# Electricity+:
## Electricity as the Backbone of an Integrated Energy System

WHITE PAPER

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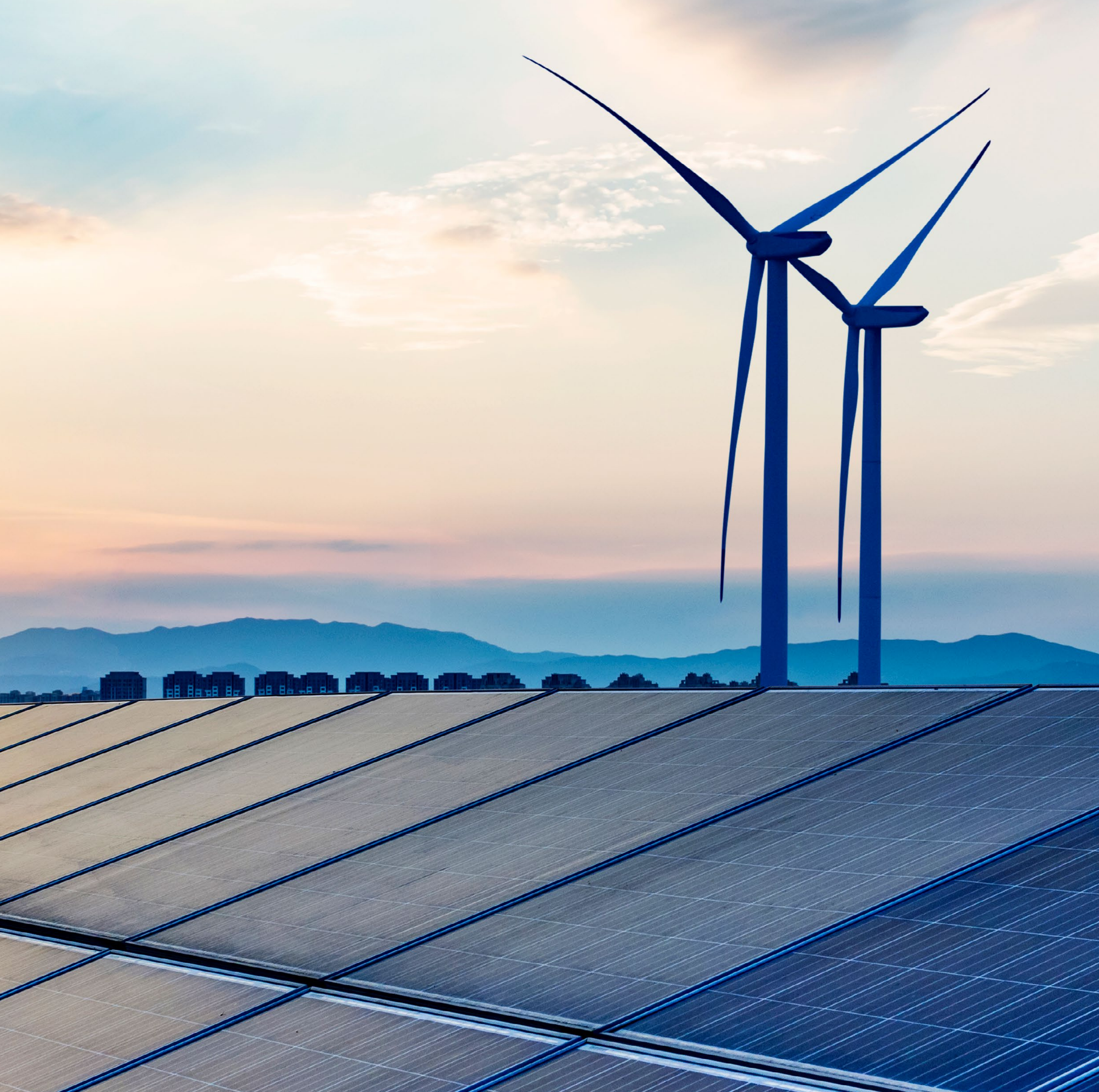


**Images:** Getty Images

# Contents

# Executive summary

## Defining “Electricity+”: the integration of the electricity system with complementary infrastructures.

Electricity+ is a new framework that highlights the opportunities to create and optimize integrations between the electricity sector and other infrastructure to enable a transition to a net-zero economy. The framework has been developed during a series of dialogues with executives from the electricity industry and other sectors. It will serve as thought leadership to kick-start further planning and collaboration across sectors.

The electricity system will evolve to be the backbone of the future energy system. To limit global temperature increases, a range of scenarios show that global final energy consumption must shift from 20% to 50-70% electricity by 2050. This is a massive economy transformation and will require a fulsome reimagining of global energy systems.

A holistic vision for a future net-zero integrated energy system is needed, delivering broader system value across society, the economy, the environment and the energy system itself. The future integrated energy system will rely on a flexible, reliable, resilient and digital electricity backbone. The multi-directional electricity system will include, a) generation comprising significant renewable capacity from both large-scale and distributed energy resources, b) expanded and modernized transmission and distribution, plus increased interconnections, c) storage development, and d) electrification of end uses including heating, transport and industrial processes.

Since the future system will be highly electric, integration with other key infrastructures must be designed to create collaborations and maximize value. The key integrations are outlined as follows:

- Electricity + gas and storage
- Electricity + digital systems
- Electricity + transport and infrastructure
- Electricity + liquid fuels and chemicals
- Electricity + water and storage
- Electricity + waste and recycling

In this paper, the Electricity+ framework has been applied to three markets: Spain, the UK and California. Yet this framework can be applied to any market and be used to assess the current state of integrations and identify collaborations and opportunities to create more efficiency.

