



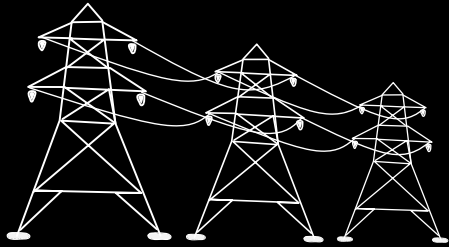
Report

May 2024

Wired for Climate Neutrality: A Paris Agreement Compatible (PAC) roadmap for power grids

PAC ROADMAP FOR POWER GRIDS

What we need according to PAC 2.0 scenario



ACHIEVING BY 2040

100% RES

in all sectors through decarbonising the EU's energy infrastructure by phasing out fossil fuels

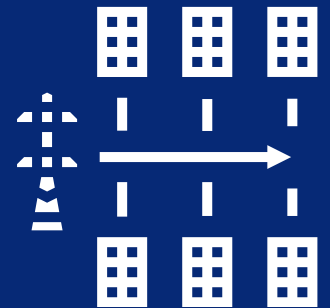
THE SCENARIO PROVIDES A PLAN FOR THE FUTURE EU ENERGY INFRASTRUCTURE

EU MEMBER STATES CAN COLLECTIVELY ACHIEVE A

51%

reduction in final energy consumption by 2040.

The PAC Scenario is developed by **civil society organisations** and sets out a roadmap for reaching this 2040 target, limiting global temperature rise to 1.5°C.



To achieve the transition, **citizen participation** and **nature protection** are needed.



€1 TRILLION

by 2030 can be the amount of direct co-benefits from investing in the Paris Agreement compatible energy demand reduction pathway.

GRID CAPACITY INCREASE

FOR TRANSMISSION NETWORK

47%

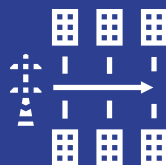
BY 2030

131%

BY 2035

144%

BY 2040



CROSS-BORDER TRANSMISSION

ADDITIONAL ELECTRICITY TRANSMISSION COMPARED TO THE CURRENT LEVELS

130 GW

BY 2030

394 GW

BY 2040

€302 BILLION

 IN 2030

€400 BILLION

 IN 2035

€411 BILLION

 IN 2040

ANNUAL GROSS INVESTMENT NEEDS

(INCLUDING TRANSMISSION, STORAGE AND ENERGY GENERATION)

Referring to EU25 (excluding Malta and Cyprus as they are not interconnected) and 12 TYNDP countries

The Paris Agreement Compatible (PAC) 2.0 scenario aims for climate-neutrality for the EU27 by 2040, with phase-outs of coal by 2030, fossil gas by 2035, and oil-based products by 2040, as well as of nuclear power by 2040.

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About

Climate Action Network (CAN) Europe and European Environmental Bureau (EEB) participate in the Paris Agreement Compatible (PAC) 2.0 project, as members of a wider consortium, 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, the infrastructural analysis of the PAC 2.0 project looks at a 100% renewable energy system at the EU27 using specialised open data (Pathways Explorer) and open source (Python for Power Systems Analysis, (PyPSA-Eur, a Sector-Coupled Open Optimisation Model of the European Energy System) software.

The scenario-building addresses the EU27, as a whole, and individual EU27 member states, built together with national experts and member organisations. A separate technical report provides the full PAC 2.0 scenario findings.

Methodological documentation: <https://can-pypsa-eur.readthedocs.io/en/latest/>

GitHub repository: <https://github.com/Climact/can-pypsa-eur>

Glossary

PAC Paris Agreement Compatible (referring to PAC 2.0 unless otherwise stated)

Units

GWh gigawatt-hours

MWh megawatt-hours

€/kWh euros per kilowatt-hour

€/MWh euros per megawatt-hour

GW gigawatt

Acronyms

AC Alternating current

DC Direct current

HVDC High-voltage direct current (used for long-distance power transmission)

BEV battery electric vehicle

DSF demand-side flexibility

DSM demand-side management

EV electric vehicle

CAPEX capital expenditure

OPEX operational expenditure

DSO Distribution system operator

TSO Transmission system operator

NRA National regulatory agency (or regulator)

CEF Connecting Europe Facility

PCI Project of Common Interest

PMI Project of Mutual Interest

TEN-E The Trans-European Networks for Energy

TYNDP Ten-Year Network Development Plan

NECP National Energy and Climate Plan(s)

LTS Long-term strategy

SEA Strategic Environmental Assessment

EIA Environmental Impact Assessment

Power grids for a +1.5 C compatible Europe

Aim of the brief

The aim of this joint policy brief to “wire the EU for climate neutrality - a Paris Agreement Compatible (PAC) roadmap for power grids”, authored by [Climate Action Network \(CAN\) Europe](#) and [the European Environmental Bureau \(EEB\)](#), is to identify the needed type of infrastructure and grid capacities necessary for a 100% renewable energy system (RES). It explores a pathway that aligns with achieving climate neutrality by 2040 across the EU27, and securing energy supply while remaining within the +1.5°C threshold.

An updated Paris Agreement Compatible (PAC) 2.0 scenario aims for climate-neutrality for the EU27 by 2040, with phase-outs of coal by 2030, fossil gas by 2035, and oil-based products by 2040, as well as of nuclear power by 2040. Aiming to enhance the EU's resilience, our pathway provides [numerous co-benefits](#) for Europe, also for minimising economic and social losses from climate change. It also illustrates a more resilient infrastructure, which acknowledges changing weather patterns and different climatic years.

The EU at climate crossroads

According to the [European Climate Risk assessment](#) published in March 2024 by the European Environment Agency, the risks are mounting. The average global temperature in the 12-month period between February 2023 and January 2024 exceeded pre-industrial levels by 1.5°C. **In 2023, the warmest year on record over more than 100,000 years globally**, temperatures were at 1.48°C above pre-industrial levels, with ocean temperature reaching new heights. **Europe is the fastest-warming continent; since the 1980s, warming on the continent was about twice the global rate.** Recent years have seen many long-time climate records broken. Europe is facing more and stronger climate hazards, including heat waves and prolonged droughts, heavy precipitation leading to flash flooding and sea level rise. Southern Europe is particularly vulnerable, facing considerable declines in rainfall and more severe droughts. These events, combined with environmental and social risk drivers, pose major challenges throughout Europe. When applying the scales of severity used in the European climate risk assessment, **several climate risks have already reached critical levels.**

The Paris Agreement Compatible scenario understands and aligns with the climate emergency. Concerning energy, it proposes a drastic shift in demand and supply, so as to avoid the worst impacts of a potential future due to inadequate action by remaining within the 1.5°C.

What is the Paris Agreement Compatible (PAC) scenario?

At its core, the PAC scenario - “Paris Agreement Compatible Scenarios for Energy Infrastructure” constructs a European-wide energy scenario aligned with the Paris Agreement’s objective to limit global warming to 1.5°C, which embodies the policy demands of civil society. In its second phase, the so-called PAC 2.0 project (with CAN Europe, RGI, EEB and REN21 as partners) disaggregates the EU27 scenario into the national level at each member-state with national experts and member organisations.

The scenario, developed by civil society organisations, shall guide the planning of European energy infrastructure, and help to ensure that we are building an infrastructure that is necessary for a future low-carbon Europe, as a renewables-based energy system.

The PAC scenario is guided by three major goals:

- A 65% reduction in greenhouse gas emissions by 2030
- Net-zero greenhouse gas emissions by 2040
- 100% renewables in Europe by 2040 in all sectors

Moreover, the PAC scenario aims for:

- At least 50% renewable energy share in gross final energy consumption in 2030 and 100% in 2040.
- At least 20% energy efficiency in 2030 (compared to 2020 Reference Scenario)
- An EU-wide coal phase out by 2030
- An EU-wide gas phase out by 2035 (power sector)
- An EU-wide phase out of fossil oil products by 2040
- A gradual nuclear phase-out by 2040
- An EU-wide phase out for sale of Internal Combustion Engine (ICE) cars, no later than 2035
- The use of hydrogen as domestically produced, renewable hydrogen (H2)

The PAC's unique pathway for climate neutrality by 2040

As a direction, the PAC 2.0 scenario assumes a drastic reduction of energy demand across all sectors (i.e. buildings, transport, industry, as well as helps show the contribution of lifestyle changes), while decarbonising the energy mix rapidly for the EU to reach 100% renewables by 2040.

To build a coherent picture, it is necessary to know how much electricity will be flowing in a 100% RES-based system, and the associated infrastructure requirements. Increasing capacities of wind and solar are complemented with electricity transmission, cross-border interconnectors, and associated storage (daily, weekly, and seasonal) in complementary roles.

Realising our pathway means shifts in infrastructural design that will also allow to maximise the gains of RES-based electrification, assisted by buildings, mobility, and industry.

