PARIS AGREEMENT COMPATIBLE SCENARIOS (PAC) 2.0

EXECUTIVE SUMMARY

September 2024

Table of Contents

September 2024

AUTHOR DETAILS

Dimitris Tsekeris — Energy Scenarios Project Manager, CAN Europe

Joni Karjalainen — Energy Transition Analyst, CAN Europe

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

ABOUT

Climate Action Network (CAN) Europe participates in the Paris Agreement Compatible (PAC) 2.0 project, as a member of a wider consortium consisting of EEB, RGI and REN21 as project partners, to construct a European-wide energy scenario aligned with the objective to limit global warming to 1.5°C.

Embodying the policy demands of civil society, this bottom-up scenario-building addresses the EU27, as a whole, and individual EU27 member states, built together with national experts and member organisations.

This project was financed by the German Federal Ministry for Economic Affairs and Climate Action with two rounds of grants realised in the timeframe of: 2018–2020 and 2021–2024.

INTRODUCTION

We are in a climate emergency. Our world is warming at an alarming rate. The disastrous impacts of climate change are impacting many vulnerable countries and communities around the world, many of which have contributed much less or negligibly to causing climate change. And now it is at Europe's doorstep. The recent IPCC synthesis report of the Sixth Assessment Report underlines that with incremental global warming, the risk of irreversible damage and coming close to or even crossing systemic tipping points increases accordingly.

Achieving the Paris Agreement's objective to limit temperature rise to 1.5°C is crucial and civil society's Paris Agreement Compatible (PAC) energy scenario shows a concrete pathway how this can be achieved. It will require a very rapid transition to a 100% renewable energy system, a fast phase-out of the use of fossil fuels and a significant reduction of demand for energy and materials.

1. Reduce energy consumption to enable faster decarbonization and electrification
2. Switch to a 100% Renewable Energy System
3. Develop a Paris Agreement compatible power grid
4. Harness the potential of flexibility - A more flexible system brings more benefits
5. Scale up energy storage
6. Frontload investments to align with Paris Agreement

The report first provides an emissions pathway until 2040, with implications for the remaining greenhouse gas budget for EU27, using climate and energy data. Then, co-benefits and avoided losses articulate why the energy transition also makes economic sense. Key sectoral transformations in power, buildings, industry and transport sectors are described through objectives and enablers. What makes PAC particularly unique, is its granularity, as it provides detailed pathways for each of the 27 Member States and the EU27 as aggregated results. Access to the Technical Summary and national data.

In addition to this report, which describes the mid to long transformative changes that are needed to align our energy sector with the Paris Agreement objectives, CAN Europe has also issued concrete policy recommendations for the 2024–2029 EU policy cycle to make this transition a reality.

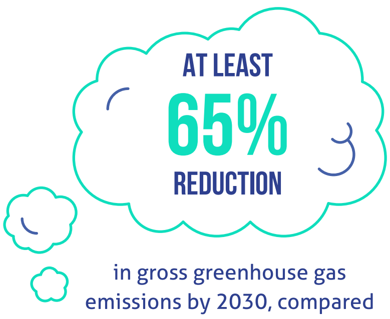
THE PARIS AGREEMENT COMPATIBLE (PAC) 2.0 SCENARIO

At its core, the Paris Agreement Compatible (PAC) scenario aims to construct a European-wide energy scenario aligned with the Paris Agreement's objective, embodying civil society demands. In its second phase (from here onwards: "PAC 2.0"), the work advances onto the national level through also examining each EU27 Member State's pathway. This will help identify the necessary conditions that must be established in order to achieve an ambitious, rapid decarbonisation of the energy system and achieve climate neutrality by 2040 in the EU.

Developed by civil society, the scenario investigates a plausible technical, political and societal framework, and its energy and climate aspects, to guide the EU's energy sector towards climate neutrality while limiting global heating to 1.5°C. It also aims to ensure that we are planning and building the infrastructure necessary for a future fossil-free, 100% renewables-based energy system as economically as possible.

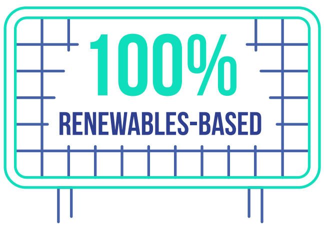
As a bottom-up, civil society led energy scenario that aims for net-zero emissions by 2040, the Paris Agreement Compatible scenario offers a scientifically-backed pathway to transform the energy system and its different demand and supply sectors. The second edition of PAC facilitates further discussion on reaching the 1.5°C Paris Agreement target between stakeholders across sectors who otherwise would not necessarily interact.

To reach the necessary scale of action, the PAC 2.0 scenario is guided by three major goals:



in gross greenhouse gas emissions by 2030, compared to the 1990 levels

greenhouse gas emissions by 2040



energy system in Europe by 2040 in all sectors

CLIMATE NEUTRALITY IN 2040

The PAC approach to Europe's transformation

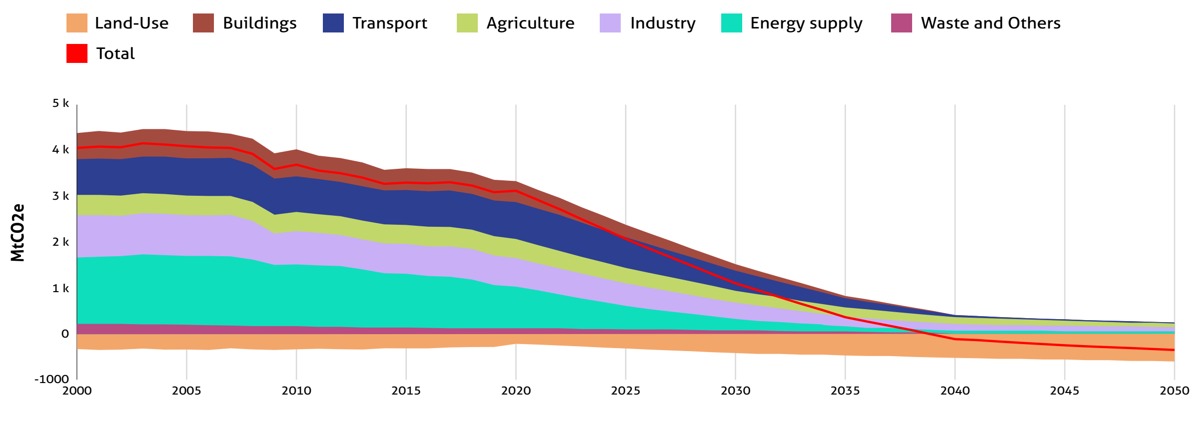
A fast achievement of climate neutrality would make a substantial contribution and help to validate the EU's claims as a climate leader. It is equally important to bear in mind discussions on Europe's fair and ambitious share of the global GHG budget, while also increasing the continent's resilience against the impacts of the climate crisis, to protect its people and future infrastructure from various risks.

EMISSIONS TRAJECTORY: GREENHOUSE GASES ARE BULLDOZED

The key element of the PAC 2.0 is achieving climate neutrality by 2040, on an EU27 level. In attaining this goal, this does not necessarily mean that all Member States can achieve climate neutrality at the same time (i.e. in 2040), taking into account different starting points and national contexts, under a common vision that requires collective effort. A common vision for Europe must be based on solidarity to tackle the huge challenge of the climate crisis and its impacts and acceptance from citizens.

The emission trajectory of the PAC 2.0 for the EU27 until 2040 visualises total emissions reductions, represented by the red line across all sectors in Figure 1, expressed in million tonnes of CO2 equivalent (MtCO2e). These emissions are disaggregated across all emitting sectors, namely buildings, transport, agriculture, industry, energy supply, and waste and others, shown in different colours. At the bottom, the light orange area marks the amount of emissions that land-use, or LULUCF should cover, perceived as negative emissions.

Figure 1: *PAC 2.0 emissions trajectory — EU27*



Source: *Pathways Explorer*

As can be seen in Figure 1, the PAC 2.0 total net emissions trajectory for the EU27 becomes negative just before 2040. Both net and gross emissions are compared with 1990 emissions based on European Environment Agency (EEA) data (Table 1 below).

Table 1: *Analysis of the EU27 — PAC 2.0 emission trajectory (MtCO2e), with European Environment Agency data*

Year	1990 (EEA)	2020	2025	2030	2035	2040
PAC 2.0 trajectory (excl. LULUCF and excl. international transport)	**4,867**	3,324	2,386	1,525	833	**419**
% of reduction (as of 1990)		-32	-51	-69	-83	**-91**
International transport (Mt) — PAC 2.0		280	256	232	66	**0**
PAC 2.0 trajectory (excl. LULUCF and incl. international transport) — GROSS (Mt)	**5,024**	3,604	2,642	1,758	900	**419**
% of reduction (as of 1990)		-28	-47	-65	-82	**-92**
LULUCF (Mt) — PAC		-207	-313	-419	-460	**-519**
PAC 2.0 trajectory (incl. LULUCF and incl. international transport) — NET (Mt)	**4,807**	3,398	2,329	1.339	440	**-100**
% of reduction (as of 1990)		-29	-52	-72	-91	**-102**

Source: *EEA GHG data, CAN Europe analysis*

Compared to *gross emissions reductions*, in calculating *net emissions* reductions LULUCF is included. From the reference year 1990, as a starting point, using EEA data, our pathway suggests:

- -65% reduction in gross emissions, and -72% net emissions reductions by 2030;
- -82% reduction in gross emissions, and -91% net emission reductions by 2035;
- -92% reduction in gross emissions, and -102% net emission reductions by 2040.