# Introduction

## A holistic vision for a future net-zero integrated energy system is needed, delivering broader system value.

Electricity will be the backbone of the future net zero integrated energy system. To limit global temperature increases to below 1.5 degrees Celsius, a range of scenarios show that global final energy consumption must shift from 20% to 50-70% electricity by 2050. This will require a fulsome reimagining of global energy systems, including integrating historically separate systems.

Today's energy systems are the result of century-old technologies and policies, built up in isolation and often based on point-to-point connections or linear flows. In most jurisdictions, the building blocks of the net-zero future – including waste, liquid fuels, gas and storage in addition to electricity, are subject to a patchwork of policies, market drivers and regulatory structures. There is no common, fundamental understanding of what is required for the net-zero integrated energy future nor of the value potential.

A holistic vision for a future net-zero integrated energy system is needed, delivering broader system value across society, the economy, the environment and the energy system itself. By integrating across sectors, collaborations will be created to help lift constraints linked to storage and use of excess capacity and flexibility in complementary infrastructures to promote the most efficient use of clean energy, supporting the uptake of clean electricity.

This paper sets out a framework for the future energy system, which has clean electricity at its core and outlines integrations with complementary infrastructure: gas and storage, digital systems, transport infrastructure, e-fuels and chemicals, water and storage, and waste and recycling. The integration of electricity with complementary infrastructures occurs in the end-use sectors, i.e. buildings, transport, industry and agriculture. Illustrating the value of integrating electricity with complementary infrastructures will inform the conversations on markets, including wholesale power markets, flexibility markets and carbon markets, that form the rules or frame for how the infrastructures and their stakeholders operate together in an integrated energy system. The framework is underpinned by key enablers (see Appendix), including workforce skills development, technology innovation, and integrated system planning and operations.

While further efforts will be essential, this high-level framework aims to serve as thought leadership to kick-start dialogue and collaboration across sectors, which will be needed at a market, regional and global level. It can be used to assess individual nations' energy systems and policies to gauge progress towards developing a future-proofed electricity backbone in an integrated energy system.

# 1 Electricity+ framework

## Clean electricity will provide the foundation of the future integrated energy system.

FIGURE 1 **Electricity+ framework**

### Net-zero electricity backbone

- Value chain integration across generation, transmission, distribution and consumption
- Increased renewable capacity, from utility scale sources and an increase in distributed energy resources
- Transmission development and modernization
- Distribution development and modernization
- Storage development to support stability
- Interconnections
- Electrification of end use (heating, transport, industrial), with more active and automated energy demand
- Integrated with, supported and supporting other clean energy sources

### Key integrations

- Electricity + gas and storage
- Electricity + digital systems
- Electricity + transport infrastructure
- Electricity + liquid fuels and chemicals
- Electricity + water and storage
- Electricity + waste and recycling

**Source:** World Economic Forum

The future integrated energy system will rely on a flexible, reliable, resilient and digital electricity backbone. Electricity generation, transmission, distribution and consumption must be optimized through multistakeholder collaboration to efficiently allocate and exploit resources. The electricity backbone will be multi-directional and must be fully integrated across all electricity infrastructure and other infrastructures.

Significant increases in renewable energy capacity will require timely onshore and offshore transmission and distribution development, modernization and deployment of flexibility solutions. Increased cross-border interconnections will be needed to manage the temporal and spatial complementarity of wind and solar while maintaining affordable supply. Additionally, developments in system operations, power and balancing markets, enhanced system services and storage will be needed to support the move from centralized power generation (synchronous) to a more distributed and variable renewables (asynchronous) grid system.

Distributed energy resources – consumer devices, electric vehicles, heat pumps, batteries and other storage devices, and rooftop solar – will be widespread. Since many of these distributed resources both consume and provide electricity and can be aggregated, they contribute to increasing the system's flexibility but also the complexity of the system. This will require multi-directional and resilient grids and networks with local flexibility.

System integration across distributed energy resources and green hydrogen provides economical electricity storage, supporting an affordable and resilient electricity backbone.

The electricity backbone must support the rise in electricity demand and increased variability across domestic, commercial and industrial consumers. More active and automated demand-side management in these sectors will contribute to ensuring energy security, affordability and sustainability.

# 2 Electricity+ framework and key integrations

## The Electricity+ framework lays out the key areas of integration between the electricity backbone and other physical infrastructure.

The framework has been applied to Spain, the UK and California, serving as case studies (see chapter 4).

### Gas and storage

A forward-looking, integrated approach is needed when carrying out activities related to planning, operations and management of electricity and gas infrastructure. Gas infrastructure is primarily used today for transporting gas to industry for heating or as raw material, to domestic users for heating and cooking and to power stations for generating electricity. Greater gas and electricity infrastructure integration will provide additional medium/long-term storage options to support the electricity backbone. Green hydrogen, green ammonia and methane (i.e. green gases), produced with renewable electricity during times of excess supply, can be fed back into the energy system.

### Digital systems

The pervasive use of data, analytics, artificial intelligence (AI) and internet of things sensors, enabled by Wi-Fi and 5G technology, will be key to automating and controlling the future energy system. A much larger number of more diverse and distributed resources will rely on wireless connectivity. Digital systems will enable more efficient operations, allowing supply and demand forecasting and optimized grid management. Holistic planning and maintenance of electrical and digital infrastructure will reduce permitting requirements, outage times and societal inconvenience (e.g. laying of fibre optic cables alongside/integrated into electrical cables enables more efficient fault finding).