What makes the PAC 2.0 pathway unique is in how it articulates the role of energy demand, with 100% RES capacities, and associated transmission needs. As an energy demand reduction scenario, it prioritises energy savings and efficiency as the main drivers of the transition. A benefit of such a scenario is in how it minimises the use of resources and materials.¹

100% renewable energy system - how much renewable energy is actually needed?

The infrastructural modelling of the PAC 2.0 pathway considers climate, energy and economic perspectives, in light of the civil society asks.

The PAC 2.0 scenario used two software tools that were connected in order to assume the same level of energy demand. The [Pathways Explorer](#) modelled demand and supply, without storage and transmission needs, through more than 200 different parameters across all demand sectors, with data openly available. After this, the [Python for Power System Analysis \(PyPSA-Eur\)](#) optimised the supply side primarily based on costs (and more constraints that were manually added e.g. emissions, diversification of renewables, etc), as an open source tool. Demand assumptions were derived directly from the Pathways Explorer.

1. Note: The energy and material inputs that are needed to build out a renewable energy system (such as the production of steel or transporting a wind turbine) are not a part of our analysis.

The table below summarises the projected renewables capacities for the EU27 for onshore wind, offshore wind and solar photovoltaics, in comparison to the current state of play for 2022, 2023, taking into account the cumulative capacities reported by the solar and wind industry. [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 onshore wind installed capacity of 224GW in 2022 and 238GW in 2023, and 30 GW of offshore wind capacity in 2022 and 34GW in 2023. All the results below should be assessed in conjunction with the proposed energy demand reduction pathway that the PAC assumes (more details below).

PAC 2.0 Solar & Wind capacities

Installed capacities per time horizon and per software. 2022 and 2023 wind and solar data were derived from Wind Europe and Solar Power Europe accordingly

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; PyPSA stands for Python for Power System Analysis;
Table: CAN Europe • Source: CAN Europe, Climact • Created with Datawrapper

Table 1: PAC 2.0 solar and wind capacities projections

Source: CAN Europe analysis

PAC 2.0 RES Installation Rates

Annual installation rates in Pathways Explorer and PyPSA, with 2023 as a reference

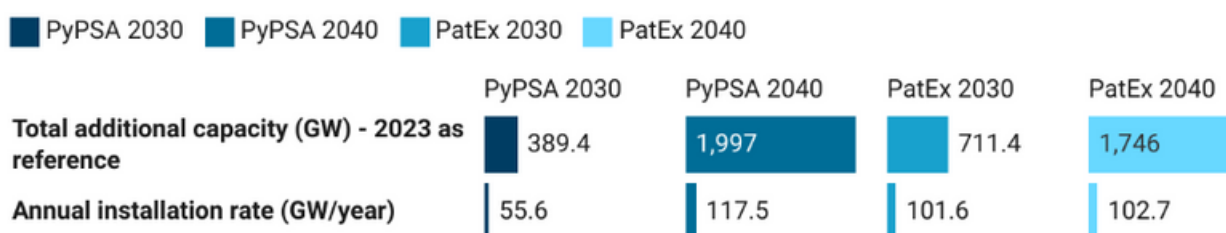


Chart: CAN Europe • Source: CAN Europe • Created with Datawrapper

Table 2: Total RES installed capacities and average annual deployment rates per time horizon

Source: CAN Europe analysis

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 the year 2023 as a reference.

As the PAC 2.0 scenario prioritises energy demand reduction across sectors, the above results also correspond to a drastic reduction of energy demand, achieving slightly more than -50% over the 2020-2040 period. It is important to keep in mind that each kilowatt-hour (kWh) that we fail to reduce on the demand side, we need to compensate by increasing supply, namely through installing additional solar and wind capacities.

BOX 1

Assessing the (modelling) differences in RES capacities

The PAC 2.0 Novelty

The Pathways Explorer's strength, as a tool, are in the comprehensive modelling of demand-side decarbonization measures; but it has limitations in modelling the supply side (flexibility and storage). PyPSA-Eur, on the other hand, is mainly oriented on robust optimization of energy supply infrastructure. For this reason, during the PAC scenario building, we combined the modelling tools. We modelled demand in the Pathways Explorer across all demand sectors (incl. energy supply), and then used these demand levels to assess the supply side (e.g. energy needs) with PyPSA-Eur for three different time horizons (2030, 2035 and 2040), under a 3-hour time resolution.

Modelling with Pathways Explorer

Specifically, the ambition when it comes to renewables capacities for solar and wind needs to be increased - by tripling annual deployment rates (as compared to the 2020-2022 average) - to reach almost 2,300 GW by 2040, with 1,360 GW of solar, 672 GW of onshore wind, and 249 GW of offshore wind, while reducing demand significantly. Using Pathways Explorer, the average annual deployment rate for wind and solar, as a cumulative capacity, is at the levels of 102GW per year, until 2030 and 2040.

Modelling with Python for Power Systems Analysis (PyPSA-Eur)

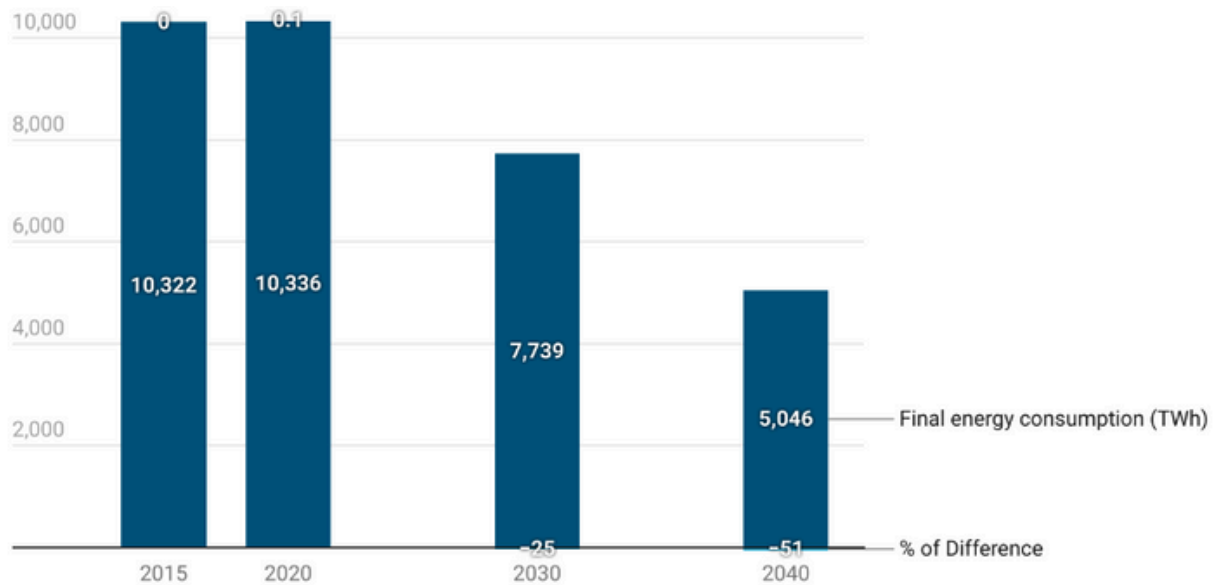
PyPSA-Eur is an open model dataset of the European energy system at the transmission network level that covers the full ENTSO-E area. [Using PyPSA-Eur](#), taking into account the demand from the Pathways Explorer, energy supply was optimised based on costs (i.e. both models assume a similar energy demand). Observing the PyPSA-Eur results, there are some deviations compared to Pathways Explorer, as expected. Our results are based on one climatic year (2013), and in further modelling, we recommend taking into account more varying climatic years.

After 2035, to sustain the energy system, when storage and hydrogen needs increase substantially, solar and wind onshore capacities also need to increase further. When using PyPSA-Eur, the obtained results for installed capacities in 2030 (with low storage and renewable hydrogen needs) are lower than in the Pathways Explorer by more than 300 GW (mainly due to the lower levels of solar). However, we observe the opposite for 2035 and 2040, when PyPSA-Eur suggests higher capacities than Pathways Explorer, as more than 2.5TW of installed RES capacity. The PyPSA-Eur results do not include the installed capacities of Malta and Cyprus. The above results focus on solar and wind technologies due to their focal role in the future energy system. Hydro, geothermal and other technologies (such as biomass, tidal) have a limited role.

Before 2030, the lack of storage means that the annual RES installation rate is a bit over 55 GW per year by 2030 (according to PyPSA-Eur). Then, after 2030, with a view to 2040, due to renewable hydrogen and ammonia production, as well as higher RES deployment, the annual renewables installation rates, i.e. wind and solar capacities shall reach an annual deployment rate of 117.5 GW.