In other words, in PAC 2.0 scenario, climate neutrality is achieved slightly before 2040, as shown by the red line crossing the zero mark (Figure 1). When net reductions are below this mark, the EU27 enters the net negative emissions zone. Accordingly, the PAC 2.0 scenario is at -102% in 2040 (net emission reductions).

Linking to the previous subsection on climate risks, the above table also shows the critical role of LULUCF for climate neutrality by 2040. Based on the PAC 2.0 figures, the EU27 can reach -100Mt CO2eq in total net emissions by 2040, provided that carbon removals are increased at least 2.5 times during this and the next decade, achieving approximately 420Mt of carbon removals. Lastly, this should in no case be perceived as a call for lowered ambition, as the target of 600Mt of carbon removals by 2030 should be the main one, supported by an accelerated energy transformation, as the PAC indicates. That would also lead to higher net emission reductions, reaching at least 76% net emission reductions compared to 1990 levels, as CAN Europe suggests.

EU27 GHG budget: The earlier, the better

REACH CLIMATE NEUTRALITY EARLY TO REMAIN WITHIN THE 1.5°C

To limit global temperature rise to 1.5°C, the EU27 should limit its domestic net cumulative amount of emissions in the period 2020–2050 as much as possible, to a maximum net GHG emissions of 27.5GtCO_2[1]. The PAC 2.0 pathway manages to keep the EU within this GHG budget, with total emissions over 2020–2050 period shown in Table 2. As domestic efforts are not sufficient to fulfil the EU's fair share of any remaining global budget taking into account historical responsibility and capacity to act, it will be necessary for the EU to deliver significant additional support to enable mitigation and wider climate action efforts in Global South countries.

Table 2: *PAC 2.0 GHG budget over 2020–2050*

Time period	2020–2050	2020–2030	2031–2050
Total GROSS emissions (Gt)	41.2	21.9	12.4
Land use (Gt)	-13.7	-3.4	-10.3
Total NET emissions (Gt)	27.5	25.4	2.1

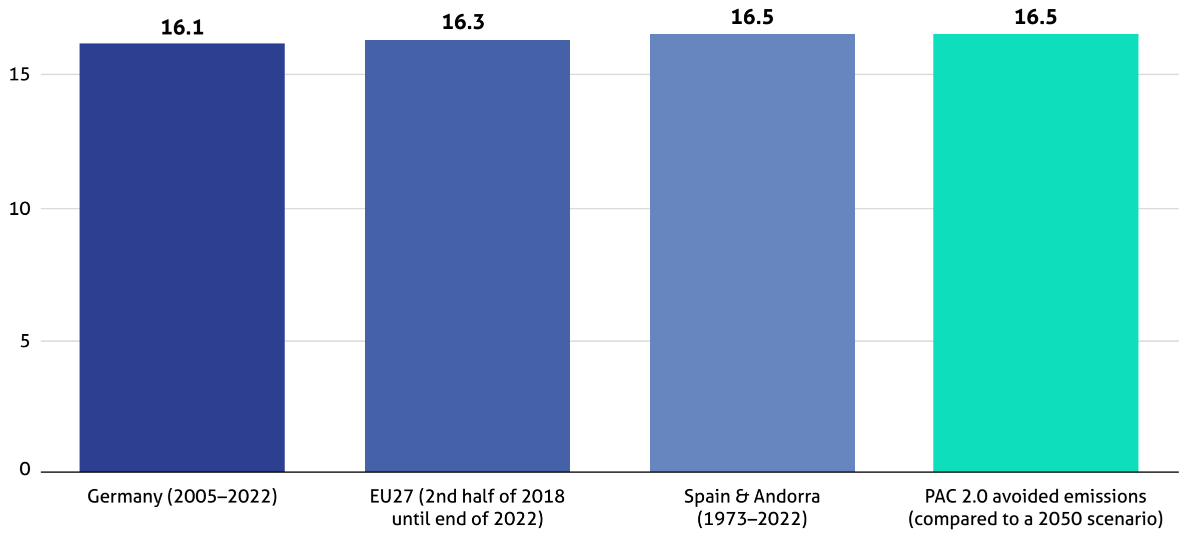
Source: *CAN Europe analysis*

As already mentioned, PAC 2.0 aims to achieve climate neutrality by 2040. When comparing this accelerated timeline to a similar (mimic) scenario aiming for climate neutrality by 2050, the difference in cumulative GHG emissions is substantial. Specifically, reaching neutrality 10 years earlier, by 2040, prevents a total emissions of 16.5 Gt CO2e, which represents a 37.5% decrease in emissions compared to a less ambitious 2050 scenario.

1 The net budget includes removals, as well as international aviation and maritime transport. We calculated this greenhouse gas budget for the EU based on the IPCC's estimated remaining carbon budget of 500 GtCO_2 for the entire world from the beginning of 2020 to limit global warming to 1.5°C with a 50% chance (IPCC report, Table SPM.2, page 29). We then assumed an equal GHG budget per capita across the world population to derive a domestic GHG budget of 27.5GtCO_2e for the EU's roughly 500 million inhabitants. This per capita approach does of course not reflect the historical responsibility of the EU as a major emitter in the past 200 years, as well as a higher likelihood (67% or 83%) of meeting the 1.5°C temperature limit. Complementing this figure with a more restrictive budget based on more encompassing equity principles and higher likelihood of meeting the 1.5°C goal is needed to fully capture the EU's global responsibility, accounting for historical responsibility and capacity to act. The remaining gap between the ambitious domestic EU greenhouse gas budget, and the equitable EU greenhouse gas budget fully aligning with equity principles, needs to be addressed through additional international climate finance and support measures for mitigation.

As a benefit, the avoided emissions of 16.5Gt CO2e resulting from achieving climate neutrality already by 2040 are monumental. To put this in perspective, this amount is equivalent to the total GHG emissions of Spain and Andorra during the last 50 years (1973–2022), or Germany's total emissions from 2005 until 2022, or even the total GHG emissions of the EU27 during 4.5 years, i.e. from July 2018 to December of 2022, as can be seen in Figure 2.

Figure 2: *Visualising the avoided emissions from achieving climate neutrality in 2040*



Source: *CAN Europe analysis, data taken from EDGAR — Emissions Database for Global Atmospheric Research*[2]

As a historical emitter and a wealthy region, the EU has a responsibility and a strategic interest to set a credible path to 1.5°C, and to show how other major emitting countries can also take decisive action in multiple fronts to do the same. This requires a fast and ambitious ramp-up in measures, and advancing the net zero target already by 2040.

2 EDGAR — Emissions Database for Global Atmospheric Research: https://edgar.jrc.ec.europa.eu/report_2023?vis=ghgtot#emissions_table

Accelerating climate action also makes economic sense

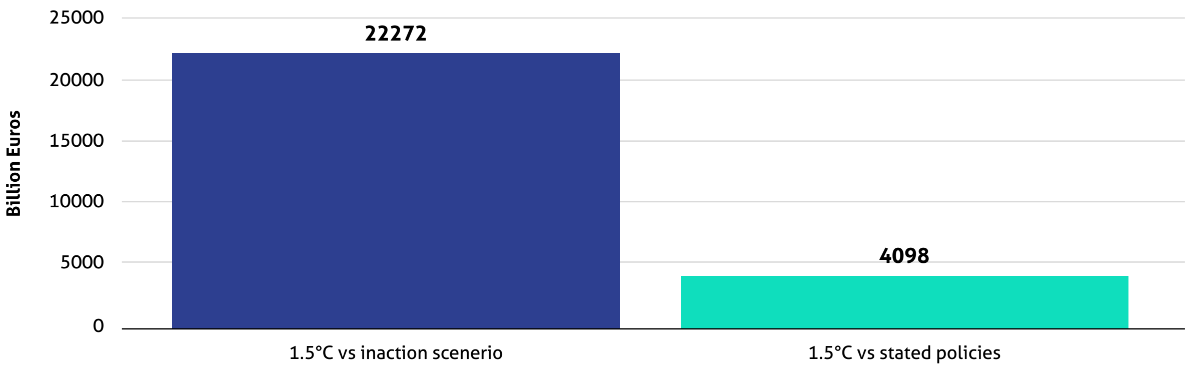
PAC 2.0 KEY SOCIO-ECONOMIC FINDINGS

Higher climate ambition in Europe in line with the Paris Agreement objectives is possible and the pathway to make this happen is beneficial socially and economically in absolute terms. As detailed in the CAN Europe report 'The Paris Pact Payoff':

- For the EU as a whole, **the benefits of ramping up and accelerating climate action by implementing a 1.5°C aligned pathway significantly outweigh the costs, by a factor ranging between 1.4 and 4 to 1**, illustrating an unequivocal rationale for taking action.
- **Avoided losses: Adopting a 1.5°C compatible pathway brings considerably less economic losses** than any other less ambitious pathway. **This pathway would allow the EU to avoid cumulative losses of €46,000 or €8,500 per capita** compared to the inaction and current policies scenarios, respectively.
- **Co-benefits: The direct co-benefits arising from a 1.5°C compatible scenario amount to at least €1 trillion by 2030 for the EU27 as a whole**. In perspective, this return is almost double to the 584 billion euros of investment called forth by the EU Grid Action Plan.