### Transport infrastructure

Road transport electrification is accelerating as battery costs fall and more charging infrastructure is deployed. Electric vehicles can eventually also act as a source of flexibility to the grid, using the properly planned deployment of vehicle-to-grid and other smart charging technologies. In many regions, rail transport is already electrified. For port and airport operations, ships and planes will increasingly plug into the grid (shore power, cold ironing) with high voltage connection requirements. Biofuels, clean hydrogen and e-fuels will also help decarbonize these hard-to-abate sectors. Holistic planning of transport and electricity infrastructure, in close cooperation with system operators, will be crucial to maintain the speed and scale of the transport sector's decarbonization.

### Liquid fuels and chemicals

Liquid e-fuels (methanol and e-crude, also known as synthetic crude oil, which makes e-kerosene and e-diesel) and green hydrogen and green ammonia from renewable power will provide energy for hard-to-abate sectors, such as high-temperature industrial processes, marine, aviation and heavy goods transport. The planful build-out of large infrastructure to produce these fuels from electricity will be critical, for example, electrolysers connected physically or virtually to wind farms/solar parks. In addition, further electrification of industrial processes via heat pumps and e-crackers, along with other technologies, will require significant collaboration among the chemicals, fuels and electricity sectors.

### Water and storage

Electricity and water infrastructures are already highly integrated. Water also plays a cooling function for both thermal and nuclear power plants. Hydroelectricity operations generate clean electricity while dam reservoirs and pumped hydro play a critical role in electricity storage and provide flexibility to the grid. Electricity is essential for desalination and water purification plants to supply fresh water to agricultural and industrial uses and clean drinking water to growing populations. Multi-function systems can provide power while using exhausted steam to run district heating systems. Examples of these systems include waste incineration or concentrated solar plants (providing heating, cooling and power) integrated with desalination plants to provide drinking water.

### Waste and recycling

A circular economy produces zero waste by reusing or recycling waste into new products. Waste can be used for power generation and heating. In addition, circular economy considerations are increasingly required from battery, solar panel and wind turbine manufacturers – component recycling requirements will probably increase in the short term, resulting in comprehensive, integrated waste management plans for businesses.

# 3 Systems enabled by the integrations

Electricity+ infrastructures will come together in four main systems.

## 3.1 Buildings and infrastructure

Efficient, connected buildings – whether residential, commercial or industrial – combine high-performance and low-carbon buildings materials with electric systems, distributed energy and intelligent management systems to maximize efficiency.

Buildings are no longer simply a consumer of energy, they are an active participant as a producer through distributed renewable resources such as solar rooftops, electric vehicle (EV) charging or even water heating. Self-generation will reduce pressure on transmission and distribution grids if integrated with the broader power system. Electrification of heat, adoption of heat pumps and implementation of district heating represent integrations of the energy system with buildings. Consumer waste, such as food waste, may be converted into bioenergy via feedstock provision for biofuels production.

**Example systems:**

Solar and wind farms providing renewable electricity for data centres. The heat from data centres is channelled through a heat pump to provide water and space heating to local apartment blocks.

**Case study:**

In the Tallaght district of Dublin, Ireland, waste heat from a data centre is used for low-cost water and space heating to buildings in the local areas.[1]

## 3.2 Mobility

EV charging points and rail electrification represent an integration between the electricity and transport sectors, providing an opportunity for electric transport to be a source of flexibility and storage for the electricity system.

Electrification mobility hubs and ports, alongside green hydrogen and e-fuels[2] for heavy-duty vehicles, maritime and aviation, will support the decarbonization of goods mobility.

**Example system:**

Electric vehicle charging systems combined with batteries, solar panels and control systems connected to the power system to manage peaks and troughs at the community level and/or at the individual level.

**Case study:**

A vehicle-to-grid charging infrastructure project in the UK enabled over 3 million “free” miles for customers that made money from exporting electricity stored in their EV back to the grid at peak times.[3]

## 3.3 Industry

Industrial decarbonization will include systemic efficiency and circularity, direct electrification, carbon neutral hydrogen (all colours of hydrogen) and carbon capture and storage (CCS). Waste heat from industrial processes (e.g. steel works) can be used in further industrial processes, and water can be used to store excess heat or electricity. Electrification of vehicles, industrial heat pumps and green hydrogen will enable the decarbonization of industrial fleets and industrial processes. There are efficiencies to be gained from pursuing decarbonization in clusters.

**Example systems:**

Solar and wind farms provide renewable electricity for industry and green hydrogen production, which is used to produce green steel that can be used in car manufacturing.

**Case study:**

In the Basque Net-Zero Industrial SuperCluster, Iberdrola is helping the cement, steel, foundry and pulp and paper industries to reach net zero through direct electrification of processes and fuel switching.[4]

## 3.4 Agriculture

Agricultural decarbonization will include electrifying equipment, vehicles and processes where possible, the use of green ammonia for fertilizer and the use of biomethane and green hydrogen. Agricultural waste is an opportunity as input for biomethane.

Adoption of agrivoltaic practices, where agricultural land is simultaneously used for solar photovolatic (PV) and agriculture, will enhance land use efficiency.

**Example system:**

Agricultural company powered by on-site solar energy, equipped with a control system to optimize energy consumption, and relying on a full electric vehicle fleet.

**Case study:**

Genagricola, Italy's largest agricultural company, partnered with Enel to install on-site solar PV capacity, combined with a control system to optimize consumption which will allow it to decarbonize processes and electrify its vehicle fleet.

# 4 Application of the framework

## The framework is an alignment tool for the public and the private sector to identify market improvement points.

To test the framework and its application for policy-makers, example test cases have been conducted for three markets: Spain (Figure 2), the United Kingdom (Figure 3) and California, US (Figure 4). This testing took place in August 2022 and has enabled the validation of the framework's robustness and identified potential improvement points within the markets.

