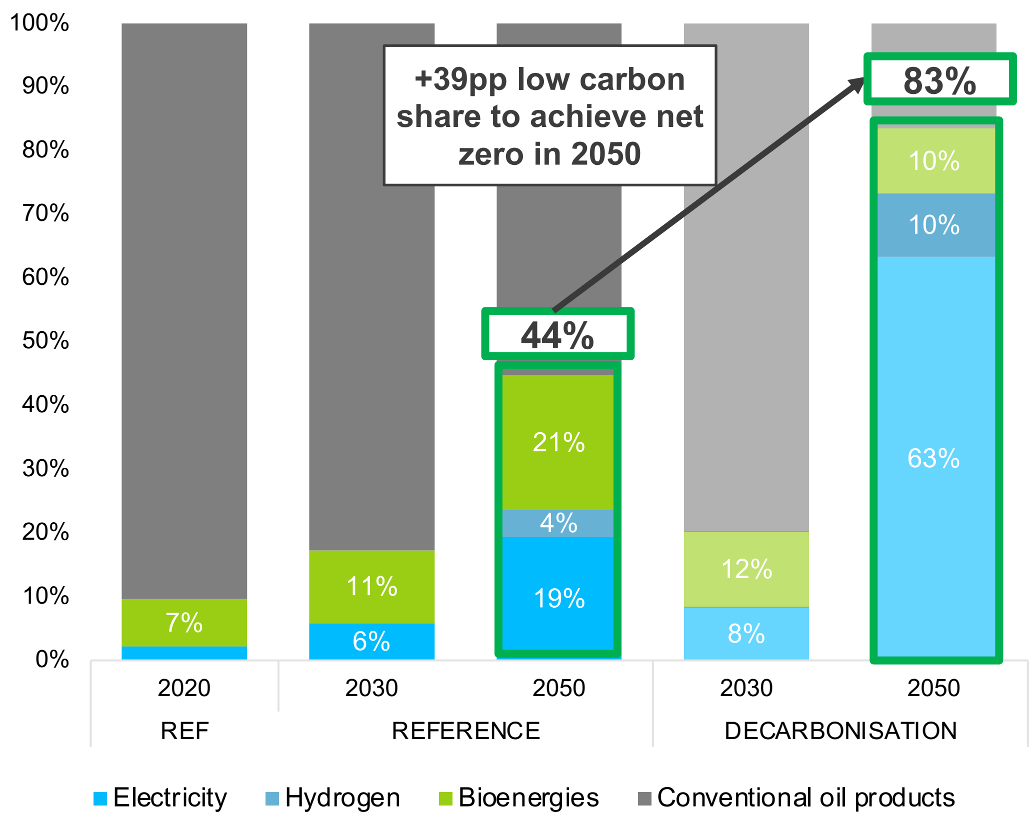
Notes : 1) e-fuels are synthetic fuels produced from decarbonised electricity, including e-gas and e-liquids
2) Heat refers to district heating and solar heat from thermal solar panels
3) All ratios are calculated to total industry demand excluding non-energy uses
4) CCS/CCU are also introduced from 2040 onwards but their development remains limited and will support the net off of emissions in the industry in 2050
5) Bioenergies include biofuels and biomass.

Source: Enerdata and CL

Supported by policies and batteries costs reduction, EVs deployment contribute to the electrification of transport

- The transport sector progressively sees a **growing role for electrification, mainly driven by the electrification of the passenger vehicle fleet through EVs:**
  - **63% electrification rate in the sector in 2050 in the Decarbonisation scenario** (19% in the Reference scenario).
  - The small level of electrification in 2030 in the Decarbonisation scenario is due to the low level of replacement of the fleet which will take a decade to materialise.
  - EVs represent 67% of new private vehicles sales in 2030 but only 24% of the passenger fleet**. In 2050, almost 80% of private vehicles are EVs** (hybrid vehicles represent an additional 9%).
  - To support the penetration of EVs, infrastructure for e-mobility through private and public charging stations needs to rapidly increase by 2030 (reaching respectively 14m and 3m stations for private vehicles by 2030).
  - The bans on ICEs sales in 2030 in a number of EU countries will support the rapid penetration of EVs.
- **To decarbonise heavy duty transport in 2050, electrification is key with 76% of EVs, as well as the use of biofuels and hydrogen** (although the consumption of fossil fuels still represents 18% in 2050). The use of hydrogen vehicles has been assumed for greater range vehicles and for fleets (buses, trucks and ships), although battery vehicles could also play a prominent role as shown by emerging projects.
- **Decarbonisation of maritime and aviation sectors will require technological progress** to develop affordable and technologically feasible solutions (biofuels and synthetic fuels) as well as infrastructure development for ports (e.g. cold ironing systems).

Share of energy carriers in the transport sector, Reference vs. Decarbonisation scenarios



Source: Enerdata and CL

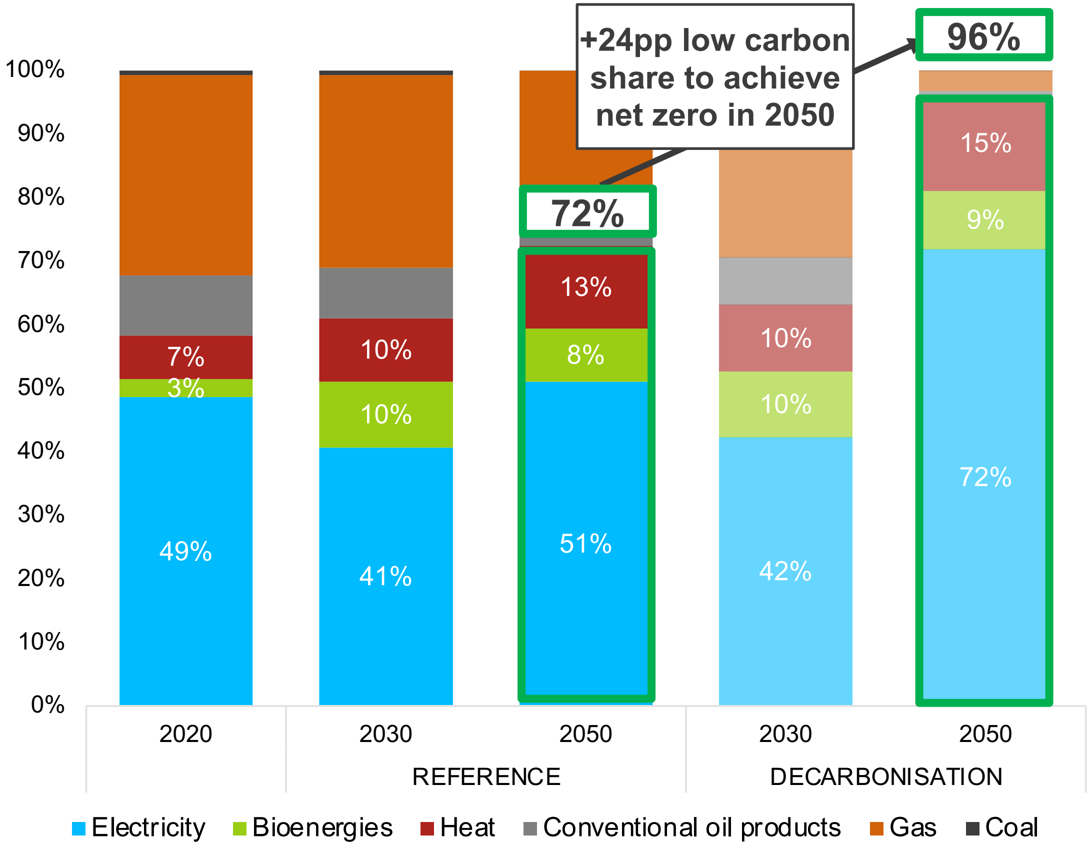
Decarbonisation of buildings relies on greater electrification through the deployment of heat pumps

- In both scenarios, **the electrification of buildings through the deployment of Heat Pumps allowing for the electrification of heating & cooling increases**:
  - In the Reference scenario, the share of electricity increases to 51% with still a remaining share of 22% for gas energy
  - **In the Decarbonisation scenario, the share of electricity increases up to 72%** of final energy demand by 2050, thereby replacing gas energy by electricity for heating purposes

- **Between 2020 and 2030, the rate of renovation of existing buildings will rapidly increase from 1% to 3.5%.** This acceleration of the annual renovation rate is in line with the objective of the EU Recovery plan that will provide funding and financing support (through the Recovery and Resilience Facility and the InvestEU scheme) to at least double the annual renovation rate.

- In the Decarbonisation scenario, **the pace of renovations is sustained after 2030 compared to the Reference scenario and stays at 3-4%** until at least 2045, in line with the rate of renovations targeted by the EC in its Green Deal. While the rate of renovation doubles between the Reference and Decarbonisation scenarios, the decarbonisation of the buildings sector is also achieved thanks to the deeper renovations incorporating electric and smart technologies (heat pumps and smart electric appliances unlocking decarbonisation potential) .

Share of energy carriers in the building sector, Reference vs. Decarbonisation scenarios



Source: Enerdata and CL

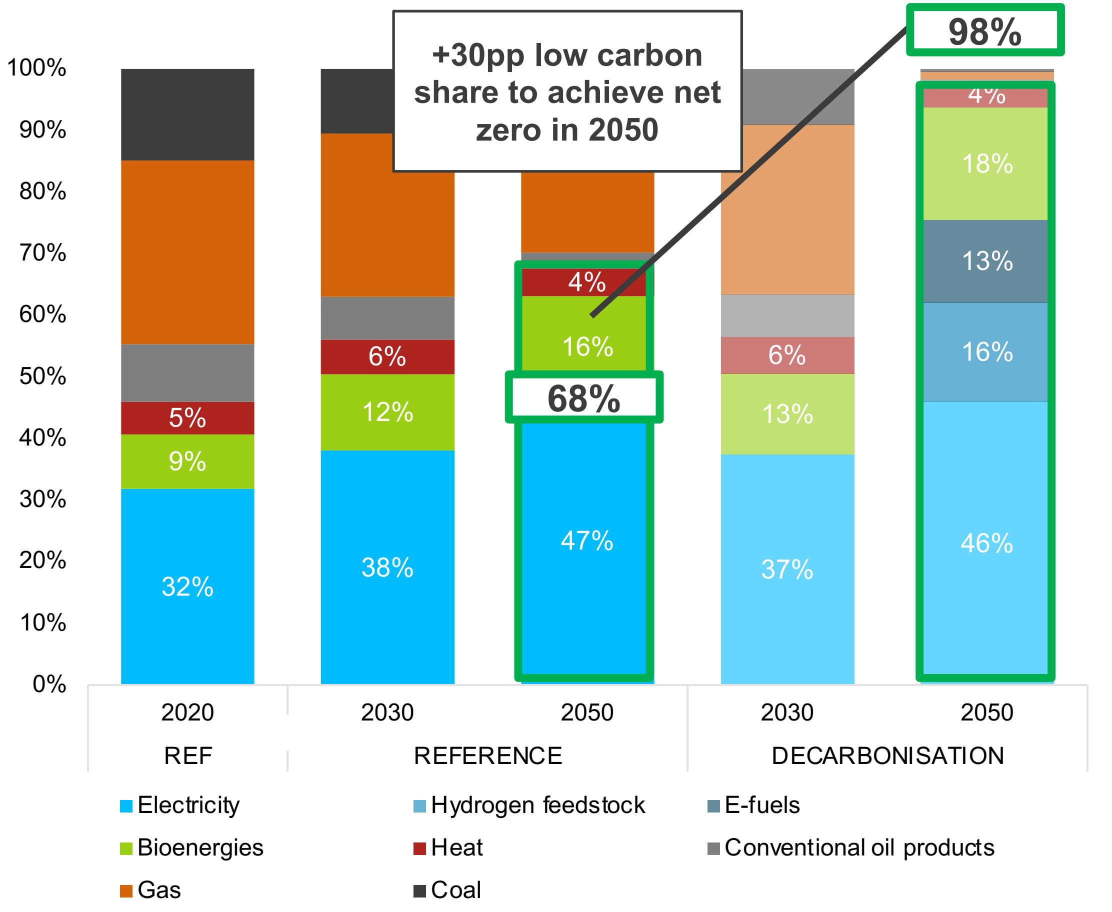
Note: Heat refers to district heating and solar heat from thermal solar panels

Electrification of industrial processes combined with production of green hydrogen and other e-fuels contribute to the decarbonisation

- **Electrification through direct electrification and indirect electrification almost triples in the Decarbonisation scenario by 2050:**
  - **Over 75% of industrial energy demand comes from electricity** including direct use of electricity and indirect use through hydrogen (16%) and e-fuels (13%)
  - Direct electrification (46%) results from the **fuel switching in industrial processes**, in industries such as iron and steel using electric arc furnaces
  - Indirect electrification through the **production of green hydrogen and e-fuels** will also increase in the Decarbonisation scenario (compared to no indirect electrification in the Reference scenario)

- **Bioenergies** represent 18% of the energy demand in the Decarbonisation scenario in 2050 and are mostly used as a **substitute for fossil fuels in industrial processes.** Fuel switching to bioenergies will notably support the decarbonisation of the cement industry, along with a limited role for CCS.

Share of energy carriers in the industry sector, Reference vs. Decarbonisation scenarios



Source: Enerdata and CL

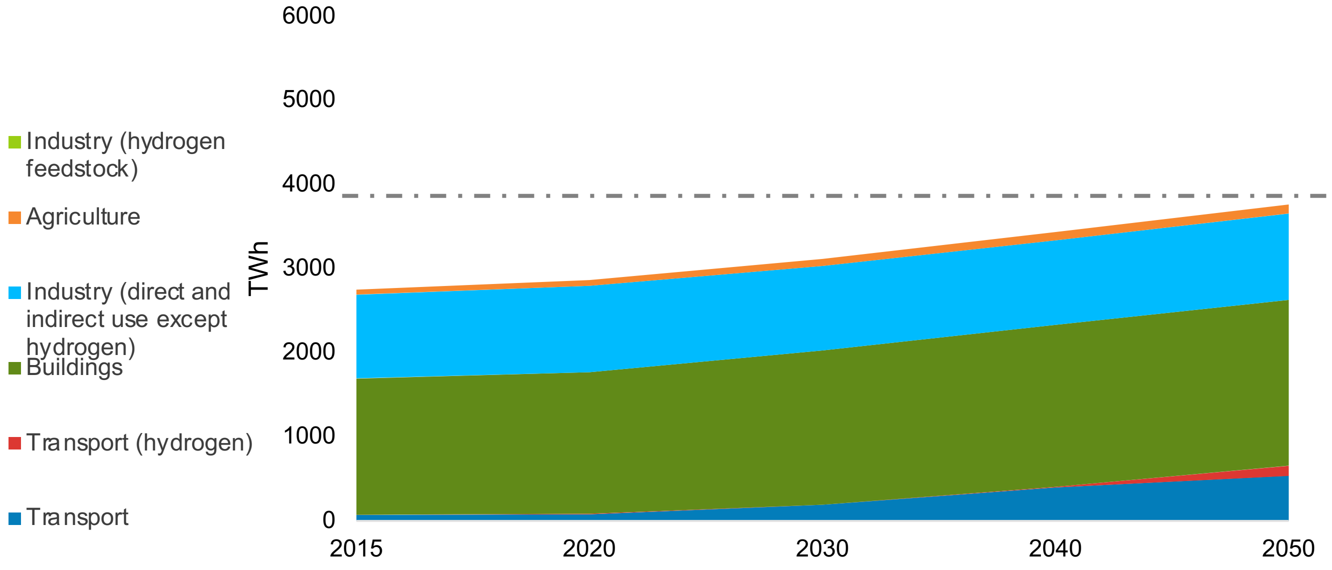
Notes: 1) Heat refers to district heating and solar heat from thermal solar panels
2) In hard to abate industry processes, there will be a role for CCS.

3. Faster and deeper decarbonisation of the power sector is achievable through increased RES and flexible technologies

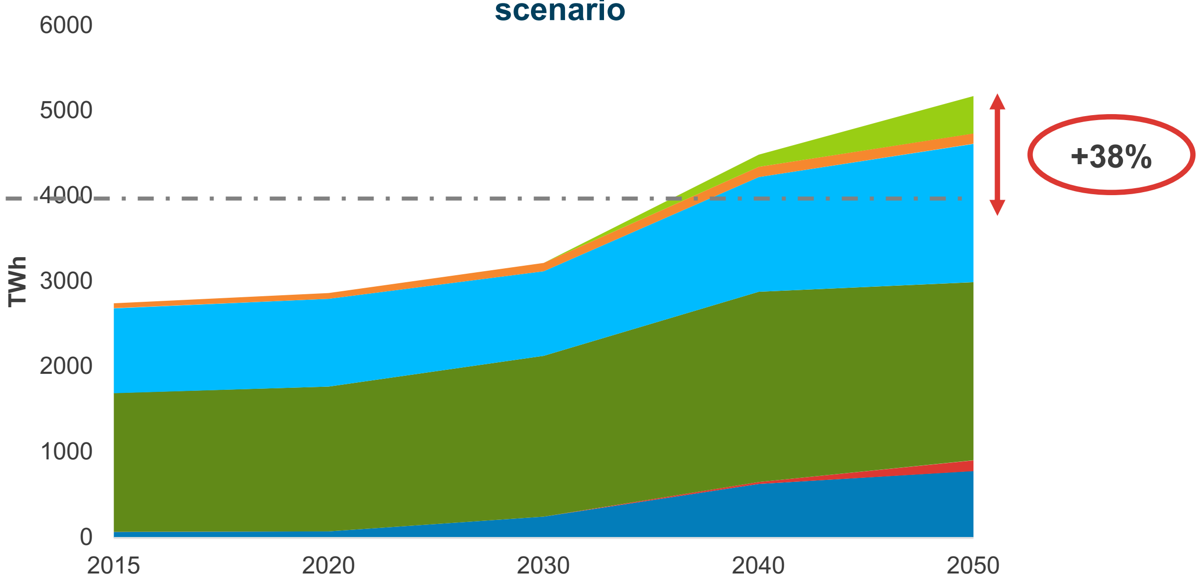
Achieving net zero in 2050 will push power demand growth, notably in transport (+46%), in industry (+58%) and for hydrogen production

- **In 2030, the electricity demand in the Decarbonisation scenario is comparable to the Reference scenario** with a slight increase in total demand (3%) attributable to the electrification of the transport sector given the number of new private EVs more than doubles reaching a total fleet of 64m in 2030.
- **In 2050, electricity demand increases by 38% in the Decarbonisation scenario compared to the Reference scenario** due to:
  - **The increase in the industry with a 58% higher demand in 2050 than in the Reference scenario**, due to electrification of processes
  - **A 46% increase in transport demand in 2050** given the share of Low Emission Vehicles (LEVs) including EVs, hydrogen and hybrid vehicles, which reaches 100% of new private vehicles in 2050 in the Decarbonisation scenario
  - The **demand for electricity to produce hydrogen** via electrolysis to act as feedstock for the industry (21% of industrial electricity demand in 2050 in the Decarbonisation scenario) and for transport
  - The increase in buildings electricity demand mostly occurs between 2030 and 2040 as the rate of renovations in the Decarbonisation scenario averages 4% (vs 2% in the Reference scenario)

Final electricity demand by sector (TWh), Reference scenario



Final electricity demand by sector (TWh), Decarbonisation scenario

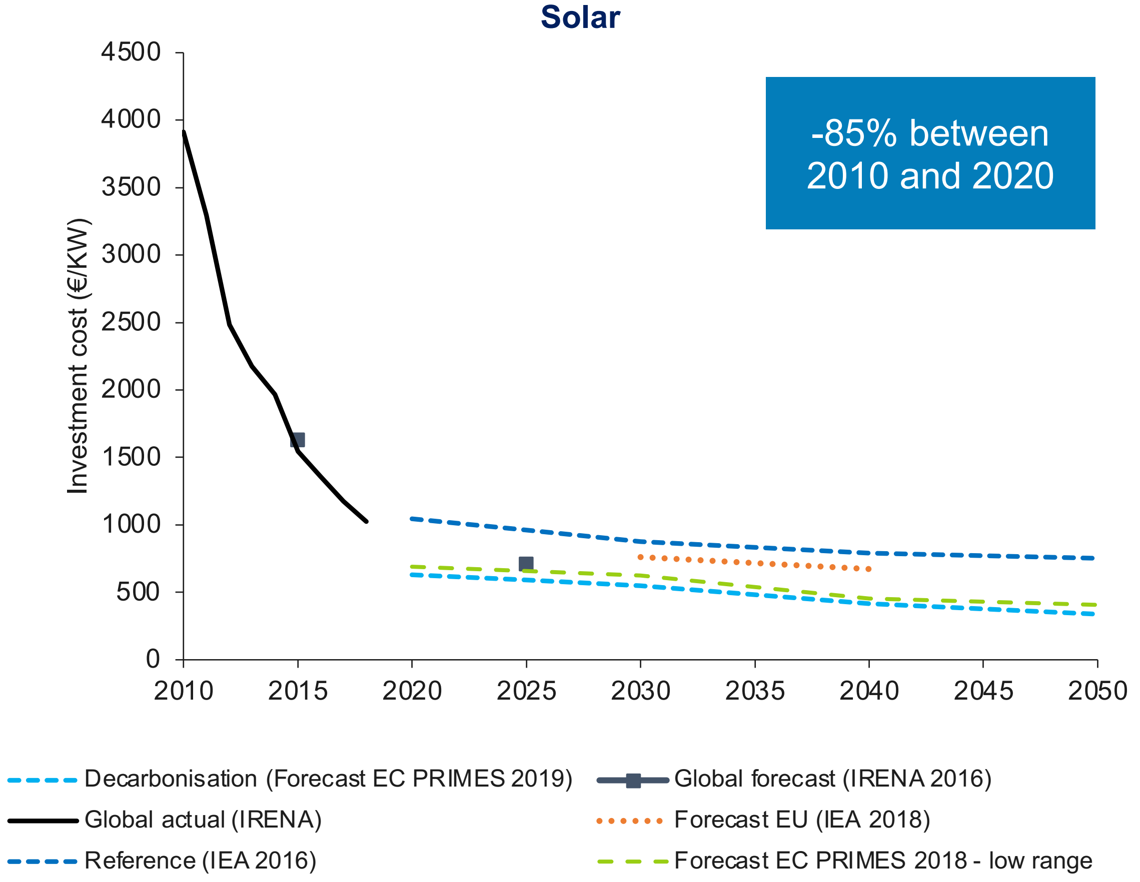


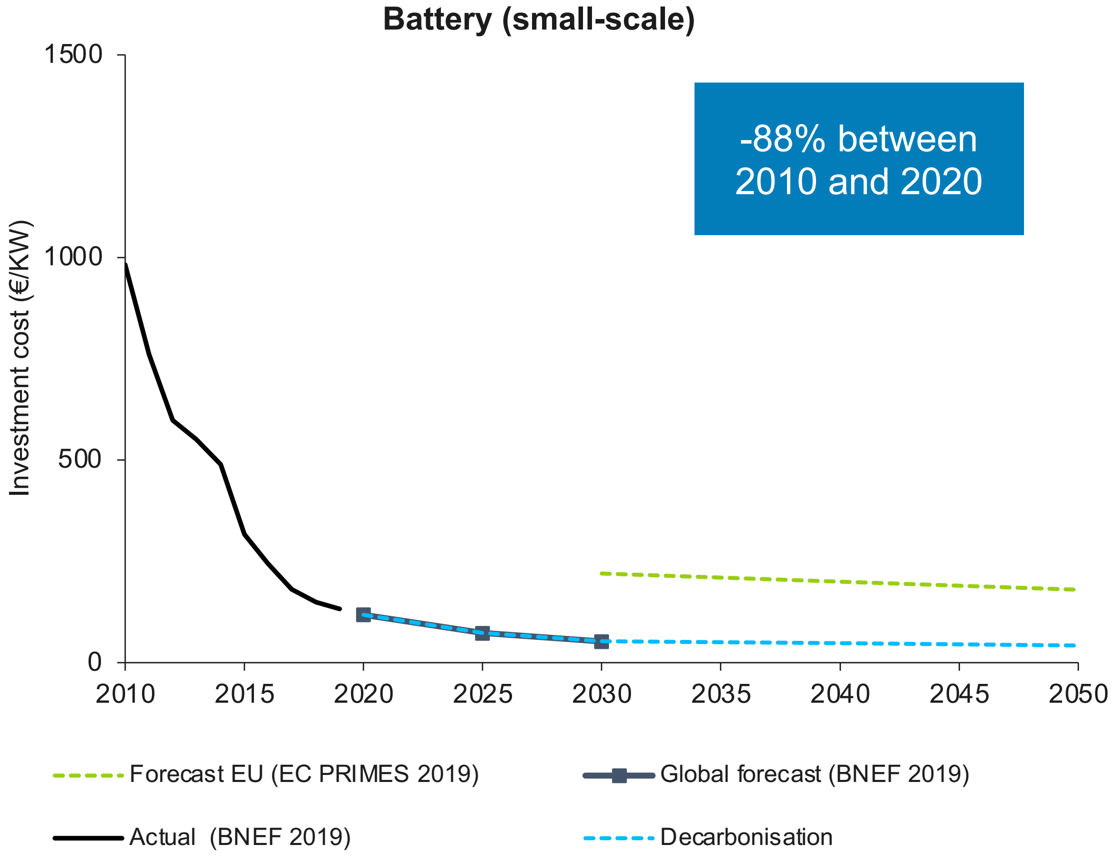
Source: Enerdata and CL

Note: Indirect use in the industry except hydrogen refers to clean gas

Technological progress has led to faster than anticipated cost reductions unlocking higher GHG reduction potential (1/2)

