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The International Network of Energy Transition Think Tanks (INETTT) connects think tanks around the world to advance ambitious energy transition policies aligned with the Paris Agreement and the UN Sustainable Development Goals. As a trusted platform for dialogue and knowledge-sharing, it fosters cross-pollination and evidence-based joint analysis.

INETTT and its members engage with policymakers, industry leaders and other stakeholders to stress the urgency of transforming energy systems.

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PLANET
SOCIETY
ECONOMY
ENERGY

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Abbreviations

ACER Agency for the Cooperation of Energy Regulators (EU)

ADME Electricity Market Administrator [Administración del Mercado Eléctrico] (Uruguay)

AEPC Alternative Energy Promotion Centre (Nepal)

AIoT artificial intelligence of things

ALMM Approved List of Models and Manufacturers (India)

AR1–AR7 Allocation Rounds 1–7 for UK renewable energy auctions

BAFA Federal Office for Economic Affairs and Export Control [Bundesamt für Wirtschaft und Ausfuhrkontrolle] (Germany)

BCA border carbon adjustment

BMWE Federal Ministry for Economic Affairs and Energy [Bundesministerium für Wirtschaft und Energie]; renamed BMWK between December 2021 and May 2025 (Germany)

BMWK Federal Ministry for Economic Affairs and Climate Action [Bundesministerium für Wirtschaft und Klimaschutz]; formerly and subsequently BMWE (Germany)

BNDES National Bank for Economic and Social Development [Banco Nacional de Desenvolvimento Econômico e Social] (Brazil)

CAPEX capital expenditure

CBAM Carbon Border Adjustment Mechanism (EU)

CCGT combined-cycle gas turbine

CCS carbon capture and storage

CCUS carbon capture, utilisation and storage

CEBRI Brazilian Center for International Relations [Centro Brasileiro de Relações Internacionais] (Brazil)

CEER Council of European Energy Regulators (EU)

CfD contract for difference

COD commercial operation date

CPUC California Public Utilities Commission (U.S.)

CREG Commission for Electricity and Gas Regulation (Belgium)

CSP concentrated solar power

DESNZ Department for Energy Security and Net Zero (UK)

DFS Demand Flexibility Service (UK)

DfID Department for International Development (UK)

DISCOM state-level distribution company (India)

DOE Department of Energy (U.S.)

DRI direct reduced iron

DSO distribution system operator

EAC energy attribute certificate

EC electric cooperative (The Philippines)

EEG Renewable Energy Sources Act [Erneuerbare-Energien-Gesetz] (Germany)

EEW Energy and Resource Efficiency in the Economy [Energie- und Ressourceneffizienz in der Wirtschaft] (Federal funding category, Germany)

EIP eco-industrial park

ENTSO-E European Network of Transmission System Operators for Electricity (EU)

EPC engineering, procurement and construction

EPRS European Parliamentary Research Service (EU)

EPSRA Electric Power Sector Reform Act (Nigeria)

ERA Electricity Regulation Act (South Africa)

ESIA environmental and social impact assessment

ESMAP Energy Sector Management Assistance Program (World Bank)

ETS emissions trading system

EU European Union

EU ETS EU Emissions Trading System

EUR euro

EWSETA Energy and Water Sector Education and Training Authority (South Africa)

FERC Federal Energy Regulatory Commission (U.S.)

FiP feed-in premium

FiT feed-in tariff

FPIC free, prior and informed consent

GEC Green Electricity Certificate (China)

GECEX/CAMEX Executive Management Committee of the Foreign Trade Chamber [Comitê-Executivo de Gestão da Câmara de Comércio Exterior] (Brazil)

GESI gender equality and social inclusion

GGGI Global Green Growth Institute

GHG greenhouse gas

GIZ German Agency for International Cooperation [Deutsche Gesellschaft für Internationale Zusammenarbeit]

GOGLA Global Off-Grid Lighting Association

GSI Global Subsidies Initiative

GW gigawatt

HTLS high-temperature low-sag (advanced transmission-line conductor)

IAIA International Association for Impact Assessment

IDAE Institute for Energy Diversification and Saving [Instituto para la Diversificación y Ahorro de la Energía] (Spain)

IDDRI Institute for Sustainable Development and International Relations [Institut du développement durable et des relations internationales] (France)

IEA International Energy Agency

IEA-RETD IEA Technology Collaboration Programme for Renewable Energy Technology Deployment

IEC International Electrotechnical Commission

IMPO Official Gazette Institute [Instituto de Prensa Oficial] (Uruguay)

INDC Intended Nationally Determined Contribution; a proposed national climate action plan submitted prior to Paris Agreement ratification, which then becomes an NDC

INR Indian rupee

IPP independent power producer

IPRI Indigenous Peoples Rights International

IPSF International Platform on Sustainable Finance

IREC International Renewable Energy Certificate (China)

IREDA Indian Renewable Energy Development Agency (India)