FIGURE 2 **Spain**

### Net-zero electricity backbone

#### Increased renewable energy capacity

2030: 74% renewable sources of electricity generation

2050: 100% renewable sources of electricity generation, net-zero carbon economy

2030 generation capacities: 50 gigawatt (GW) wind, 39 GW PV, 14.6 GW hydro, 9.5 GW pumping, 7 GW concentrated solar power (CSP), 3 GW nuclear plus 27 GW gas-fired combined cycle gas turbine (CCGT)

2050: about 250 GW renewable generation capacity

#### Transmission and distribution development

Increasing distributed energy sources with impact on low-medium voltage grids

Renewable energy sources self-consumption and demand side management promotion

Integrating bulk renewables, like floating offshore, and reinforcing existing grid

#### Storage

2030: 6 GW additional system capacity. In addition, distributed storage provided by electric vehicles, thermal storage in concentrating solar power systems, and hydrogen storage

Total storage capacity: 20 GW in 2030, 30 GW in 2050

#### Interconnections

2030: 3,000 MW with Portugal, 8,000 MW with France, to reach 15% interconnection capacity target

Enhancement of insular interconnectors

#### Value chain integrations

Promotion of independent aggregators

Renewable energy communities promotion

Streamlined administrative procedures for renewable sources of electricity integration

Financing of energy efficiency measures (inclusive of electrification) through a dedicated fund

#### Electrification of end use (domestic, commercial, industrial)

Energy provided by heat pumps grows from 627 thousand tons of oil equivalent (ktoe) (2020) to 3,523 ktoe (2030)

2030: buildings electrification: 53% 2040: 72%, 2050: 86%

## Key integrations

### Electricity and gas and storage

2030 electrolysers capacity 4 GW, 25% hydrogen consumption in industry is renewable, 150-200 fuel cell electric vehicle (FCEV) buses, 5,000-7,500 FCEV vehicles, two hydrogen railway lines.

Renewable energy gases (biogas and renewable hydrogen) promotion (support mechanisms, guarantee of origin (GdO), transportation regulations).

Operating merchant projects to store electricity and/or avoid renewable spillage through hydrogen production.

2050: large-scale renewable hydrogen production deployment to decarbonize hard-to-abate sectors.

### Electricity and water and storage

Pumping station investments.

Desalination by using renewable energy, in turn, used as an input for green hydrogen production.

Improved hydro management to deal with droughts.

Regulations for electricity production and other uses.

### Electricity and waste and recycling

Biogas production is expected to be dominated by anaerobic digestion of agricultural materials.

10.4 terawatt-hour (TWh) production by 2030, to be used in heating, transport and electricity generation.

Support measures and regulations for batteries recycling.

### Electricity and digital systems

Regulation and systems to facilitate citizens' access to the data generated by advanced metering systems.

Smart grids support measures.

Projects and regulatory sandbox to structure and launch local flexibility markets.

More than 99% penetration of smart meters across the country.

### Electricity and transport infrastructures

2030: 28% renewable energy sources transportation, mainly through electrification and advanced biofuels.

2030: 5 million electric vehicles with optimized pricing, e.g. smart charging by time of use.

2050: share of renewable energy at 79%.

Development of charging infrastructures.

Rules for access to urban areas that prioritize electric vehicles.

Support to ease the transition of the automotive sector from fossil to electric and connected vehicle manufacturing, including batteries and fuel cells.

5G deployment in roads.

### Electricity and liquid fuels and chemicals

Measures to ease advanced biofuel penetration in transport, inclusive of specific goals in aviation and labelling regulation.

## Key recommendations

- Further improvements in the permitting and consenting process for transmission, distribution, renewable energy, self-generation and EV charging infrastructure will enable faster deployment of the infrastructure required for the net-zero electricity backbone.
- Due to the increased prevalence of droughts, particularly in southern Spain, desalination using renewable energy is becoming more essential. However, the cost of desalination technology is high, so more research and development (R&D) is needed to make it economically viable.
- Further support to incentivize waste integration and circular economy, such as recycling of batteries as EV deployment increases and wind turbine blades as the fleet ages.
- Improvements and risk reduction in distribution regulation and review of the investment cap provision will enable an increase in investment to support the net-zero electricity backbone.
- Ensuring regulatory certainty will enable investor confidence required to build out the necessary infrastructure.