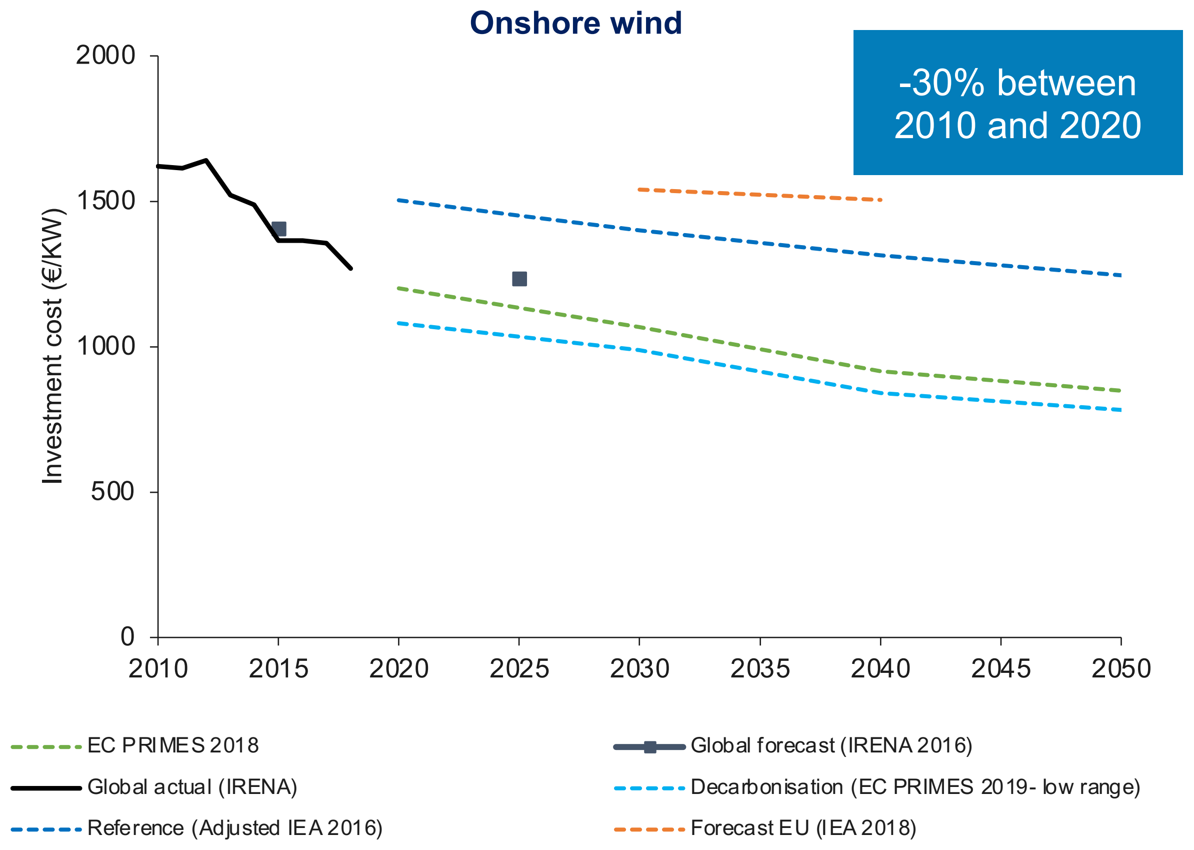
- **Recent technological progress and scale effects have led to significant cost reductions for Solar PV and batteries, faster than previously anticipated.** This cost reduction is reflected in the Decarbonisation scenario through reduced Solar and batteries cost:
  - Solar costs are aligned with the EC PRIMES 2019 forecast which is 74% lower in 2020 than the IEA 2016 forecast used for the Reference scenario.
  - For battery cost, forecasts assumed in the Decarbonisation scenario are aligned with the global BNEF 2019 forecast for 2030 while the Reference scenario is aligned with the IEA 2016 forecast.

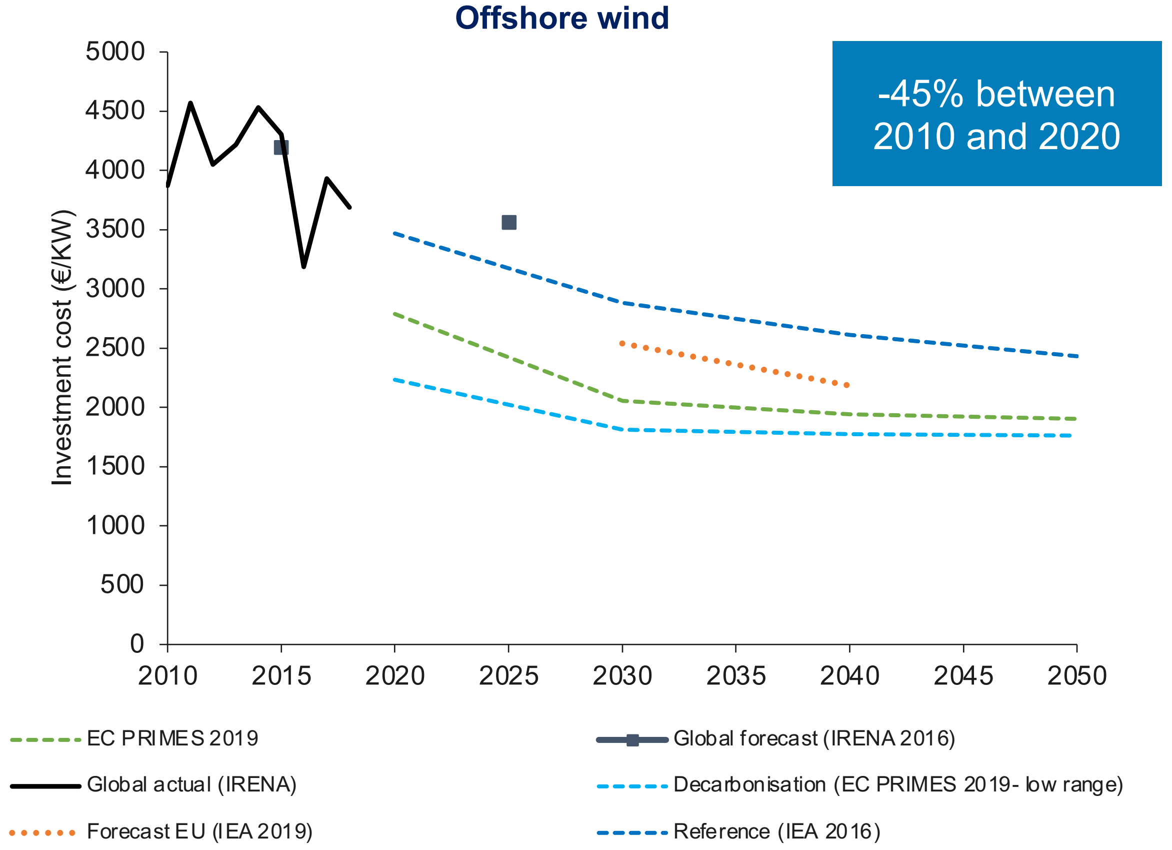




Technological progress has led to faster than anticipated cost reductions unlocking higher GHG reduction potential (2/2)

- **Recent technological progress has also led to faster cost reduction than anticipated for wind onshore and wind offshore which is reflected in the Decarbonisation scenario:**
  - Onshore and offshore wind costs are aligned with the EC PRIMES 2019 forecasts while in the Reference scenario, costs are aligned with the IEA 2016 forecasts.
  - In the Decarbonisation scenario, we take into account the recent costs reductions in onshore and offshore wind, representing respectively 30% and 45% between 2010 and 2020. In comparison, costs in the Reference scenario which are aligned with 2016 forecasts are 27% higher in 2020 than in the Decarbonisation scenario for onshore wind, and 37% higher for offshore wind.

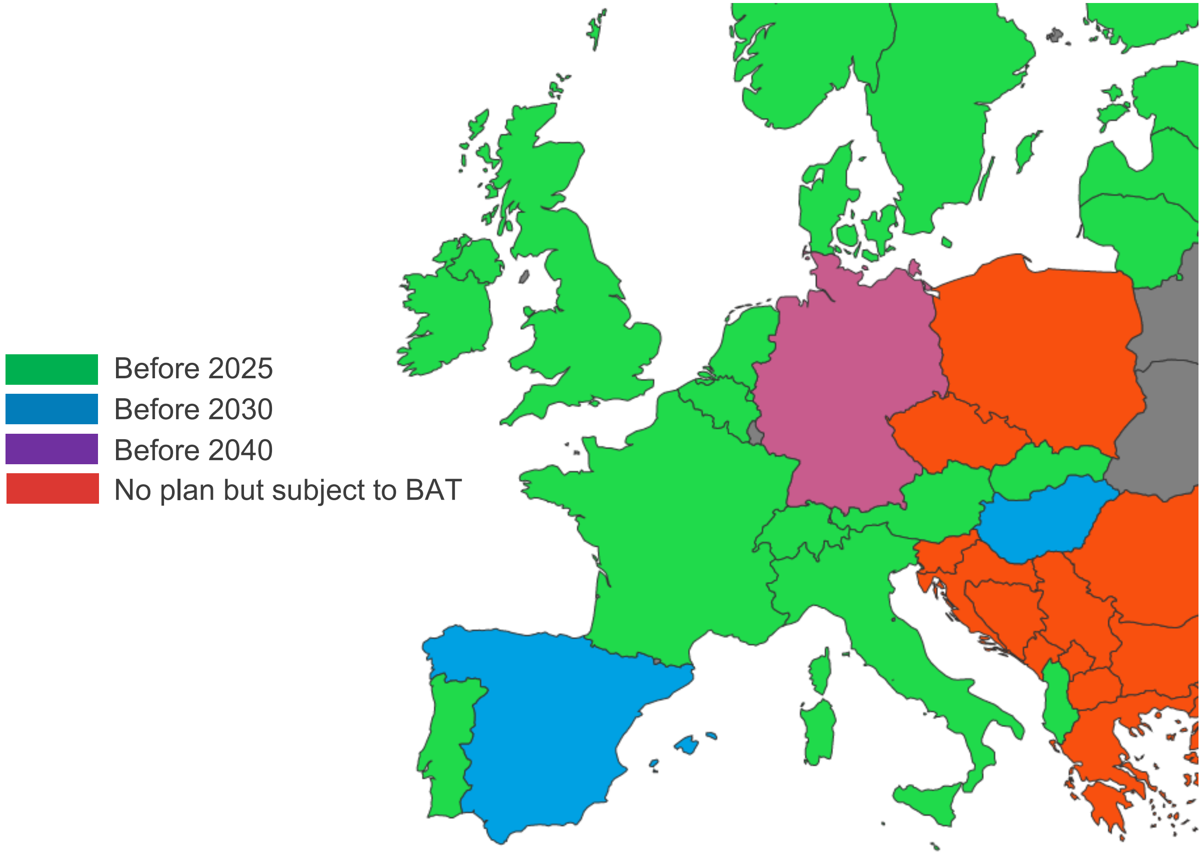




National commitments to accelerate coal phase-out enable increased ambition in the power sector for GHG reduction by 2030

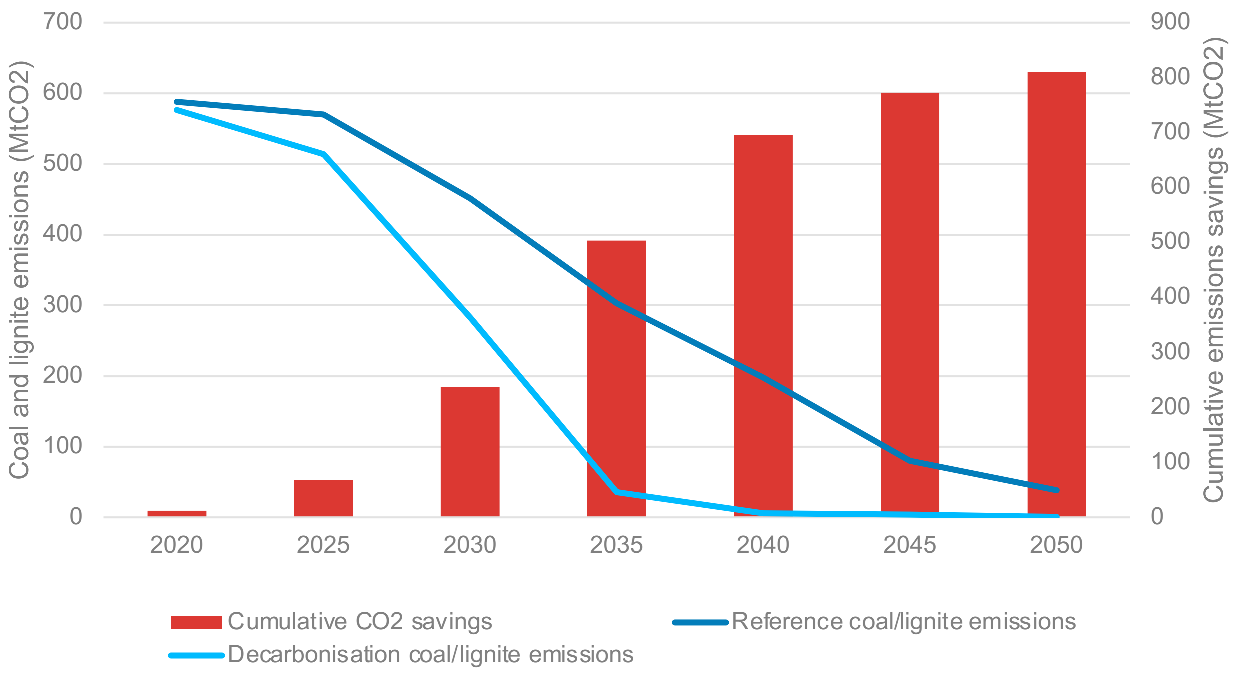
- **Recent national policies announcements to accelerate coal phase out allow to go further in the decarbonisation ambition in 2030.**
- Coal phase-out plans assumed in the Decarbonisation scenario allow to **reduce power emissions by an additional 23% by 2030** and will result in more than 800 $MtCO_2$ of cumulated emissions avoided by 2050.

Map of coal plants phase-out in Europe



Cumulative emissions savings associated with coal phase-outs

- The combined national commitments would more than halve European coal and lignite capacities by 2030 from 111 GW in the Reference scenario to 54 GW in the Decarbonisation scenario.



Note: Part of the cumulative emissions savings from coal phase outs will be offset by emissions from gas that will replace coal until RES takes over the main share of generation.

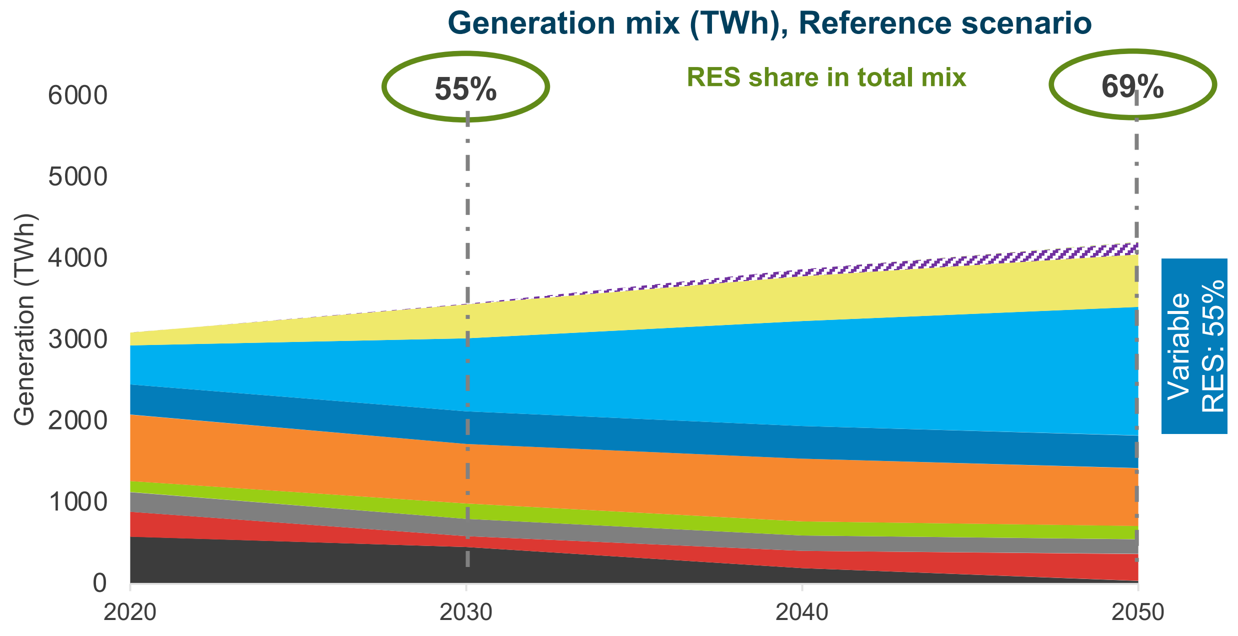
With 84% share of renewables and the coal phase out, the power sector is fully decarbonised in 2050 in the Decarbonisation scenario

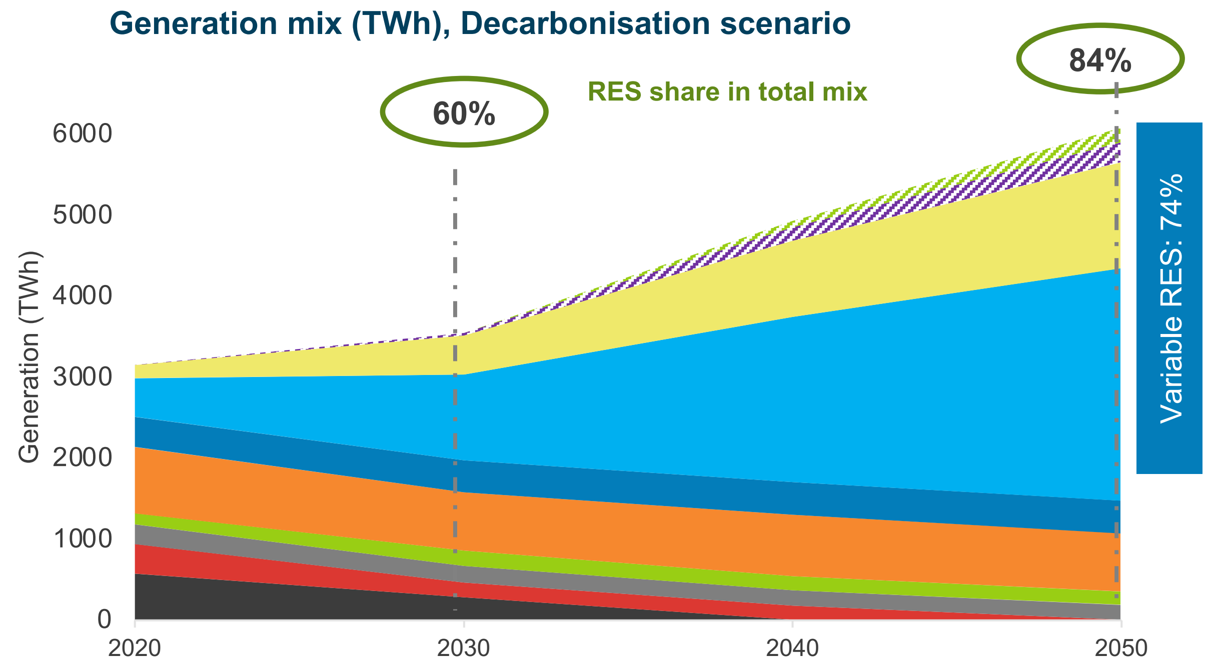
Faster and more ambitious deployment of RES supports decarbonation of the power sector:

- In the Reference scenario, RES reach 69% of total 2050 generation, with 55% penetration of variable RES.
- In the Decarbonisation scenario, RES reach 84% of total 2050 generation, with 74% penetration of variable RES.

The deployment of a range of flexibility options enables the transformation of the electricity system:

- In the Reference scenario, RES would produce 7% of non consumed energy, 80% of which being stored and redistributed through P2G or batteries.
- In the Decarbonisation scenario, RES would produce 14% of non consumed energy, 86% of which being stored and redistributed through P2G or batteries.





Source: FTI-CL Energy modelling

Note: Batteries and P2P2G generation are shown on chart but cannot be added to the rest of the generation mix. Sum of generation is higher than net power demand due to storage consumption.