In case of no action ("inaction scenario" shown below in Figure 3), costs resulting from the climate crisis are predicted to soar to 347 billion euros annually by 2100. In contrast, adopting the 1.5°C aligned transition pathway (as described in PAC 2.0), would result in a substantially lower expenditure, 94 billion euros annually — almost 4 times lower.

Figure 3: *Avoided cumulative climate change losses under a 1.5°C pathway vs inaction and stated policies scenarios to 2100 in Europe*



Source: *Paris Pact Payoff, Climact and CAN Europe calculation based on COACCH model*

The full methodology and an explanation of the models our findings are based on, can be found in the report 'The Paris Pact Payoff', published in January 2024.

Transforming the key sectors

The Paris Agreement Compatible (PAC) 2.0 energy scenario is a story of hope and resilience. By transforming the key sectors, it reveals how a transition towards climate neutrality, aligned with the internationally agreed target to remain within 1.5°C, can be realised. Table 3 outlines the key transformations on the selected key sectors.

Table 3: *PAC 2.0 key sectoral transformations, objectives and enablers*

Power	Buildings	Industry	Transport
The PAC 2.0 power sector development foresees a quick decarbonization of the power sector first. The key levers are the ambitious roll out of renewable energy sources (mainly solar and wind), in conjunction with storage which increases in significance after 2030, as well as a substantial increase in the needed grid infrastructure (transmission and H2). Electrification serves as a key pillar of the quick decarbonization of the sector.	Buildings across the EU are old and consume a lot of energy. On top of this renovation rates remain very low on an annual basis. In order to decarbonize this sector, **a large renovation wave that strongly boosts energy demand reduction is needed** and couples with quick electrification (and other measures) especially when it comes to buildings' heating needs.	**Circularity emerges as a key feature of Europe's industrial logic**, as an increase of secondary materials, rising with a wide-spread sharing economy. With a shift in how value is generated, new opportunites arise for entrepreneurs and firms to collaborate and innovate. **Low-temperature industrial processes are electrified, and high-temperature processes begin to use renewable hydrogen.**	The transport sector is one of the hardest to abate, as it relies heavily on fossil fuels. In the future when the sector decarbonises, **the quality of life around Europe, also with Europe's cities improves dramatically thanks to enhanced air quality and less noise pollution, due to electrified vehicles as well as less traffic, as a result of car-sharing, car pooling, and development of electrified public transport infrastructure**, covering citizens' transport and commuting needs.
Key Objective			
100% future renewable energy system supplies Europe's energy in the future	Lowering the bills & securing well-being — Substantial reduction in CO2 emissions	Towards green, fair, circular and resilient EU industry	Beyond EVs — Transforming the way we move
Key Enablers			
• Accelerate renewables deployment (118 GW per year) • Invest in grids, storage and flexibility • Decarbonize the power sector first	• Triple the annual renovation rate 3% by 2030 • Couple renovations with heat pump installations • Develop district heating networks	• Reduce consumption of primary materials • Increase secondary-use rates of key materials up to 70–80% through circularity • Electrify processes — Green H2 for high temperature processes	• Invest in public transport (train, bus, metro), walk and cycle more • Smaller fleets with joint mobility — All new vehicles are electric as of 2030 • E-fuels for aviation and marine sector

Source: *CAN Europe, PAC 2.0 project*

6 KEY ACTIONS FOR A PARIS AGREEMENT COMPATIBLE TRANSITION

1 Reduce energy consumption to enable faster decarbonization and electrification

The PAC scenario demonstrates how combining sustainable lifestyles, increased energy efficiency, technological innovation, and reduced material usage can collectively decrease energy demand across all sectors. In other words, the PAC 2.0 is an energy demand-reduction scenario.

PRIMARY ENERGY CONSUMPTION (PEC)

The primary energy consumption under the PAC 2.0 more than halves between 2020 and 2040. With a primary energy consumption of 855.3 Mtoe in 2030, there is a significant energy savings potential in the EU (Table 4). PAC 2.0 suggests a primary energy consumption reduction of 23.9% for 2030 compared to the PRIMES EU 2020 Reference Scenario projections, thus it becomes clear that the 11.7% energy efficiency target for 2030 as set in the 2023 Energy Efficiency Directive can be outperformed.

For 2040, the PAC 2.0 indicates an absolute reduction of 62%, reaching 490.8 Mtoe for primary energy consumption, compared to the PAC 2.0 baseline year 2020. Compared to the PRIMES EU 2020 Reference Scenario projections, it is 51.3% lower in 2040.

Table 4: *Evolution of PAC 2.0 primary energy consumption. These are estimates for seeking alignment with the new Eurostat methodology and scope of the indicators in the 2023 Energy Efficiency Directive. Given the different methodologies, the PAC 2.0, Eurostat and the 2023 EED might present small differences.*

2015 2020 2030 2035 2040

	2015	2020	2030	2035	2040
Total Primary energy consumption (TWh)	15,586.7	15,586.1	9,944.8	7,026.4	5,706.9
Total Primary energy consumption (Mtoe)	1,340.5	1,340.4	855.3	604.3	490.8
Delta (%) compared to 2020 PAC baseline			-33.7	-53.2	-62
% of reduction compared to the EU 2020 Reference Scenario			-23.9	-43.2	-51.3

% of Difference for different time horizons. PAC 2.0 achieves a 51.3% reduction of primary energy consumption between 2020 and 2040, compared to the EU 2020 Reference Scenario.

Source: *Pathways Explorer, CAN Europe analysis*

FINAL ENERGY CONSUMPTION (FEC)

Within two decades, final energy consumption in the EU is almost halved under the PAC 2.0 scenario. The scenario shows potential for an absolute consumption of 685.75 Mtoe for final energy in 2030. This translates into a **20.7% reduction for 2030** compared to the PRIMES 2020 Reference scenario projections, also showing that for final energy consumption, the **current EU energy efficiency target of 11.7% can be outperformed** (Table 5).

For 2040, the final energy consumption under the PAC 2.0 leads to 460.47 Mtoe for the EU. **This equals a reduction of 49.4% compared to the PAC baseline year 2020**, meaning that final energy consumption is almost cut in half. Compared to the PRIMES 2020 projections, **final energy consumption is 42.8% lower in 2040**.

Table 5: *Evolution of PAC 2.0 final energy consumption. These are estimates for seeking alignment with EC's new Eurostat methodology and scope of the indicators in the 2023 Energy Efficiency Directive. Given the different methodologies, the PAC 2.0, Eurostat and the 2023 EED might present small differences.*

2015 2020 2030 2035 2040

	2015	2020	2030	2035	2040
Total Final energy consumption (TWh)	10,830	10,572	7,974	6,488	5,354
Total Final energy consumption (Mtoe)	931	909.2	686	558	460
Delta (%) compared to 2020 PAC baseline			-24.6	-38.6	-49.4
% of reduction compared to the EU 2020 Reference Scenario			-20.7	-32.9	-42.8

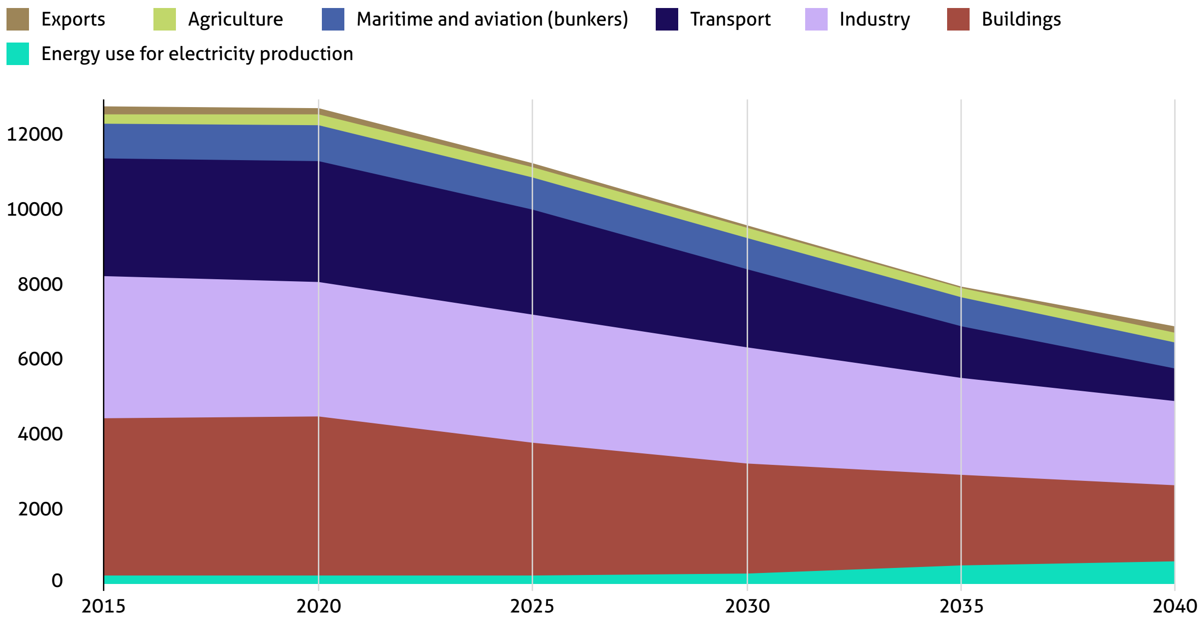
% of Difference for different time horizons. PAC 2.0 achieves 1) 42.8% reduction of final energy consumption between 2020 and 2040, compared to the EU 2020 Reference Scenario. 2) 49.4% reduction of final energy consumption between 2020 and 2040, compared to the 2020 PAC value

Source: *Pathways Explorer, CAN Europe analysis*

SECTORAL ENERGY DEMAND REDUCTION

Each sector, and their transformation, contributes to the PAC 2.0 scenario, so that climate neutrality can be achieved by 2040. Therefore, sector-specific aspects, dynamics, and their interplay describe how power, buildings, industry, transport (as well as maritime and aviation) would contribute to the 2040 pathway, as illustrated in Figure 4.