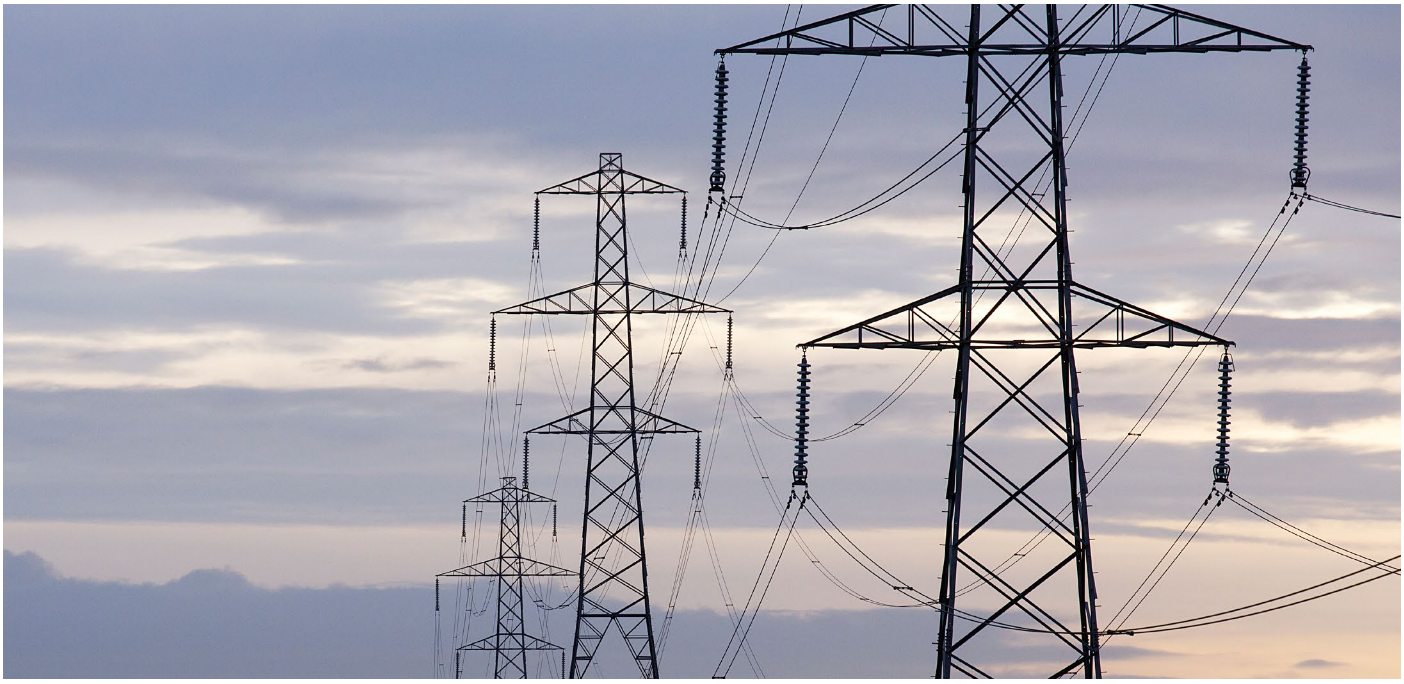


FIGURE 3 | **United Kingdom**

## Net-zero electricity backbone

### Increased renewable energy capacity

Ambitious renewables targets, including 50 GW offshore wind by 2030 and reforms to the planning system to cut approval times.

Acceleration of nuclear power, with one financial investment decision (FID) before the end of parliament and support for small nuclear reactors (SMRs).

### Transmission development

2035 net zero electricity grid, 90% net zero grid by 2030, no limit on wind and solar by 2025.

### Distribution development

Multiple distribution system operator (DSO) pathfinders and demand flex pathfinders.

### Storage

Flexibility Innovation Programme

Longer Duration Energy Storage Demonstration Competition

Relaxation of planning legislation for easier battery construction at wind and solar sites

EV pathfinders

### Interconnections

Offshore coordination project

Double interconnection capacity (seven interconnectors providing 7% of UK electricity in 2020)

Piloting a cap and floor scheme for multiple-purpose interconnectors and incentivizing the development of meshed offshore grids

### Value chain integrations

Creation of future system operator

Electricity market reform

Open data initiative

### Electrification of end use (domestic, commercial, industrial)

Heating:

- New heating appliances in homes and workplaces to be low carbon from 2035.
- No new gas boilers will be sold by 2035.
- 600,000 heat pump installations per year by 2028.
- £450 million boiler upgrade scheme to incentivize domestic consumers to install low-carbon heating.
- Heat Pump Investment Accelerator Competition

£3 billion fund to address building energy efficiency

By 2030, expect 10 million battery EVs on the road (27% of today's total vehicles) and 300,000 public EV charge points at a minimum

## Key integrations

### Electricity and digital systems

Modernising Energy Data programme working to embed data best practice, regulatory expectations for data and digitalization, and funding an energy data visibility service.

Energy Digitalisation Taskforce was established to focus on modernizing the energy system to unlock flexibility and drive clean growth towards net zero.

£2 million innovation competition called Modernising Energy Data Access.

£2.6 billion National Cyber Strategy 2022 to improve the cyber resilience of individuals and organizations across the UK.

Virtual Energy System initiative from National Grid ESO to create a digital twin of the UK energy ecosystem. This will be a shared industry asset and improve simulation and forecasting to support system planning.

### Electricity and transport infrastructures

**Rail:** Target for net-zero rail network by 2050, with ambition to remove all diesel only trains by 2040.

**Road:** Target for all cars to be zero-emission capable by 2035. By 2030, expect 10 million battery EVs on the road (27% of today's total vehicles) and 300,000 public EV charge points at a minimum. £1.3 billion investment to accelerate charge point roll out and £500 million for development of electric vehicle batteries. Target for 4,000 new zero emissions buses and infrastructure by 2050. Hydrogen trials for buses and large goods vehicles (HGVs) are in progress, and trials for zero-emissions HGV technologies at scale on UK roads.

**Aviation:** Jet Zero Strategy to help UK aviation reach net zero emissions by 2050.

**Waterborne transport:** £20 million for Clean Maritime Demonstration Competition, Hydrogen trials for shipping in progress, ongoing public consultation on supporting the development of shore power.

### Electricity and gas and storage

Future system operator to integrate long/medium-term electricity and gas planning efficiently.

Target for 10GW of low-carbon hydrogen production capacity by 2030, with at least half coming from green hydrogen and utilising excess offshore wind power to bring down costs.

Definition of hydrogen and CCUS business models.

Three hydrogen innovation programmes to support development of the hydrogen market, including green hydrogen: Industrial Hydrogen Accelerator Programme, Low Carbon Hydrogen Supply 2, Hydrogen Skills and Standards for Heat.

### Electricity and liquid fuels and chemicals

Renewable Transport Fuel Obligation with biofuels blending mandates that increase the share of alternative fuels, including ethanol, bio/renewable diesel, biomethane.