PAC 2.0 Final Energy Consumption - EU 27

Visualization of the final energy consumption of the PAC 2.0 (TWh)



% of Difference using 2020 as a reference. PAC 2.0 achieves a 51% reduction of final energy consumption between 2020 and 2040.

Chart: CAN Europe • Source: Pathways Explorer/Climact & CAN Europe • Created with Datawrapper

Figure 1: PAC 2.0 final energy consumption for different time horizons

Source: CAN Europe analysis

Note: It does not include international aviation and marine, as well as industrial feedstock

According to the PAC 2.0 results, in terms of final energy consumption, a 25% reduction is achieved between 2020 and 2030, and over 20 years, a 51% reduction to meet climate neutrality by 2040. Such reduction could be achieved, through sectoral transformation, at each sector, as can be seen in [Pathways Explorer](#). Respectively, these also include some changes in lifestyles, such as consumption patterns (e.g. more car sharing, flying less, more teleworking, lower meat consumption), which should be viewed as a proposed direction in a collective manner. Demand-reduction pathways have specific advantages, because they lower resource needs, minimise spatial requirements, and address the challenge of increasing scarcities.

Power grids - without action, a hurdle for the energy transition

Electricity is the first sector that needs to decarbonize². To stay below the limit of the 1.5°C temperature increase, the energy transition must accelerate by deploying available technologies by 2030, ensuring cost-effectiveness within our remaining GHG budget.

For the EU to take decisive action on the climate crisis, it must increase attention to infrastructure needs to facilitate renewables deployment. At the moment, congested grids, connection queues and curtailment are increasing, underscoring the need to create more efficient electricity infrastructure. Creating climate-compatible infrastructure means upgrading existing and expanding new grid lines on the distribution and the transmission level. To assess related opportunities and barriers, it is imperative to understand the current state of play with power grids.

The condition of the grid in the EU27 presents a challenge in efforts to multiply renewables capacities and harness the flexibility potential. Already, the EC expects electricity consumption in the EU to increase by 15% by 2030 (compared to 2020), while the European Ten-Year Network Development Plan (TYNDP) scenarios project a +20-44% increase by 2040. According to ENTSO-E, the cross-border transmission capacity of today's power system, at 93 GW, must double by 2030. And, although the energy system is gradually becoming more decentralised, 40% of our distribution grids are already more than 40 years old. Overall, according to IEA's recent publication on grids, around half of the EU grids were built more than 20 years ago, approximately 20% between 10 and 20 years ago, and 30% of the current grids over the last ten years. If addressing ageing grids is one aspect, determining how much distribution and transmission grid will be needed is another important question.

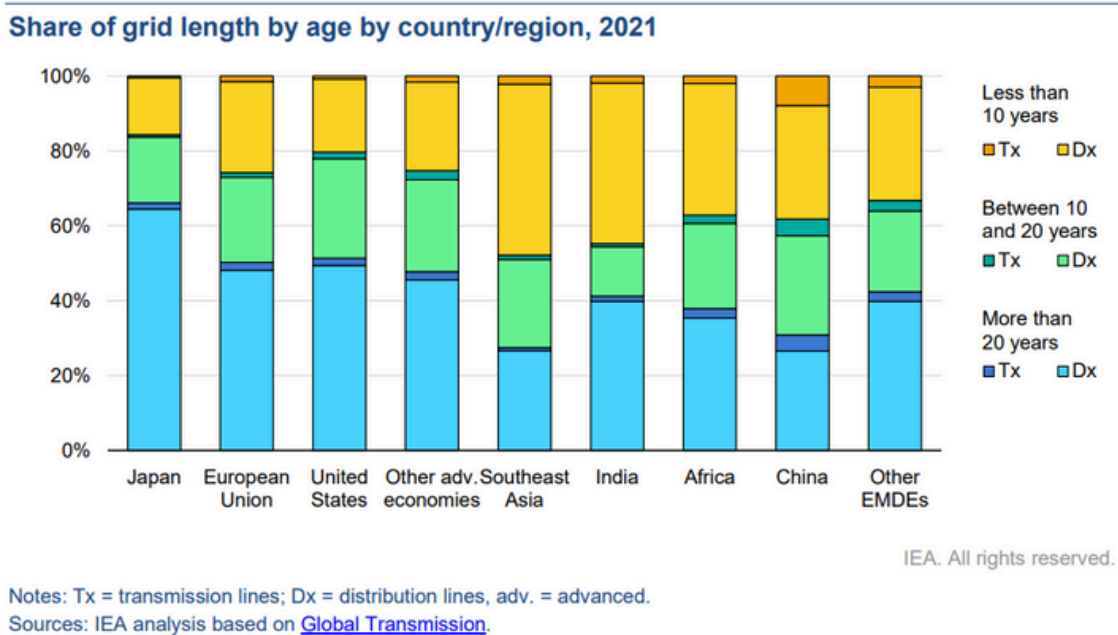


Figure 2: Grid length by age by country/region, 2021,

Source: IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris <https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions>, Licence: CC BY 4.0

2. Speed of technological transformations required in Europe to achieve different climate goals
Marta Victoria, Elisabeth Zeyen and Tom Brown, Joule 6, 1066–1086, May 18, 2022

For the EU27, the IEA assumes that the distribution grid would need to grow from 10.3 million kilometres in 2021 to 11 million kilometres (+6%) by 2030, and reach 14 million kilometres by 2050 (+35%). Ageing grids will need to be replaced, existing ones maintained, and substantial investment will be needed in new grid infrastructure, amounting up to €584 billion in investments until 2030.

Installed line length, transmission and distribution, by region in the Announced Pledges Scenario (million km)

	Transmission			Distribution			Total		
	2021	2030	2050	2021	2030	2050	2021	2030	2050
United States	0.5	0.6	1.0	11.1	11.5	15.2	11.6	12.1	16.1
European Union	0.5	0.6	0.9	10.3	11.0	14.0	10.8	11.7	14.9
Japan	0.04	0.04	0.05	1.3	1.3	1.7	1.4	1.4	1.8
Other advanced economies	0.5	0.6	1.0	6.9	8.0	13.7	7.4	8.5	14.7
Southeast Asia	0.2	0.3	0.8	4.7	6.3	11.9	4.9	6.6	12.7
India	0.5	0.7	1.7	11.3	14.0	25.6	11.8	14.7	27.2
Africa	0.3	0.4	1.1	3.9	5.0	14.0	4.2	5.3	15.0
China	1.6	2.4	3.7	7.8	12.3	27.6	9.4	14.8	31.4
Other EMDEs	1.2	1.5	2.5	14.4	16.8	30.0	15.6	18.3	32.5
World	5.3	7.2	12.7	71.7	86.1	153.7	77.1	93.4	166.4

IEA. CC BY 4.0.

Sources: IEA analysis and [Global Transmission](#).

Figure 3: Installed line length, transmission and distribution, by region in the Announced Pledges Scenario

Source: IEA (2023), Electricity Grids and Secure Energy Transitions, IEA, Paris <https://www.iea.org/reports/electricity-grids-and-secure-energy-transitions>, Licence: CC BY 4.0

The EU Action Plan for Grids (2023), which considers grids as a missing link, proposes seven measures to address some of the identified gaps:

1. Accelerating the implementation of European Projects of Common Interests (PCIs) and developing new projects.
2. Improving long-term grid planning for a higher share of renewables and increased electrification.
3. Regulatory incentives for grid build-out.
4. Incentives for a better usage of grids.
5. Improved access to finance.
6. Accelerating deployment through faster permitting and public engagement.
7. Strengthening grid supply chains.

It also provides the civil society the opportunity to become a partner in these efforts, with a Pact for Engagement.

However, the Action Plan is less vocal on other important design aspects for future energy infrastructure. Besides addressing the power grid, infrastructure planning will have to dedicate attention for repurposing and decommissioning infrastructures, and planning how to phase out remaining fossil fuels. It will also be necessary to consider what will happen to infrastructures that will no longer be needed in Europe, well in advance.

Climate ambition must also be elevated in the TYNDP³, as a plan, which has a focal role in the development of future⁴ energy infrastructure in Europe. The TYNDP acts as a basis for the selection of joint European Projects of Common Interest (PCI) and Projects of Mutual Interest (PMI), for the European policy goals to be met. Additionally, more detailed plans will be needed on investment needs, what share (%) of commissioned grids should be new, and what share (%) of them should be modernised, assisted by adequate implementation of the electricity market design (EMD) reforms introduced in recent years.

At the national level, the national regulators (NRAs), transmission system operators (TSOs), and distribution system operators (DSOs) need to ensure that the energy transition is reflected in their respective network development plans.

BOX 2

Design of common European energy infrastructure

As an assessment of pan-European energy infrastructure projects in the EU, the Ten-Year Network Development Plan (TYNDP) plays an essential role in the European Commission's energy strategy. Updated in two-year cycles, the TYNDP assists the Commission to identify and select key infrastructure projects to be developed.