Figure 4: *PAC 2.0 Energy demand per sector — EU27*



Source: *Pathways Explorer, CAN Europe analysis*

Through actions taken in the current and the next decade, more energy-efficient **buildings** that have been renovated will apply heat pumps and phase-out inefficient fossil fuels, halving the energy demand from buildings from 4,191 TWh and 33% of the total demand (in 2015) to 2,019 TWh by 2040 and 29% of the total demand (in red colour). More energy-efficient **industries**, as 2.5 times more electrified than in the present, apply circularity and deploy green H2 for high-temperature processes, see energy demand decrease (from 3,835 TWh and 32% of the total demand) to 2,230 TWh and 30% of the total energy demand (in purple). The **transport** sector, although very difficult to decarbonise, with modal shifts, a smaller, electrified car and truck fleet, and rail prioritisation, sees energy demand (at 3,127 TWh in 2015 and 25% of the total energy demand) fall down to 890 TWh (in dark blue) and 13% of total energy demand by 2040. **Maritime and aviation** (international bunkers) see a relatively small demand decrease from 921 TWh and 7% of the total energy demand down to 716 TWh (in lighter blue) and 10% of the total energy demand by 2040. **Agriculture** is assumed to remain almost constant, becoming around 6% more efficient (shown in yellow) and reaching 3% of the total energy demand by 2040 (from 2% in 2015).

2 Switch to a 100% Renewable Energy System

The PAC 2.0 scenario envisions a 100% renewable energy system. This scenario not only emphasises the need for a high share of renewable energy sources, but also focuses on reducing the EU's energy demand. While promoting high RES efforts, we already anticipate the forthcoming needs for significant demand reduction. Accordingly, the key figures in this scenario correspond to a simultaneous demand reduction. The PAC 2.0 power sector development foresees a quick decarbonization, as the first sector to fully phase out coal (by 2030) and gas (by 2035), as well as nuclear energy gradually until 2040. In order for this transformation to take place, in tandem with the reduction of energy demand across all sectors, the key levers are the ambitious roll out of renewable energy sources (mainly solar and wind), in conjunction with storage (both long term and short term) which increases in significance after 2030, as well as a substantial increase in the needed grid infrastructure (transmission of electricity and renewable hydrogen). Electrification serves as a key pillar of the quick decarbonisation of the energy system, in order to reach 100% renewables by 2040, reaching 43% by 2030 and a staggering 80% by 2040.

Table 6: *PAC 2.0 solar and wind capacities projections, EU27 (Excl. Malta and Cyprus)*

Installed capacities (GW)	2022	2023	PyPSA 2030	PatEx 2030	PyPSA 2035	PatEx 2035	PyPSA 2040	PatEx 2040
Solar	207	263	541	723	1,191	1,040	1,622	1,360
Wind onshore	224	238	312	397	667	535	717	673
Wind offshore	30	34	72	127	180	188	194	249
Total solar & wind	**462**	**536**	**925**	**1,247**	**2,038**	**1,763**	**2,533**	**2,282**

PatEx stands for Pathways Explorer 2050; PsyPSA stands for Python for Power System Analysis;

Source: *PyPSA-Eur, CAN Europe analysis*

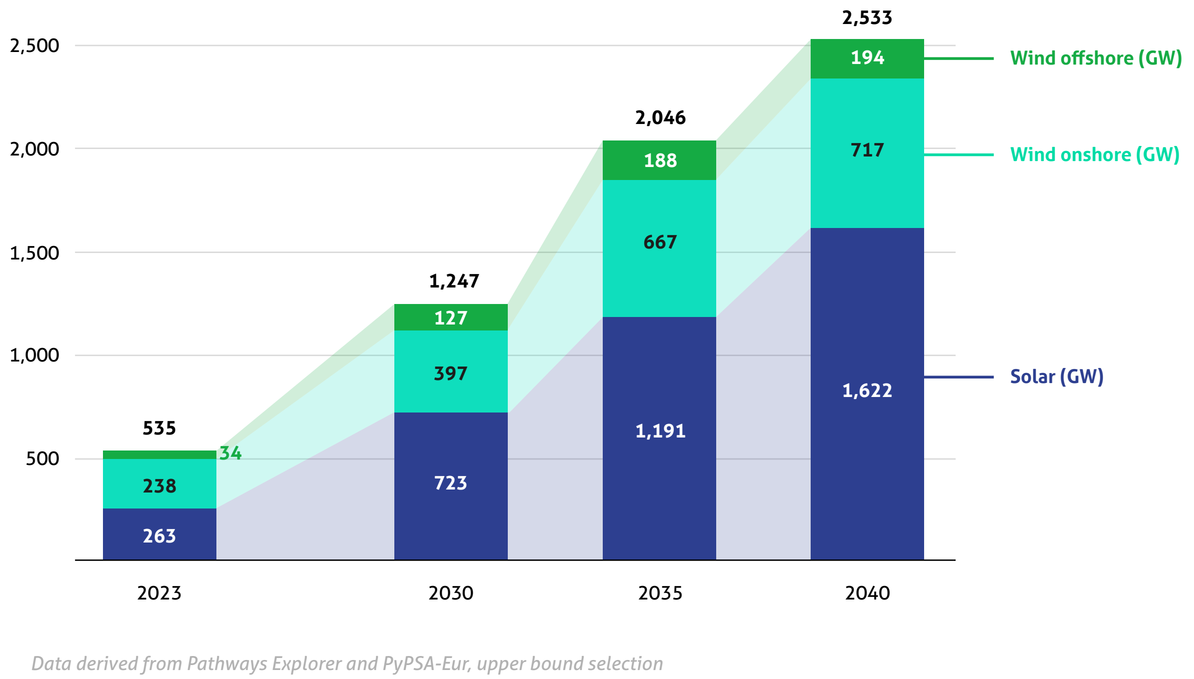
Table 6 summarises the projected renewables capacities for the EU27 for onshore wind, offshore wind and solar photovoltaics (PV), in comparison to the current state of play for 2022, 2023, taking into account the cumulative capacities reported by the solar and wind industry[3].

3 For more details regarding the difference in the RES installed capacities between the 2 softwares used (Pathways Explorer and PyPSA-Eur), please refer to the ***Technical Summary***, *Section: 100% future renewable energy system supplies Europe's energy in the future, Box: The how and the what — modelling RES capacities*

SolarPower Europe announced new records for solar installations for 2023, reaching a total installed capacity of 263 GW, up 27% from the 207 GW in 2022. Moreover, Wind Europe announced a cumulative offshore wind installed capacity of 224 GW in 2022 and 238 GW in 2023, and 30 GW of offshore wind capacity in 2022 and 34 GW in 2023. **All the results below should be assessed in conjunction with the proposed energy demand reduction pathway that the PAC assumes.**

In total, to meet the PAC scenario, **the annual rate of renewables installations ranges from 102–118 GW per year**. Based on the lower and upper limits of our estimates, if we want to achieve climate neutrality by 2040, and meet the PAC pathway, **we need to increase the annual RES deployment rate by +38–59%**, with 2023 as a reference (at the record year for solar, 40% additional capacity was installed than in 2022). **If we compare with the 2020–2022 average RES installations (approx. 35GW annually), we need to at least triple the ambition for renewables deployment.**

Figure 5: *Total wind and solar installed capacities per technology and time horizon (EU27)*

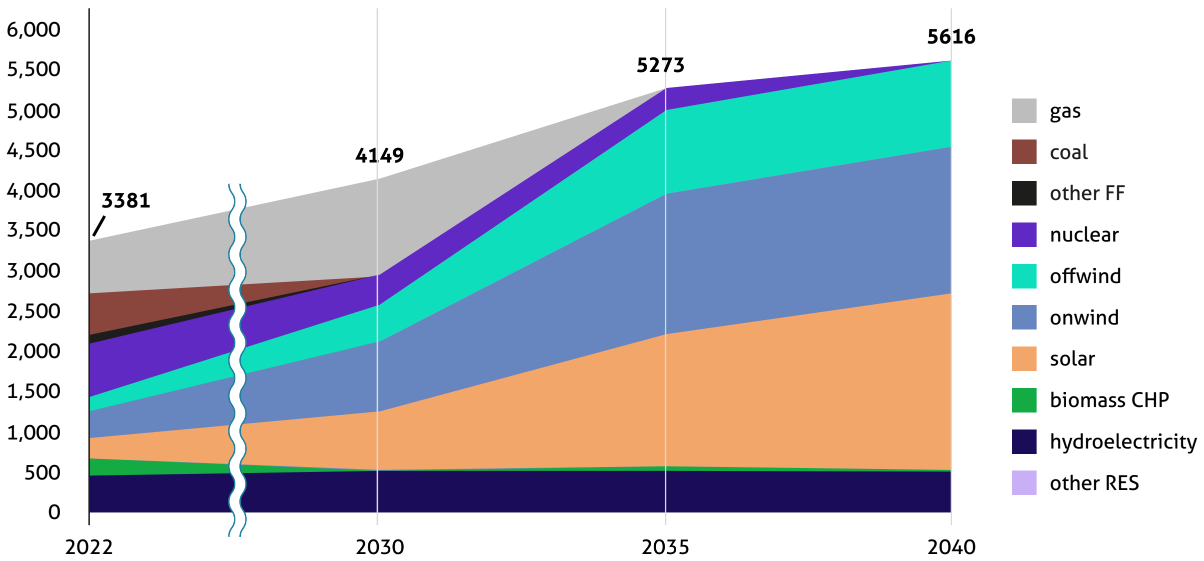


Source: *CAN Europe analysis, based on Pathways Explorer and PyPSA-Eur results (upper bound selection)*

As illustrated in Figure 6, using the PyPSA-Eur modelling tool, coal is phased out already by 2030, and fossil gas and nuclear are (fully) phased out by 2035 and 2040 respectively. Pumped hydro storage (PHS) remains at the same (historical) levels until 2040 as well as hydroelectricity.