### Electricity and water and storage

Heat Networks Investment Project (HNIP): £19 million investment into five new heat networks in UK announced 2021. These heat networks use hot water in pipes to deliver heating and can be powered by any dedicated source, e.g. heat pumps, biowaste, recovered heat from industry, combined heat and power. The UK government estimates that heat networks could supply up to 20% of UK heat demand by 2050.

### Electricity and waste and recycling

£75 million on net-zero related R&D for natural resources, waste and fluorinated gases, which may include electricity generation.

Biomass Feedstocks Innovation Programme, which can be used for electricity, biogas and biofuels.

## Key recommendations

- The UK has ambitious hydrogen targets focused on supporting the decarbonization of industry in the UK. Further ambition is needed into the role that carbon neutral gas and hydrogen can play in storage for the electricity backbone and in clean electrification of industrial processes as green hydrogen will inevitably include hybrid systems.
- Further support is needed to enhance the distribution network capability (from a distribution network operator (DNO) to a distribution system operator (DSO)) to ensure it can manage increasing electrification requirements, distributed energy resources and demand-side interaction.
- Further support is needed for networks and grids to enable tighter integration with other infrastructures, e.g. gas.
- Increased emphasis on energy efficiency measures alongside insulation and building standards to upgrade the UK building stock and support the implementation of the net-zero electricity backbone infrastructure.
- Increased emphasis on valuing demand-side measures requiring further integration of digital systems, transport infrastructures and water and waste infrastructures.

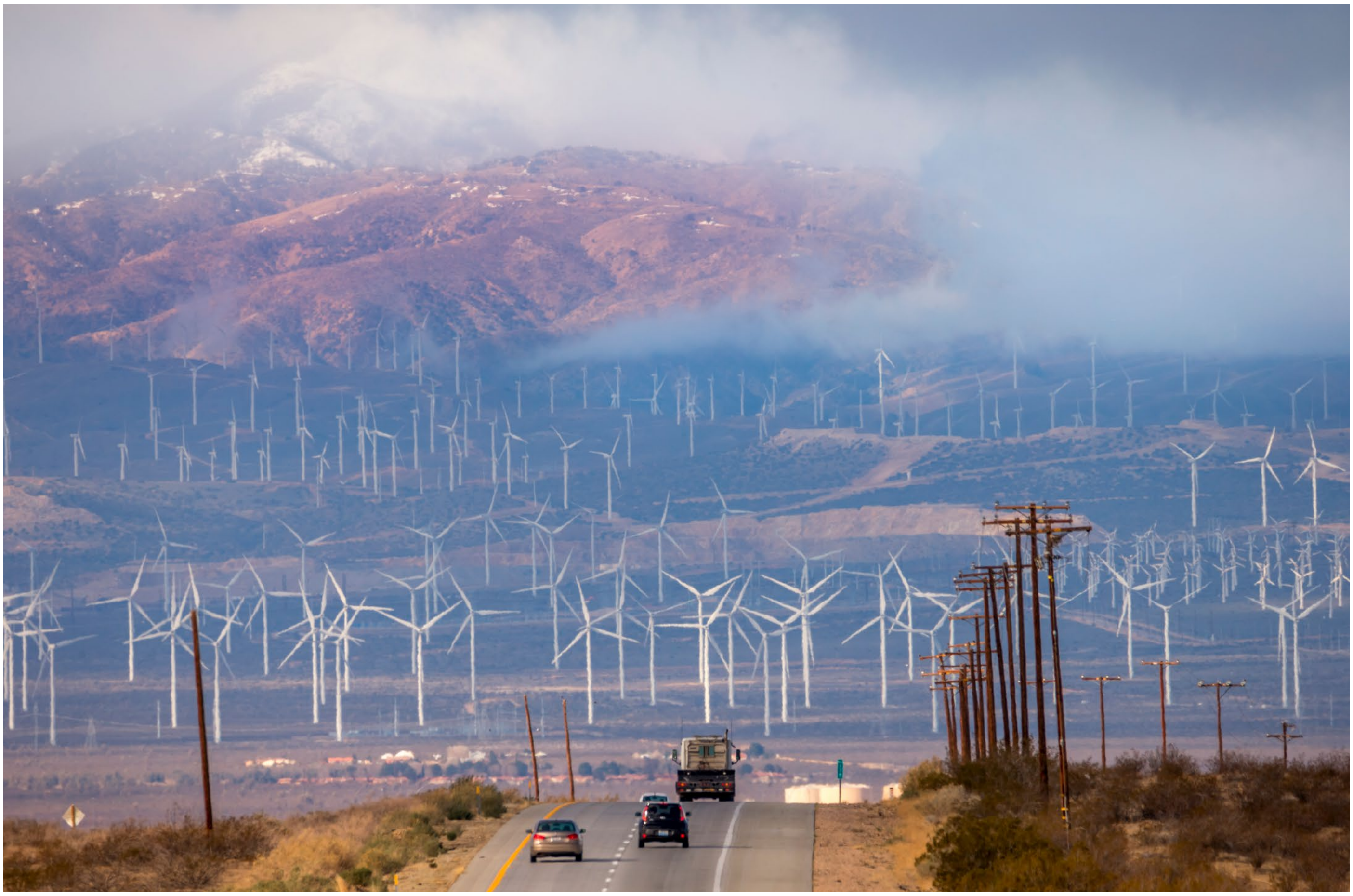


FIGURE 4 | **California, US**

## Net-zero electricity backbone

### Increased renewable energy capacity

California's Renewables Portfolio Standard (RPS) Program was established in 2002 by Senate Bill 1078 (Sher, 2002) with the initial requirement that 20% of electricity retail sales must be served by renewable resources by 2017.