As a result of the two-year cycle, Projects of Common Interest (PCIs) and Projects of Mutual Interest (PMIs) are selected, as cross-border infrastructure, to benefit from accelerated planning and permitting, and funding especially from the Connecting Europe Facility (CEF).

Guided by the Trans-European Networks for Energy ('TEN-E') regulation, this infrastructure should promote renewables deployment so the EU can meet its climate and energy targets, and stay within +1.5 C degrees.

3. European Scientific Advisory Board on Climate Change, 2023. Towards a decarbonised and climate-resilient EU energy infrastructure: recommendations on an energy system-wide cost-benefit analysis.

<https://climate-advisory-board.europa.eu/reports-and-publications/towards-a-decarbonised-and-climate-resilient-eu-energy-infrastructure-recommendations-on-an-energy-system-wide-cost-benefit-analysis>

The Advisory Board found that the ten-year network development plan (TYNDP) process does not sufficiently address the transformational changes and rapid reductions in greenhouse gas emissions necessary to achieve the EU's climate neutrality and climate resilience targets by 2050. This observation pertains to the entire TYNDP process, in particular the scenario development, system needs assessment and cost-benefit analysis (CBA), and the subsequent selection of Projects of Common Interest (PCI) and Projects of Mutual Interest (PMI).

PAC 2.0 pathway for electricity infrastructure

With a view to the 2040 pathway for climate neutrality in Europe, it will be necessary to outline the new systemic principles and identify associated timelines, as Europe moves towards a considerably more flexible energy system, while also minimising unnecessary infrastructures. For the reasons below, PAC 2.0 pathway has a high potential to maximise social acceptance among citizens.

Related necessities derive from specific advantages of our proposed demand-reduction pathway:

- The more we reduce energy demand, the less effort would be needed on the *supply side* to produce the necessary energy to meet this demand.
- PAC 2.0 pathway lowers the needed capacities for renewables, and also the capacities for grids, in turn minimising material requirements, lowering necessary land use (for RES areas, cables, sub-stations), as well as reducing the total energy system costs.
- Many of the PAC 2.0 measures also are about adopting, advancing and implementing the principles of circularity, in a far more concrete way.
- The PAC 2.0 trajectory presents the highest co-benefits for societies - at least € 1 trillion by 2030 - while minimising economic, social and environmental losses, with an aim to align with the 1.5C, minimising climate impacts, as raised in the "[Paris Pact Payoff - Speeding up the green transition for socio-economic co-benefits](#)" report.

OUR KEY FINDINGS

Higher climate ambition in Europe that is in line with the Paris Agreement objectives is possible and the pathway to make this happen is beneficial in absolute terms

- 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.

Figure 4: The key socio-economic benefits (as co-benefits) stemming from accelerated climate action **CAN Europe (2024)** - Paris Pact Payoff: Speeding up the green transition for socio-economic co-benefits.

Opportunities for a Paris Agreement compatible power grid

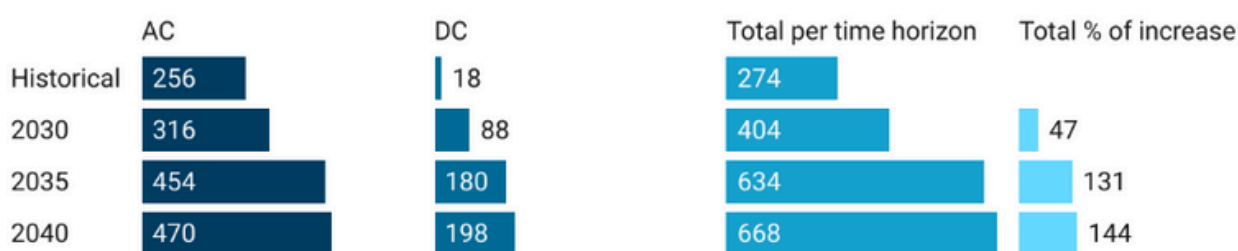
Concerning the role of power grids in meeting the Paris Agreement Compatible 2.0 pathway, our focus is on transmission capacities. Existing grids must be improved and considerably more grids will be necessary, as enhanced transmission capacities that accelerate RES deployment and their integration, and address storage needs. Finally, electricity and renewables-based hydrogen transmission need to be well integrated.

Transmission for Europe - less isolated, more connected

According to the PAC 2.0 results, as compared to 2021, the European power grid's transmission capacity (EU25 & 12 TYNDP countries) would need to grow by at least +47% by 2030, reaching 404 GW. Furthermore, reaching a 634 GW grid capacity by 2035 means an increase of +131%. We observe a substantial increase in direct current (DC) cables by 2035 that transfer renewable energy around an increasingly electrified Europe. Finally, grids would need to reach 668 GW of capacity by 2040, indicating a total increase of +144% in their capacity, compared to current levels.

PAC 2.0 Transmission Capacities (GW)

AC and DC transmission cables capacity - EU27



AC: Alternate Current DC: Direct Current

Chart: CAN Europe • Source: Climact - CAN Europe • Created with Datawrapper

Table 3: Transmission grid capacities for 2030, 2035, and 2040 for the EU27 in PAC 2.0 scenario (compared to 2021), expressed in GW.

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, as thermal power plants are phased out, also to remove fossil gas out of the power sector by 2035. Overall, transmission expansion is the least affected by cost uncertainty. So, from a cost-optimisation perspective, it appears as a no regret action. The uptake of RES capacities can be maximised only with a robust grid, and will be undermined without grid adjustments. At the moment, planned network developments are 'out of step' with the reality of the energy transition in a number of countries.

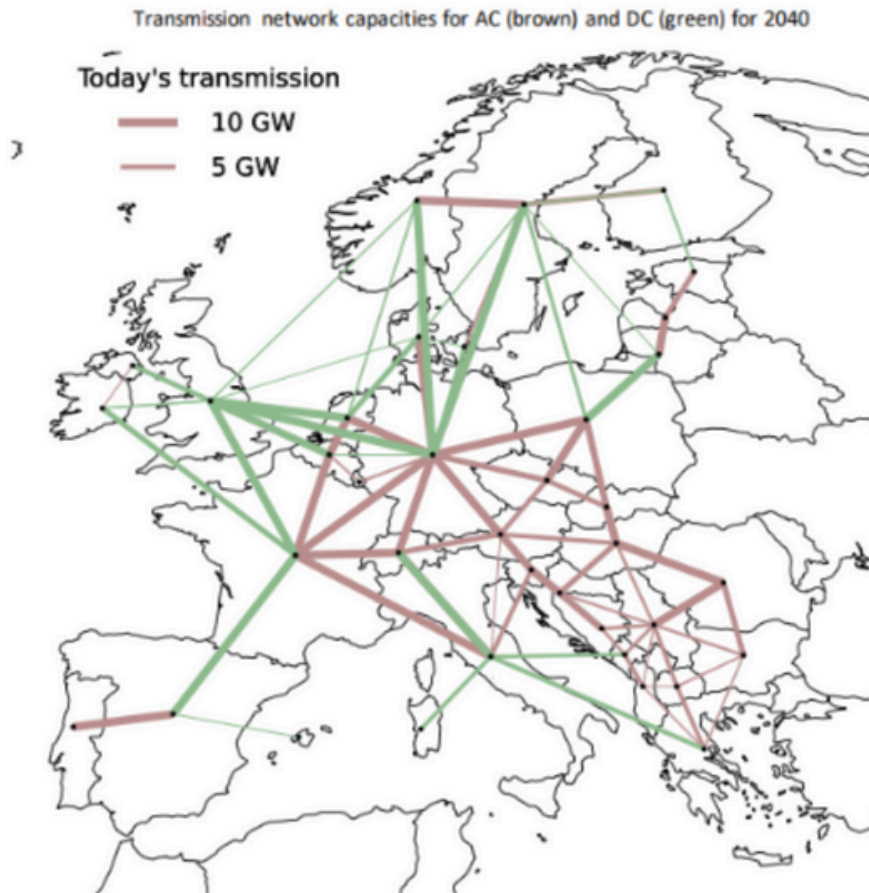


Figure 5: Transmission network capacities for AC and DC cables, in 2040
Source: CAN Europe, Climact, PyPSA-Eur analysis

Cross-border interconnection - cooperation over competition

More grid interconnection between European countries assists countries 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 also create a more solid backbone in Eastern Europe.

The importance of cross-border transmission can also be understood by the following trade-off. Isolating a country will lead to an increase in storage (and renewable) capacity, whereas by connecting countries with more transmission links or interconnections, storage becomes less necessary. Additionally, inadequate levels of transmission would lead to higher H2 storage needs and most importantly, a bottleneck in renewables deployment rate, due to lack of electrical space or even costly curtailments.