At the same time, we see an uptake of offshore and onshore wind as well as utility solar and solar rooftop installations, necessary to support the power sector. Figure 6 below presents an overview of the projected annual production (in TWh) until 2040. According to PAC 2.0, by 2040 the energy production is based solely on onshore wind (light blue), offshore wind (green), solar (light orange) and use of existing hydropower capacities, in dark blue. Biomass CHP production is gradually decreased by 2030 and fully phased out by 2040 in the EU (dark green).

Figure 6: *Annual production — Power generation technologies mix — A 100% fossil free energy system (EU27)*



Source: *PyPSA-Eur*

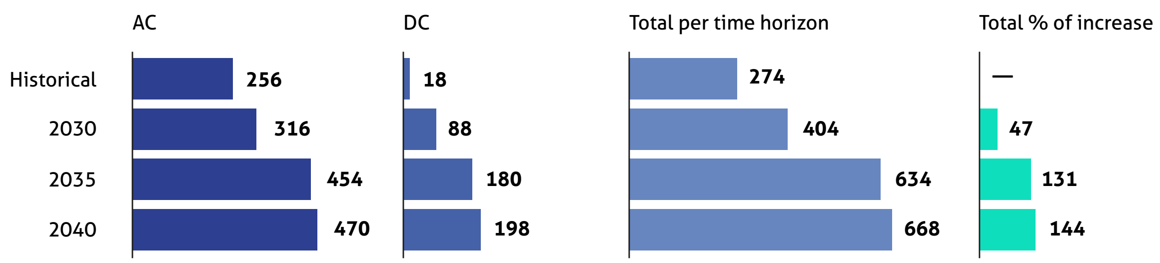
3 Develop a Paris Agreement compatible power grid

Concerning the role of power grids in meeting the Paris Agreement Compatible 2.0 pathway, our focus is on transmission capacities. Existing grids must be improved and considerably more grid infrastructure will be necessary, for enhanced transmission capacities that accelerate RES deployment and their integration, and address storage needs. We did not assess capacity needs at distribution grids. Finally, electricity and renewable hydrogen transmission need to be well integrated.

A. TRANSMISSION FOR EUROPE – LESS ISOLATED, MORE CONNECTED

According to the PAC 2.0 results (Table 7), as compared to 2021, the European power grid's transmission capacity would need to grow by at least +47% by 2030, reaching 404 GW, consisting of both AC and DC cables. Furthermore, reaching a 634 GW total grid capacity by 2035 translates into an increase of +131%. Moreover, we observe a substantial increase in DC cables by 2035 that transfer renewable energy around an increasingly electrified Europe. Finally, grids would need to reach 668 GW of total capacity by 2040, indicating an increase of +144% in their capacity over time, compared to current levels. Those figures reflect the minimum levels of transmission capacity.

Table 7: *Transmission grid capacities for 2030, 2035, and 2040 for the EU27 in PAC 2.0 scenario (compared to 2021), expressed in GW.*



AC: Alternate Current | DC: Direct Current

Source: *CAN Europe analysis*

All of the above points to significant investment needs in transmission grids. Anticipatory investment, strong grid reinforcement, and planning for additional flexibility are needed, when thermal power plants are phased out (also to remove fossil gas out of the power sector by 2035). From an investment perspective, transmission expansion is little affected by cost uncertainty. Problematically, in a number of countries, planned network developments are 'out of step' with the reality of the energy transition. At the moment, the uptake of RES capacities can be maximised only where the grid is adequate, but in the present situation, not where the potentials are best.

B. CROSS-BORDER INTERCONNECTION — COOPERATION OVER COMPETITION

More grid interconnection between European countries assists them in exchanging electricity, and minimising unnecessary system losses or constraints. For instance, a reinforced grid from Western Europe to Central Europe can facilitate RES power transmission, and create a more solid backbone in Eastern Europe. The importance of cross-border transmission can also be understood by the following trade-off. In planning, isolating a country will lead to an increase in required storage capacity, whereas by interconnecting countries, storage needs can be reduced. Additionally, inadequate levels of transmission would lead to higher hydrogen storage needs and most importantly, a bottleneck in renewables deployment rate, due to lack of electrical space or even costly curtailments.

4 Harness the potential of flexibility – A more flexible system brings more benefits

At transmission level, flexibility solutions help integrate renewable energy, so that demand and supply match at all times, encouraging efficient expansion. Alongside efficiencies and cable pooling, the various modes of flexibility (also demand-side flexibility) help reduce growing pressures on the grid capacity, and further optimise the use of existing infrastructures, where the electricity system and grid adjust to a range of generation and consumption patterns across different time horizons.

Overall, flexibility options increase in importance by 2035, with the phase-out of fossil gas from the power sector. PAC 2.0 pathway also sees it important to renovate buildings to enhance system design to lower demand in the energy system effectively. In transport, operating an electrified fleet of electric vehicles (EVs) with batteries will offer new storage capacity. Additionally, flexibility options can be explored with industrial demand-side management (DSM) at specific industries.

DID YOU KNOW THAT...

...buildings could have an important role in flexibility?

- Building renovations have the most impact, as they enable 44–51% space heat demand savings and can reduce total system costs with 14% cost savings.[4]
- Heat pumps, domestic hot water demand and storage (which can increase local PV self-consumption by 21%–26%) are important flexibility options in buildings.[5]
- Harnessing the demand response of electricity, heating and cooling reduce a need to run expensive power plants at peak hours of demand.
- Demand response means that momentary consumption can either be reduced or re-allocated to a time when more power is available. Without decreasing service quality, it advances resource efficiency.

Overall, if system flexibility options in buildings are harnessed, then demand-side response by consumers would have less of an impact in terms of effectiveness, minimising costs and emissions.

4 Elisabeth Zeyen, Veit Hagenmeyer, Tom Brown, Mitigating heat demand peaks in buildings in a highly renewable European energy system, *Energy*, 231, 2021, 120784. https://doi.org/10.1016/j.energy.2021.120784

5 Arthur Rinaldi, Selin Yilmaz, Martin K. Patel, David Parra, What adds more flexibility? An energy system analysis of storage, demand-side response, heating electrification, and distribution reinforcement, *Renewable and Sustainable Energy Reviews*, 167, 2022, 112696. https://doi.org/10.1016/j.rser.2022.112696

...a small EV fleet can actually provide the needed flexibility?

- Batteries in electric vehicles present a high potential. A fleet just 50% of the size of today, could totally replace utility-scale batteries. EV batteries could be repurposed for the grid, rather than recycling them, lowering the pressure on minerals, especially at the end of their lifecycle, as also the IEA recently suggested[6], as making more economic sense.
- Controlled charging that lets an electricity provider manage, in real time, when an EV should be charged, is the most important flexibility option, given the size of the fleet potentially available in the future.
- The PAC scenario focuses on car-sharing and fully electrified transport to meet its transport needs. The (existing) passenger car fleet is reduced by approximately 65% until 2040, still covering needed transport demands, due to higher utilisation of the electrified and reduced fleet, an increase in active transport modes, and public transport.
- A smaller, electrified car fleet catalyses the demand-side management (DSM) benefits from battery EVs. If 25% of the total fleet participates, it could lead to 10% lower energy system costs, with a maximum potential of 14%, if 35% of the total fleet participates (as in PAC 2.0).[7] [8]

When electric vehicles act as batteries, they offer new storage capacity. In a future energy system, with vehicle to grid adoption, thousands of EVs work in unison, acting as a large distributed energy system, as a service to the electricity grid.

...industry can also play a role in demand-side flexibility?

- Although flexibility is only possible for selected industries, it should be encouraged, given the efficiency of this option.
- For a plant operator, load shifting can reduce electricity costs by about 5%.[9]

6 Energy Technology Perspectives 2023, IEA: https://iea.blob.core.windows.net/assets/a86b480e-2b03-4e25-bae1-da1395e0b620/EnergyTechnologyPerspectives2023.pdf In other words, repurposing EV batteries for secondary use in stationary energy storage could help reduce demand for critical materials.