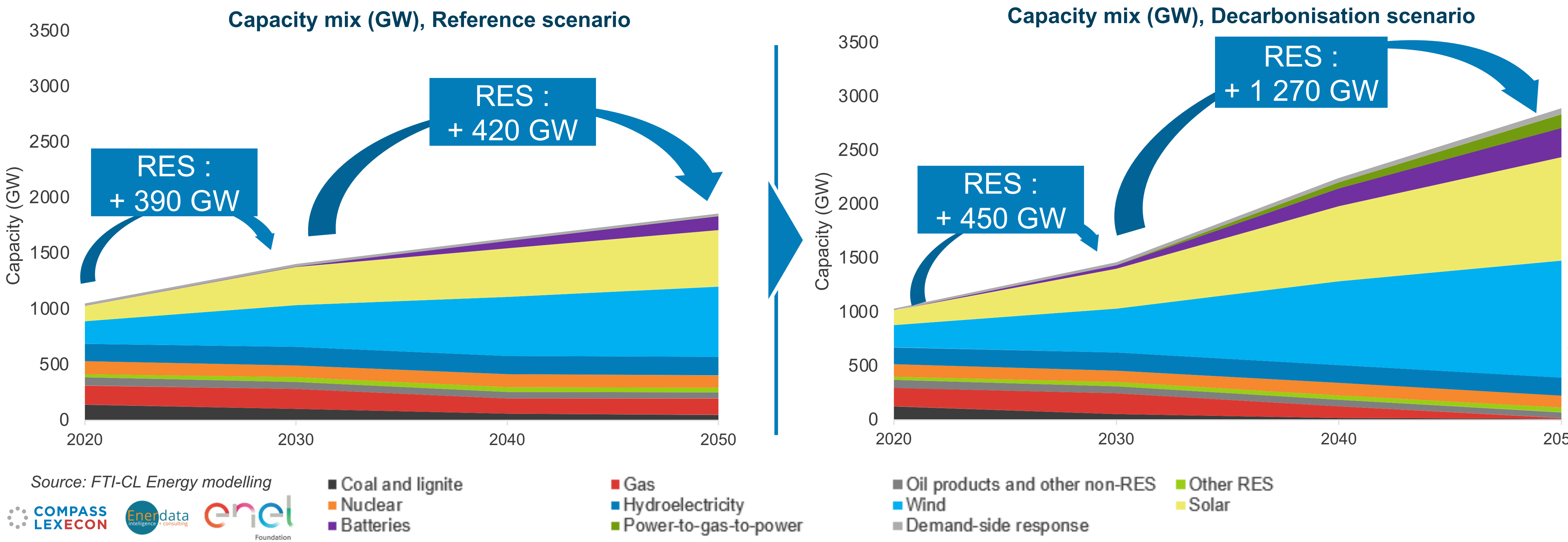
Renewable capacity in the Decarbonisation scenario would increase by 70% in 2050 reaching a total of 2210 GW in 2050

By 2050, the faster costs reduction in RES technologies in the Decarbonisation scenario allows a faster deployment of renewables (5% per year) compared to the Reference scenario (3% per year)

- Reference: 810 GW of new RES are installed between 2020 and 2050, reaching a total of 1300 GW including 510 GW of solar and 630 GW of wind.
- Decarbonisation: 1720 GW of new RES are installed between 2020 and 2050, reaching a total of 2210 GW including 960 GW of solar and 1090 GW of wind. Demand response will contribute with additional 43 GW by 2050.

By 2030, the Decarbonisation scenario implies a significant and ambitious increase of 60 GW of RES capacity beyond the Reference scenario which is based on current NECPs[1].

- Additional RES capacity by 2030 is however limited by the potential constraints in each country (societal, land use or supply-chain constraints). In a scenario in which potential constraints are removed, RES capacity additions beyond NECPs would double in 2030 compared to the Decarbonisation scenario.



Source: FTI-CL Energy modelling

[1] : Between 2020 and 2030, 390 GW of new RES in the Reference scenario, reaching a total of 880 GW including 345 GW solar, 375 GW wind. In the Decarbonisation scenario, 450 GW of new RES, reaching a total of 940 GW including 370 GW solar, 410 GW wind.

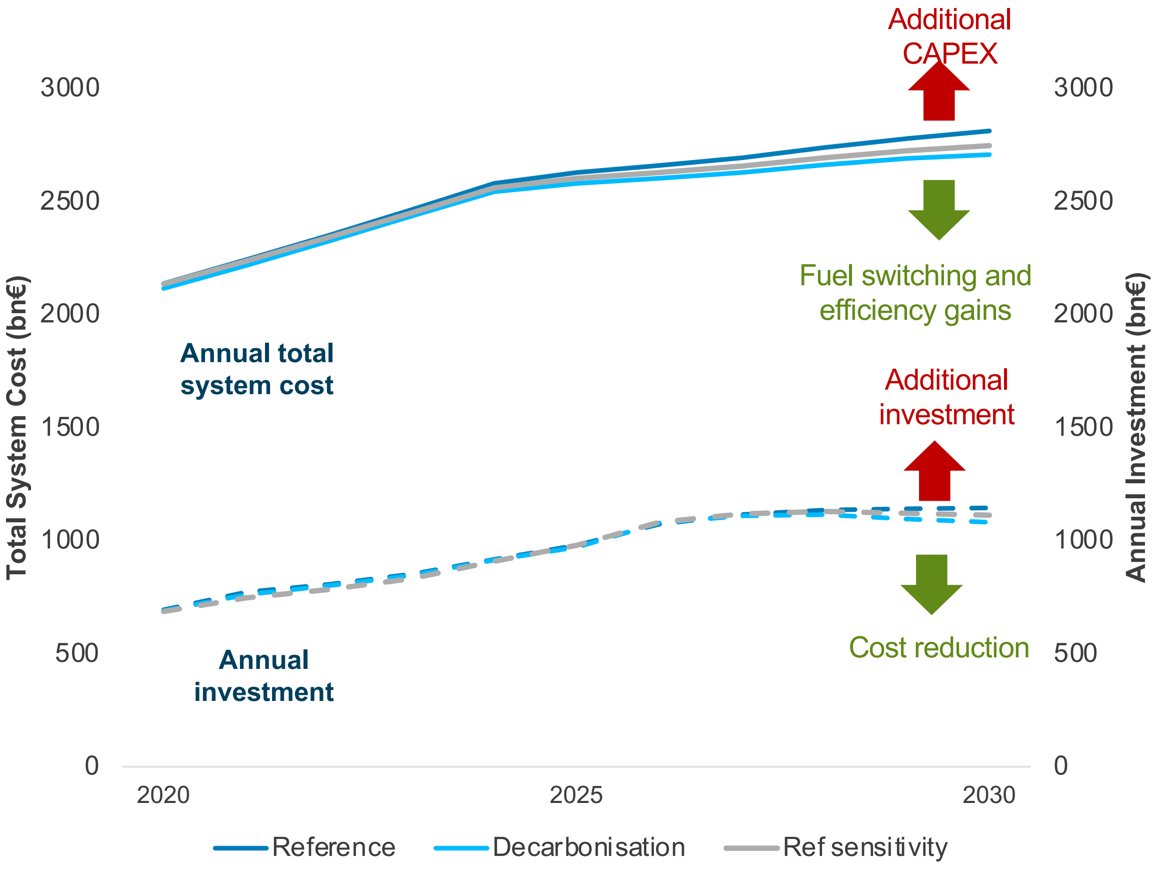
4. The reductions in costs of clean and flexible resources and new business models will help to contain costs

Increased ambition in 2030 can be reached with slightly reduced system cost and comparable investment

- **Annual investments in the Reference scenario increase by 65% between 2020 and 2030**.
- Despite the increased ambition in the **Decarbonisation scenario** and greater emission reductions in 2030, **annual investments remain similar thanks to the cost reductions in RES technologies and batteries.**
- Similarly, in the **sensitivity analysis of the Reference scenario, investments are lower than in the Reference scenario thanks to the costs reduction assumed in the power generation and transport sector**. However, investments are still higher than in the Decarbonisation scenario as a reduction of the passenger fleet is assumed in the Decarbonisation scenario therefore lowering the transport costs.

- **Total energy system costs in the Decarbonisation scenario are slightly lower than the Reference scenario**, thanks to energy efficiency gains and fuel switching.
- The increase in ambition to reach the higher 55% GHG emissions reduction in 2030 targets has thus no impact on consumers, and would be aligned with the objectives of the EU recovery plan to prioritise green investments and steering private and public investments towards green projects.

Annual total system costs and annual investments (bn€) in Reference, Decarbonisation and Reference sensitivity scenarios, 2021-2030

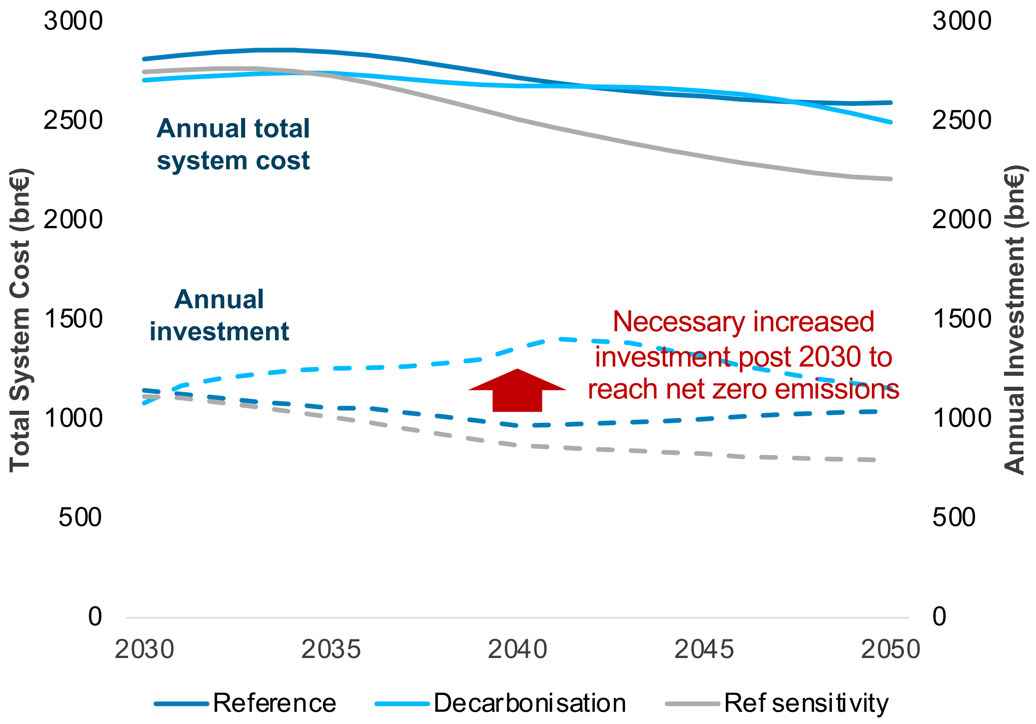


- Annual investments : CAPEX on a yearly basis excluding power network costs
- Annual total system costs : annualised CAPEX + OPEX + fuels costs (including network costs) on a yearly basis
- Capital expenditures are accounted for in the system costs as annuity payments. A discount rate of 5% is applied for all sectors to annualise the capex.

Complete decarbonisation in 2050 requires to sustain investment beyond 2030 but does not increase system costs thanks to the recent clean technologies cost decreases

- **Complete decarbonisation by 2050 requires increasing clean energy investment after 2030 and until 2040 compared to the Reference scenario**, in order to deploy clean technologies. Total investment starts declining in the last decade of the outlook (2040-2050) and eventually reaching similar levels to the Reference scenario beyond 2050.
- **Despite this temporary increase in investment, total energy system costs in the Decarbonisation scenario remain comparable to the Reference scenario throughout the outlook** thanks to the decrease in clean technologies costs, the decrease in flexibility technology costs on the supply side and the increase in embedded demand-side flexibility. Fuel switching to electricity enables end-uses to capture those reductions in costs and to achieve energy efficiency gains unlocked by EVs, HPs, and electrification.
- **By construction, the sensitivity analysis of the Reference scenario has both lower investments and system costs compared to both the Reference and Decarbonisation scenarios**, as it does not achieve higher climate ambition in 2050 but it benefits from the costs reduction in the power and transport sector.

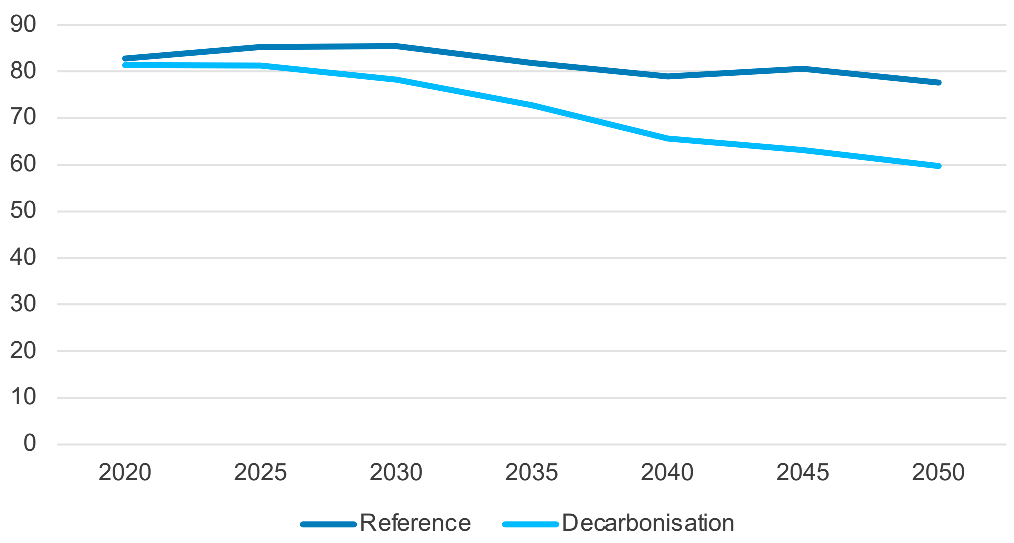
Annual total system cost and annual investment (bn€) in Reference, Decarbonisation and Reference sensitivity scenarios, 2031-2050



- Annual investments : CAPEX on a yearly basis excluding power network costs
- Annual total system costs : annualised CAPEX + OPEX + fuels costs (including network costs) on a yearly basis
- Capital expenditures are accounted for in the system costs as annuity payments. A discount rate of 5% is applied for all sectors to annualise the capex.

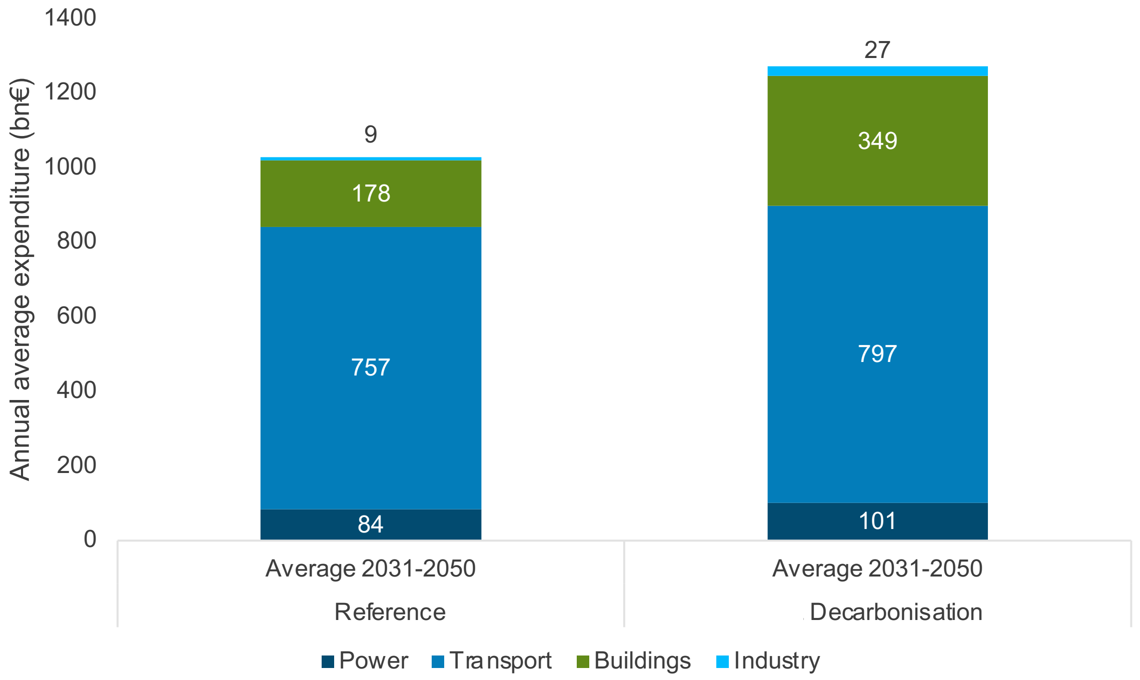
Despite increased investments to reach carbon neutrality in 2050, system costs remain comparable to the Reference scenario thanks to the decrease in power sector costs

Average LCOE in the power sector (€/MWh), Reference vs Decarbonisation scenarios, 2020-2050



- Thanks to the decrease in RES technology costs (wind and solar), flexibility technology costs and the digitalisation of power generation*, **the average LCOE in the Decarbonisation scenario is 23% lower** than in the Reference scenario in 2050.
- **The decrease in power costs will feed into** the different sectors (industry, buildings, transport) and **generate system costs savings** for those sectors in the Decarbonisation scenario.

Average annual investments (bn€) in Reference vs Decarbonisation scenarios, 2030-2050



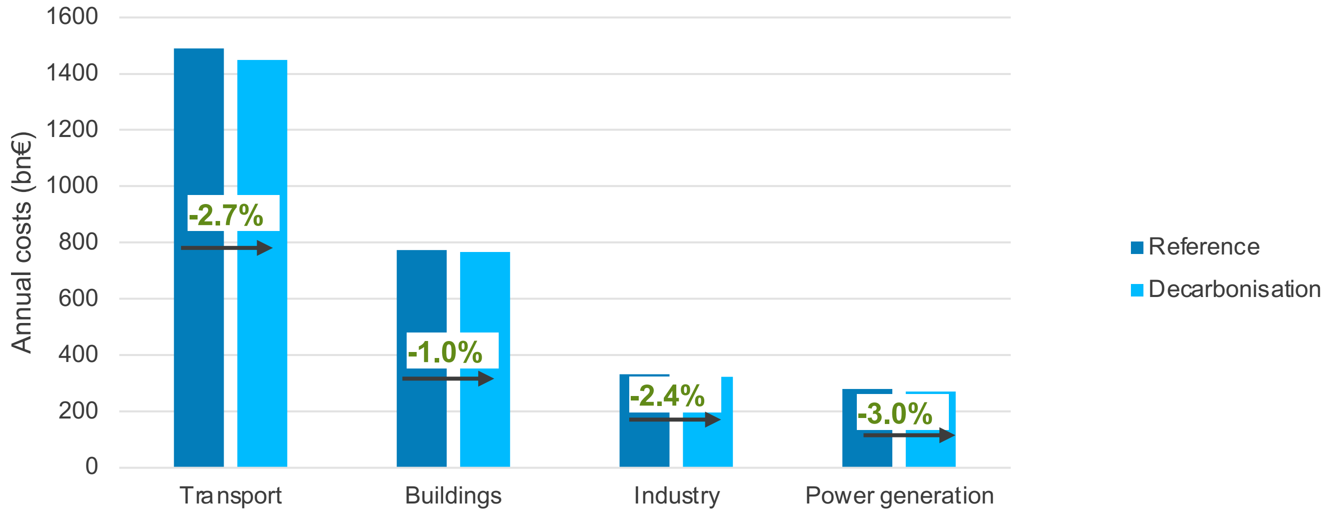
- **To reach carbon neutrality in 2050, average annual investments over the period 2030 and 2050 increase by 24% in the Decarbonisation scenario** compared to the Reference scenario with investments increasing in all sectors.

* See slide in Annex on digitalisation of power generation

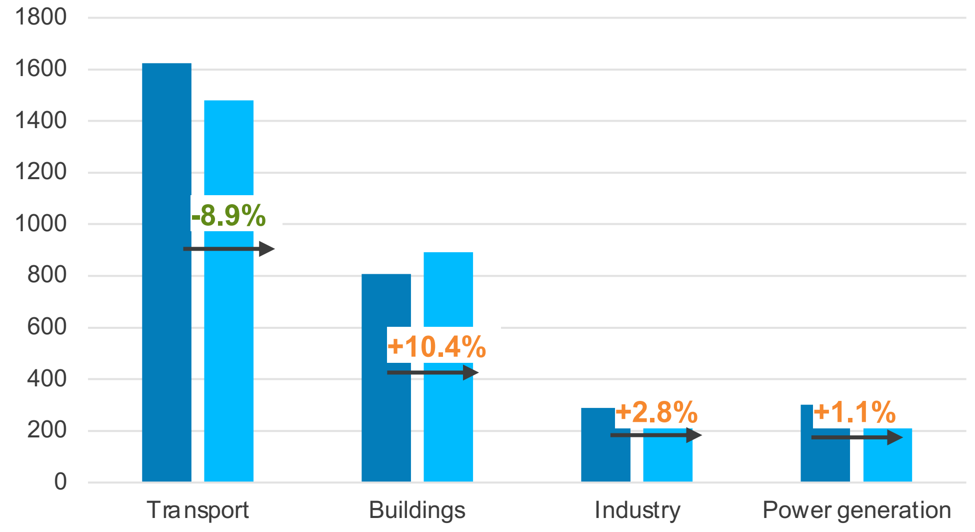
Increased decarbonisation ambition in 2030 can be achieved with system costs similar to today and carbon neutrality in 2050 can be achieved at comparable costs

- **In all the sectors considered, the decarbonisation scenario with increased ambitions in 2030 can be achieved at a comparable or lower cost compared to the Reference scenario with lower ambitions**
  - In the power and transport sector, increased ambitions in 2030 result in reduced costs thanks to the costs decrease in RES (mainly onshore wind) and batteries for electric vehicles in transport
  - In the industry and building sectors, increased ambitions in 2030 are reached with comparable costs.
- **Carbon neutrality in 2050 is achieved at comparable cost to the Reference scenario on average although sectors will be affected differently:**
  - To achieve deep decarbonisation in 2050, increased efforts in the industry and buildings must be made resulting in greater costs (+2.8% and +10.4%)
  - The reduction in the transport sector costs (-8.9%) is driven by the reduction of EV costs, increased utilisation rate and efficiency gains
- In the Reference sensitivity scenario, by construction all system costs by sector are lower than in the Reference scenario over the period 2021-2050, with a particular decrease in transport costs thanks to the decrease in batteries costs. Buildings and industry system costs also see a decrease thanks the reduced electricity costs in these sectors as RES generation costs are lower than in the Reference scenario.