IRENA	International Renewable Energy Agency
IISD	International Institute for Sustainable Development
I-TRACK	International Tracking Standard Foundation
IWGIA	International Work Group for Indigenous Affairs
JEPIC	Japan Electric Power Information Center
JETP	Just Energy Transition Partnership
JETP-IP	JETP investment plan
JEPX	Japan Electric Power Exchange (Japan)
KEPCO	Kansai Electric Power Company (Japan)
KSG	Federal Climate Protection Act [Bundes-Klimaschutzgesetz] (Germany)
kW	kilowatt
kWh	kilowatt-hours
LFI	local financial institution
LPG	liquefied petroleum gas
LT-LEDS	long-term low-emission development strategy
MASEN	Moroccan Agency for Sustainable Energy (Morocco)
MECS	Modern Energy Cooking Services
METI	Ministry of Economy, Trade and Industry (Japan)
MIEM	Ministry of Industry, Energy and Mining [Ministerio de Industria, Energía y Minería] (Uruguay)
MIIT	Ministry of Industry and Information Technology (China)
MNRE	Ministry of New and Renewable Energy (India)
MRV	monitoring, reporting and verification
MWh	megawatt-hour
NDA	National Data Administration (China)
NDC	Nationally Determined Contribution; a national climate action plan submitted under Article 4 of the Paris Agreement (2015)
NDRC	National Development and Reform Commission (China)
NEA	National Energy Administration (China)
NEPRA	National Electric Power Regulatory Authority (Pakistan)
NERSA	National Energy Regulator of South Africa (South Africa)
NESO	National Energy System Operator (UK)
NGCP	National Grid Corporation of the Philippines
NRECA	National Rural Electric Cooperative Association (U.S.)
NREL	National Renewable Energy Laboratory (U.S.)

NTER	National Total Electrification Roadmap (The Philippines)
NZIA	Net-Zero Industry Act (EU)
OCCTO	Organization for Cross-regional Coordination of Transmission Operators (Japan)
OECD	Organisation for Economic Co-operation and Development
Ofgem	Office of Gas and Electricity Markets (UK)
OPEX	operating expenditure
OTC	Community Transformation Office [Oficina de Transformación Comunitaria] (Spain)
PCI	Project of Common Interest (EU)
PPA	power purchase agreement
PPIAF	Public-Private Infrastructure Advisory Facility (World Bank)
PPCA	Powering Past Coal Alliance
PPP	public-private partnership
PUE	productive use of energy
PURE	productive use of renewable energy
PV	photovoltaic (solar power)
R&D	research and development
RDSS	Revamped Distribution Sector Scheme (India)
REA	Rural Electrification Agency (Nigeria)
RED	Renewable Energy Directive (EU)
RED II	Renewable Energy Directive II (EU)
REF	Rural Electrification Fund (Nigeria)
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme (South Africa)
RES4Africa	Renewable Energy Solutions for Africa
RMI	RMI; formerly Rocky Mountain Institute
RPS	renewable portfolio standard
RVO	Netherlands Enterprise Agency [Rijksdienst voor Ondernemend Nederland] (The Netherlands)
SALGA	South African Local Government Association (South Africa)
SAREM	South African Renewable Energy Master Plan (South Africa)
SCADA	supervisory control and data acquisition
SDE++	Sustainable Energy Production and Climate Transition Incentive Scheme [Stimulering Duurzame Energieproductie en Klimaattransitie] (The Netherlands)
SEBI	Securities and Exchange Board of India
SECI	Solar Energy Corporation of India

SEforALL	Sustainable Energy for All
SEI	Stockholm Environment Institute
SGAM	Smart Grid Architecture Model (Japan)
SHS	solar home system
SIRGE	Securing Indigenous Peoples Rights in the Green Economy
SME	small or medium-sized enterprise
smarten	Smart Energy Europe
TERI	The Energy and Resources Institute (India)
TOU	time-of-use
TIPS	Trade and Industrial Policy Strategies (South Africa)
TSO	transmission system operator
TWh	terawatt-hours
TYNDP	Ten-Year Network Development Plan (EU)
UDAY	Ujwal DISCOM Assurance Yojana; government programme to strengthen state-owned electricity distribution companies (India)
UAE	United Arab Emirates
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development / UN trade & development
UNDP	United Nations Development Programme
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States dollar
UTE	National Administration of Power Plants and Electrical Transmissions [Administración Nacional de Usinas y Transmisiones Eléctricas] (Uruguay)
VAT	value-added tax
VRE	variable renewable energy
VRFB	vanadium redox flow battery
WRI	World Resources Institute
WTO	World Trade Organization
ZAR	South African rand (South Africa)

Introduction

Countries around the world are scaling up their renewable energy ambitions in response to rising climate risks, domestic environmental concerns, fossil-fuel market volatility, and the need for affordable energy. Many have also come to recognise that unlocking renewable energy potential creates new business and industrial development opportunities, alongside expanding low-cost energy access, strengthening energy security, advancing sustainable development and helping achieve climate goals.

Yet, as experience shows, successful deployment depends on more than technological readiness and a clear vision of future opportunities. Critically, it also hinges on the quality, coherence and adaptability of the policies that shape key investment decisions and market acceptance at both the national and subnational levels.

This policy guide presents proven best practices for designing and implementing robust, context-sensitive policy frameworks for renewables, ensuring a transition consistent with broader socio-economic objectives. It offers an overview of energy transition policies across five interrelated policy sets, from strategic planning and financing to maximising renewables, boosting industrial resilience, and ensuring an inclusive transition (see Figure 1, below).

The aim is to facilitate renewable energy deployment and investment decisions for policymakers, regulators, and the public institutions responsible for energy, climate, and development issues, as well as to inform public utilities, development partners, and policy advisors on the specific challenges and opportunities presented by renewables.