7 T. Brown, D. Schlachtberger, A. Kies, S. Schramm, M. Greiner (2018) Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system, *Energy* 160, 720-739. https://doi.org/10.1016/j.energy.2018.06.222

8 Victoria, M.; Zhua, K.; Brown, T.; Andresen, G.B.; M. Greiner (2019) The role of storage technologies throughout the decarbonisation of the sector-coupled European energy system. *Energy Conversion and Management* 201, 111977. https://doi.org/10.1016/j.enconman.2019.111977

9 Nebel, A.; Krüger, C.; Janßen, T.; Saurat, M.; Kiefer, S.; Arnold, K. (2020) Comparison of the Effects of Industrial Demand Side Management and Other Flexibilities on the Performance of the Energy System. *Energies*, 13, 4448. https://doi.org/10.3390/en13174448

Enablers like digitalisation, market signals and future electricity market reforms, if widely adopted by 2040, may help these flexibility measures to be taken up, while further innovative approaches like vehicle-to-grid can be mainstreamed. Combined deployment of distributed solar PV, battery electric vehicles and domestic heat pumps could even reduce the need to expand the distribution networks. New innovations that reward flexibility would likely assist in supportive lifestyle changes, and accelerate phase-outs. As explained next, the role of energy storage becomes increasingly crucial, when the share of fossil fuels drops significantly.

5 Scale up energy storage

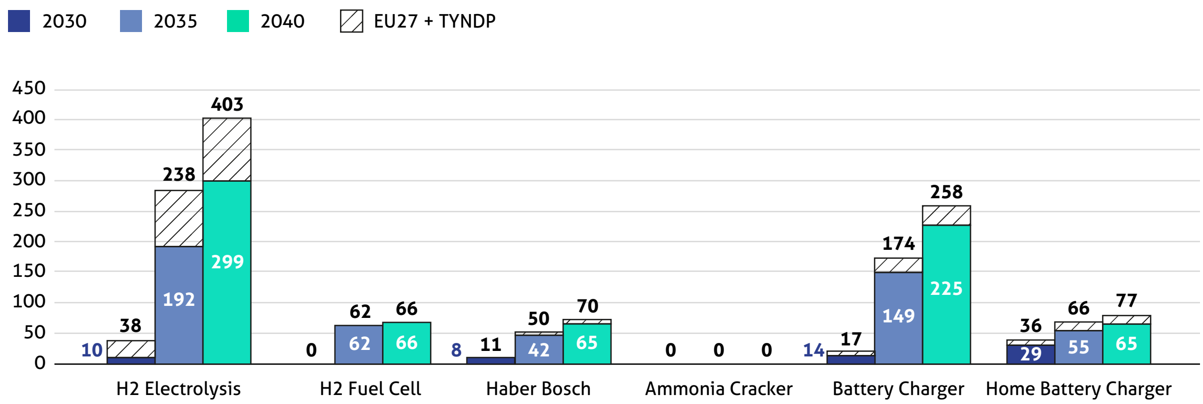
As we move into a 100% renewable energy system, alongside flexibility and transmission, energy storage, across timespans, assumes an important role especially after 2030.

SHORT-TERM STORAGE

Short-term storage refers to daily storage needs, such as batteries, directly correlated with solar due to the daily fluctuation, as solar capacities will grow. Batteries will be used for the daily storage of electricity primarily to compensate for solar production at night time. After 2030, some hydrogen will also be consumed at night, for short-term storage, although its weak system efficiency should be taken into consideration.

We illustrate the growing role of energy storage through home batteries, utility-scale batteries, the production of green ammonia (Haber-Bosch), complemented with the use of hydrogen (H2) through electrolysis and fuel cells, as a system back-up.

Figure 7: *Batteries see an important uptake with the phase-out of fossil fuels, supplemented by the use of domestically produced renewable H2.*



Source: *CAN Europe, Climact, PyPSA-Eur analysis*

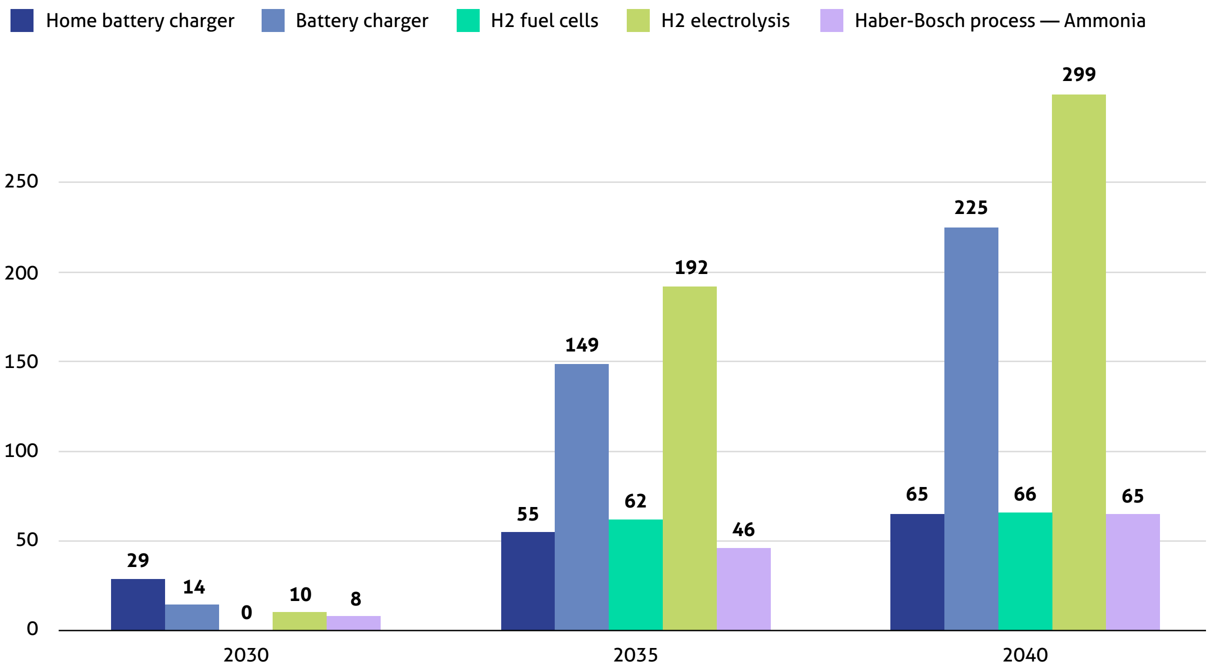
In the PAC 2.0 pathway, shown in Figure 7, home battery chargers reach 29 GW in 2030, 55 GW in 2035 and 65 GW in 2040 in the EU25 (Malta and Cyprus not included). Battery chargers, at only 17 GW in 2030, see a dramatic increase to 149 GW in EU27 and 225 GW in 2040. The battery storage and discharge power needed remain similar in almost all of our simulated scenarios. As earlier mentioned, pumped hydro storage (PHS), able to respond to demand and generation changes within minutes, is anticipated to remain at 48 GW across 2030, 2035 and 2040 for EU27.

LONG-TERM, SEASONAL STORAGE

Long-term energy storage refers to seasonal storage needs, which in PAC 2.0 are increasing from 2035 onwards[10]. As a note, long-term thermal storages or other future storage technologies are not included in the assessment. Long-term storage, such as H2, is highly correlated with wind, due to the longer period of fluctuation, for instance in winter periods (as a substitute to fossil gas turbines of today). H2 acts as a back-up to balance the energy system for the rare occasions during long winter periods of low wind, as seasonal storage. This means that the use of H2 for storage purposes would have to be properly sized. At the same time, in light of competing H2 demands, the uses of H2 (as renewable H2) have to be carefully prioritised[11].

As for the use of hydrogen for storage purposes, the role of H2 fuel cells begins to be seen from 2035 onwards, at 62 GW, and 66 GW by 2040. All in all, H2 fuel cells will reach around one fourth of battery capacities. H2 electrolysis capacities will grow from 10 GW in 2030, to 20-fold to 192 GW in 2035 and 30-fold at 299 GW in 2040. Finally, ammonia also plays a role in long-term storage. Green ammonia will reach 46 GW in 2035 and 65 GW in 2040.

Figure 8: *PAC 2.0 H2, batteries and ammonia capacities (GW) for different time horizons*



As can be seen, storage capacities are really advancing after 2030.

Source: *CAN Europe analysis*

10 In urban areas in some countries, storage technologies require to be implemented alongside the introduction of renewable district heating. Although individual storage cannot match seasonal variation, they are still necessary for rural heating.

11 As relates to the use of hydrogen, also with a view to industry demands, decommissioning and repurposing gas pipelines are necessary to phase-out remaining fossil gas. In addition, it will be necessary to avoid the risk of reliance on hydrogen (H2) imports.