The RPS Program was accelerated in 2015 with Senate Bill 350 (de León, 2015), which mandated a 50% RPS by 2030.

In 2018, Senate Bill 100 (de León, 2018) was signed into law, which again increases the RPS to 60% by 2030 and requires all the state's electricity to come from carbon-free resources by 2045.

### Transmission development

Streamlined federal permitting proposal, federal return on equity "adders" for participating in regional transmission organizations or independent system operations.

### Distribution development

State-based regulations and legislation for safety, investment, etc. (various)

### Storage

As part of Assembly Bill 2514 and implemented by the California Public Utilities Commission (CPUC), set an energy storage procurement target of 1,325 megawatts (MW) by 2020.

Numerous hydrogen production, storage and blending demonstration projects and proposals are underway.

### Interconnections

TBD

### Value chain integrations

TBD

### Electrification of end use (domestic, commercial, industrial)

Transport electrification: 100% of in-state sales of passenger vehicles to be zero emission by 2035, 100% medium and heavy-duty zero-emission vehicles (ZEVs) in California by 2045 where feasible.

## Key integrations

### Electricity and transport infrastructures

Advanced Clean Cars II Regulation sets 100% of in-state sales of passenger vehicles to be zero emission by 2035. Advance Clean Fleets Regulation 100% medium and heavy-duty ZEVs in California by 2045 where feasible.

Executive Order B-48-18 doubled the state's construction goal for hydrogen stations, establishing new targets of 200 stations, 250,000 light-duty EV chargers, and 5 million ZEVs by 2030.

Assembly Bill 841 requires utilities to cover the front-of-the-meter costs of grid upgrades and infrastructure related to EV charging.

Senate Bill 1505 requires no less than 33% of the hydrogen produced for, or dispensed by, fueling stations that receive state funds be made from eligible renewable energy resources.

Hydrogen Fuel Cell Yard Truck at the Port of Los Angeles: Public-private collaboration to develop and demonstrate two zero-emission hydrogen fuel cell yard trucks at the Port of Los Angeles. This project is part of the Zero-Emissions for California Ports (ZECAP) programme, funded in part by the California Air Resources Board.

### Electricity and liquid fuels and chemicals

Incentives earned through the low carbon fuel standard (LCFS) provide steady financial support to low-carbon fuel producers, distributors and blenders in California. In 2019, about 81.3% of LCFS credits were granted for biofuels including biomethane, ethanol, biodiesel and renewable diesel.

### Electricity and waste and recycling

Senate Bill 1383 requires the CPUC, CARB and the California Department of Food and Agriculture (CDFA), to direct utilities to implement at least five dairy biomethane pilot projects to demonstrate interconnection to the common carrier pipeline system. Requires diversion of 75% of organic waste by 2025, in partnership with Calrecycle.

Assembly Bill 2313 offers monetary incentives for biomethane projects for individual and dairy cluster biomethane projects.

Carbon-negative waste-to-energy technology: Private sector demonstration of technology designed to divert organic waste from landfills and convert it into carbon-negative hydrogen and RNG, which can be used for power generation.

### Electricity and gas and storage

Senate Bill 1440: CPUC's decision to establish renewable gas standards has set targets for California gas utilities to supply 12.2% renewable natural gas (RNG) by 2030.

Senate Bill 32 requires state-wide greenhouse gas (GHG) emissions to be 40% below 1990 levels by 2030. SB 100 requires that renewable energy and zero-carbon resources supply 100% of the electric retail sales to end-use customers by 2045.

Senate Bill 1369 requires the CPUC, California Air Resources Board (CARB), and California Energy Commission (CEC) to consider green electrolytic hydrogen as an eligible form of energy storage and to consider other potential uses of green electrolytic hydrogen.

Joint IOU Hydrogen Blending Demonstration Application seeks CPUC authorization to establish multiple hydrogen blending projects in California to inform a future hydrogen injection standard and will test hydrogen blends between 5% and 20% hydrogen by volume.

Utility to construct first-in-US "hydrogen home" showcasing how a microgrid composed of solar arrays, a battery, an electrolyser and a fuel cell can provide clean, reliable energy to the homes of the future.

Angeles Link: Utility is proposing to develop the nation's largest green hydrogen energy infrastructure system to safely deliver hydrogen from outside of the Los Angeles Basin to industries that need it most.

Assembly Bill 2514, as implemented by the CPUC, set an energy storage procurement target of 1,325 MW by 2020.

In 2017, a utility completed what was then the largest lithium-ion battery storage facility in the world, Escondido Energy Storage project (30MW/120 MW-hour).

Reliability-related installations, such as a replacement for the decommissioning of San Onofre Nuclear Generating Station (SONGS), have led to significant additions to energy storage.

### Electricity and digital systems

No clear targets

### Electricity and water and storage

Hybrid direct air capture: Private sector demonstration of a technology that simultaneously captures $CO_2$ and water from the air.

Direct ocean capture: A university-backed startup is working to design, develop and demonstrate operation of an electrochemical system capable of capturing $CO_2$ from ocean water.

## Key recommendations

- Companies are investing in digital and cyber on an individual basis, but there needs to be more central backing or policy to support the development of the digital systems required in the integrated energy system.
- Further clarity and support are required for the build-out of the transmission and distribution infrastructure to support the net-zero electricity backbone and enable tighter integration with other infrastructures, e.g. gas.
- Encouraging investments in the built environment's end use of electricity, particularly heating and cooling, is required to enable the electrification of end-use required in the integrated energy system.