Within the five-part guide, the various sections follow a standard format:

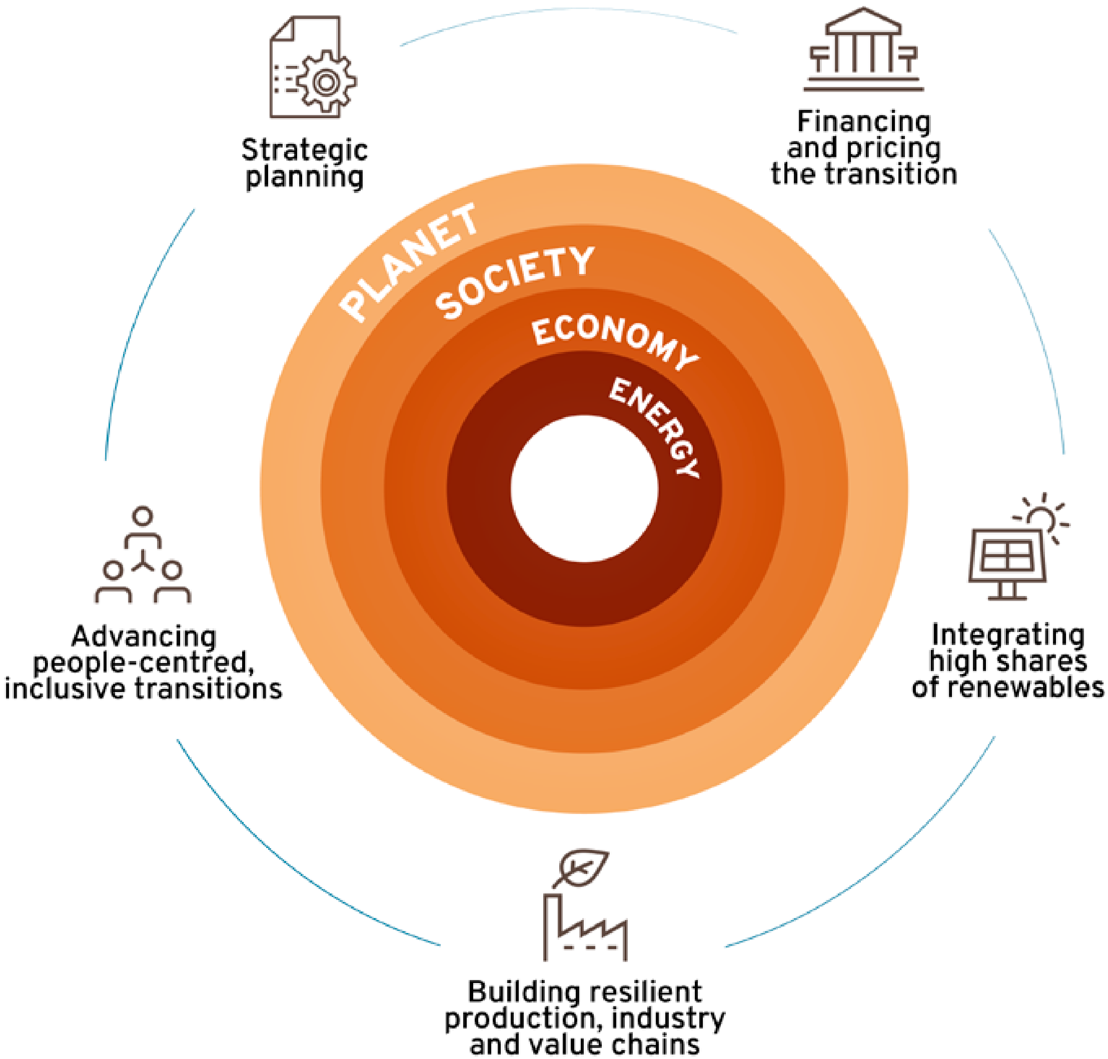
- **Short descriptions** of each policy approach.
- **Case studies** showing how each policy was enacted in a specific country.
- **Further reading** for more detailed policy design.

This guide seeks to help recognise policy gaps and identify options based on existing institutional capacity, market structure and development priorities. Rather than prescribing a single policy model, it distils lessons from diverse country experiences, offering a range of policy and design choices to support informed decision-making on renewables anywhere.

A core premise is that energy systems do not operate in isolation. The policy approach and experiences described here have evolved within wider social, economic and environmental systems, up to planet level (see Figure 1). Energy transitions both shape and are shaped by labour markets, industrial development, public finance, trade and investment policy, structure of the energy sector and existing infrastructure. Inevitably, it also reflects each country's resource endowments, geography and demography, economic structure, land-use patterns, social relations and environmental and regulatory frameworks.

Conversely, advances in education and skills development, industrial capabilities, fairly designed trade and investment frameworks, enabling infrastructure, inclusive social policy and sound governance can either enable or, if lacking, constrain the pace and impact of the energy transition. Effective renewable energy uptake, therefore, depends on a "systems perspective," recognising the energy sector as both a driver and a result of broader socio-economic development. Policymaking to accelerate renewables are most effective when designed with these interdependencies in mind.

Figure 1: The interdependent ecosystem for energy transition goals



Source: Based on IRENA (2025)

Interrelated policy areas

Within the systems perspective, renewable energy policy frameworks can be understood to comprise several interrelated sets of policies. These include deployment policies that incentivise investment and scale-up; integration policies that ensure power systems and end-use sectors can reliably absorb renewables; and structural policies addressing issues like industrial transformation, workforce transitions and local impacts.

"Just transition" policies can be vital to support affected workers and communities, manage distributional effects, and maintain political support and social buy-in for ambitious energy transition plans. Weaknesses or inconsistencies in any of these policy domains can undermine implementation and compromise transition outcomes, even where specific instruments appear well designed.

Ownership and governance structures also shape the possibilities for transforming energy systems. Around the world, energy assets range from state-owned and vertically integrated utilities to liberalised markets involving private competitors and diverse communities, with many countries opting for hybrid arrangements combining elements of both. Policy instruments that work well with one kind of ownership structure may be ineffective or counterproductive in another.

Whether renewables are mainly a profit- or an impact-driven investment makes an enormous difference throughout the project cycle. Recognising these differences is essential in adapting proven practices and approaches to unique national and local realities. In all cases, however, consistent policy frameworks aligned around a holistic vision can promote collaborative interactions that maximise wider benefits.