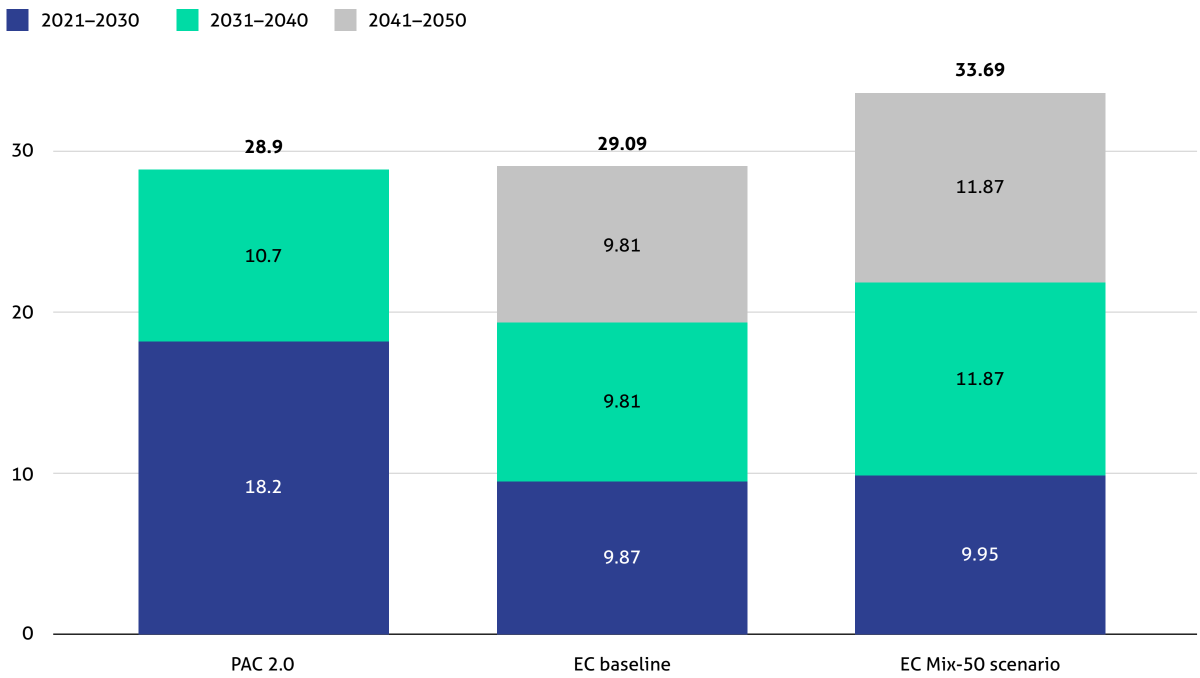
6 Frontload investments to align with Paris Agreement

The more appropriately the future energy system is designed and planned for, taking into consideration the different mentioned aspects, the lower the overall system costs could become.

A. TOTAL GROSS INVESTMENT NEEDS

The PAC 2.0 achieves climate neutrality by 2040, so the total gross investment needs were calculated until 2040 using both Pathways Explorer and PyPSA-Eur data. As can be seen in Figure 9 below, the total amount of gross investment needs of the PAC 2.0 is 28.9 trillion Euros, referring to EU27, as investments into energy supply, transport, buildings and industry (i.e. capital expenditures, in short CAPEX).

Figure 9: *Total gross investment needs to achieve climate neutrality*



PAC 2.0 achieves climate neutrality by 2040. EC Baseline (BSL) is assumed to reach a 60% emission reduction by 2050. EC Mix-50 scenario is assumed to reach climate neutrality by 2050

Source: *CAN Europe analysis, data from Pathways and PyPSA Eur and EC data, see Footnote 12*

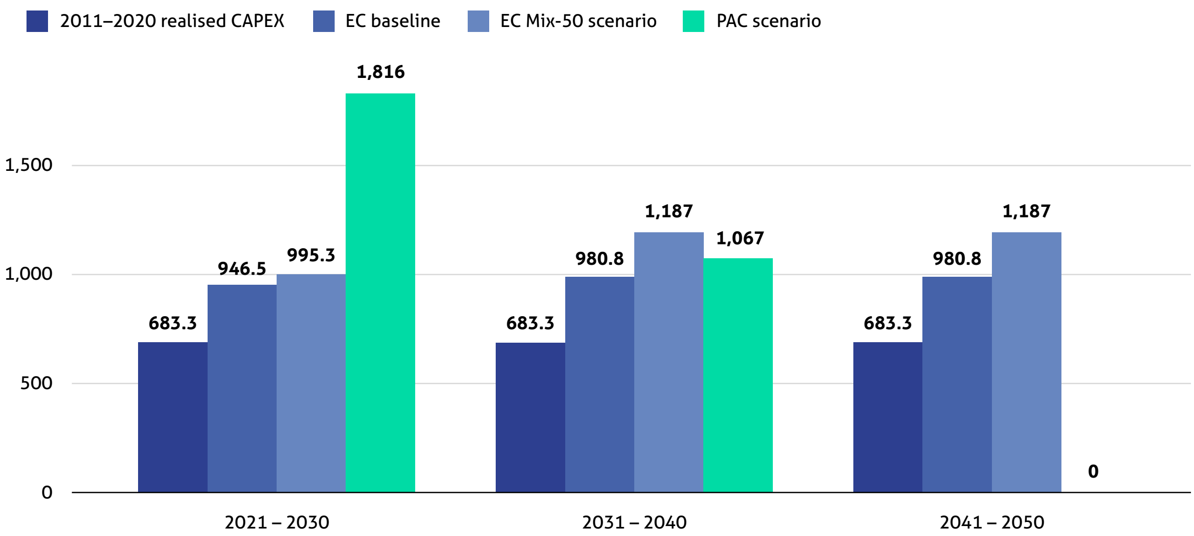
Note: *PAC 2.0 includes energy supply, transport, buildings and industry sectors. It does not include energy, storage and transmission costs for Malta and Cyprus for the decade 2031–2040*

The total gross investment needs of the EC baseline scenario[12] reach 29.09 trillion Euros (for achieving approximately 60% of emissions reduction compared to 1990) translated into 200 billion Euros more compared to the PAC 2.0, which achieves climate neutrality by 2040. The total gross investment needs of the **EC Mix-50 scenario reach 33.7 trillion Euros** in order to achieve climate neutrality by 2050. **PAC 2.0 requires less gross investments to reach climate neutrality, being reflected also in the total (gross) investment needs, requiring almost 4.8 trillion Euros less, compared to the EC Mix-50 scenario.**

B. AVERAGE ANNUAL GROSS INVESTMENT NEEDS

As the current decade (2021–2030) is critical to deliver steep emissions reductions, PAC requires 63% of its total investments (18.2 trillion Euros) to be frontloaded. Comparing the average annual gross investment needs with the 2011–2020 realised CAPEX, the EC baseline or the EC Mix-50 scenario (one of the core scenarios examined by the European Commission), the PAC 2.0 (in green in Figure 10 until 2040) requires almost double annual investments in the 2021–2030 decade, reaching 1.82 trillion Euros annually as an average but significantly lower investments for the decade 2031–2040, with 1.07 trillion Euros annually.

Figure 10: *Average annual gross investment needs (2020–2040) per scenario*



Source: *CAN Europe analysis, data from Pathways and PyPSA-Eur*

Note: *Includes energy supply, transport, buildings and industry sectors. It does not include energy, storage and transmission costs for Malta and Cyprus for the decade 2031–2040.*

12 The baseline scenario projects that in 2050 GHG emissions will be reduced by around 60% compared to 1990. The EC Mix-50 scenario aligns with the EU target of climate neutrality by 2050, according to Figure 99, Data taken from: COMMISSION STAFF WORKING DOCUMENT - IMPACT ASSESSMENT - Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people; Table 46: Average annual investment for BSL, all policy scenarios and MIX-nonCO2 variant (2011–2015, 2016–2020, 2021–2030 and 2031–2050, billion euros 2015) https://eur-lex.europa.eu/resource.html?uri=cellar:749e04bb-f8c5-11ea-991b-01aa75ed71a1.0001.02/DOC_2&format=PDF

C. ADDITIONAL ANNUAL INVESTMENT NEEDS

Based on the existing levels of investments, it is obvious that there is a significant gap in order to realise a successful energy transition towards climate neutrality, aligned with the Paris Agreement.

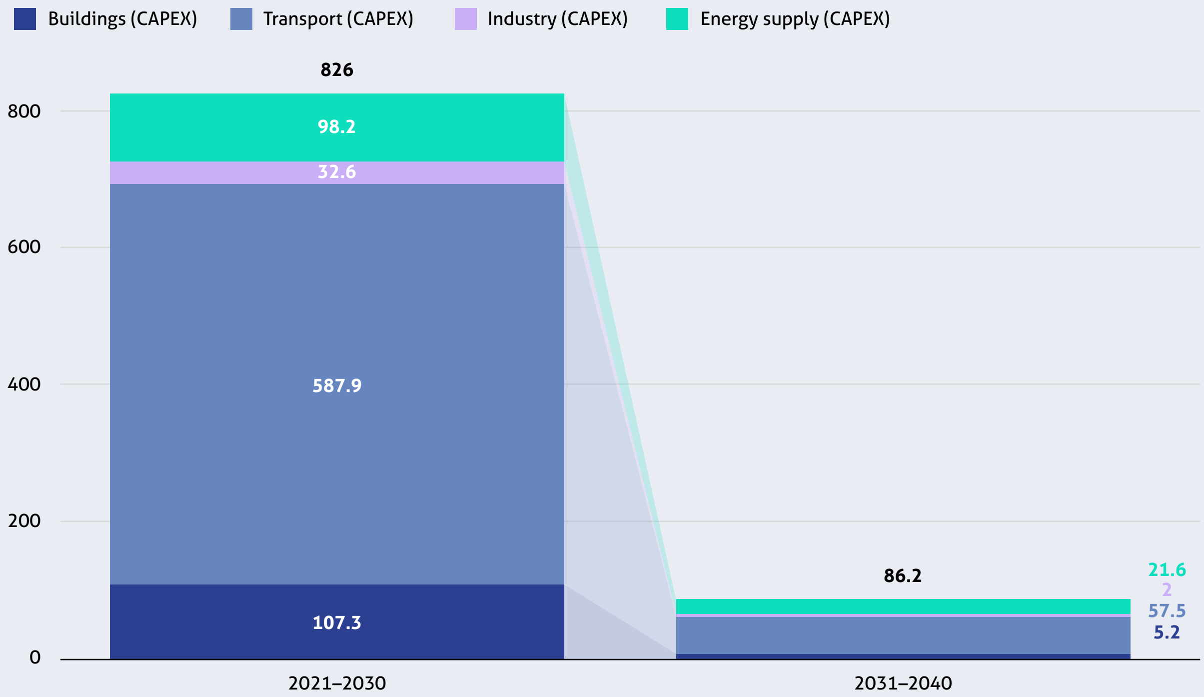
To measure the investment needs for achieving specific decarbonisation pathways, the standard methodological approach is to compare the total investment needs of a given pathway with baseline investment needs (i.e. investments that would have been needed anyway in respective sectors, under a business-as-usual scenario), in order to derive the "additional investment needs" in respective sectors. We replicate this approach by comparing the investment needs for achieving a PAC scenario pathway with the baseline investment needs provided by the European Commission (see Footnote 12 for more details).