# Conclusion

The past decade, and especially the past year, saw transformative changes across the energy system. There is significant momentum for the build-out of net-zero electricity and related infrastructure, as well as further electrification of the economy. Electricity is expected to be the backbone of the future integrated energy system. The Electricity+ framework highlights key integration opportunities between the electricity sector and other infrastructures to enable a transition to a net-zero economy.

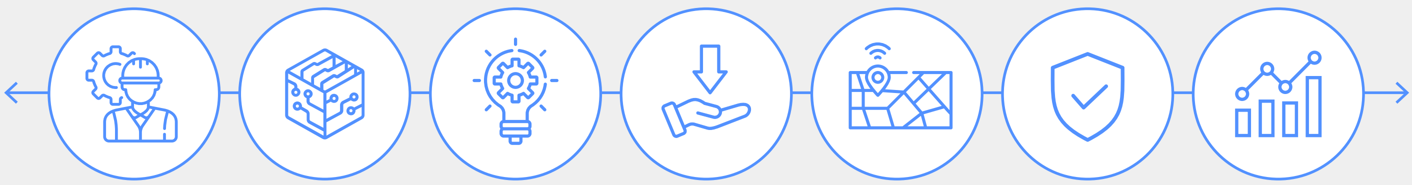
The energy transition aims to accelerate transformation whilst addressing the dimensions of the "energy trilemma" – energy security, sustainability and climate impact, and an affordable and just system. Yet there is an opportunity to take this a step further. It will be easier to manage reliability and resiliency, identify opportunities for flexibility and improve overall energy productivity and systemic efficiency by examining and planning for the physical integrations of infrastructures and making targeted investments and system upgrades accordingly. Government and business can pursue solutions and pathways that deliver broader system value across the economy, environment and society. The outcomes can include job creation, economic development and improved health through reduced air pollution. The Electricity+ framework encourages stakeholders to consider the system value framework while assessing opportunities to plan and deploy key integrations.

It is hoped that this high-level framework can serve as a guide for dialogue, collaboration and planning across sectors to gauge progress and highlight opportunities to create a net-zero integrated energy system for the future.

# Appendix: Integrated energy system foundations

The Electricity+ framework is underpinned by enabling elements critical to the transition to an integrated energy system as well as to ensure its enduring success.

FIGURE 5 | **Enablers of an integrated energy system**




**Source:** World Economic Forum

### Labour force and skill development

Labour force needs to be planned to ensure that employees have the skills needed to plan, design, operate, maintain and evolve the future integrated energy system. Adequate education, training and retraining need to be provided to ensure a sufficiently skilled workforce and an inclusive and just transition. The energy sector needs to be attractive to younger generations and their career expectations. Overlooking this aspect may cause decades of delay in deploying the transition due to the long lead time of the education cycle.

### Data and digitalization

Data and digital processes will play a foundational role in providing visibility, automation and control, as well as enhancing user interfaces and improving consumer engagement, for example, digital twins can not only be used for better management of the energy ecosystem but to tell a story to improve consumer consent for new assets. Digital will be a critical enabler of system integration by enabling predictive algorithms and automation.

### Technology and innovation

Many of the technologies necessary for the integrated energy system exist today but need the effort to scale at speed. Moreover, there will be a need for ongoing innovation in technologies and other areas, such as business models and planning, to support the new system.

### Demand dynamics

Behavioural change from consumers (residential, commercial and industrial) to reduce waste, implement energy efficiency behaviours and technologies, and be more flexible across all infrastructures and technologies in order to optimize demand. Alongside this, energy communities are a powerful way for consumers to drive change in supply. Market design and regulatory and commercial reform should value actions to optimize demand side capabilities in a similar way to how supply is valued, incentivizing consumers to flex load to support the grid, defer capital investment, reduce mismatch with the variable generation, and support distributed resilience and security of supply.

#### Integrated system planning and operations

Markets must move away from one-off infrastructure project approvals. The development of holistic forward-looking, integrated system plans, combining and connecting different infrastructures by taking into account their different characteristics as well as considering flexibility and resilience solutions, is imperative. Non-wire options should be considered to ensure a holistic and technology-neutral approach. These types of long-term, integrated plans will help overcome supply chain cost increases and delays, as well as allow for taking advantage of economies of scale. Integrated system plans also enable a "dig once" approach, e.g. installing or maintaining electrical cables, fibre optic cables and completing road civil works in parallel. In addition, other planning approaches, such as climate, cyber and physical risk-related resilience plans, must take an overall integrated energy system approach. This should consider the impact of an outage of one critical infrastructure on the broader ecosystem. A large-scale electricity outage would have ramifications on telecommunications, ports and airports, the role of water storage for flood management, energy system flexibility, and the impact of climate change-induced droughts on hydropower sources.

#### Sustainable and secure supply chains

Securing the supply of metals and materials critical to net-zero infrastructure, for example, nickel, copper or aluminium, is crucial to support the increase in renewables deployment, grid and network infrastructure development and modernization, as well as demand electrification. These materials must be mined and produced sustainably, using clean power, with emissions profiles minimized across multiple locations. Sustainable working practices, particularly in mining, must be embedded. Circularity, recycling and disposal of materials, for example, batteries, must be considered. Longer-term visibility of project needs, e.g. larger tenders, will help suppliers offset delays and cost increases through resourceful materials ordering.

#### Valuing carbon

Carbon targets coupled with a negative value for carbon through carbon markets, carbon tax and carbon border adjustments need to be in place to economically incentivize investment in components of the integrated energy system.

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# Endnotes


1. "How district heating could play a key part in decarbonisation", *Engineers Ireland*, 23 February 2020, https://www.engineersireland.ie/Covid-19-information-base/how-district-heating-could-play-a-key-part-in-decarbonisation.
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