Total transmission capacities per time horizon (GW)

Includes both AC and DC capacities, figures are cumulative per time horizon

Country	Total historical (GW)	Total 2030 (GW)	Total 2035 (GW)	Total 2040 (GW)
AT	36	41	46	47
BE	17	29	43	46
BG	12	12	14	14
CZ	22	22	27	28
DE	89	108	169	175
DK	11	13	29	31
EE	3	3	17	17
ES	22	74	77	88
FI	6	6	33	33
FR	43	114	168	184
GR	7	10	19	20
HR	20	20	28	29
HU	20	26	37	39
IE	2	3	17	17
IT	18	34	58	58
LT	7	7	16	16
LU	4	5	7	8
LV	6	6	20	20
NL	22	31	47	53
PL	17	17	33	34
PT	15	15	15	15
RO	15	17	21	22
SE	18	19	69	70
SI	12	21	26	26
SK	13	17	26	26

Table: CAN Europe • Source: CAN Europe, Infrastructure analysis (PyPSA) • Created with Datawrapper

Table 4: National transmission capacities break-down, per time horizon

Source: CAN Europe analysis, PyPSA results

Note 1: The connections between nodes of the same country are not considered in this table; Malta and Cyprus are not part of the calculation.

Note 2: The interconnection capacity takes into account also non-EU countries (like Great-Britain and Norway).

Example: If Germany is connected to Belgium with a 10GW interconnector, Belgium is also connected to Germany through a 10GW interconnector. This capacity is attributed to both countries, as needed capacity.

Flexibility - a more flexible system brings more benefits

Flexibility means a more flexible power system, and it also means more interactions, and more flexible demands in the key sectors that consume energy.

At transmission level, flexibility helps our PAC 2.0 pathway for integrating variable renewable energy, so that demand and supply match at all times, and also in encouraging efficient expansion. Alongside efficiencies and cable pooling, the various modes of flexibility, also demand-side flexibility, can help alleviate growing pressures on the grid capacity, and to further optimise the use of existing infrastructures.

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

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 costs with 14% cost savings.⁴
- Heat-pumps, domestic hot water demand and storage (increase local PV self-consumption by 21%-26%) as flexibility options in buildings.⁵
- Harnessing the demand response of electricity, heating and cooling will reduce a need to run expensive power plants, especially 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 also 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*, Volume 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*, Volume 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 to replace needs for large utility-scale batteries. This is of particular interest, as 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 the IEA also recently suggested.⁶ This might also make more economic sense.
- Much of the demand-side management (DSM) benefit from battery EVs can be achieved with only 25% of the total fleet participating, leading to -10% lower system costs. If all EVs were to participate, the system costs would be reduced by -14%.
- 50% of the fleet (constant) can totally replace batteries. In other words, a future energy system that benefits from an electrified fleet can also be smaller than today's fleet.
- Controlled charging is the most important flexibility option, given the size of the fleet potentially available in the future. Charge control allows the charging of an electric vehicle, with real time control, to be postponed during times of peak demand. Additionally, the vehicle user and the power company can better track a vehicle's usage and performance.

The PAC scenario focuses on car-sharing and electrified transport to meet our transport needs: the (existing) passenger car fleet is reduced by approximately -65% until 2040, still covering needed transport demands, due to a higher utilisation rate of the electrified, reduced fleet, and an increase in active modes and public transportation.

- Even with 35% of the existing fleet size, we could already lower the costs by -14%.^{7 8}

Electric vehicles as batteries offer new storage capacity. In a future two-way energy system, with vehicle-to-grid adoption, thousands of EVs can act as a large, distributed energy system, as a service to the electricity grid, working in unison.

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

7. Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable European energy system, Brown, T., et al., Energy, 160, 2018, 720-739 <https://doi.org/10.1016/j.energy.2018.06.222>

8. The role of storage technologies throughout the decarbonisation of the sector-coupled European energy system, Victoria, M., et al., Energy Conversion and Management, 201, 2019, 119777. <https://doi.org/10.1016/j.enconman.2019.111977>

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

- Although flexibility is primarily feasible at selected industries, especially in these industries, it should be encouraged, given the efficiency of this option.
- For a plant operator, load shifting, which moves electricity consumption to a different time, with the same consumption, can reduce electricity costs by about 5%.⁹

Enablers like digitalisation, market signals and electricity market reforms, as widespread by 2040, can assist in these flexibility measures to be taken up, while catalysing further innovative approaches like vehicle-to-grid. The combined deployment of distributed solar PV, battery electric vehicles and domestic heat pumps could also decrease the need to expand distribution networks. If new innovations that reward flexibility are expedited, they would likely assist supportive lifestyles changes, and accelerate phase-outs.

Short-term storage

The role of storage becomes increasingly crucial, when the use of fossil fuels drops significantly. We illustrate the growing role of storage through home batteries, utility-scale batteries, and pumped hydro storage (PHS), complemented with the use of hydrogen (H2) as a system back-up. Long-term thermal storages or other future storage technologies are not included.

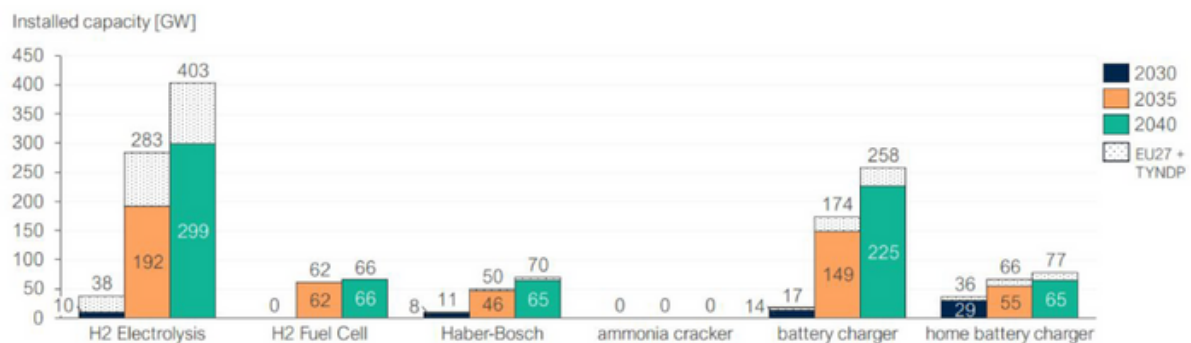


Figure 5. Batteries see an important uptake with the phase-out of fossil fuels, supplemented by the use of domestically produced renewable H2.

Source: CAN Europe, Climact, PyPSA analysis

9. Comparison of the Effects of Industrial Demand Side Management and Other Flexibilities on the Performance of the Energy System, Nebel, A., et al., *Energies*, 13, 2020, 4448. <https://doi.org/10.3390/en13174448>

In the PAC 2.0 pathway, home battery chargers reach 36 GW in 2030, 55 GW in 2035 and 66 GW in 2040 in the EU27. Battery chargers, as utility scale-batteries, 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. Pumped hydro storage (PHS), able to respond to demand and generation changes within minutes, is anticipated to have a role of 48 GW across 2030, 2035 and 2040 for EU27.

Short-term storage refers to daily storage needs, such as batteries, directly correlated with solar due to the daily fluctuation. Batteries will be used for the daily storage of electricity primarily to compensate for solar production at night time. After 2030, some H2 will be consumed at night, although its weak system efficiency should be taken into consideration.

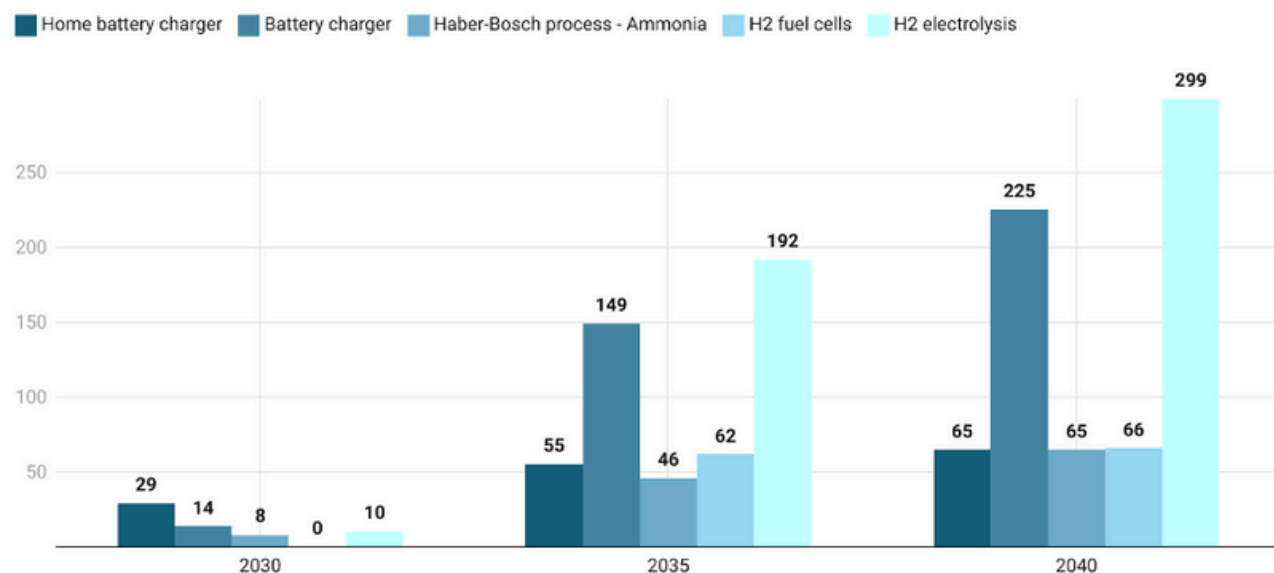
Long-term, seasonal storage

Long-term storage refers to seasonal storage needs, increasing from 2035 onwards.¹⁰