Annual total system costs and power generation costs, Reference vs. Decarbonisation scenarios, 2021-2030



Annual total system costs and power generation costs, Reference vs. Decarbonisation scenarios, 2031-2050



- Annual total energy system cost include industry, buildings and transport costs
- Industry, buildings, and transport system costs include energy capex, opex and fuel costs (including network costs)
- Power generation costs include generation capex, opex and fuel costs

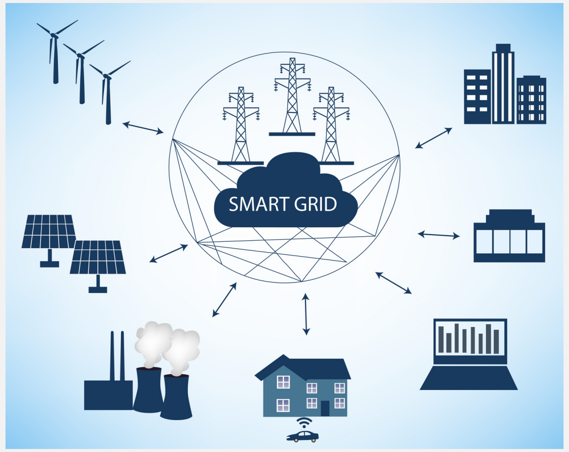
5. The study identifies the critical enablers to unleash the potential of decarbonisation and flexible resources in the power sector

A. Smartening infrastructure will provide and unlock flexibility of the power system

Digitalisation of distribution grids supports the optimisation and reliability of the power system in the context of increased electrification and penetration of RES

- **The pace of decarbonisation and electrification of the energy system brings new challenges for power grids and systems:**
  - More requests for connection and capacity increases and increasingly diverse technologies requiring network access
  - Customers and distributed renewable generation plants asking grids for power to flow in increasingly less predictable ways
  - More need for real-time network visibility
- **"Smartening" electricity grids through digitalisation is key to provide and enable further flexibility of the power system:**
  - **Smart Grids** can help manage power flows more efficiently and therefore support the integration of more variable resources and distributed resources control
- **Digitalisation of grids provides the following benefits to the power system:**
  - Peak load demand reduction and congestion management
  - Grid losses reduction
  - Grid stability and reliability
  - Flexibility services capabilities from distributed energy resources assets, potentially deferring or reducing distribution grid reinforcement investments
  - Optimal network resource allocation

Smart Grid technologies



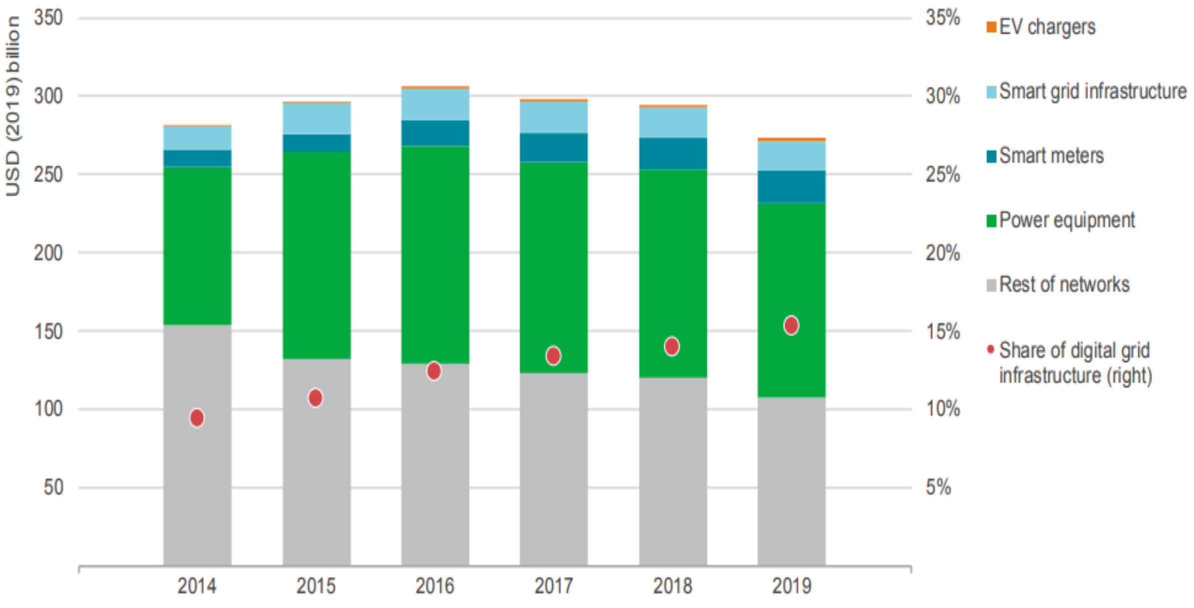
Digitalisation and smart grid technologies include:

- Robust network system and security management protocols together with **cybersecurity technologies**
- **Installed advanced sensors** aimed at monitoring data analysis of the MV grid, loads of connected users and also Distributed Generation
- **Grid Automation** technologies, aimed at defining automatic operational schemes for real-time grid optimization, advanced fault detection and system restore
- **Big data analysis** could enable predictive maintenance programs, also thanks to the potential of **AI technologies**
- **Augmented reality and drones deployment** for inspection and maintenance activities

Smart grids enable the integration of Decentralised Energy Resources (DERs) and support demand-side flexibility

- **Smart grid technologies are necessary to enable DERs and demand-side flexibility:**
  - The increasing penetration of DERs will lead to a more frequent reverse of power flow, which can challenge the traditional planning and operation of distribution and transmission networks.
  - New market players (prosumers, aggregators and active consumers) pose new needs and require the introduction of third-party business models being introduced.
  - By procuring flexibility services such as voltage support and congestion management from their network users, once proper regulatory framework and market rules are defined, DSOs could optimize system operations and future grid investments, for the benefit of both the distribution grid and consumers.
- **Digitalisation of grids supports the integration of variable renewable energies:**
  - By using data and communication tools to manage the variability and uncertainty associated with RES and EV recharging network needs
  - Smart grids enhance the flexible operation of the grid, reduce the operational costs and improve efficiency

Investment in electricity networks by equipment type (USD billion), 2014-2019



Source : IEA (2020)

- Global investments in digital grid infrastructure are increasing year by year. Grids are becoming more digital, distributed and smart, depending less on traditional equipment and more on new drivers.
- Investment in digital grid infrastructure reached over 15% of investments in electricity networks in 2019 in the world

The increase in networks costs in the Decarbonisation scenario is driven by increased distributed RES and electrification of end uses

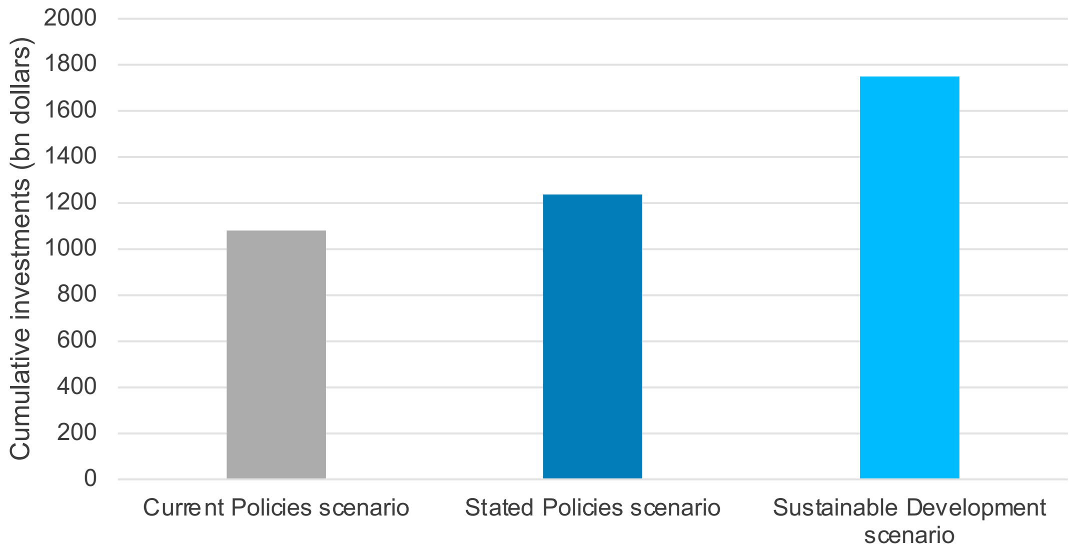
Network costs increase over 2020-2030 in the Decarbonisation scenario due to:

- The increase of distributed RES penetration
- The increase of electricity consumptions (peak demand) and electrification of mobility
- Modernisation and digitization of the grid

On average, annual network costs increase by more than 40% over 2030-2050 in the Decarbonisation scenario.

- The higher CO_2 reduction target of the Decarbonisation scenario induces a significant cost increase of more than $500 bn in total network costs between 2019 and 2040 (IEA, 2019) due to the increased RES penetration and higher peak demand from the increased electrification of end-uses.
- Distribution network costs in EU, according to IEA World Energy Outlook, will increase from an average $30 bn/year in 2019 to a value between 40 $bn/year (Stated Policy Scenario – INECP) and $60bn/year in 2040 (Sustainable Development Scenario[1]).
- In addition other relevant reports estimate an investments range flooring in accordance with IEA scenarios (CPS) up to 60 $bn/year (e.g. DNV, BNEF) in 2030, in the current policy scenario.

Cumulative investments in power networks, 2019-2040 (bn dollars)



Source : IEA (WEO 2019) – nearly 70% of total network investments addressed to Distribution based on the current share

1 : IEA Sustainable Development Scenario: foreseen a rapid path of changes to meet 100% of the United Nations Sustainable Development Goals

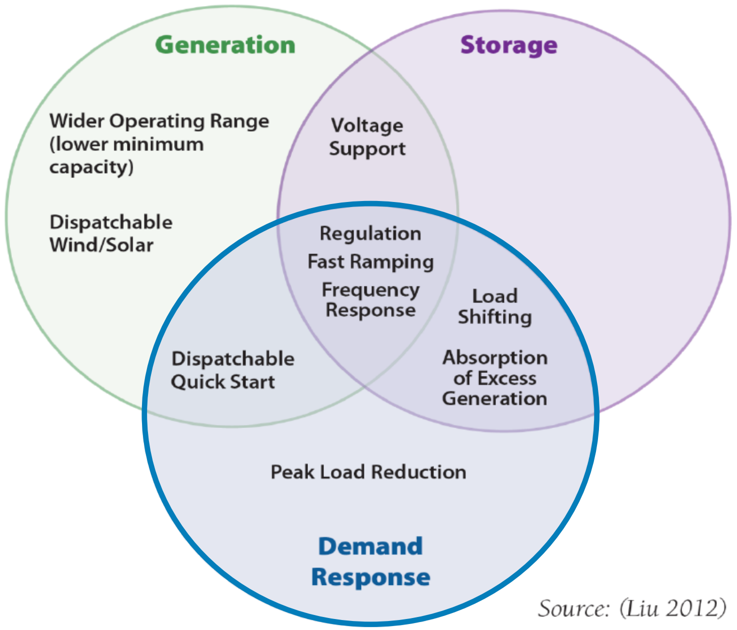
5. The study identifies the critical enablers to unleash the potential of decarbonisation and flexible resources in the power sector

B. Flexibility of demand will be a key element to respond to the flexibility needs of the system

Flexibility of demand supports the integration of variable RES through peak load reduction and load shifting

- Flexibility of demand (or Demand Side Response (DSR)) can be defined as the actions taken by customers, or agents on their behalf, to change their electric usage at strategic or peak times.
- **Changes in consumption patterns occur in response to changes in the price of electricity over time, or to incentive payments** designed to induce lower electricity usage at times of high wholesale market prices or when system reliability is jeopardised.
- **Beyond peak load reduction, DSR provides services that compete with and/or complement generation and storage technologies:**
  - DSR mitigates the need for peak generation
  - DSR supports short term and long term system reliability
  - DSR supports the penetration of intermittent renewable energy resources by absorbing excess generation of solar and wind for example
- **Flexibility of demand in a Decarbonisation scenario can come from the following sources which we detail in the next slides:**
  - EVs charging
  - Heat Pumps and cooling demand
  - Hydrogen production in the industry

Services provided by DSR : more than just peak load reduction



Source: European Commission (2016)

Flexibility of EVs demand allows load shifting during hours of high solar production in the Decarbonisation scenario

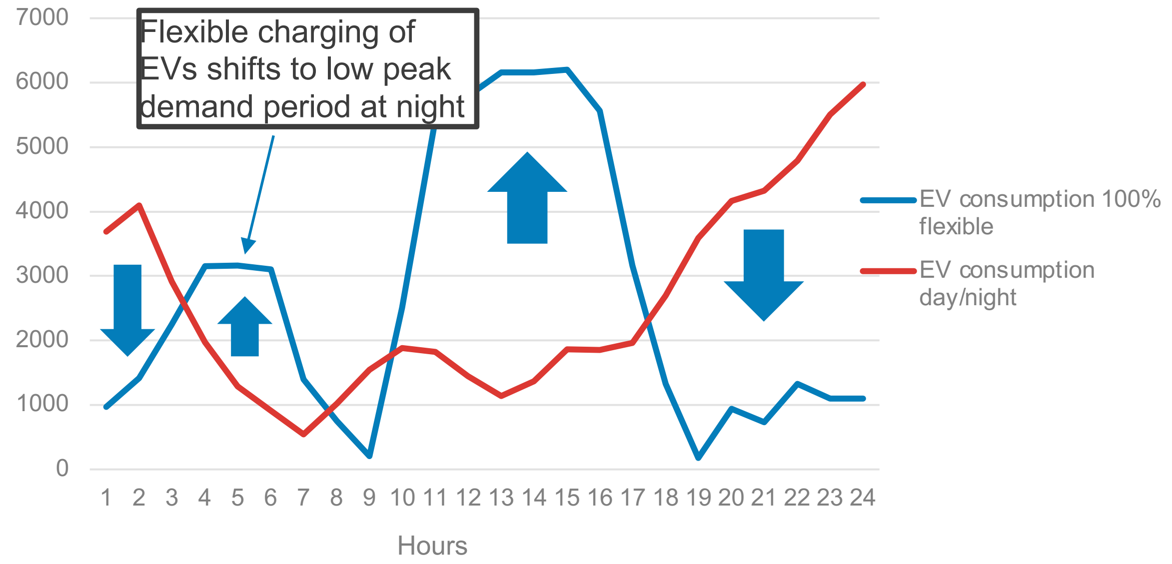
The increasing penetration of EVs raises challenges for the power system if vehicle charging is not monitored and optimised to avoid an increase in daily peak demand but also opportunities if smart charging is introduced

- Monitoring and optimising EVs charging would allow to adapt consumptions to variations in solar and wind production thereby avoiding renewable curtailment and allowing charging when production costs are the lowest.

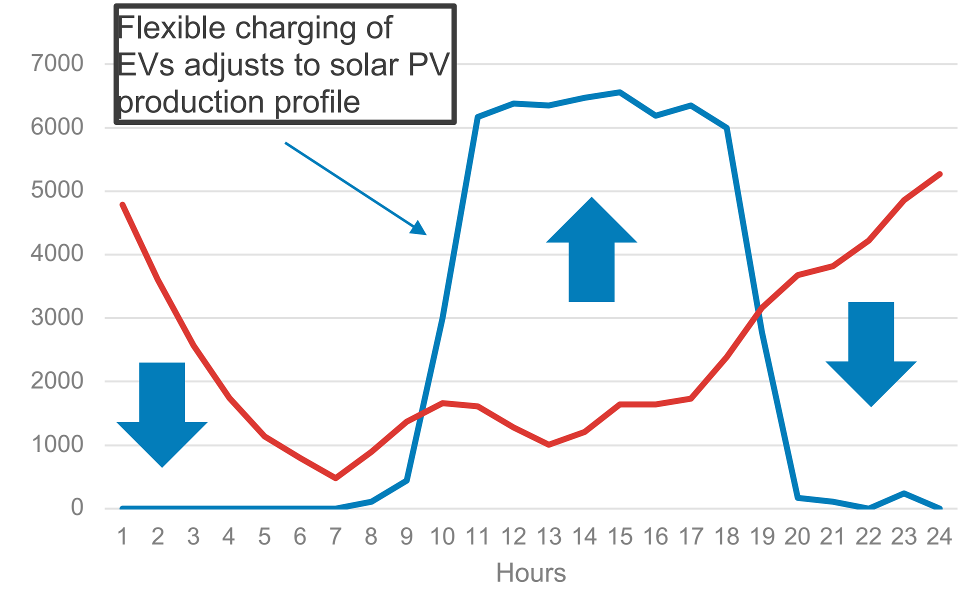
Moreover, the optimisation of EVs charging patterns provides a significant source of flexibility of demand allowing charging periods to match with system needs

- The optimised charging profile of EVs depends on the month: during summer months, flexible charging will typically happen during peaks of solar production, whilst during winter months, flexible charging will also typically concentrate during the drops in demand at night
- In the Decarbonisation scenario, dynamic charging of EVs is assumed compared to a simple Time of Use charging (day/night) in the Reference scenario.

Average consumption of EVs during January (MW)



Average consumption of EVs during July (MW)

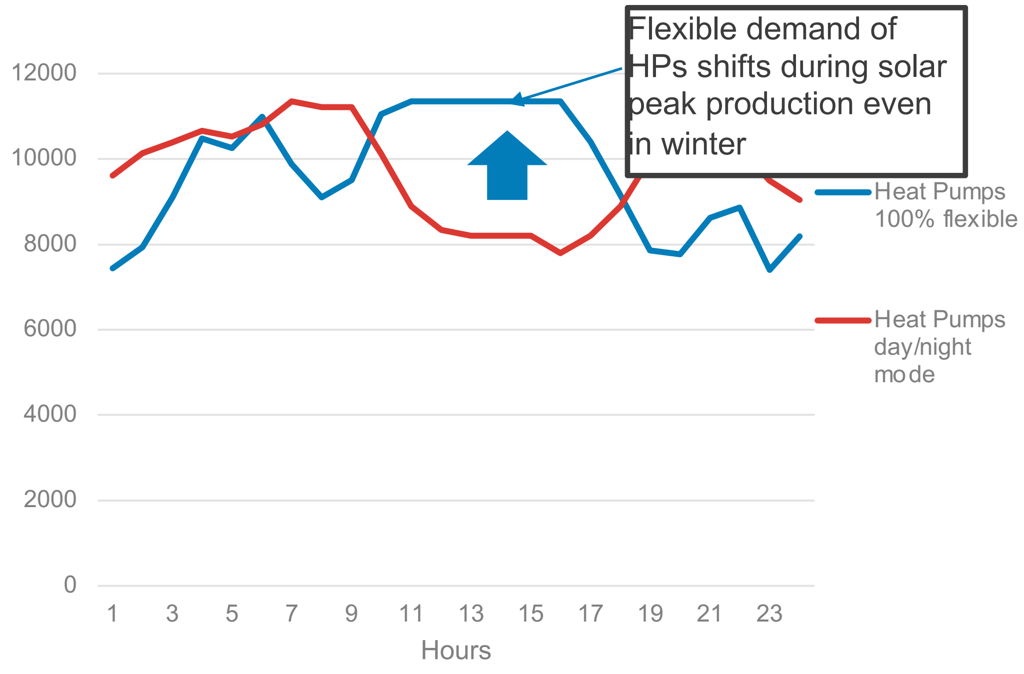


Flexible demand of Heat Pumps and cooling leads to load shifting during peaks of solar production in the Decarbonisation scenario

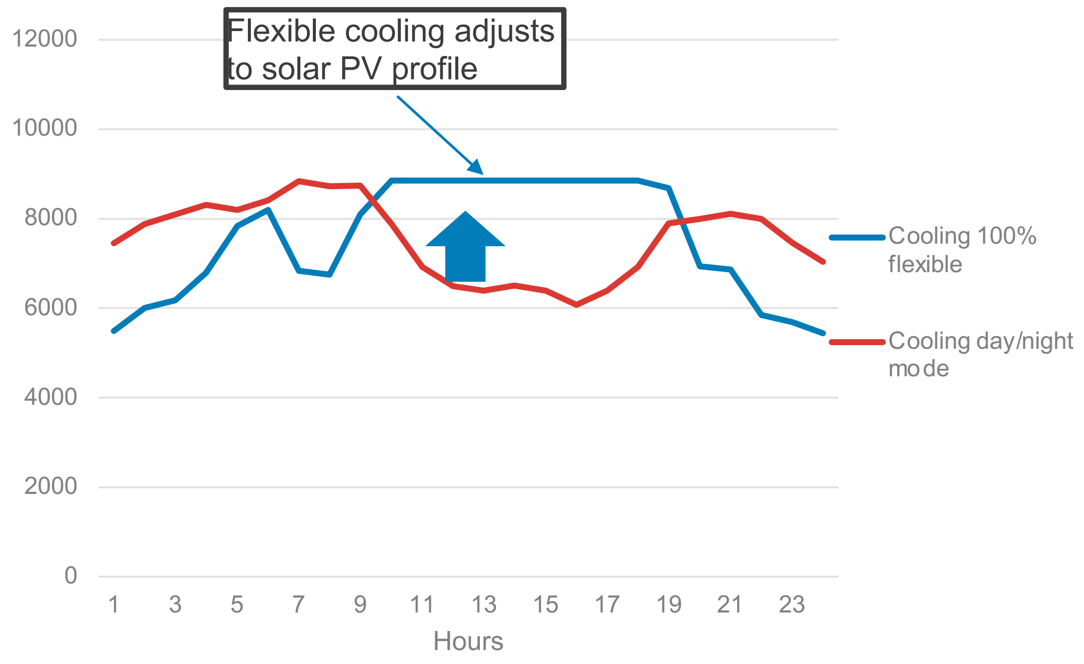
The electrification of buildings via Heat Pumps provides a significant source of flexibility of buildings demand that can be optimised to integrate RES generation

- For Heat Pumps (HPs) and cooling, daily needs allow little room for load shifting. Nonetheless, load shifting during hours of peak solar production (even in winter) provides some flexibility to the system.

Average consumption of HPs during January (MW)



Average consumption of cooling during July (MW)



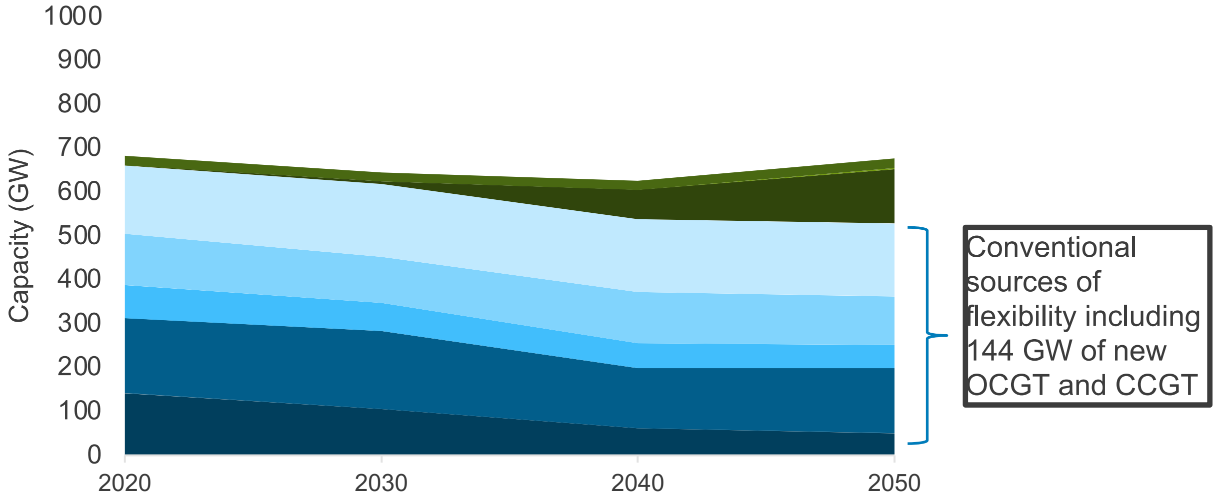
5. The study identifies the critical enablers to unleash the potential of decarbonisation and flexible resources in the power sector

C. Supply side flexibility will also play a central role in integrating additional RES

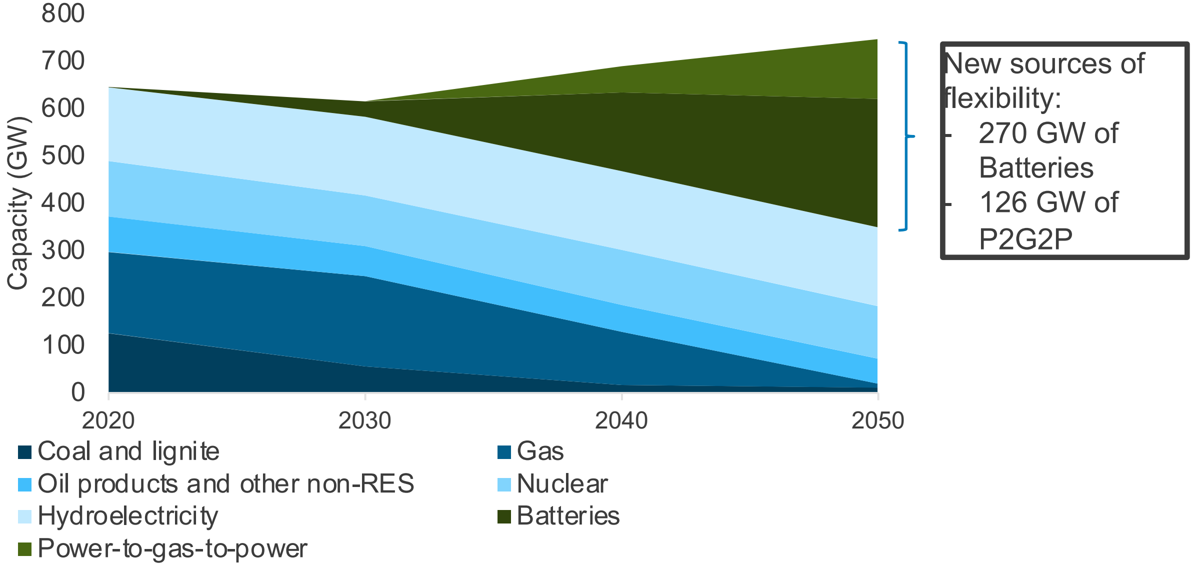
The development of storage technologies (batteries, P2G) in addition to demand flexibility is necessary to meet the growing flexibility system needs

- **The significant increase in 2050 of variable RES generation to achieve deep decarbonization will increase the flexibility needs of the system:**
  - The increase in flexibility needs will be particularly striking during the day due to the solar peak production
  - On a weekly basis, wind generation creates the most flexibility needs
  - On an annual basis, flexibility needs are more moderate given the inverse seasonality of wind and solar generation
- **The development of new sources of flexibility including storage technologies such as batteries and Power-to-Gas-to-Power (P2G2P)** is necessary to meet the flexibility needs of the system in a Decarbonisation scenario with increased RES penetration.
- **By 2050, 270GW of new batteries will be developed in the Decarbonisation scenario, of which:**
  - 220 GW of stationary large scale batteries
  - 10 GW of behind-the-meter batteries, associated with PV solar
  - 40 GW of batteries embedded in Vehicle-to-Grids
- **Stationary batteries can provide a range of key energy services in an affordable manner.** As the cost of emerging technologies falls further, storage will become increasingly competitive, and the range of market services it can provide will only increase.