Renewable power generation, for example, can be approached in different ways. Centralising it reduces costs per megawatt, boosts the system operator's visibility, and facilitates services like frequency and voltage regulation, which help keep the power system stable. Distributed generation, in contrast, increases citizen involvement and awareness. Democratising the power system, in turn, can enhance the government's social licence for the energy transition, as well as enabling electricity access beyond the reach of the central grid and public utilities.

Renewable-based electricity systems, because of their distributed resource base, tend to be characterised by a wider range of stakeholders compared to fossil fuels and nuclear plants. A system that depends on synergies between solar, wind and other resources in numerous different locations inherently requires deeper social outreach. The transition to renewables, therefore, requires updated procurement practices to ease all the resulting interactions.

Industry policy is a critical complementary pillar of energy transitions. Strategic support for domestic manufacturing, resilient supply chains, and innovation ecosystems can help capture economic gains, strengthen local value creation and support job creation. Aligning industrial, energy and development objectives also helps address uneven regional development and reduce dependency risks. These efforts can be reinforced by trade policy, which shapes how the benefits of the energy transition are distributed across countries. Trade governance can preserve policy space for green industrialisation and strengthen regional value chains, enabling countries to capture greater value from the transition.

Finally, renewable energy policy frameworks must respond to widely differing socio-economic priorities. Countries approach the energy transition from distinct starting points, reflecting different income levels, energy access challenges, industrial structures, labour markets, fiscal conditions, and institutional capacities. For some, renewable energy deployment is closely linked to electrification and development goals; for others, it is bound up with industrial competitiveness, system flexibility or the phase-out of carbon-intensive assets.

Good practices, therefore, are not uniform. Policies must address immediate national and local needs, along with long-term climate and sustainability objectives.

Guide structure

This guide sets out essential policy principles for countries aiming to scale up renewables, combined with real-word examples of good practices and implementation.

Its five main parts correspond to different steps and policy objectives:

- **Part I: Strategic plans and getting started**

Countries can adopt a range of mechanisms to initiate the energy transition, from netzero targets and strategies to renewable energy targets and portfolio standards. This part of the guide also explores tracking mechanisms, financing options to expand energy access, and fossil-fuel phase-out plans, as well as subnational transition plans.

- **Part II: Financing and pricing the transition**

Carbon pricing, tariffs and subsidies can pay for the transition and send proactive price signals, depending on national context. This part highlights derisking tools for developing countries, explores international cooperation options, and outlines guarantees, carbon adjustment schemes, and procurement mechanisms to mobilise capital. It also considers how to regulate the market and target public investments to protect vulnerable consumers.

- **Part III: Maximising renewable power**

Specific policies are needed to maximise renewables on the electricity grid, including reforms to ensure reliable operation with large shares of solar and wind power. This part covers longterm grid planning, grid access and smart grids, distributed generation, and market interactions with prosumers, as well as forecasting, intraday and balancing markets, electricity storage, demand response and other flexibility measures that maintain stability and affordability.

- **Part IV: Building resilient production, industry and value chains**

Policy choices can focus on decarbonising industrial processes, building domestic green value chains, and safeguarding industrial and export competitiveness. This part of the guide addresses localisation strategies, industrial policy and trade tools, border carbon adjustments and powershoring, along with financing and incentives to boost renewables, green hydrogen, biomass, and low-carbon electrification in key sectors and industrial clusters.

- **Part V: Advancing people-centred transitions**

Policymakers also need to consider potential disruptions, how to ensure fairness for workers, and how to safeguard affected communities and vulnerable groups. This part covers planning and permitting, community projects, inclusive siting and assessments, and helpful labour and skills-development measures. It also shows how rural minigrids, offgrid solar solutions, productive energy uses, and clean cooking can all help reduce poverty and inequality.

Ultimately, this policy guide aims to help scale up renewables for a better future. Beyond each country's energy mix, success in the transition means building resilient and environmentally sustainable societies and economies.

Part I: Strategic plans and getting started

1. Energy transition targets and strategies

Many jurisdictions adopt targets and strategies to steer the long-term energy transformation process. The crucial interaction between these elements is obvious in the case of net-zero decarbonisation pathways, typically extending two to three decades into the future.

Net-zero targets represent long-term emissions reduction goals, while national net-zero strategies translate these targets into concrete policies, sectoral pathways, and timelines for implementation. Through an iterative process, ambitious targets guide strategic planning, while evolving strategies can, in turn, strengthen, clarify, or recalibrate the original targets based on technological progress, evolving economic conditions, and social considerations.

Targets for renewable energy and other components are an increasingly important tool to manage the complex energy transition process. Renewable energy targets are typically embedded in a larger framework, ideally with a hierarchy of goals bridging a net-zero economic vision with deployment targets for technologies such as wind and solar photovoltaic (PV) power generation. In total, the framework should encompass energy and electricity decarbonisation, renewable electricity targets, and deployment targets for specific technologies.

Renewable energy targets can be either indicative or legally binding. If legally binding, they are likely to be combined with policies to measure the shares of various renewables in the electricity mix and verify that obligatory levels are met. For this purpose, some jurisdictions have adopted Renewable Portfolio Standards or Renewable Energy Certificate systems.

Target-based monitoring and governance enable effective guidance, transparent implementation, and continuous adjustment where needed. Systematic tracking and accountability help align the transition to renewables with broader energy-security and climate-related objectives.