Ammonia also plays a role in long-term storage. The use of green ammonia will reach 46GW in 2035 and 65GW in 2040. 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 66GW by 2040. All in all, H2 fuel cells will reach around one fourth of battery capacities. H2 electrolysis capacities will grow from 10GW in 2030, to 20-fold to 192 GW in 2035 and 30-fold at 299GW in 2040.

H2, batteries and ammonia capacities needed

All values are in Gigawatts (GW)



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

Chart: CAN Europe • Source: CAN Europe • Created with Datawrapper

Figure 6: PAC 2.0 H2, batteries and ammonia capacities (GW) for different time horizons

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.

Long-term storage, such as H2, is highly correlated with wind, due to the longer period of fluctuation (to substitute fossil gas turbines). During prolonged periods with low production, for instance in winter periods when wind production is low, H2 storage acts as a back-up to support the energy supply. This means that the use of H2 for storage purposes has to be properly sized. Furthermore, in light of also other H2 demands and the energy cost of producing it, the uses of H2 have to be very carefully prioritised.

Minimising annual energy system costs

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 can be anticipated to be. Along the way in the modelling, a variety of near-optimal scenarios, comparable in terms of system cost, were noticed.

A key shift in moving into a 100% RES system is a shift from fuel costs, as operational expenditure (OPEX) into capital expenditure (CAPEX). As fossil fuel use drastically decreases, fuel costs practically disappear in the 2030s. Of any remaining operational expenditure, 99% will stem from nuclear, onshore wind and biomass. In terms of maintaining the energy system, capital costs will mostly derive from the use of wind (36.1%), solar (18.9%), flexibility (15%) and transmission (13.8%). Overall, annual gross investment needs in future energy infrastructure (including RES capacities, transmission, flexibility, with storages) should amount to €302 billion in 2030, €400 billion in 2035 and €411 billion in 2040, in return, providing us with a substantial return on investment.

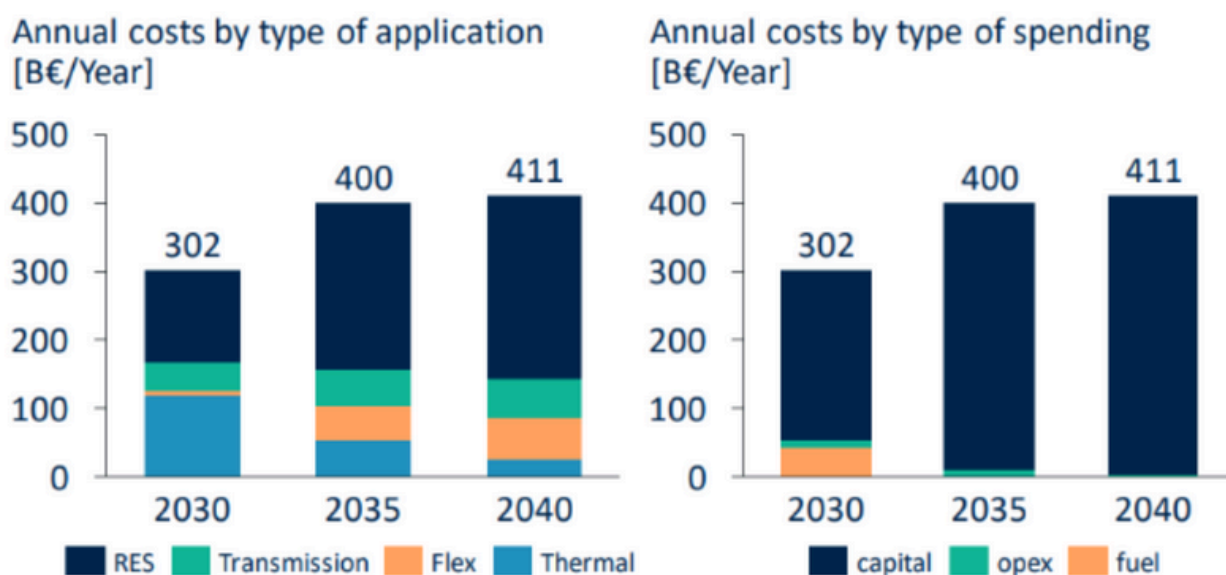


Figure 8: Annualised energy system costs in PAC 2.0 scenario by type of application and by type of spending / Gross investment needs - Supply side

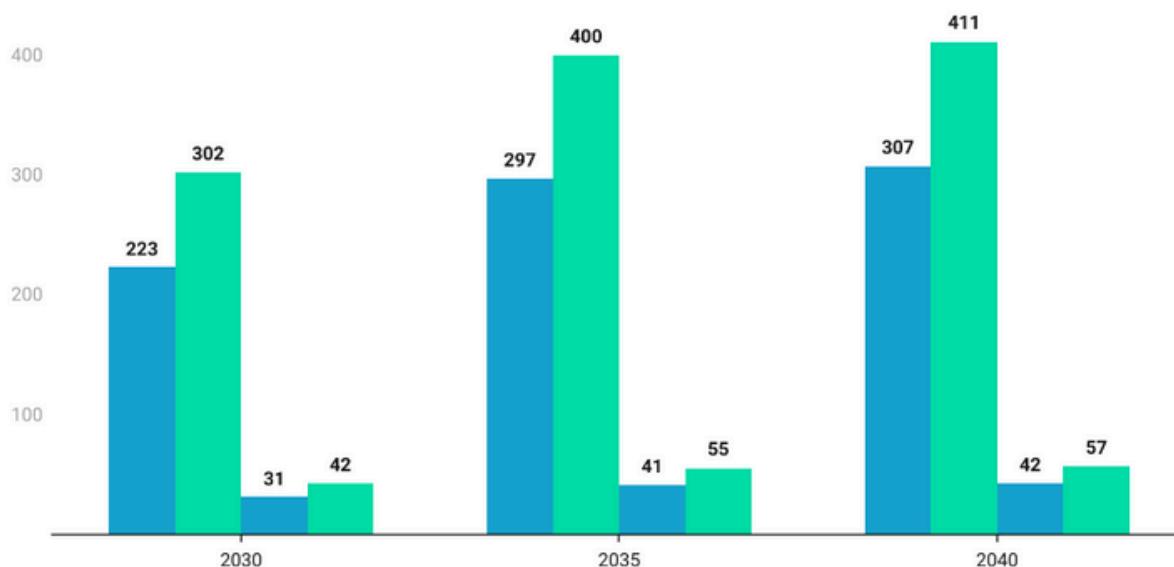
Source: Climact, CAN Europe analysis

Note: Refers to EU25 member states (excl. Malta and Cyprus) + 12 TYNDP countries.

Gross investment needs and transmission costs

Annualised energy system costs in PAC 2.0 scenario - Supply side only

■ Gross investment needs (EU25, billion Euros)
 ■ Gross investment needs (EU25 & TYNDP, billion Euros)
 ■ Transmission costs (EU25, billion Euros)
 ■ Transmission costs (EU25 & TYNDP, billion Euros)



Includes generators, transmission and storage. Malta and Cyprus are not included.

Chart: CAN Europe • Source: Climact, CAN Europe • Created with Datawrapper

Figure 9: Annualised gross investment needs and transmission costs in PAC 2.0 scenario per different time horizons - Supply side only

Source: CAN Europe analysis, based on PyPSA-Eur results (Climact)

Note: Blue colour refers to EU-25 member states (excl. Malta and Cyprus) - The amount of investments in transmission grids corresponds to the minimum level of investments needed, due to model limitations (one node per country), leading to underestimation of cross-border needs.

From theory to (best) practice

The technical needs have been described in the previous sections of this report. One important element and question is how this implementation should happen. At the same time, the implementation process should facilitate the accelerated energy transition that is needed, but also to realise it in a nature-positive and nature-friendly way, through an inclusive, open, transparent and participatory process for citizens.