Flexible resource capacity in Reference scenario (GW)



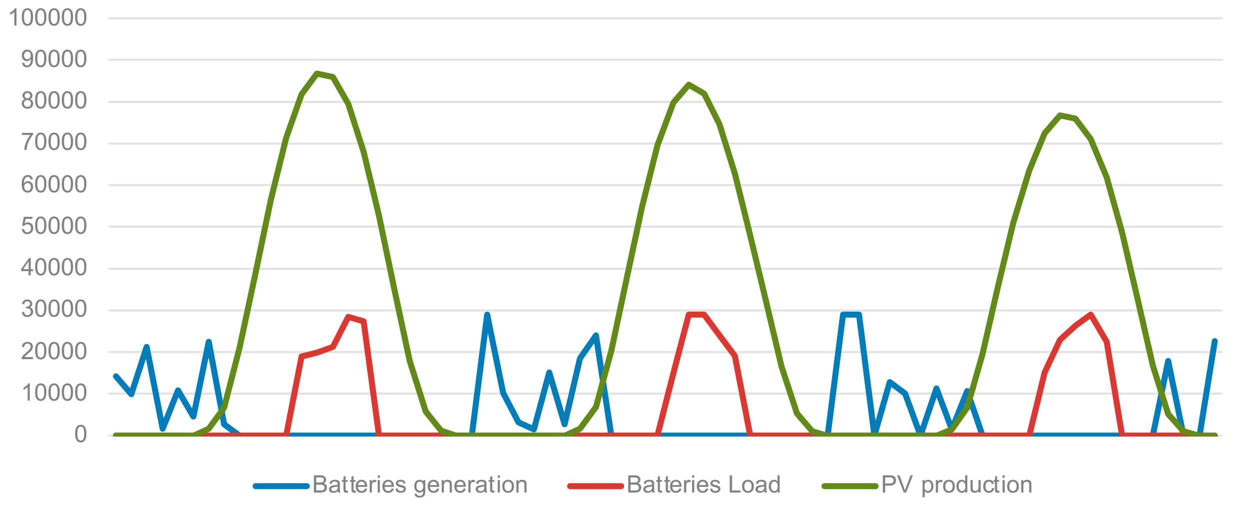
Flexible resource capacity in Decarbonisation scenario (GW)



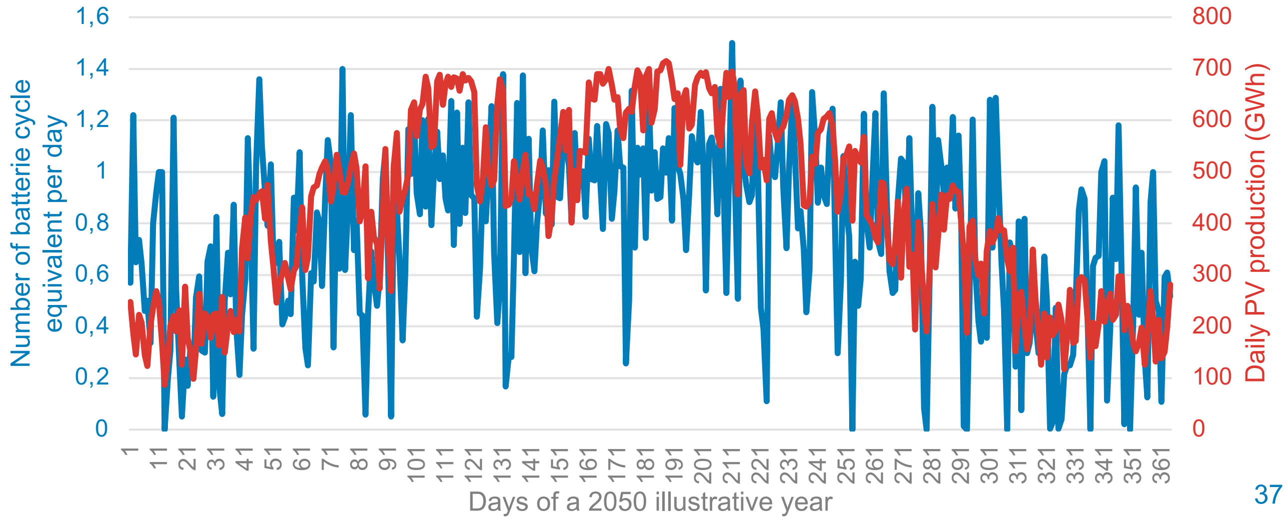
Batteries play an important role in providing short term daily storage and ensuring day/night flexibility

- Batteries typically operate a storage cycle of several hours (from 1 to 4 hours in the modelling, depending on the type of batteries – large-scale batteries, behind-the-meter batteries or EV batteries): they usually complete **their charge/discharge cycle within the same day.**
- The number of charge/discharge cycles is highly dependent on sunshine conditions as described on the bottom graph for an illustrative 2050 year in France: the higher the PV generation (in particular during summer), the higher the batteries utilisation (measured by the number of cycles)
- The modularity of batteries, short lead times, wide range of applicability, economies of scale and overall technological progress underpin the **significant growth of batteries in the Decarbonisation scenario.**
- Continuing recent trends, **many utility-scale battery installations are set to be paired with solar PV and wind** power to increase their dispatchability, gain revenues from energy arbitrage and to offer ancillary services to the grid.
- Batteries embedded in vehicle-to-grid will also significantly ease RES integration by providing daily flexibility (40 GW of EV batteries are expected to be developed in 2050 in the decarbonisation scenario)

Illustration of battery operation over 3 days in July 2050 (GW)



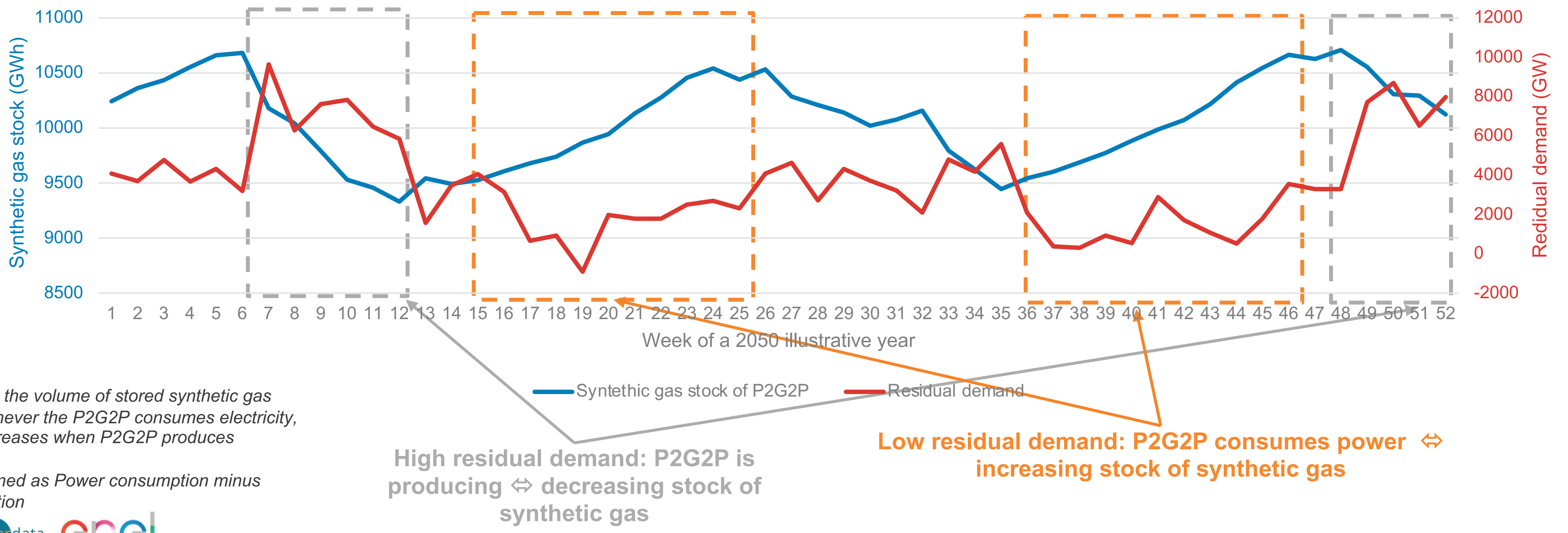
Evolution of the number of battery cycles per day and the daily PV production over an illustrative 2050 year in France



Seasonal storage is also necessary (e.g. power-to-gas-to-power) to meet flexibility needs induced by seasonal variations of residual demand

- **Long duration storage is essential to stabilise the power system by capturing excessive production and generating during scarcity situations.**
  - Power-to-gas-to-power (P2G2P) can provide such long-term storage: by consuming electricity during periods with excess RES generation, P2G2P will produce synthetic gas (including hydrogen), that will be stored and burnt later on (e.g. in OCGT or CCGT power plants) to produce electricity during scarcity situations.
  - Given the large gas storage volume, P2G2P can provide seasonal flexibility and follow seasonal fluctuations in residual demand
- **For instance, based on the below illustrative graph for 2050, P2G2P will tend to:**
  - Generate in February-March and December given the high residual demand (explained by a high consumption and moderate RES production)
  - Consume in April-May and September-October given the low residual consumption (due to moderate demand and high RES production)

Evolution of P2G2P stock[1] and residual demand[2] in 2050 – illustration for France (weekly average)



1: P2G2P stock represents the volume of stored synthetic gas (including hydrogen). Whenever the P2G2P consumes electricity, this stock increases. It decreases when P2G2P produces electricity.
2: Residual demand is defined as Power consumption minus variable renewable generation

6. Conclusion

Deep decarbonisation supports the economic recovery effort and future sustainable growth thanks to feasible and affordable clean, flexible technologies, and sector coupling

- **Increased ambition to achieve close to 55% emissions reduction in 2030 is feasible in the Decarbonisation scenario and is key stepping stone to achieve net zero emissions in 2050 thanks to:**
  - **Recent technological advances** in RES and batteries for electric vehicles enabling faster decarbonisation
  - **Sector coupling and the electrification** of end uses in the transport, building and industry sectors
  - **Business initiatives** deploying innovative solutions and business models leveraging clean technologies and digital solutions that unlock additional GHG emission reduction potential across the transport sector
  - **New national and local energy policies and regulations** including coal phase-out, ICE bans and tighter emission limits that support deeper ambition for decarbonisation

- **The power sector plays a key role as enabler of deep decarbonisation through sector coupling. Developments in the power sector allow it to act as a catalyser for decarbonisation and fast track emissions reductions to 2030:**
  - **Costs reduction in RES** allow greater penetration of variable RES
  - **Coal phase out policies** drive further emission reductions in the next decade
  - **Development of flexible solutions on the demand and supply side** allow to meet increasing flexibility needs arising from the integration of RES:
    - Short term and long term storage with batteries and P2G2P installations
    - Flexibility of demand through EVs, Heating and Cooling, and hydrogen production leveraged by the development of aggregators
  - **The digitalisation of distribution grids will support the integration of variable RES** unlocking the flexibility potential of demand-side response as well as ensuring the reliability of the system

- **Increased decarbonisation requires additional investment but the 55% target by 2030 can be achieved at a slightly lower cost for consumers than the previously agreed 2030 target, and complete decarbonisation by 2050 does not increase system costs:**
  - Total energy system costs in the Decarbonisation scenario are slightly lower than in the Reference scenario featuring lower ambitions until 2030, thanks to energy efficiency gains and fuel switching despite the necessary increase in investments to reach the increased ambition in 2030.
  - Achieving complete decarbonisation in 2050 requires to increase investments beyond 2030 until 2040, but system costs remain affordable and comparable to the Reference scenario thanks to the decrease in clean technologies costs, new business models as well as policies and regulations.

- **Increased ambition for 2030 supports the economic recovery effort and green transition by providing more renewable capacity, infrastructure, and energy efficiency investments for buildings with a limited impact on costs thanks to the reduction of clean technologies.**

Effective EU policy design can support a clean and affordable energy transition and enhance the potential technologies have to increase EU decarbonization ambition

- **EU policies should support increasing 2030 GHG ambition to 50-55% and a 2050 climate neutrality objective with corresponding amendments of RES and EE targets**
  - **An increased GHG ambition policy framework should be based as much as possible on the realistic potential of decarbonization technologies** taking into consideration most recent cost evolution and their resilience to change while promoting innovation and technological disruption
  - **The "technology neutrality" concept should evolve to encompass other SDGs** such as air quality and circular economy and carefully assess distributional impacts.
  - **The impacts on regions, communities, workers and consumers need to be managed** so as to ensure that through *a just transition* process no one is left behind
  - **The assessment should take into account cross-sectorial synergies** and not limit itself to optimize individual sectorial contributions
- **The power sector can effectively contribute to deeper decarbonization provided that an investment framework for RES and carbon neutral firm and flexible capacity is adequately designed and in place**
  - **A revised market design is needed to support increased RES penetration**
  - **Wind and solar renewable energy technologies should be acknowledged as key strategic value chains**
  - **Corporate Power Purchasing Agreements (PPAs) should be promoted** in order to encourage the participation on the industry demand side
- **Electrification of end-use sectors (transport, buildings and industry) is an unprecedented opportunity to decarbonize the uses of energy**
  - **Clean and smart electrification is the cheapest and simplest route to decarbonize large portions of total final energy uses.** This is already valid for light-duty transport, domestic and water heating and cooling and many industrial and manufacturing processes
  - **A roadmap with concrete milestones on the electrification of energy demand is needed to support the decarbonisation of the economy by 2050**
  - **The smart integration of electricity with final electric uses should be promoted more strongly** as it provides much needed additional flexibility to manage increasing volumes of variable RES. When smartly integrated in a power grid, EVs, heat pumps and electric boilers can help by adjusting their demand profile based on price signals and providing a source of energy storage as well as demand response
- **The energy infrastructure needs to be enhanced and digitalized in order to exploit cross-sector synergies, leveraging on increased decentralization, electrification of end-uses and increasingly active consumers, ensuring at the same time adequacy, security and resilience**
  - **There is an urgent need to boost investments in infrastructures** to accommodate new electrification technologies and increase RES penetration
- **Direct electrification can be complemented by indirect electrification (Hydrogen and P2X technologies) to decarbonize hard-to-abate sectors**
  - **Green hydrogen produced by RES power via electrolysis is the only future proof sustainable solution.** Hydrogen needs to be produced on a 100% RES basis and must be produced mainly locally

Annexes

Annexes

1. Modelling assumptions

2. Detailed KPIs by sectors

3. Detailed results of power sector

4. Hydrogen assumptions

5. Digitalisation of generation

6. Sensitivity analysis of the Reference scenario results

Both scenarios relies on a set of assumptions from the EU 2050 Roadmap updated with recent technological progress and policies

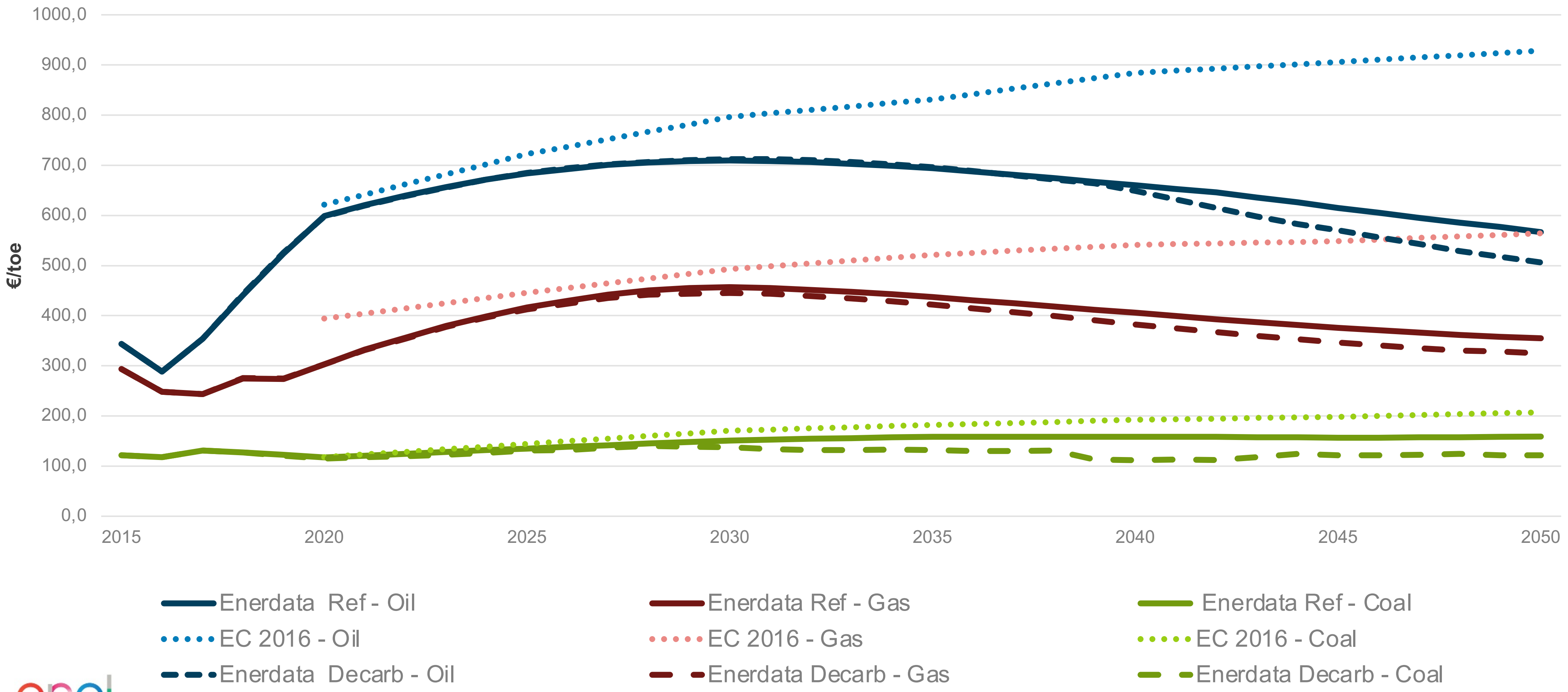
		Reference	Decarbonisation
GDP		Based on EU REF 2016 (*1.5% CAGR*)	
Population growth		Based on EU REF 2016 (*0.1% CAGR*)	
International fuel prices		Endogenous in POLES but starting point in line with EU REF 2016	Endogenous prices, therefore evolving compared to the REFERENCE scenario
Technology costs	**Power generation**	Based on IEA WEO cost curves in line with EU REF 2016	Based on lower range of EC PRIMES 2018
	Transport	Based on EC PRIMES 2018	Assumed Cost parity between EVs and ICEs in 2025
	Building and Industry		Based on EC PRIMES 2018
Energy policies		EU3232.5* in 2030 + EU REF 2016 in 2050	50-55% GHG emission reduction by 2030 + Net zero in 2050

** EU3232.5 refers to the binding EU 2030 objective of 32% RES and 32.5% Energy Efficiency (EE) in 2030*

Commodity prices are based on Enerdata endogenously calculated oil, coal and gas prices

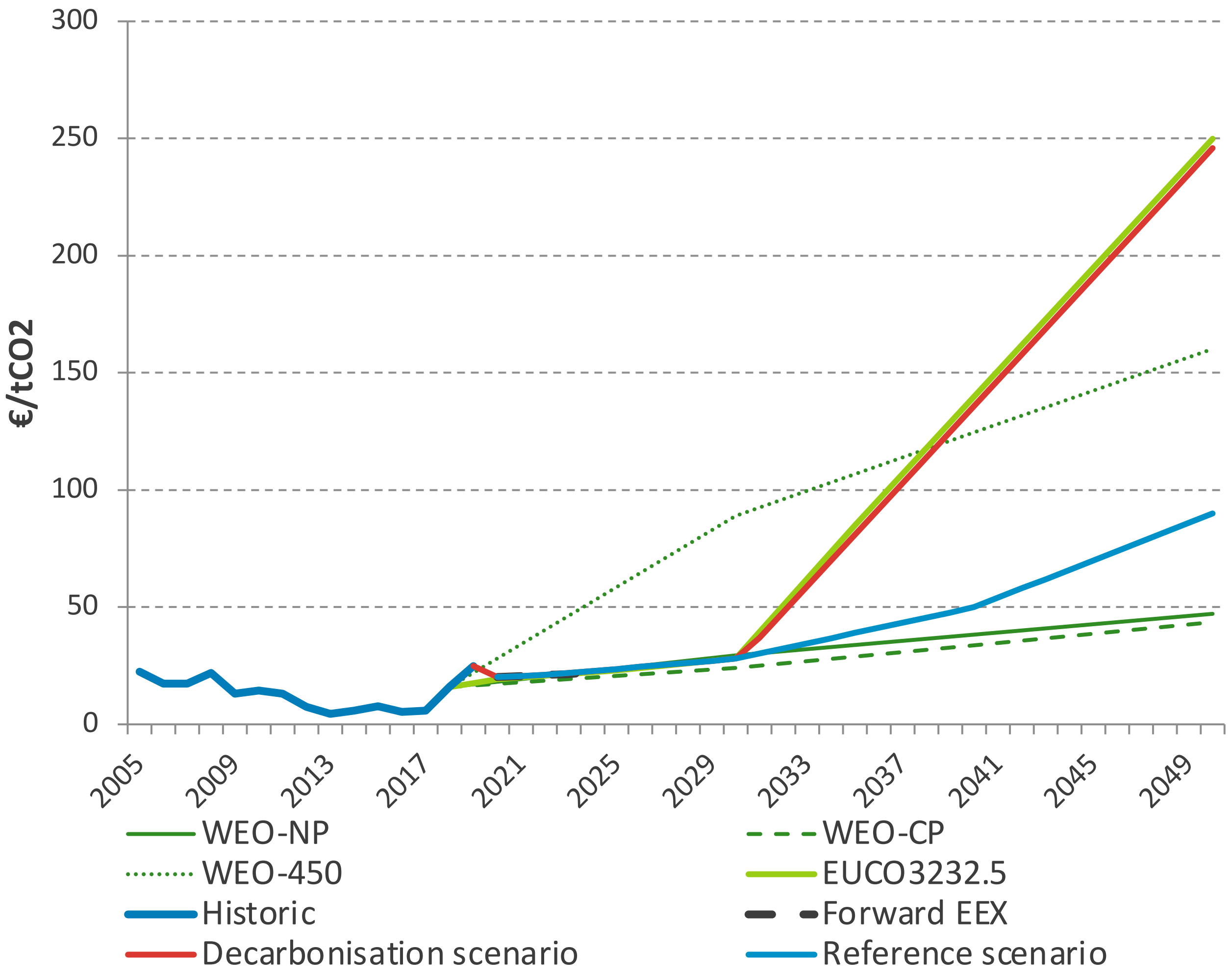
- The coal and gas price trajectories are defined based on Enerdata endogenously calculated oil, coal and gas prices
- Endogenous calculation of commodity prices lead to much lower prices than the European Commission 2016 reference scenario, thanks to further fossil fuel demand reduction in both scenarios