As can be seen in Figure 11 in the next page, **the additional annual investments for the decade 2021–2030 reach 826 billion Euros annually (EU27)**, with the largest share being the transport one (587.9 billion Euros). **Buildings and energy supply transformation** based on the PAC 2.0 pathway **require approximately an additional 100 billion Euros annually each compared to the EC baseline scenario, whereas industry follows with an additional annual investment need of 32.6 billion Euros**.

Compared to the EC baseline, **the additional annual investment needs for the 2031–2040 period reach 86.2 billion Euros annually**, with transport in particular (57.5 billion) and energy supply (21.6 billion Euros) being the most significant sectors in terms of additional needs.

The key message is that we need more investments across all sectors now, in order to decarbonize the system faster compared to the current pace. The PAC 2.0 scenario pathway could potentially also lead to lower overall investment costs, resources and spatial needs in order to realise the transition — compared to other decarbonisation pathways, that place a lower emphasis on energy demand reduction. This should also be reflected in the EU level decision-making process and associated financing frameworks.

Figure 11: *Additional annual investment needs (2020–2040) compared to EC baseline*



Source: *CAN Europe analysis, data from Pathways and PyPSA-Eur*

Note: *Includes energy supply, transport, buildings and industry sectors. It does not include energy supply, storage and transmission costs for Malta and Cyprus for the decade 2031–2040.*

KEY TAKE-AWAYS

- **We are already experiencing the tremendous impacts of the climate crisis, which presents an existential threat to humanity and biodiversity. Europe is warming twice as fast compared to other continents, while the impacts of the climate crisis will affect everyone, but the most vulnerable ones disproportionately.** Changing weather patterns and intensified extreme weather events will challenge our societies, as well as how the different demand sectors interact with our future energy system in the coming decades.
- **An energy transition that leads to climate neutrality by 2040 is both feasible and desirable from a climate and from an economic perspective. Major transformations are needed across all sectors of the economy.** But the more we delay, the more difficult it becomes to stay within the 1.5°C limitation goal of the Paris Agreement, the higher the economic losses and the less the co-benefits.
- At the same time, a transition into a fast-changing energy system for the future should take into account that different countries have different starting points. For this reason, **it is crucial to promote a just transition for all countries and actors to be equally on board**.
- **A 100% renewables based and flexible energy system is feasible and necessary,** while moving away from fossil fuels as well as nuclear before 2040. In order to achieve this, we need to substantially increase the annual deployment rate of renewable energy sources — to reach around 102–118 GW in EU27 and much more if we fail to substantially reduce the energy demand.
- **Grids will play a significant role in the energy transition.** In the absence of adequate infrastructure (achieved by both upgrading existing grids as well as increasing grid capacity), renewables will probably face hurdles.
    - **The future grid is a flexible grid. Flexibility solutions should be an integral part of the future energy system,** as they bring benefits for consumers and the system alike. Although technological and energy system principles will be the same around Europe, different countries may have slightly different flexibility needs.
    - **Cooperation over competition:** The more we interconnect, the lower the storage capacity needs are. In finding an optimal balance, we avoid and alleviate unnecessary grid congestions.
    - **Distribution level was not part of this exercise, but remains a chapter that is worth exploring in the future** because on the whole, the energy system will become more and more decentralised, distributed and flexible.
- **Electrification increases the overall efficiency of the system, especially when coupled with flexibility.** Electrification is also a powerful ally in sectoral decarbonisation, especially in hard-to-abate sectors. PAC 2.0 presents a high total electrification rate, reaching 43% by 2030 and 80% by 2040.
- **The PAC transition pathway favours a demand reduction pathway,** which has a positive impact on materials, land and costs.
- **Energy security is promoted as electricity production gradually moves to renewables-only**, while phasing out coal, gas and nuclear, alleviating their various associated risks, as elevated security of supply, as well as the minimization of imports, contributing to resilience, on the whole.

- **Major investments are needed in the energy system (both demand and supply side) in order to meet the demand for energy** — investment needs could also openly reflect the parallel transitions of buildings, industry and transport. Robust financing mechanisms are essential to support the substantial investment needs.
- As concerns phase-outs of internal combustion engine (ICE) cars, unless we can rapidly begin to renew the existing car fleet, **there is a considerable risk of prolonging the circulation of 'old' cars (ICE) on Europe's roads in 2040.**
- **Lifestyle changes present a major opportunity and a challenge, but should be seen as a key lever only as a result of cultural shifts, as a collective decision-making process in an organised society** (e.g. flying less, eating less meat, more teleworking, stable indoor temperature). The impacts though, directly and indirectly, are quite important.

*More details on the needed sectoral changes, the impacts as well as all **the EU27 national cards with selected key indicators** can be found in the **Technical Summary**. Selected aggregated EU27 data can be found in the **Key Figures section** presented next.*

KEY FIGURES

EU27 — Aggregated KPIs

2040 pathway (PatEx)						
Total energy use	**Unit**	**2015**	**2020**	**2030**	**2035**	**2040**
Primary energy consumption	**TWh**	15587	15586	9945	7026	5707
	Mtoe	1340	1340	855	604	491
Final energy consumption (FEC)	**TWh**	10830	10572	7974	6488	5354
	Mtoe	931	909	686	558	460
Renewable energy sources (RES) over FEC	**%**	16%	19%	52%	76%	104%
Electrification rate	**%**	26%	26%	43%	60%	80%
Total GHG emissions (incl. carbon removals)	**MtCO2e**	3300	3120	1110	373.2	-100.3
Carbon removals	**Unit**	**2015**	**2020**	**2030**	**2035**	**2040**
Land-use change (LULUCF)	**MtCO2e**	-311.0	-206.7	-418.9	-460.0	-518.9
Sectoral change						
Buildings	**Unit**	**2015**	**2020**	**2030**	**2035**	**2040**
Electrification rate (buildings)	**%**	34.5	34.9	47.4	53.9	60.0
Renovation rate	**annual %**	1.0	1.0	3.0	3.0	3.0
GHG emissions	**MtCO2e**	480.4	460.5	149.5	59.3	4.3
Industry	**Unit**	**2015**	**2020**	**2030**	**2035**	**2040**
Electrification rate (industry)	**%**	23.2%	24.0%	39.4%	48.4%	57.2%
Industrial production volume	**Mt**	1.18	1.21	1.13	1.08	1.04
GHG emissions	**MtCO2e**	647.6	611.4	355.5	212.8	131.4
Transport	**Unit**	**2015**	**2020**	**2030**	**2035**	**2040**
Electrification rate (transport)	**%**	1.8%	2.0%	18.6%	44.1%	79.4%
Passenger car fleet size	**million cars**	224.7	231.4	144.7	106.7	80.9
GHG emissions	**MtCO2e**	795.9	852.9	469.8	202.6	45.4

100% renewable energy system									
Installed capacities	Unit	2015	2020	PyPSA 2030	PatEx 2030	PyPSA 2035	PatEx 2035	PyPSA 2040	PatEx 2040
Solar	GW	85.0	136.0	541.0	723.3	1191.0	1040.0	1622.0	1360.0
Wind on-shore	GW	121.0	164.5	312.0	397.0	667.0	534.6	717.0	672.5
Wind off-shore	GW	5.9	14.5	72.0	127.0	180.0	188.0	194.0	249.0
Total solar & wind	GW	211.9	315.0	925.0	1247.3	2038.0	1762.6	2533.0	2281.5

Power and hydrogen (H2) grids	Unit	2015	2020	2030	2035	2040
Electricity transmission (AC)	GW	N/A	256.0	316.0	454.0	470.0
Electricity transmission (DC)	GW	N/A	18.0	88.0	180.0	198.0
New H2 pipeline	GW	N/A	N/A	3.0	34.0	34.0
Retrofitted H2 pipeline	GW	N/A	N/A	51.0	115.0	115.0

Flexibility, batteries and storage	Unit	2030	2035	2040
Home battery charger	GW	29.2	54.6	64.9
Home battery charger storage	GWh	97.5	194.3	233.0
Battery charger	GW	15.6	151.5	227.5
Battery charger	GWh	49.3	1082.3	1525.8
Haber-Bosch process (Ammonia)	GW	8.4	46.0	65.0
Ammonia store	GWh	3518.5	35735.5	48454.5
H2 fuel cells	GW	0.0	61.6	65.9
H2 electrolysis	GW	10.4	192.0	298.6
Pumped hydro storage	GW	47.6	47.6	47.6
H2 store	GWh	54.7	23728.1	31085.3

- More detailed information related to the sectors and levers of the PAC 2.0 scenario can be found in the Pathways Explorer link
- All relevant energy supply and infrastructure data for all countries can be retrieved from the PyPSA-Eur link

Note: *Includes EU25 (as Malta and Cyprus were not modelled with PyPSA-Eur) and 8 TYNDP countries.*