Grid expansion projects are associated with a high risk of delays

Power grid project development typically goes through three phases, comprising planning, permitting and construction. Delays are frequently encountered in each phase, especially for high-voltage interconnections, which add to the already long lead times associated with these projects.

In the planning phase, infrastructure projects, regardless of their nature, can encounter financial challenges depending on the business model they rely on. Power transmission and distribution projects, for instance, often operate within a regulated assets business model that imposes controls on revenues and investment returns. Several developed economies have established mechanisms to support the financing of such projects (whereas emerging markets often face obstacles due to the high cost of capital and struggles in attracting private investment).

Unlike local projects for wind farms and solar PV systems, power grid projects often involve multiple authorities and jurisdictions along their entire route, which all need to review and accept the related plans before granting approval. Route plans and reports, feasibility studies and soil reports must be prepared, conditions and specifications must be evaluated, and stakeholders involved over the entire planned path for the infrastructure. **For instance, the construction of the 340 km long Ultrahigh Voltage Direct Current line in Germany requires around 13 500 permits.** Significant delays can result from complexities in the permitting procedure, such as overloaded staff members at permitting agencies, flawed government agency review processes, subjective interpretation or insufficient review of relevant regulations by government officials, complex land use change requirements, and estimation errors. In Europe, over a quarter¹¹ of electricity projects of common interest (PCIs) are subject to delays, most frequently due to permit granting.

11. See ACER's 2023 report on the progress of PCIs, p. 14. Accessible [here](#).

Societal participation

Similar to renewable energy projects, citizen consultation and involvement are crucial to prevent bottlenecks in energy infrastructure expansion. Without societal support, lead times can significantly increase, exacerbated by the absence of consensus among political parties and interest groups on long-term goals and a strategic vision for energy infrastructure.

Opposition from groups living close to the energy infrastructure developments is frequently described in the literature as the NIMBY (Not In My Back Yard) response. That is, while someone may enjoy the benefits or the idea of new infrastructure from a distance, they are opposed to bearing the costs of having this infrastructure in their neighbourhood. These reactions to proposed developments and the resulting public opposition dynamics depend on a number of factors like residents' perceptions of the negative impacts of the development.¹² These could include the effects of new networks on the environment, landscape, tourism, health (the effects of electric and magnetic fields) or property prices. Importantly, such concerns can lead to conflicts and legal challenges, significantly slowing the permitting and realisation of electricity infrastructure.

In such cases, it may become necessary to reassess and replan the route, and give consideration to the use of undergrounding of some sections, essentially restarting the entire process and work involved. This is why public participation and stakeholder engagement, or the lack of those, are critical for the successful and timely implementation of network expansion projects.

It is essential that the public are given early and meaningful opportunities to express their views and influence both the planning and approval processes for network development projects. Clear and transparent information on proposed projects and their benefits should be proactively made available to the public at an early stage of the planning process. When all options are still open, this will enable local communities and the wider civil society (including environmental NGOs, academics, local residents and businesses, representatives of indigenous communities) to engage constructively and also to improve proposed plans and projects. Transboundary Strategic Environmental Assessments (SEAs) are essential to ensure cross-border coordination, and are particularly important for interconnections.

12. According to ENTSO-E, the most discussed issues driving public opposition include the visual aspects, human and animal health, audible noise and biodiversity.

Public participation through appropriate communication, consultation and negotiation can help identify the right project design features and routes where alternatives are available. Importantly, this will increase certainty at the permitting level by facilitating screening decisions, enabling more rapid Environmental Impact Assessments (EIAs), and in guiding project developers on what mitigation measures need to be taken. Proper and transparent public participation can also speed up project implementation. When environmental and social concerns, including potential legal issues, are addressed early in the process, with public consultations that inform the design and siting of grid and utility-scale projects, this can dramatically reduce the likelihood of later administrative or judicial challenges.

There is a need for closer cooperation between competent authorities (and in particular single points of contact) and project developers to facilitate the availability of timely and easily accessible information to all interested parties.

Steps should be taken to involve local authorities, encourage the creation of citizens' assemblies and to channel the debate through open, science-based stakeholder dialogue in platforms with clear gender quotas to ensure inclusiveness. Such institutions can play a mediating role¹³ between public authorities, project developers and conservation organisations. Their role is to find solutions that make energy infrastructure development more environmentally-friendly and increase local support - such as tender criteria that award points for citizen participation. All in all, it is necessary to enhance the legitimacy of projects, shorten development times and reduce the risk of lengthy legal challenges.

13. See e.g. the initiative "[West Coast Line: Planning in Dialogue](#)", a best practice example where the government of Schleswig-Holstein and the TSO, TenneT, developed an informal dialogue procedure for the realisation of a new transmission line along Northern Germany's West coast, realised in 2013. Design and technology options were discussed with residents, municipalities and NGOs before the permitting phase began. The initiative included a citizens' dialogue - moderated by the environmental NGO Environmental Action Germany (DUH) - a planning dialogue, and a plan approval procedure.

BOX 4

Local disputes can hold up key projects

Suedlink is a high-voltage direct-current transmission line designed to link northern and southern Germany. The project is expected to have a combined transmission capacity of 4GW, making it strategically important, as a link for the large offshore generation capacity in the North Sea to the industrial clusters in the southern part of the country.

The project was proposed by the German government as early as 2013 through the Network Expansion Acceleration Act (NABEG), but construction would not start before 2023 due to numerous disputes and **local opposition dynamics that caused significant delays during the permitting phase**. In addition to public health concerns raised by several citizens' initiatives, mainly in Bavaria, issues related to the impact of the new line on the soil and the expected vibrations have been raised. Following opposition in Bavaria, a significant section of the line will run underground, instead of resting on pylons, which add considerably to the cost and technical challenge of realising the project.

This and other examples (see also the case of the "Ventilus" high-voltage project in West Flanders) show that local opposition and consequent legal disputes can severely hamper the development of key projects needed to connect significant generation capacity to European electricity consumers. **Early and meaningful public information campaigns, dialogue initiatives and consultations** need to be put in place to address these risks and improve the capacity of civil society to engage proactively, rather than reactively, in grid planning.

Public opposition remains a significant barrier to grid expansion. This could hamper the overall penetration of renewables - if generation capacity comes online, but grid capacity remains limited. Even local delays in grid projects could have significant EU-wide impacts, as bottlenecks that affect the ability of EU countries to share their renewable energy production. As with environmental issues, however, specific sensitivities can be addressed and conflicts prevented or resolved through early and effective public participation tools and campaigns, with the aim of:

- Clearly explaining the benefits and need for new grid developments at the outset of the planning process. At the same time, highlighting existing policies to mitigate potential impacts is essential.

- Engaging in inclusive and proactive consultation with neighbouring communities. This ensures that all segments of society, especially those historically underrepresented in energy planning, are involved and that their perspectives are considered.
- Providing comprehensive and transparent information about plans and projects during consultations. It is important that public feedback influences siting and design decisions as much as possible. This approach not only minimises legal disputes but also speeds up project implementation.
- Developing stakeholder dialogue platforms that involve local authorities and environmental NGOs. These platforms should be used to proactively address local issues. By ensuring that the concerns of all relevant stakeholders are voiced, collaborative and consensual solutions can be developed.

Grid expansion requires sound environmental planning

The construction of new electricity grid infrastructure, such as power lines and substations, can **fragment habitats and disrupt ecosystems**¹⁴ if poorly planned and managed. The most known effects of electricity infrastructure are those related to their direct **interactions with wildlife**, as they are estimated to cause death or injury to several species of birds and other animals, including mammals, through electrocution and collision with wires. These hazards impact mortality rates across a wide range of species - particularly true of large bird of prey species such as eagles and hawks. Of particular concern is the impact on **endangered species** that are already considered vulnerable due to their poor conservation status. Wildlife interactions with power lines - especially electrocution, but also nesting, as power lines may influence **demographic variations** of ground-nesting bird species in their vicinity such as by reducing breeding density - also represent a problem for electricity companies and can be costly and disruptive, causing power outages, equipment damage and fires. It is therefore also in the interest of companies to avoid negative interactions between power lines and biodiversity.

The construction and maintenance of above-ground power lines requires the clearing of large areas of land and the removal of native trees. This process disrupts local ecosystems, resulting again in **habitat loss and fragmentation**. Traditionally, TSOs have used vegetation clearing as the main method of removing trees that naturally regrow in power line corridors, but this is not sustainable from either an operational or an environmental perspective.