Policies and targets for fossil-fuel phase-out also provide a crucial signal about the required pace and direction of structural change in the energy system. By setting timelines for the decline and eventual cessation of coal, oil, and gas use, these policies help align infrastructure investment, workforce planning, and innovation with long-term decarbonisation goals. They also reduce carbon lock-in and the risk of creating stranded assets, with new high-emissions projects being actively discouraged while renewables, energy efficiency, and supporting technologies such as storage and grids are increasingly rolled out.

When integrated into broader transition planning, fossil-fuel phase-out targets can be combined with regional or local transition plans to ensure that communities depending on the fossil fuel industry can achieve a smoother transition to other industries and activities.

Net-zero targets

A "net-zero" target sets a target year (*e.g.* 2050) by which the greenhouse gas (GHG) emissions in any given market or sector must either be eliminated or sufficiently balanced by offsets to ensure that overall climate impact is neutral. Such targets have been adopted or announced by growing numbers of countries around the world (see https://zerotracker.net), although not all those targets are anchored in legislation or detailed implementation plans.

Net-zero targets can take various forms, including:

- **Defined target year with interim steps:** A clearly specified long-term target year – such as 2050 – provides strategic direction and policy certainty for investors and institutions. Interim milestones translate long-term ambition into measurable progress, enhancing credibility, enabling course correction, and reducing the risk of a delayed or disorderly transition.
- **Sector-specific targets:** Disaggregated emissions reduction targets across different sectors – such as energy, transport and industry – clarify responsibilities, reflect varied mitigation potential and investment cycles, and support more precise policy design. Sectoral benchmarks also improve accountability and help monitor progress in relation to net-zero aims across the entire economy.
- **Sector-specific strategies:** Coherent strategies aligned with sectoral targets translate economy-wide ambition into actionable pathways. In the energy sector, long-term system planning, deployment trajectories, and targets for renewables provide visibility on infrastructure, investment and technology choices, strengthening implementation and policy consistency over time.

Case study: Germany's climate law and sectoral targets

In 2019, Germany adopted a strategy to reach net-zero carbon emissions by 2045. First, the country defined economy-wide emissions reduction targets. Second, these overall targets were broken down into sector-specific emission limits. Policies in all sub-sectors are focused on reaching those targets. If a sector exceeds the emissions allowed for a given year, the responsible ministry must immediately submit an emergency programme to comply with GHG emission budgets in subsequent years.

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Net-zero strategies and related long-term plans

Various strategies have emerged to help national policymakers manage the transition to a decarbonised energy sector. Most famously, the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) gave rise to Nationally Determined Contributions (NDCs), a bottom-up framework to steer decarbonisation by setting country-specific mitigation targets. Since then, countries and regions have increasingly adopted long-term low-emission development strategies (LT-LEDS), net-zero strategies, integrated energy and climate plans, and other approaches.

Such long-term strategies depend on several crucial policy elements, namely:

- **Medium- and long-term targets:** Clearly defined milestones provide strategic direction and investment certainty, helping align public and private decision-making with a net-zero trajectory. Interim benchmarks enable the systematic tracking of progress and timely policy adjustments where gaps emerge.
- **Governance:** Different ministries, institutions and levels of government need effective coordination to ensure policy coherence and reduce the risk of conflicting objectives. Formal alignment between climate, energy and broader development strategies strengthens implementation and improves overall effectiveness.
- **Scenarios and modelling:** A strong analytical foundation based on reliable data and realistic modelling supports evidence-based decision-making. Clear assessments of trade-offs, costs, system impacts and feasibility enhance the credibility and robustness of decarbonisation pathways.
- **Monitoring:** Transparent monitoring, reporting and verification (MRV) systems enhance accountability and investor confidence. Regular tracking of outcomes against targets facilitates course correction and reinforces the integrity of long-term strategies.
- **Stakeholder engagement:** Inclusive engagement processes and attention to social impacts strengthen political legitimacy and public support. Addressing distributional effects and employment implications reduces resistance to structural change and supports a just transition.

Case study: Costa Rica's phased pathway to net zero

Costa Rica submitted its National Decarbonization Plan 2018–2050 to the UNFCCC as a long-term low-emission development strategy (LT-LEDS) in December 2019, with implementation spanning three phases: initial (2018–2022), inflection (2023–2030), and massive deployment (2031–2050).

The plan sets a goal of net-zero GHG emissions by 2050, aligning long-term climate ambition with national development planning. It integrates renewable energy scale-up with other decarbonisation measures, such as sustainable mobility, land-use management, and low-carbon agriculture, specifying clear phases and focus areas for implementation.

The Climate Change Directorate within the Ministry of Environment and Energy coordinated and led the planning process with presidential support, strengthening stakeholder engagement and subsequent governance.

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• *Renewable energy targets*

Targets for renewable sources and technologies indicate the future trajectory of the energy system and provide long-term investment predictability. Setting targets and tracking progress also helps coordinate investments in power generation, grid enhancement and storage capacity. Targets can be either indicative or legally binding, with the possibility of financial penalties for non-compliance.

Renewable energy targets can take various forms:

- **Energy sector targets:** Economy-wide renewable energy targets for the entire energy sector – including electricity, heating and cooling, and transport – provide an overarching signal that guides system-wide decarbonisation. Such targets help align investment decisions across sub-sectors and reduce the risk of fragmented or inconsistent policy development.
- **Sub-sector targets:** Disaggregated targets for electricity, heating and cooling, and transport allow for differing mitigation potential, infrastructure needs and technology readiness. They enhance clarity on responsibilities and support tailored policy design, improving implementation and accountability in each sub-sector.
- **Technology-specific targets:** Benchmarks informed by least-cost system modelling provide technology-level visibility on expected capacity expansion and infrastructure requirements. This can strengthen investor confidence, support supply-chain planning, and reduce uncertainty about the future energy mix.
- **Green hydrogen targets:** Dedicated renewable energy targets linked to hydrogen production signal long-term demand for renewable electricity and related infrastructure. They can catalyse early investment, foster industrial development, and help provide green power for hard-to-abate industries.