Commodity prices in both scenarios, €/toe



The value of CO_2 in the Decarbonisation scenario is based on the latest scenarios of the European Commission, aiming at a strong reduction of GHG emissions in 2050

Value of CO_2 in €/tCO_2

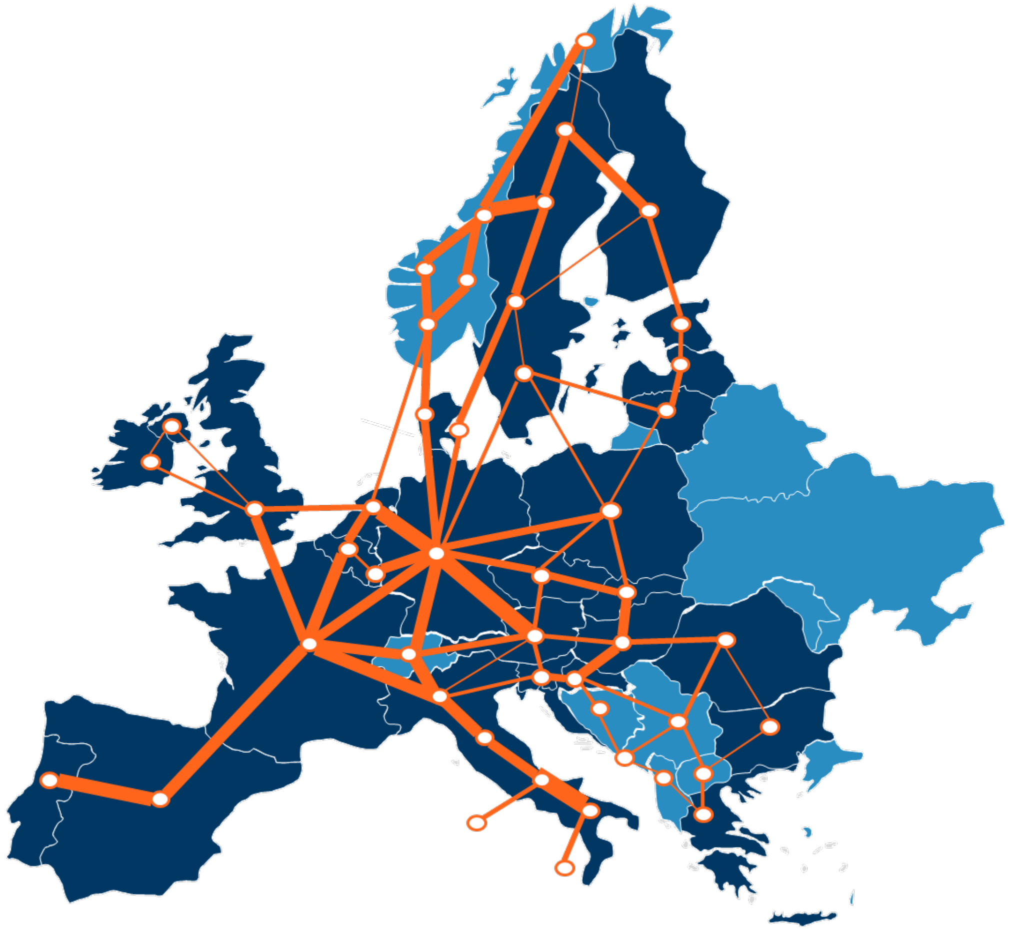


Note: The EUCO3232.5 trajectory curve was slightly shifted for graphical reasons to avoid overlapping with the Decarbonisation scenario curve. In reality, from 2030 onwards, these two curves are exactly the same.

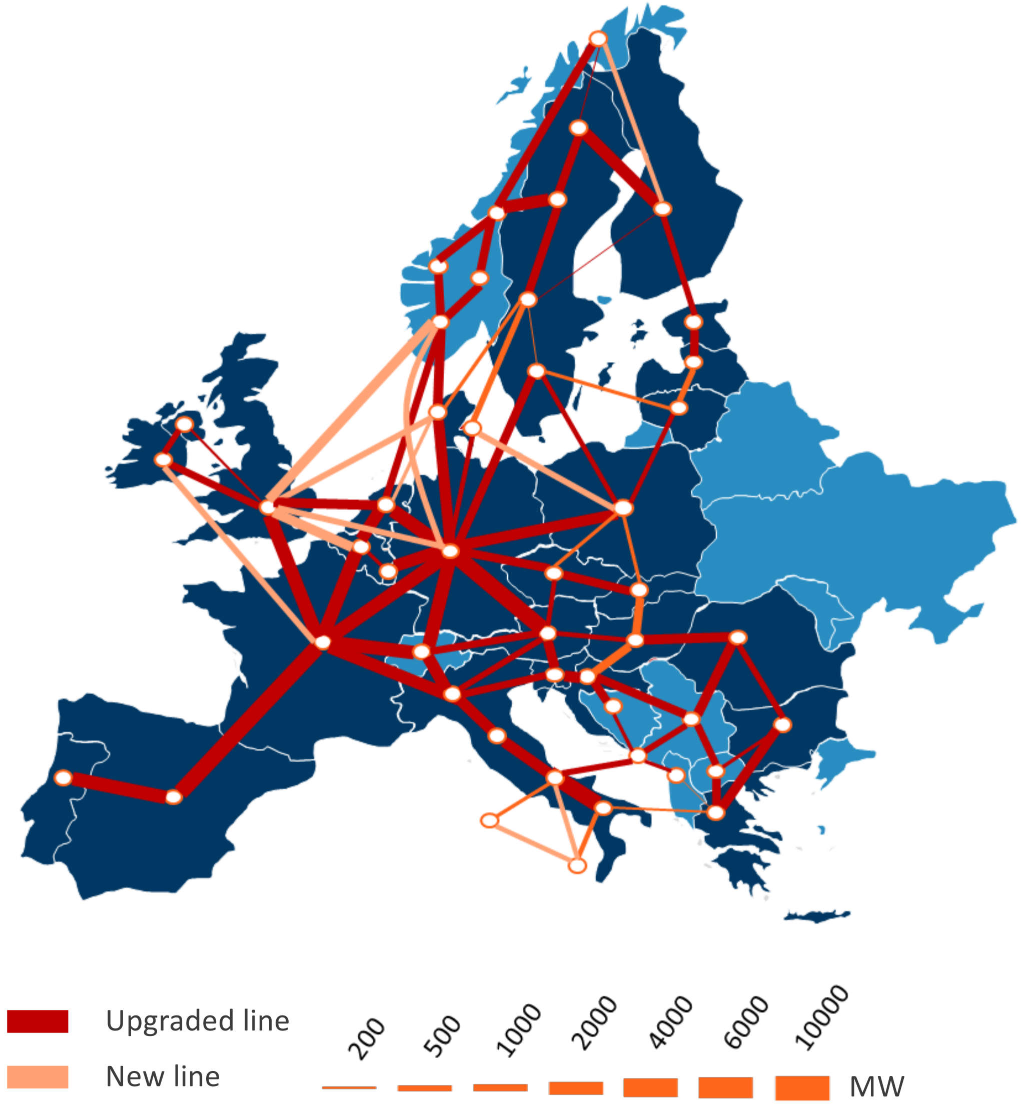
- The value of CO_2 represents the marginal abatement cost of CO_2. It both considers the explicit and implicit values of CO_2.
- Explicit CO_2 price (the EU ETS price) was historically low due to a surplus of emission allowances.
- However, recent reforms of the EU ETS market have led to an increase in this price, now around €28 per tonne (July 2020).
- Our long-term projection is based on :
  - For the reference scenario: end point of 90€/t in 2050, aligned with EC reference 2016 scenario trajectory
  - For the Decarbonisation scenario: end point of 250€/t in 2050 in line with the European Commission's EUCO3232.5 scenario
  - In both scenarios, we align the 2030 price with the higher 2030 RES target (ETS price estimated at 28€/t in 2030)
- The CO_2 value trajectory in the European Commission's EUCO3232.5 scenario reflects the implicit carbon price (e.g. marginal carbon abatement cost) of the different policies implemented to reach an ambitious decarbonisation by 2050.
- This does not necessarily imply that the EU ETS price would reach these carbon prices, but reflects the equivalent carbon price embedded in the different policies and measure implemented.

Our interconnection NTC development is based on ENTSOE TYNDP 2018 development plan featuring a doubling of NTC by 2050

Network in 2015 **NTC: 225 GW**



Network in 2050 **NTC: 439 GW**



Note: NTC stands for Net Transfer Capacity

KPIs of the two scenarios are comparable to EC baseline and 1.5 TECH scenarios and Eurelectric pathways study

Comparison for 2030

	EC 2050 Roadmap Baseline 2030	EUCO 3232.5 2030	CL Reference 2030	CL Decarbonisation 2030	Eurelectric Scenario 3 2030	ENTSOE TYNDP 2020 2030
Energy efficiency (2030)	**-32.50%**	**-32.50%**	**-32%**	**-35%**		
RES share in the power sector	**57%**	**56%**	**55%**	**60%**	**61%**	**62%**
Direct Electrification share *(excluding non-energy uses)*	**29%**	**28%**	**29%**	**31%**	**38%**	**30-32%**
Transport	*4%*		*6%*	*8%*		
Residential	*39%*		*31%*	*33%*		
Services	*64%*		*58%*	*59%*		
Industries (including non-energy uses)			*26%*	*25%*		
Industries (excluding non-energy uses)			*38%*	*37%*		

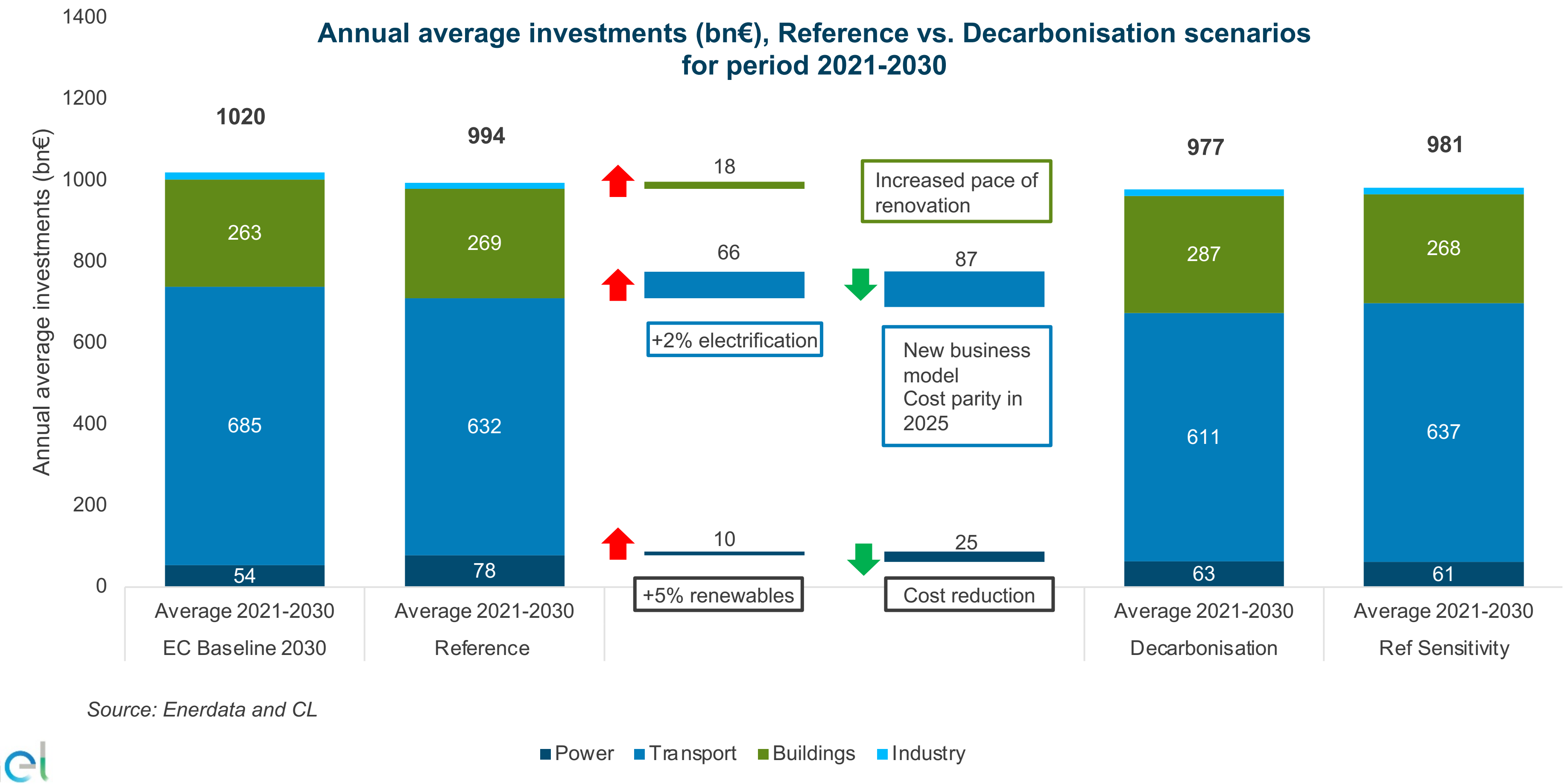
KPIs of the two scenarios are comparable to EC baseline and 1.5 TECH scenarios and Eurelectric pathways study

Comparison for 2050

	EC 2050 Roadmap Baseline 2050	CL Reference 2050	CL Decarbonisation 2050	EC 2050 Roadmap 1.5 TECH	Eurelectric Scenario 3 2050
RES share in the power sector	**73%**	**69%**	**84%**	**83%**	**81%**
Direct Electrification share *(excluding non-energy uses)*	**40%**	**40%**	**60%**	**50%**	**60%**
Transport	*11%*	*19%*	*63%*	*26%*	**63%**
Residential	*54%*	*39%*	*60%*	*64%*	**63%**
Services	*79%*	*70%*	*89%*	*80%*	
Industries (including non-energy uses)		*30%*	*41%*		
Industries (excluding non-energy uses)		*47%*	*46%*		**50%**
Indirect Electrification share *(excluding non-energy uses)*	**1%**	**1%**	**13%**	**23%**	**5%**
Transport	*2%*	*4%*	*10%*	*42%*	*4%*
Buildings					
Industries (including non-energy uses)		*0%*	*26%*		
Industries (excluding non-energy uses)		*0%*	*29%*		*10%*

Technology cost reduction enables to reach more ambitious targets by 2030 with comparable annual expenditure

- Expenditures in Decarbonisation scenario with increased ambition in 2030 are comparable to the Reference scenario and remain lower than in the EC Reference scenario thanks to :
  - Cost reduction in the transport sector limiting the impact of further electrification
  - Cost reduction in the power sector limiting the impact of further RES development
  - Expenditures increase slightly in the buildings sector due to the slightly higher renovation rate over the period



Source: Enerdata and CL

COMPASS LEXECON Enerdata enel Foundation

Total system costs remain comparable in the Decarbonisation scenario, as increases in buildings offset reduction in power and transport sectors

- Average total system costs are similar in both scenarios thanks to technology cost reduction and energy efficiency gains and fuel switching

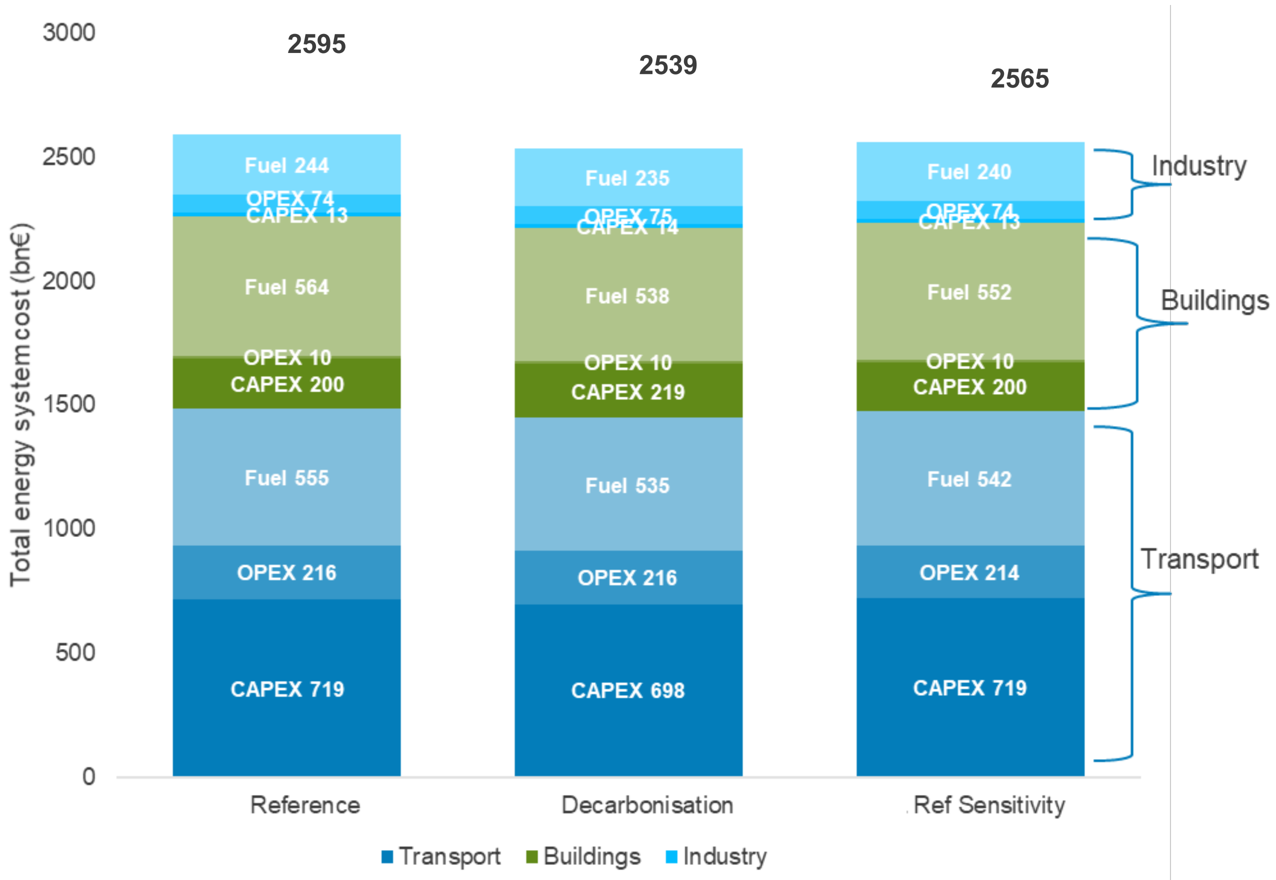
- The additional reduction in emissions achieved in the Decarbonisation scenario with comparable system costs to the Reference scenario is enabled thanks to:

Transport
- Reduction of annualised CAPEX of vehicles and infrastructure, thanks to the reduction of private vehicle fleet and reduction of EV unit cost reaching cost parity in 2025 more than offsetting the additional cost of infrastructure
- Reduction of fuel costs thanks to electrification of vehicles

Buildings
- Increase of annualised CAPEX of buildings through slightly higher renovation pace by 2030 - this increase is more than offset by the fuel opex reduction

Industry
- No material change between the two scenarios

Average total system cost (bn€) 2021-2030

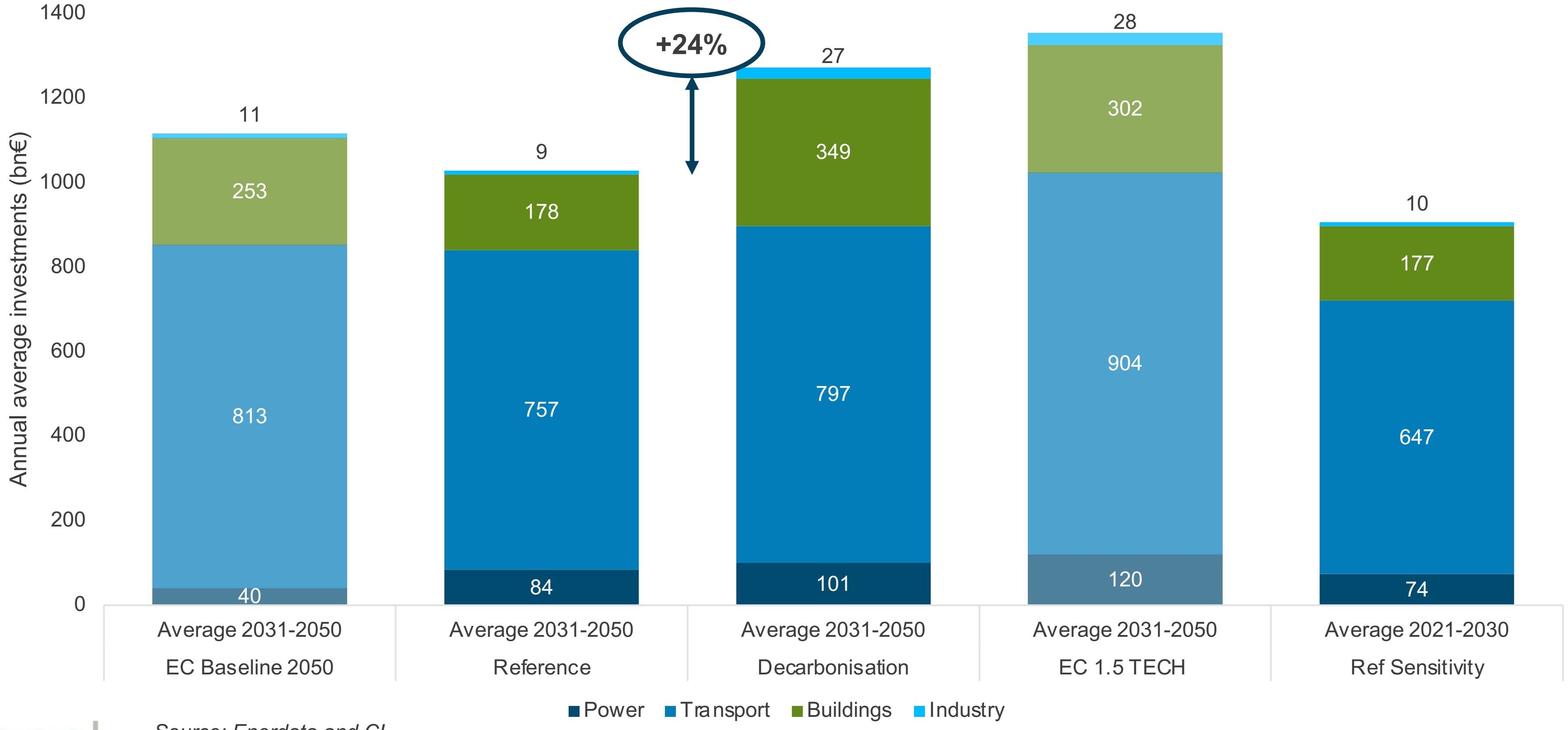


Source: Enerdata and CL

Complete decarbonisation by 2050 requires a moderate increase of investments post 2030, reduced compared to the EC previous estimates