14. Habitat loss and disturbance refers to the removal or degradation of natural habitat. In terrestrial ecosystems, this primarily occurs through vegetation clearing and bulk earth works during construction. This fragmentation can impede the movement of species, disrupt breeding patterns and increase the risk of habitat loss and degradation. Habitat disturbances caused by vegetation clearing and earth works during construction can also facilitate the establishment and spread of Alien Invasive Species (AIS). Alien plant infestations can spread exponentially, suppressing or replacing indigenous vegetation. This may impact ecological integrity and functioning and terrestrial biodiversity.

Adverse effects of electricity infrastructure on wildlife and wider ecosystems can occur wherever power lines are poorly planned or lack appropriate design and construction features. If not appropriately tackled, this risks becoming a **major obstacle to infrastructure development**, particularly as grid extensions will be increasingly required in rural landscapes. Risk analysis, prevention and minimisation of impacts on local ecosystems and biodiversity should therefore be important aspects of the electricity grid throughout the project life cycle (planning, permitting, construction, operation and decommissioning).

Fortunately, a **mitigation hierarchy** (i.e. avoid, reduce, mitigate, compensate) **and measures** exist. For example, the use of accurate and frequently updated bird presence data can enable the creation of alternative network sites that **avoid sensitive habitats**. This data also facilitates the identification of areas where bird-friendly features and insulation should be installed to reduce the risk of electrocution, as well as the addition of visible markers to reduce collision incidents. When technically viable, the risk can be completely eliminated by burying power lines underground.

Furthermore, **Integrated Vegetation Management (IVM)** is a method of maintaining vegetation under power lines that focuses on ecological balance while removing plants that pose a safety risk. This includes the selective removal of fast-growing trees and invasive species, while encouraging the creation of new habitats through native vegetation, promoting biodiversity and stability.

BOX 5

Pact for Engagement

Following the publication of its "EU Action Plan for Grids", as a Communication, the Commission launched a Pact for Engagement to ensure early, regular and meaningful stakeholder involvement in grid development. The Pact aims to bring together representatives of the electricity sector **to raise public awareness of the crucial role of grids** in accelerating the transition to clean energy. It calls on EU countries, National Regulatory Authorities (NRAs), project developers and civil society to work together to ensure early and regular public participation in grid development projects and to take into account the **views, ideas or concerns of local communities**.

The Pact is based on **five pillars**:

- Design and implementation of national and European **communication activities** on the key role of transmission and distribution networks as enablers of the energy transition;
- A joint **cooperation effort between national and local authorities** to ensure effective implementation of grid and renewable energy project permitting rules and best practices adopted and/or recommended at local, national and EU level;

- A commitment by Member States to increase their in order to accelerate the **implementation of PCIs**, involving TSOs and project promoters as well as national regulators and stakeholders;
- An open dialogue between ministries, regulators and transmission and distribution system operators on **appropriate regulatory support** for early, regular and meaningful stakeholder engagement activities, based on dedicated stakeholder engagement chapters accompanying network investment plans;
- The provision of the necessary **organisational conditions** for all parties involved in authorisation or stakeholder engagement processes, in line with the significant needs for network development.

The Commission will work with the parties to the Pact for Engagement through various network-related **cooperation platforms**. These include events such as the PCI Energy Days, the Energy Infrastructure Forum (also known as the Copenhagen Forum) and the National Competent Authorities Platform (NCA Platform). The aim is to strengthen the implementation of the five pillars of the Pact. The Commission will also use these platforms to **monitor the progress** of these initiatives and promote the exchange of best practices.

Adaptability and a concern for time delays

Europe will have to equip its infrastructure planning machinery that balances a long-term view and adaptability. Adding new infrastructure, and their operations, are essential to the infrastructural equation.

With a view to the lifetime foreseen for infrastructure, from planning to operating stage, for several decades, Europe has not upgraded its energy infrastructure fast enough. Realising a single interconnector can take 10 years altogether, as was the case of a power transmission line between Sweden and Finland, in Northern Europe. Different infrastructure planning streams are not yet fully aligned, and call for a better alignment of local, national, regional and European objectives.

Plans have to be prepared for phase-outs of fossil gas (and other fossil fuels), and repurposing or decommissioning infrastructures. Planned infrastructure is difficult to dismantle, as already illustrated by infrastructural lock-ins concerning large-scale coal, centralised nuclear power plants or gas distribution grids, and associated political, economic and social motives. At the same time, the European Ten-Year Network Development Planning (TYNDP) has to think of the interplay between electricity and hydrogen infrastructures. It is also worth discussing an appropriate balance between transmission grids and storage technologies, as complementary measures within a far more flexible, 100% RES-based system.

Recommendations for a Paris Agreement compatible power grid

To become Paris Agreement compatible, the primary focus of these recommendations is on the power grid. We point to infrastructural change, with selective regulatory or policy issues relevant for the 100% RES system design, and for the role of RES-based electricity to gain increasing prominence.

1. Plan Infrastructures by Coupling Demand Reduction with Higher RES shares

- Prioritise energy demand reductions: Every kilowatt hour saved translates into lower capacities for energy production and power transmission, lower material needs and minimisation of spatial needs.
- Acknowledge demand reduction as a practical, rational, as well as an environmentally and climate-friendly strategy to accelerate the energy transition towards climate neutrality, and for EU's strategic autonomy.
- Substantially increase renewables capacities to reach a range of at least 102 GW -117.5 GW of annual deployment rate, with a view to 2040 across the EU.

2. Recognise RES-based Electrification and Flexibility as a Strategy to Optimise Costs

- Promote a more flexible power system to make maximal use of already existing infrastructure.
- Advance more flexible sectors - buildings, transport and industry - to result in lower pressures for the power system.
- Enforce the inclusion of energy storage technology (daily, weekly, seasonal) potential in grid planning across all relevant planning horizons. The regulator could have an advanced role in assessing the respective network plans.

3. Foster Political Vision and Strategic Planning

- Ensure network development plans and strategies reflect the climate neutrality target and intermediate targets, such as the 2030 renewable ambition, as a minimum threshold. As a first step, this has crucial implications for grid planning, in ensuring that also policies are forward-oriented.
- Reflect grid needs and ensure forward-looking grid planning in NECPs and LTSs, to accelerate the energy transition, in order to reach climate neutrality.
- Recognise flexibility and RES-based electrification in planned network developments, and also related scenarios.

4. Recognise Importance of Substitutes and Trade-Offs

- More efficient infrastructure can minimise infrastructure expansion needs; more interconnections can complement storage needs.
- Recognise how more home batteries, EVs acting as batteries, and domestic heat pumps, in interaction, can decrease needs for large-scale infrastructure.

5. Improve Transparency and Data Accessibility for Decision-Making and Innovation

- Create public visibility and access on national transmission level plans and grid capacity maps to assist in more coordinated approaches.
- Ensure visibility on distribution network development plans to assist leveraging the distribution level.
- Address data gaps concerning transmission and distribution.

6. Engage in Cross-Sectoral Dialogue

- Make more integrated and horizontal sectoral plans and strategies, as RES-based electrification and flexibility measures advance, as an emergent paradigm.
- Couple vehicle charging infrastructure planning with power system planning.

7. Promote Integrated Plans to Use EU and National Funds Wisely

- Optimise the use of non-wire solutions and avoid oversizing infrastructures (as investment needs in infrastructure are seen to grow).
- Bring significant overall cost savings with integrated planning of electricity and H2 networks, as renewable H2, instead of siloed approaches.
- Minimise build-up of unnecessary or inefficient H2 infrastructure, and avoid allocating public funds to any new or existing nuclear projects.

8. Engage Community Inclusively and at Early-Stage

- Communicate clearly and early in the planning process about the benefits and need for new grids, and about existing solutions to mitigate their potential impact.
- Engage in inclusive and early consultation with surrounding communities, ensuring that those segments of society that have historically been less involved in energy planning decisions are reached.
- Ensure that consultations are based on full and transparent information about plans and projects, and that public feedback is able to influence siting and design decisions as far as is technically feasible.
- Foster the creation of stakeholder dialogue platforms, involving local authorities and environmental NGOs, to proactively address localised issues.

9. Make Best Use of Resources and Employment Potential

- Establish strong circular economy requirements (e.g. promoting the reuse of spare parts and scrap metal from thermal power plant demolition) to reduce the material footprint and dependency on imported raw materials of grid expansion.
- Provide funding for training and re-skilling of workers for jobs in grid construction and management, and promote gender balance to make the transition more equitable.

10. Exploit Synergies with Nature Protection and Restoration

- Establish appropriate non-price criteria to reward projects with strong nature-inclusive design. Apply the full mitigation hierarchy (avoid, reduce, mitigate, compensate) in all procurement processes.
- Promote strategic spatial planning that prioritises routes through the least sensitive ecosystems. Provide staff and resources to speed up and improve the quality of environmental impact assessments.
- Foster the uptake of Integrated Vegetation Management in combination with environmental stewardship activities by the local community in rural contexts.