Case study: Germany's renewable energy target framework

The German energy transition is guided by a clear set of targets for renewable energy deployment.

First, targets were determined for the share of renewables in final energy consumption, encompassing all sub-sectors (electricity, transport, and heating and cooling). In accordance with the European Union's Renewable Energy Directive II (RED II), Germany aims to achieve at least 41% renewables in final energy consumption by 2030, although this objective is not anchored in national law.

Second, the Renewable Energy Source Act defines specific targets for the electricity sector. By 2030, renewables are expected to account for 80% of total final power demand. A climate-neutral electricity system is envisaged for 2035.

Third, technology-specific targets were adopted for solar PV and wind energy. Accordingly, solar PV deployment must continue growing from 99 gigawatts (GW) in 2024 to 215 GW by 2030. Installed capacities need to increase from 63 GW to 115 GW for onshore wind and 9 GW to 30 GW for offshore wind over the same period.

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Renewable portfolio standards and energy certificates

Renewable portfolio standards (RPS) and similar quota-based mechanisms have been used in various jurisdictions to establish binding renewable energy targets. This type of legislation typically requires electricity suppliers or vertically integrated utilities to obtain a defined proportion of their total electricity supply – *e.g.* 40% each year – from renewable energy sources.

Obligated entities may comply in various ways, typically by: (i) generating solar or wind power themselves; (ii) procuring renewable electricity from other producers; or (iii) proving compliance via tradable certificates. In this last case, the power-consuming entity must present the required total in green certificates at the end of each year or pay penalties.

Several countries, notably, have introduced RPS not to promote renewables but instead cap deployment at low levels, with the binding target serving in practice like a ceiling on deployment. This way, existing fossil-fuel assets were protected from competition by renewable energy projects.

Successful RPS use hinges on a range of mechanisms, including:

- **Compliance flexibility:** Options such as competitive procurement, certificate trading or own-deployment reduce overall system costs and allow obligated parties to meet targets more efficiently. Such flexibility can enhance market liquidity and encourage innovation while maintaining the integrity of the standard.
- **Target setting:** Ambitious and progressively increasing targets, accompanied by interim milestones, prevent RPS from functioning as a de facto ceiling on deployment. Well-calibrated targets reinforce long-term market growth and align the mechanism with broader decarbonisation objectives.
- **Penalties for non-compliance:** Credible and proportionate financial penalties strengthen enforcement and enhance investor confidence in the durability of demand for renewable energy. Clear consequences for non-compliance reduce the risk of underachievement on strategic targets.
- **Clear coverage and eligibility:** Specifying covered entities, applicable load, eligible technologies and certificate rules reduces loopholes and regulatory ambiguity. Precise definitions support additionality (e.g. incremental emission reductions or capacity additions), discourage companies from gaming the system, and ensure that deployment outcomes reflect policy intent.
- **Credible certification:** Transparent and reliable systems for measuring power generation, issuing certificates and preventing double counting bolster market trust. Robust tracking and verification mechanisms enhance the environmental integrity and credibility of renewable energy certificates.
- **Stabilising certificate prices:** Price-management tools, such as banking and borrowing provisions, floor and ceiling prices, or market reserves, can reduce excessive price volatility. Greater price stability improves predictability for investors while preserving market-based incentives.

Case study: Provincial renewable targets and certificate trading in China

China has introduced a "responsibility weight" for renewable electricity consumption, an RPSstyle mechanism that sets binding minimum shares of renewables in total power consumption at the provincial level. The weight is defined as the proportion of locally consumed renewable electricity in total electricity use within each provincial administrative region, with two subweights: one for total renewable electricity and one specifically for nonhydropower renewables.

Target weights, differentiated mainly based on local resource endowments, are overseen by the National Energy Administration (NEA). Provincial authorities and obligated market participants, including large electricity consumers, are required to meet associated quotas.

China's Green Electricity Certificate (GEC) system, piloted in 2017 as a voluntary scheme, has been expanded since 2023 to provide full coverage, making this the main instrument to document renewable electricity consumption across the country. For provinces, the fulfilment of responsibility weights is determined mainly based on actual consumption, while for obligated market participants, it mainly reflects the number of GECs each participant holds and surrenders.

Tradable certificates allow provinces with high renewable power generation to sell GECs to those with lower renewable shares, increasing flexibility and helping reduce overall compliance costs. However, certificate trading has raised concerns about regional equity, distributional impacts, and coordination between provinces with surplus certificates and those that remain structurally dependent on energy imports.

The NEA and other regulators use performance assessments, public reporting and, in some cases, constraints on project approvals or access to subsidies to enforce compliance, although provincial-level penalties and enforcement practices continue evolving.

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• *Monitoring and governance*

Diligent monitoring and effective governance support clear guidance, transparent implementation, and continuous adjustment throughout the energy transition, with designated institutions tracking progress, enforcing accountability, and aligning actions at every level with strategic climate and energy objectives.

Key monitoring and governance elements include:

- **Monitoring, reporting, and verification:** Standardised indicators, consistent data collection methodologies and independent verification strengthen data reliability and comparability over time. A robust monitoring, reporting and verification (MRV) framework enhances policy credibility, supports evidence-based decision-making, and underpins accountability in the transition process.
- **Regular review and adjustment cycles:** Structured review processes at predefined intervals link monitoring outcomes to policy-revision cycles. The resulting feedback loop enables timely course correction, reduces the risk of persistent implementation gaps, and improves the adaptability of long-term strategies.
- **Transparent and publicly accessible data:** Public access to monitoring results and methodologies reinforces accountability and strengthens stakeholder confidence. Transparent reporting supports informed debate, facilitates external scrutiny, and contributes to sustained public trust in the energy transition.
- **Institutional responsibility:** Clearly defined roles in data collection, reporting, independent evaluation and follow-up actions reduce institutional overlaps and governance gaps. Well-defined mandates enable enhanced coordination among ministries and regulators, improving overall effectiveness and policy coherence.