- Further expenditures are necessary after 2030 to achieve net zero in 2050 (+24% average expenditures in the Decarbonisation scenario compared to the Reference scenario between 2031 and 2050)
  - Buildings expenditures to renovate the stock of existing dwellings (+96% increase in the Decarbonisation scenario)
  - Industrial expenditures to electrify processes and heat (expenditures multiplied by 3 in the Decarbonisation scenario)
  - In contrast, transport expenditures increase is limited (+5% in the Decarbonisation scenario) thanks to the reduction of vehicle fleet
- Annual average expenditure to reach net zero are lower than previous EC scenario estimates

Annual average investments (bn€), Reference vs. Decarbonisation scenarios for period 2031-2050

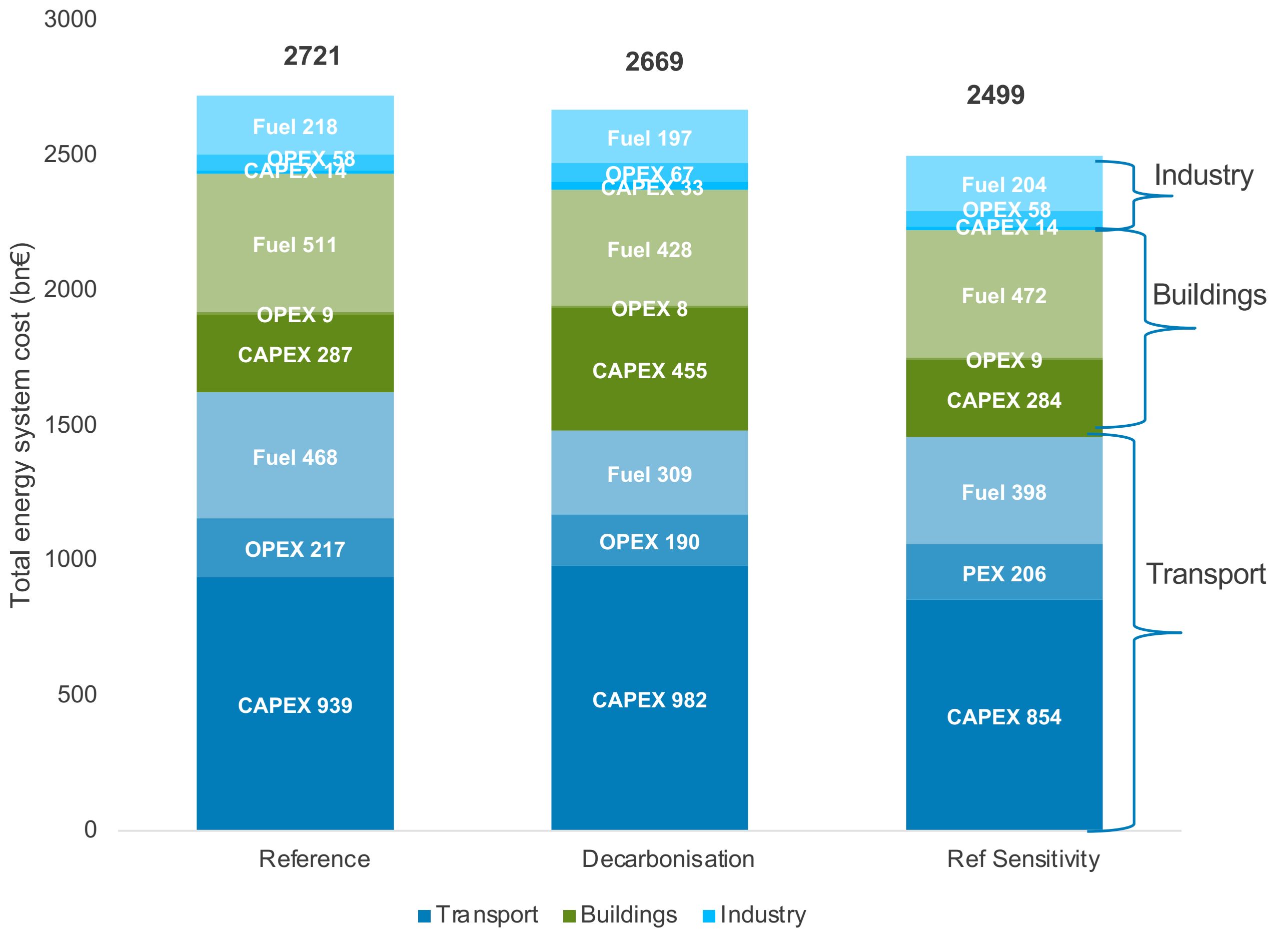


Source: Enerdata and CL

Total system costs remain comparable in the Decarbonisation scenario, as increases in buildings offset reduction in power and transport sectors

- **System energy costs increase by 5% in the Reference scenario between the 2021-2030 average and the 2031-2050 average** (compared to 10% in the previous EC Baseline scenario)
- **Despite additional investments to reach net zero emissions in 2050, the increase in system costs in the Decarbonisation scenario is similar to the Reference scenario thanks to the decrease in clean and flexible technologies costs and the increase in embedded demand-side flexibility** (+5% compared to the EC 1.5C 2050 scenarios increase of 22%)
  - The biggest growth in total energy system costs is in the buildings sector as significant investments are necessary to renovate buildings.
- This illustrates how increased ambition in 2030 would enable to reduce the necessary increase of total system cost to reach carbon neutrality in 2050.

Average total system cost (bn€) 2031-2050



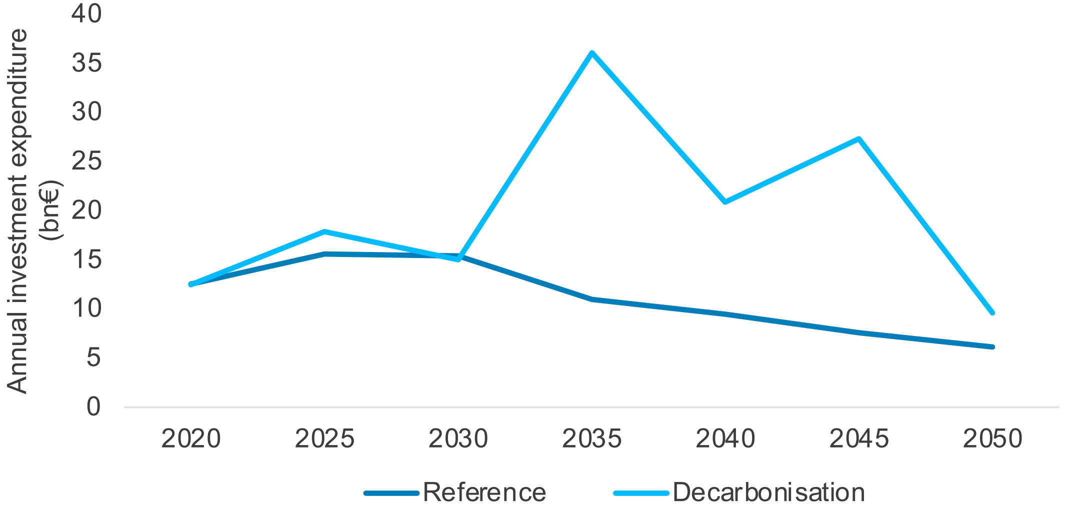
Source: Enerdata and CL

Note: Mitigated increase of system cost in Decarbonisation scenario is mainly driven by limited transport cost increase because of reduced private vehicle fleet

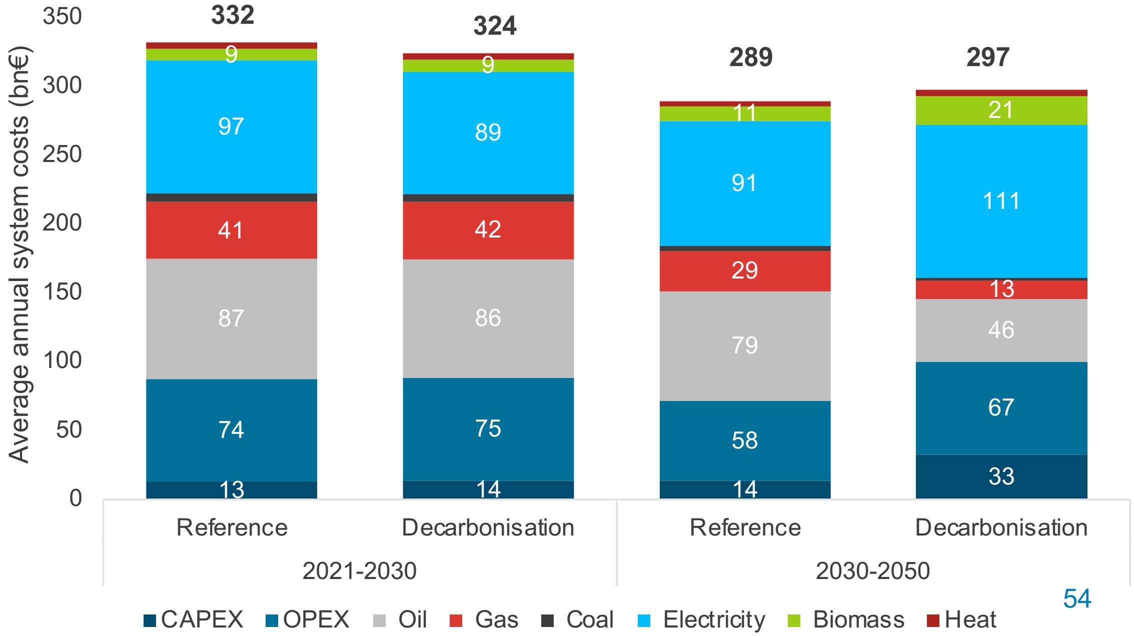
Industry system costs decrease driven by an increased energy efficiency as a result of regulation and climate targets

- **Annual investments in the industry sector significantly increase after 2030 in the Decarbonisation scenario in order to achieve deep decarbonisation in 2050:**
  - Investments in fuel switching processes to decarbonise the sector are necessary after 2030.
- **Between 2021-2030 and 2031-2050, industry system costs decrease in both the Reference and Decarbonisation scenario** (by 13% in the Reference scenario and by 8% in the Decarbonisation scenario).
- **The decrease in industry system costs is driven by an increased energy efficiency in the sector that results from the regulation and targets for energy efficiency:**
  - In the Decarbonisation scenario industry energy intensity decreases by 30% after 2030 in order to achieve deep decarbonisation in 2050 (compared to 21% in the Reference scenario)
  - Additionally, a shift from industry to services in the economy is observed in Europe, as the industry added value increases at a slower rate than the GDP rate (+0.6% over 2020-2050 vs +1.5% for the GDP growth and +1.7% for services).
- The decrease in fuel costs from fuel switching and increased energy efficiency mitigates the increase in system costs in the Decarbonisation scenario (only +3% compared to the Reference scenario).

Annual investment expenditure in the industry sector(bn€), 2020-2050



Average total system costs in the industry sector(bn€), 2021-2050



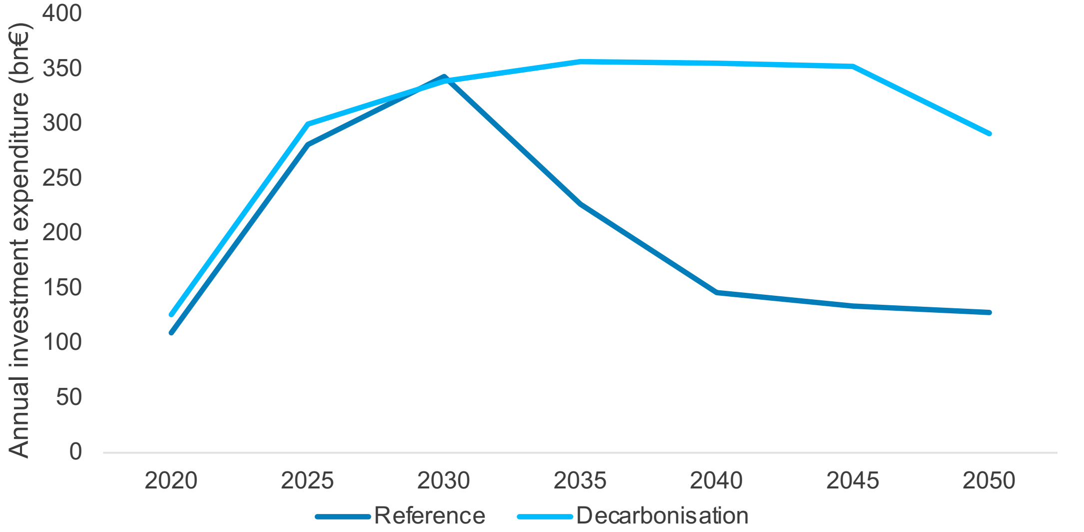
Source: Enerdata and CL

Note: Capital expenditures are accounted for in the system costs as annuity payments. A discount rate of 5% is applied for all sectors to annualise the capex.

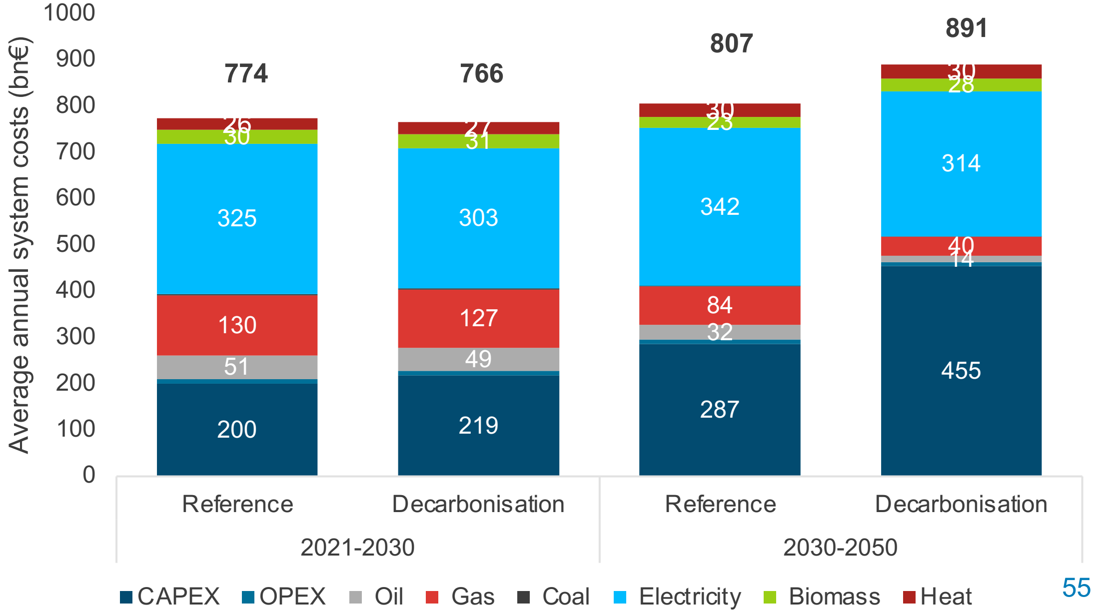
Building system costs increase as a result of the sustained pace of renovations after 2030 in order to achieve deep decarbonisation of the sector

- **Annual investments in the buildings sector are sustained after 2030 in the Decarbonisation scenario in order to achieve deep decarbonisation of the sector in 2050:**
  - The pace of renovation in the Decarbonisation and Reference scenario are similar until 2030 around 3%, but **after 2030 the renovation rate increases to 4% until 2045 in the Decarbonisation scenario** (compared to a drop to 1% in the Reference scenario).
- **Between 2021-2030 and 2031-2050, buildings system costs increase in both the Reference and Decarbonisation scenario** (by 4% in the Reference scenario and by 16% in the Decarbonisation scenario).
- **The increase in buildings system costs in the Decarbonisation scenario** compared to the Reference scenario (10% over the period 2031-2050) **is driven by the increased rate of renovations until 2045 in order to decarbonise the sector.**
- The increase in capex costs to decarbonise the buildings sector is mitigated by the reduction in fuel costs in the Decarbonisation scenario thanks to energy efficiency gains resulting from fuel switching.

Annual investment expenditure in the buildings sector(bn€), 2020-2050



Average total system costs in the buildings sector(bn€), 2021-2050



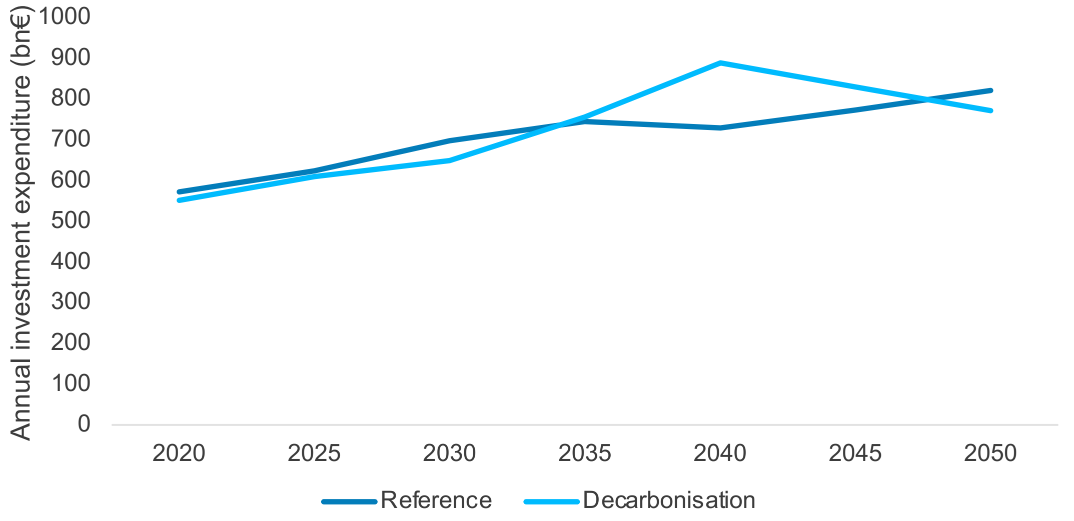
Source: Enerdata and CL

Note: Capital expenditures are accounted for in the system costs as annuity payments. A discount rate of 5% is applied for all sectors to annualise the capex.

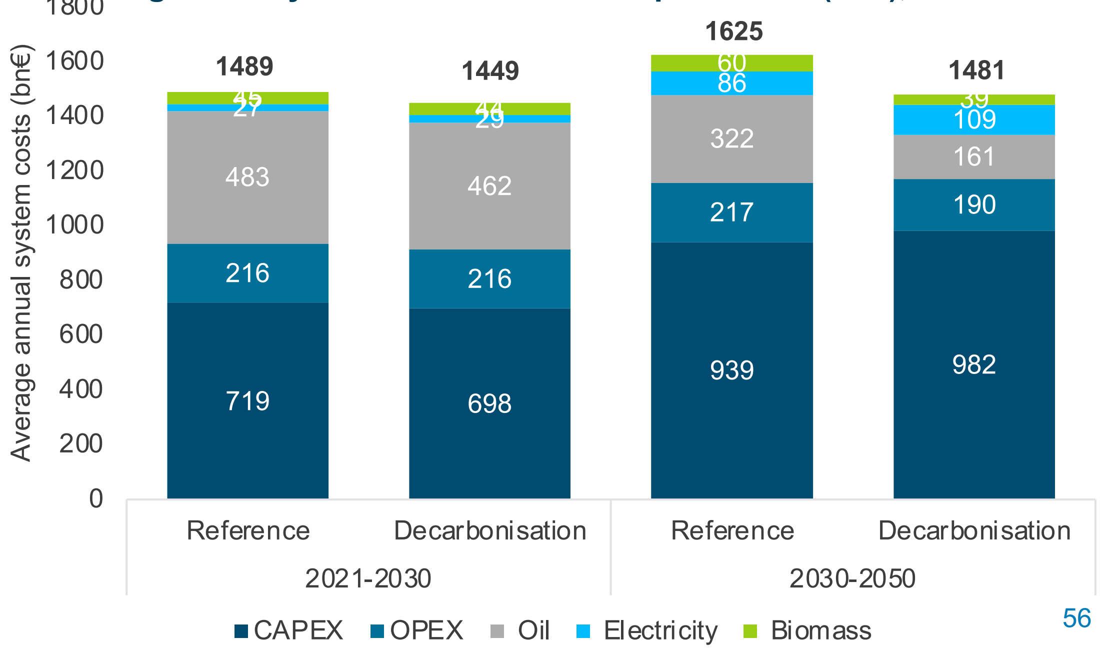
Transport system costs decrease in the Decarbonisation scenario in 2050 thanks to efficiency gains from electrification and changes in consumer behaviours

- **Annual investments in the transport sector increase in 2040 in the Decarbonisation scenario in order to achieve deep decarbonisation in 2050.**
  - Investments in the transport sector in the Decarbonisation scenario are comparable to the Reference scenario thanks to changes in consumer behaviours whereby passenger km and car ownership decrease resulting in increased utilisation rate of vehicles.
- **Between 2021-2030 and 2031-2050, transport system costs increase in both the Reference and Decarbonisation scenario** (by 9% in the Reference scenario and by 2% in the Decarbonisation scenario).
- **Between 2021-2030, transport system costs decrease by 3% in the Decarbonisation scenario compared to the Reference scenario:**
  - Capex costs decrease as a result of the decrease in passenger fleet due to the changes in consumer behaviours
  - Increased penetration of EVs lead to small costs savings
- **The transport system costs between 2031-2050 decrease by 9% in the Decarbonisation scenario compared to the Reference scenario:**
  - As a result of the electrification of the fleet with EVs representing more than 80% of new private vehicles after 2030, efficiency gains in the Decarbonisation scenario lead to reduced fuel costs compared to the Reference scenario.

Annual investment expenditure in the transport sector(bn€), 2020-2050



Average total system costs in the transport sector(bn€), 2021-2050



Source: Enerdata and CL

Note: Capital expenditures are accounted for in the system costs as annuity payments. A discount rate of 5% is applied for all sectors to annualise the capex.