Case study: Germany's Energiewende monitoring framework

Germany uses a formal, recurring monitoring process for the energy transition (Energiewende), centred on the federal government's Energiewende Monitoring Report, published annually and complemented by an in-depth Progress Report every four years. These reports track quantitative indicators for energy security, affordability, environmental impact and innovation.

In addition, an independent Expert Commission on the Energy Transition (Expertenkommission) critically evaluates the government's monitoring reports. The separation between reporting and evaluation strengthens transparency, credibility, and evidence-based policy adjustments.

Results captured in transition monitoring are explicitly used to inform policy revisions, periodic legislative reforms, grid expansion planning, and climate programmes. The process emphasises learning and course correction rather than fixed plans, enabling adaptive governance over time.

The Federal Ministry for Economic Affairs and Climate Action (BMWK) and other institutions also publish regular monitoring reports on further aspects of the energy transition, namely grid development, energy efficiency, security of electricity and gas supply, and progress in energy research.[1]

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Expanding and financing energy access

Rural electrification presents specific and complex challenges. A dedicated government agency can provide leadership and coordination and establish accountability among various institutions and the communities involved. It can also ensure consistency in planning, regulatory oversight, and long-term investment strategies that often eludes separate ministries or ad-hoc programmes.

Energy access governance and finance ideally include:

- **Specialised oversight:** A rural electrification agency (REA) or similar institution can be put in charge of implementing all rural electrification activities and strategies.
- **Ring-fencing national funding:** Funds for rural electrification activities, including mini-grids and off-grid solutions, can be ring-fenced for exclusive use by the REA or equivalent, with rules in place to define stable funding sources, such as levies, budget lines, and donor co-finance.

[1] Federal Ministry of Economic Affairs and Energy (Germany), Monitoring der Energiewende [Monitoring the Energy Transition]: www.bundeswirtschaftsministerium.de/Redaktion/DE/Artikel/Energie/monitoring-prozess.html.

- **Clear regulatory frameworks:** Licensing, tariff and connection rules must be transparent and predictable, with uniform technical and service standards and quality controls enabling private and community participation.
- **Financial support and incentives:** The responsible agency must facilitate access to long-term, affordable financing for off-grid solutions, including innovative funding mechanisms like microfinance, results-based finance, and crowdfunding aimed at underserved areas.

Case study: Rural electrification in Nigeria

Nigeria's REA and Rural Electrification Fund (REF) were originally established under the Electric Power Sector Reform Act (EPSRA) of 2005. This framework was subsequently updated and consolidated under the Electricity Act of 2023, which now serves as the principal legislation governing Nigeria's power sector, with the REA and REF retained as core institutions for energy access.

The Electricity Act, 2023, formally reaffirms the REA as the federal agency responsible for promoting universal access to affordable, reliable, and sustainable electricity in rural, unserved, and underserved communities (Section 127(1)). This mandate positions the REA as the central implementing body for off-grid and decentralised electrification in Nigeria.

The same act establishes the REF as a dedicated financing mechanism to support rural electrification projects, with a strong emphasis on renewable energy and sustainable energy solutions. The fund is intended to ensure predictable and targeted allocation of resources to priority communities and projects.

The REA and its governing board are entrusted with REF management, overseeing fund mobilisation, eligibility and allocation criteria, and expenditures. This institutional arrangement aims to strengthen accountability, coordination, and alignment between policy objectives and project implementation.

Over the past decade, the REA has rolled out more than 200 solar mini-grids and other decentralised renewable energy solutions. These interventions have provided electricity access to over one million Nigerians and have catalysed more than USD 1 billion in public and private financing for rural electrification.

Nigeria's experience illustrates how a dedicated agency and ring-fenced fund, anchored in Legislation and policy documents, can support the deployment of decentralised renewables at scale while leveraging private investment to unlock energy access for previously underserved areas and communities.

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Phase-out plans for fossil fuels

Achieving very high shares of renewable-based electricity requires a carefully managed and gradual phasing down of fossil fuels. Clear and credible phase-out plans provide direction to investors, utilities and workers, signalling that carbon-intensive assets will be retired in line with decarbonisation objectives.

Policymaking plays a central role in setting timelines, aligning market rules and investment frameworks, and addressing social and regional impacts to ensure that fossil fuels are replaced by clean alternatives in a predictable and economically efficient manner. Well-designed phase-out strategies reduce stranded-asset risks, support system reliability during the transition, and create the policy certainty needed to accelerate investment in renewable energy and power-system flexibility.

Fossil-fuel phase-out strategies typically include:

- **Phase-out timelines and regulatory mandates:** Clearly defined and legally anchored retirement schedules for fossil-fuel power plants provide long-term certainty and align asset lifetimes with climate objectives. Complementary restrictions on new fossil capacity – such as permit rules or emissions-performance standards – reduce the risk of lock-in and stranded assets, while signalling the direction of the energy system to investors and operators.

- **Market and pricing reforms:** Carbon pricing and the gradual removal of fossil-fuel subsidies help internalise environmental and social costs, correcting market distortions that favour carbon-intensive power generation. By improving the relative competitiveness of renewable energy and low-carbon alternatives, such reforms support efficient capital allocation and accelerate the transition.