DETAILED RESULTS – ENERGY CONSUMPTION BY SECTOR

Consumption by sector (Mtoe), Reference scenario, EU-28 (non-energy uses excluded)

	2015	2020	2025	2030	2035	2040	2045	2050
Final energy consumption (Mtoe)	**1035**	**1068**	**1010**	**921**	**859**	**826**	**807**	**788**
Residential, of which	**277**	**283**	**274**	**250**	**232**	**222**	**214**	**207**
Conventional oil products	34	32	27	22	19	17	16	15
Gas	100	107	101	84	72	65	59	53
Coal	9	8	5	3	1	0	0	0
Electricity	68	71	74	77	79	80	80	81
Bioenergies	42	41	40	36	32	30	28	26
Heat	23	24	26	28	29	30	30	31
Services, of which	**148**	**153**	**149**	**139**	**132**	**130**	**128**	**126**
Conventional oil products	16	15	12	9	8	7	6	6
Gas	46	48	43	33	26	23	20	18
Coal	1	1	1	0	0	0	0	0
Electricity	71	74	78	81	84	86	88	88
Bioenergies	5	4	4	4	3	3	2	2
Heat	10	11	10	11	11	11	12	12
Transport, of which	**312**	**326**	**301**	**278**	**258**	**248**	**244**	**239**
Transport, by energy								
Conventional oil products	291	295	262	230	197	176	159	132
Bioenergies	14	24	29	32	34	37	42	50
Electricity	6	7	10	16	26	34	39	46
Hydrogen	0	0	0	0	0	1	4	10
Transport, by mode								
Road	294	307	283	260	240	230	227	222
Rail	7	7	8	8	8	8	8	8
Air (domestic)	6	7	6	5	5	6	6	6
Other (maritime domestic)	5	4	4	4	4	4	3	3
Industry	**273**	**279**	**258**	**227**	**209**	**199**	**193**	**189**
Industry, by energy								
Conventional oil products	26	26	21	16	12	9	6	5
Gas	78	83	76	60	52	49	46	44
Coal	43	41	33	24	19	16	14	13
Electricity (including direct and indirect uses)	86	89	89	86	85	86	87	88
Bioenergies	24	25	26	28	28	29	29	31
Heat	15	15	14	13	12	11	10	8
Industry, by sector								
Steel	49	47	35	25	18	14	11	9
Non-metallic minerals	34	34	32	28	26	24	24	23
Chemistry	51	52	50	45	43	42	41	41
Other industry	139	145	140	129	122	119	117	117
Agriculture	**25**	**27**	**27**	**28**	**27**	**28**	**28**	**28**
Fossil energies	18	20	19	16	14	14	13	14
Electricity	5	5	6	8	9	9	9	9
Bioenergies	2	2	2	4	5	5	5	5

Consumption by sector (Mtoe), Decarbonisation scenario, EU-28 (non-energy uses excluded)

	2015	2020	2025	2030	2035	2040	2045	2050
Final energy consumption (Mtoe)	**1035**	**1071**	**1000**	**894**	**809**	**730**	**669**	**613**
Residential, of which	277	283	271	246	221	196	169	147
Conventional oil products	34	32	27	20	13	7	3	1
Gas	100	107	100	80	53	29	14	7
Coal	9	8	3	1	1	0	0	0
Electricity	68	71	76	80	91	97	93	88
Bioenergies	42	41	39	35	35	35	31	23
Heat	23	24	26	29	29	29	28	28
Services, of which	**148**	**153**	**148**	**138**	**129**	**121**	**112**	**103**
Conventional oil products	16	14	12	8	5	2	1	1
Gas	46	48	42	31	17	8	3	1
Coal	1	1	0	0	0	0	0	0
Electricity	71	74	79	82	90	95	94	92
Bioenergies	5	4	5	5	5	5	3	0
Heat	10	10	10	11	11	11	11	10
Transport, of which	**312**	**327**	**294**	**256**	**214**	**166**	**128**	**107**
Transport, by energy								
Conventional oil products	291	296	254	204	140	81	39	18
Bioenergies	14	24	29	30	37	28	17	11
Electricity	6	7	11	21	37	54	66	68
Hydrogen	0	0	0	0	0	2	6	11
Transport, by mode								
Road	294	308	277	240	200	155	119	99
Rail	7	7	8	8	7	6	6	5
Air (domestic)	6	7	5	5	5	4	3	2
Other (maritime domestic)	5	4	4	3	2	0	0	0
Industry	**273**	**281**	**259**	**228**	**219**	**223**	**237**	**234**
Industry, by energy								
Conventional oil products	26	27	21	16	9	4	2	1
Gas	78	84	79	63	37	17	7	3
Coal	43	41	30	21	12	6	2	1
Electricity (including direct and indirect uses)	86	89	88	85	98	128	163	177
Bioenergies	24	25	28	30	50	56	51	43
Heat	15	15	14	14	13	12	11	10
Industry, by sector								
Steel	49	48	35	25	18	13	10	8
Non-metallic minerals	34	35	32	28	25	22	20	17
Chemistry	51	53	50	45	43	42	42	40
Other industry	139	146	142	130	133	146	166	169
Agriculture	**25**	**27**	**27**	**26**	**25**	**24**	**23**	**22**
Fossil energies	18	19	16	13	10	8	5	4
Electricity	5	6	7	8	9	10	10	11
Bioenergies	2	2	4	5	6	6	7	8

DETAILED RESULTS – POWER CAPACITY AND GENERATION

Power generation (TWh) and capacity (GW), Reference scenario, EU-28

	2020	2025	2030	2035	2040	2045	2050
Electricity production (TWh)	**3095**	**3247**	**3444**	**3637**	**3869**	**4044**	**4208**
Coal and lignite	583	570	451	303	198	80	38
Gas	305	261	136	167	206	273	332
Conventional oil products and other non-RES	241	222	215	201	196	185	179
Bioenergies and waste	129	120	182	167	162	153	148
Nuclear	816	756	728	800	766	760	713
Hydroelectricity	372	385	399	405	402	404	402
Geothermal energy	8	10	10	10	11	13	14
Wind	480	658	904	1103	1295	1451	1581
Solar	160	260	411	469	553	605	648
Batteries	1	4	8	12	80	112	143
Power-to-gas-to-power	0	0	0	0	0	8	8
DSR	0	0	0	0	0	0	0
Electric capacity (GW)	**1056**	**1178**	**1407**	**1495**	**1637**	**1743**	**1861**
Coal and lignite	142	115	105	79	62	53	51
Gas	171	178	178	162	137	130	148
Conventional oil products and other non-RES	75	67	64	60	57	55	53
Bioenergies and waste	27	27	41	41	41	40	40
Nuclear	117	109	106	119	116	117	111
Hydroelectricity	155	156	166	166	166	166	166
Geothermal energy	1	1	2	2	2	2	2
Wind	208	279	374	459	530	586	631
Solar	137	220	344	376	438	476	509
Batteries	1	3	5	9	67	94	124
Power-to-gas-to-power	0	0	0	0	0	3	3
DSR	21	21	21	21	21	21	21

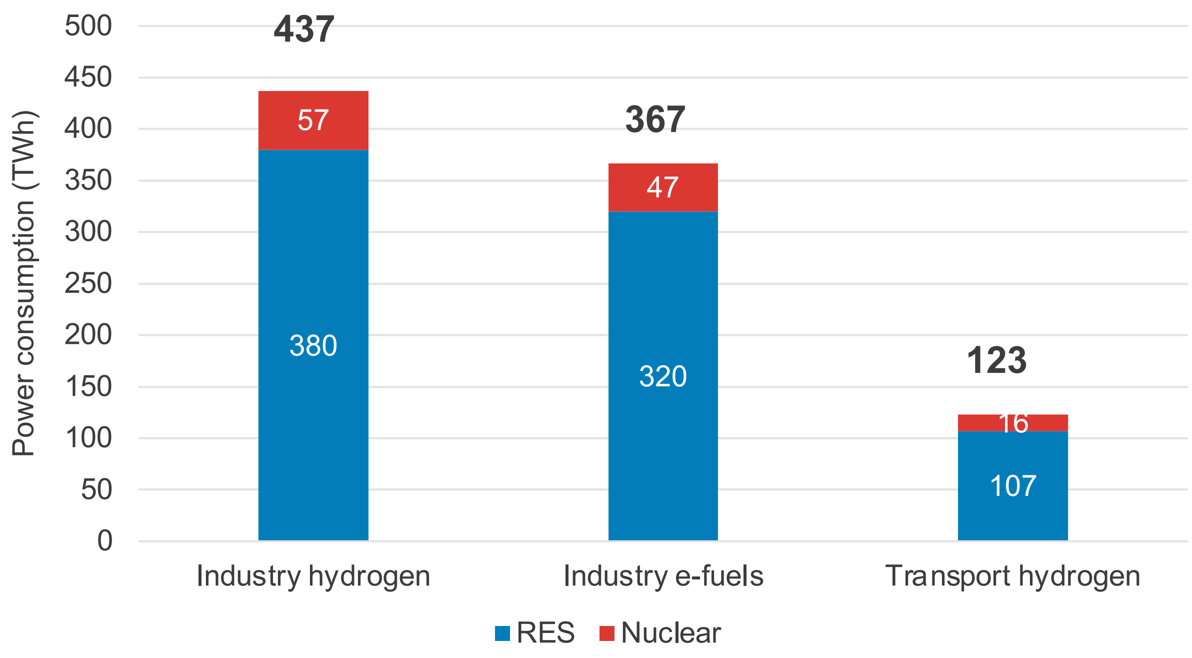
Power generation (TWh) and capacity (GW), Decarbonisation scenario, EU-28

	2020	2025	2030	2035	2040	2045	2050
Electricity production (TWh)	**3153**	**3340**	**3553**	**4238**	**4934**	**5741**	**6087**
Coal and lignite	576	514	283	36	5	4	1
Gas	367	364	182	212	176	39	8
Conventional oil products and other non-RES	242	226	210	196	193	200	185
Bioenergies and waste	130	122	176	160	155	160	150
Nuclear	818	760	720	786	759	769	715
Hydroelectricity	372	383	399	405	404	405	404
Geothermal energy	8	10	10	11	15	17	14
Wind	480	684	1058	1606	2044	2542	2874
Solar	160	273	479	705	942	1199	1307
Batteries	1	5	38	79	166	252	247
Power-to-gas-to-power	0	0	0	41	75	154	182
DSR	0	0	0	0	0.4	1.4	0
Electric capacity (GW)	**1040**	**1177**	**1465**	**1863**	**2248**	**2654**	**2894**
Coal and lignite	126	89	56	30	17	16	11
Gas	171	203	190	157	112	19	8
Conventional oil products and other non-RES	75	67	64	60	57	55	53
Bioenergies and waste	27	27	41	41	41	40	40
Nuclear	117	109	106	119	116	117	111
Hydroelectricity	155	156	166	166	166	166	166
Geothermal energy	1	1	2	2	2	2	2
Wind	208	279	409	607	775	951	1087
Solar	137	220	369	534	698	878	961
Batteries	1	4	33	77	167	257	271
Power-to-gas-to-power	0	0	0	34	55	103	126
DSR	21	21	28	35	42	50	57

Hydrogen (and e-fuels) energy carriers would be used in hard-to-electrify uses in the Decarbonisation scenario

- Hydrogen as well as e-fuels are used in **hard-to-electrify applications** in the Decarbonisation scenario:
  - Industry as feedstock
  - Transport long distance
  - Long-term storage for power sector
- Indirect electrification (green hydrogen and e-fuels) represents 13% in the Decarbonisation scenario (vs 1% in the Reference scenario) in 2050:
  - Transport: 10% hydrogen
  - Industry: 16% hydrogen and 13% e-fuels (excluding non-energy uses)
- **The production of green hydrogen and e-fuels is modelled to come at 87% from RES and 13% from nuclear.**

Power consumption for hydrogen and e-fuels in 2050 (TWh), Decarbonisation scenario

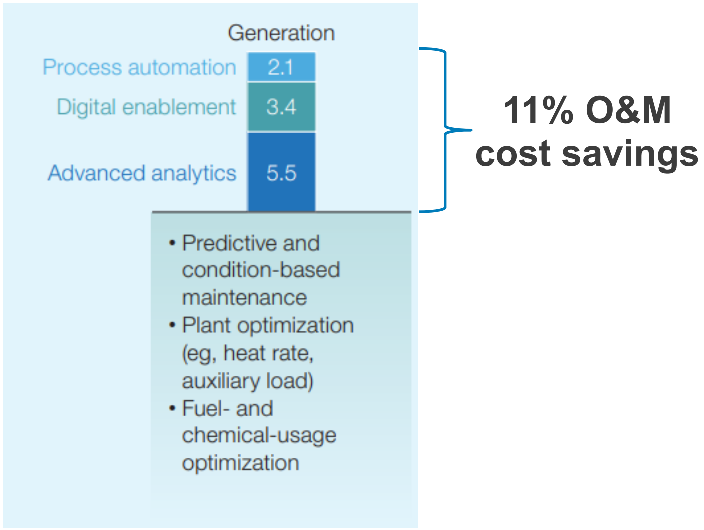


Through improved performance and system costs savings, digitalisation can contribute to further decarbonisation

The benefits of digitalisation of power plants are wide ranging and include:

- **Enables further decentralisation** via distributed energy resources
- **Improves productivity** thanks to enhanced forecasting which enables adaptative behaviours of physical assets. IRENA (2019) references an example of a GE wind turbine's output in Japan enhanced by 5% thanks to AI.
- **Decreases O&M costs (by about 11% according to McKinsey 2018) through e.g.**
  - Predictive maintenance allows the minimization of plant maintenance shutdowns leading to operating costs savings in some cases up to 50%.
  - Automation of processes, remote control of assets
  - Data analytics make possible to identify non-optimal performance and engage into corrective operations resulting in maintenance and lost production savings. .
- **Decreases energy system cost** through enhanced forecasting enables to better estimate energy output, but also transmission capacity (which depend on meteorological conditions)
- **Extend assets lifetime,** as tailormade operations and maintenance plans result in longer lifetime of physical assets

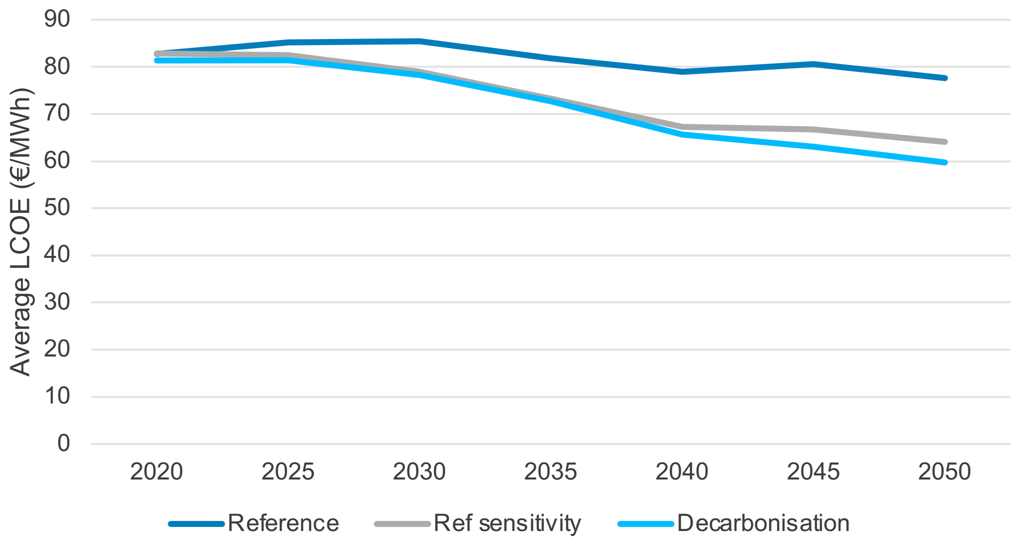
Operations and maintenance cost saving for power generation (%)



Source : McKinsey analysis

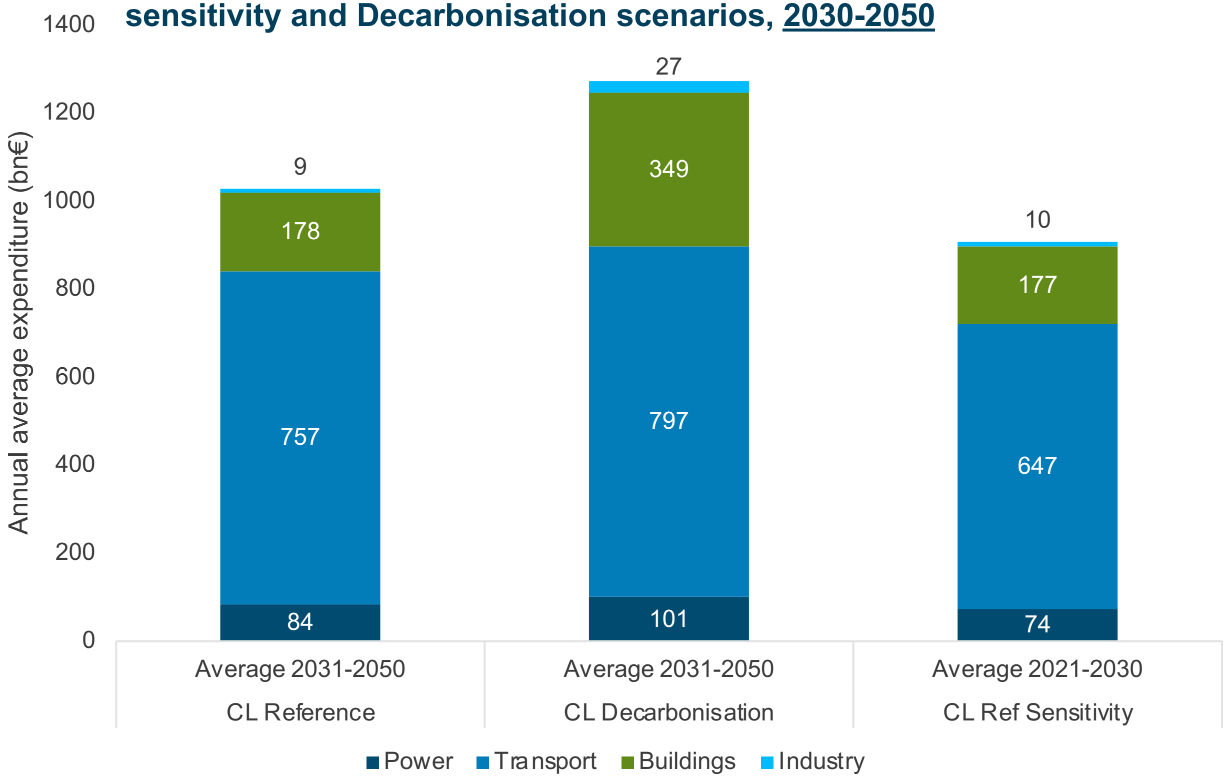
System costs in 2050 in the sensitivity analysis of the Reference scenario are the lowest thanks to decreased power sector costs feeding into sector's fuel costs, and decreased transport costs

Average LCOE in the power sector (€/MWh), Reference vs Reference sensitivity and Decarbonisation scenarios, 2020-2050



- Thanks to the decrease in RES technology costs (wind and solar) and flexibility technology costs, **the average LCOE in the Reference sensitivity is 17% lower** than in the Reference scenario in 2050. Increased capacity factor in the Decarbonisation scenario explains the further decrease in LCOE.

Average annual investments (bn€) in Reference, Reference sensitivity and Decarbonisation scenarios, 2030-2050

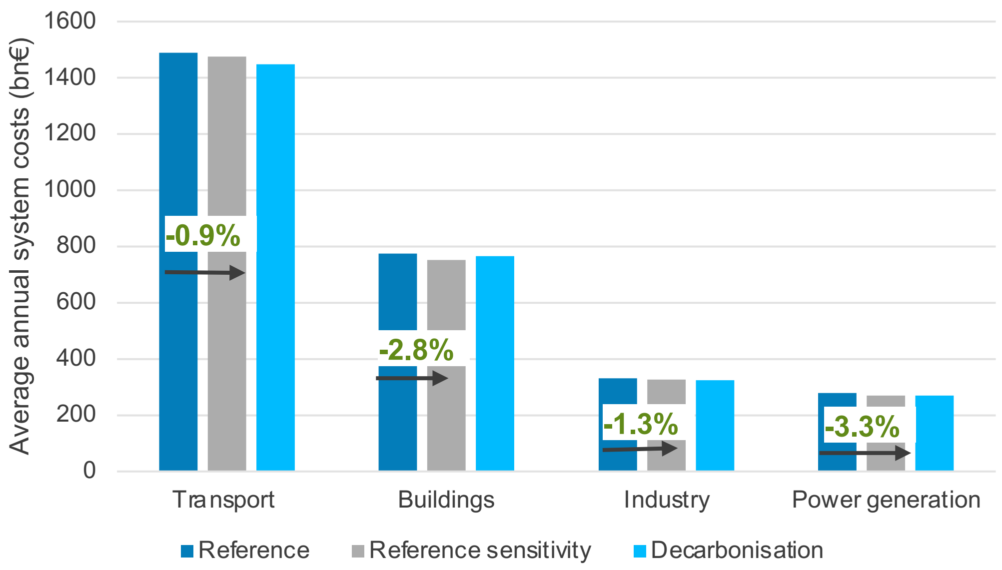


- **Average annual investments over the period 2030 and 2050 decrease by 12% in the Decarbonisation scenario** compared to the Reference scenario as investments in the transport and power sector decrease thanks to the reduction in RES and battery costs. Investments in the buildings and industry sectors are similar given the climate ambitions remain the same as well as the costs.

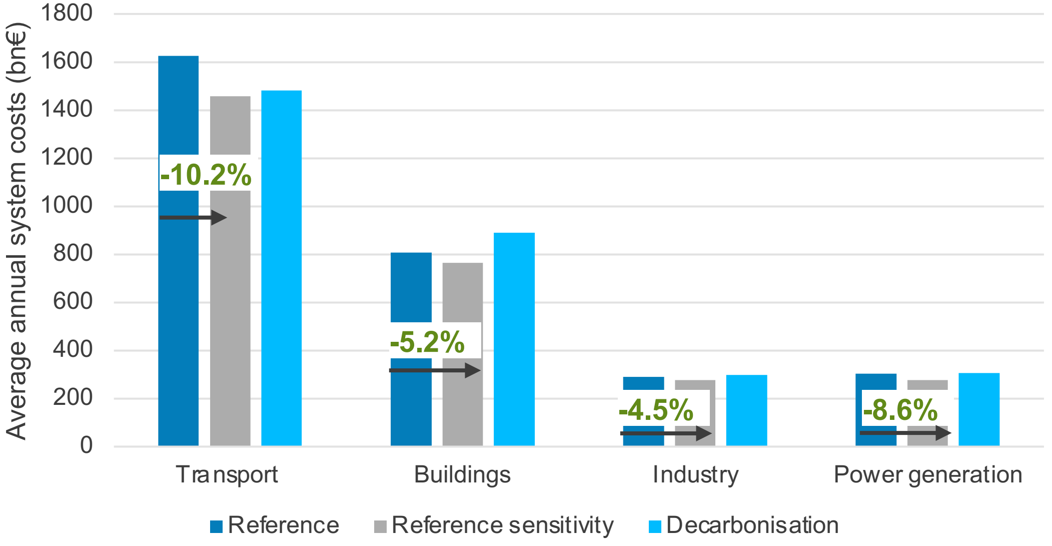
Transport and power system costs are lower in the sensitivity analysis thanks to reduced technology costs while buildings and industry benefit from reduced electricity costs

- By construction, system costs for all sectors are lower in the sensitivity analysis of the Reference scenario than in the Reference scenario over the period 2021-2050.
- Between 2031 and 2050, the decrease is the highest in the transport and power sectors (respectively 10.2% and 8.6%) as the sensitivity analysis assumes lower RES and batteries costs than in the Reference scenario. Buildings and industry system costs also see a decrease thanks the reduced electricity costs that will feed into the fuel costs of those sectors.

Annual total system costs and power generation costs, Reference vs. Reference Sensitivity and Decarbonisation scenarios, 2021-2030



Annual total system costs and power generation costs, Reference vs. Decarbonisation scenarios, 2031-2050



- Annual total energy system cost include industry, buildings and transport costs
- Industry, buildings, and transport system costs include energy capex, opex and fuel costs (including network costs)
- Power generation costs include generation capex, opex and fuel costs

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Contact: Fabien Roques
Executive Vice President
Compass Lexecon
+33 (0) 1 53 06 35 29
FRoques@compasslexecon.com

Contact: Sylvain Cail
Head of Global Energy Forecasting
Enerdata
Sylvain.cail@enerdata.net

Contact: Giuseppe Montesano
Deputy Director
Enel Foundation
Giuseppe.Montesano@enel.com