- **Just transition and social protection measures:** Measures addressing workforce and regional impacts – such as retraining programmes, economic diversification initiatives, and inclusive stakeholder consultation processes – can mitigate social and economic disruptions linked to plant closures. A structured approach to managing distributional effects strengthens political legitimacy and public support for fossil-fuel phase-out strategies.

- **System adequacy and reliability planning:** Coordinated planning, particularly for generation, storage, grids and demand-side flexibility, reduces the risk that fossil-fuel retirements compromise system reliability. Clear sequencing between plant closures and the deployment of clean capacity helps avoid supply gaps and price volatility.

- **Financial mechanisms for asset retirement:** Dedicated transition funds, securitisation mechanisms or negotiated buy-out schemes can help manage stranded-asset risks and smooth the financial impact of early retirements. Structured approaches to cost recovery reduce litigation risks and provide clarity to investors.

- **Repurposing and site redevelopment strategies:** Planning for the reuse of grid connections and industrial infrastructure, combined with brownfield redevelopment of fossil-fuel sites, can lower transition costs and support local economic renewal. Early redevelopment planning can avert long-term decline in affected areas and communities.

Case study: Chile's coal phase-out strategy

In Chile, the Ministry of Energy has maintained agreements with the main coal-power operators – AES Gener, Colbún, Enel and Engie – to refrain from developing new coal-fired power plants without carbon capture and storage and to gradually retire the existing coal fleet by 2040. These initially voluntary arrangements were formalised in the ministry's Decree N° 50/2020.

The initial schedule foresaw the retirement of eight out of 28 coal-fired units (about 19% of coal power capacity) by 2024 and the remainder by 2040, with the option for retired units to maintain strategic reserve status for up to five years with remuneration for their available capacity. In practice, Chile had surpassed the initial eightunit closure target by 2022.[2]

The country has committed to achieving carbon neutrality by 2050, with the gradual shutdown of its coal fleet as a key component of its decarbonisation strategy. Its most recent NDC and climate legislation set a target of at least 80% renewable electricity generation in the power mix by 2030.[3]

Chile has completely ceased domestic coal mining, closing its last site, Mina Invierno, in 2020. All coal currently used in the country's power sector is imported, particularly from Colombia and Australia. As a result of targeted energy transition policies, the share of coal in Chile's power mix fell from 34% in 2019 to 16% in 2024.[4]

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Sub-national transition plans

Governments can provide substantial support to replace high levels of fossil-fuel value creation as the energy transition reshapes traditional economic foundations. As coal, oil and gas activities decline, proactive transition strategies focused on affected parts of a country help channel investment and industrial policy toward emerging sectors, ensuring that affected localities participate in new sources of growth.

Targeted measures – such as prioritising battery manufacturing, renewable energy projects or other suitable industries in phase-out areas – can anchor new value chains, sustain local employment, and maintain social and economic stability during and after the transition.

Important elements for sub-national transition planning include:

- **Localised industrial diversification strategies:** Targeted diversification strategies reduce economic dependence on fossil-fuel activities and mitigate the risk of long-term decline in affected areas. Strategies that identify competitive advantages and support alternative sectors – including clean energy value chains and other industries, such as tourism – can broaden the local economic base and create new sources of employment and revenue.
- **Local procurement targets:** Well-designed procurement provisions can strengthen linkages between incoming clean energy projects and local firms. By encouraging local sourcing and workforce participation, this targeted procurement approach can support job creation and embed investment benefits within the communities most affected by the transition.
- **Infrastructure investment:** Upgrading transport, grid and digital infrastructure can enhance the attractiveness of transition-affected areas for new industrial and clean energy investments. Recycling public revenues or leveraging international financial support for infrastructure reduces structural disadvantages and facilitates economic renewal.
- **Investment incentives and tax credits:** Fiscal incentives, grants and public-private partnership models can help offset higher perceived risks in areas formerly dependent on fossil-fuel extraction or related industries. Such measures improve the risk-return profile for investors and can catalyse private capital flows into emerging low-carbon industries.
- **Regional development funds:** Dedicated funding mechanisms provide targeted support for community-led initiatives, small and medium-sized enterprises (SMEs), innovation activities and workforce retraining. Structured financial support strengthens local capacity to adapt and fosters inclusive economic transformation.

- **Social-protection and income-support mechanisms:** Temporary income support, mobility assistance and early retirement schemes can smooth the adjustment for affected workers and households, reducing social disruption during restructuring.
- **Stakeholder participation frameworks:** Inclusive regional planning processes enhance legitimacy and ensure that transition strategies reflect local priorities and socio-economic realities. Meaningful engagement with workers, local authorities and communities reduces resistance and improves the quality and sustainability of investment decisions.
- **Monitoring and evaluation mechanisms:** Systematic tracking of employment trends, investment flows and social outcomes strengthens accountability and policy learning. Evidence-based assessments further support timely adjustments to local or sub-national transition measures, which in turn can reinforce government credibility in the transition process.

Case study: Spain's Just Transition Agreements and coal-sector closure

Spain's 2019 Just Transition Strategy has guided the closure of coal mines and power plants through Just Transition Agreements with unions, companies and local governments, covering multiple coal power stations (around 10 GW in total) and several thousand workers.

Spain's Institute for Just Transition coordinates funding, reskilling and territorial redevelopment and aligns national support measures with the EU Just Transition Fund. Affected workers have been offered early retirement options, reemployment pathways and training programmes, while companies commit to prioritising local labour for dismantling and site restoration.

Public investment has focused on renewable energy projects, environmental rehabilitation and support for local entrepreneurship to revitalise formerly coaldependent areas.

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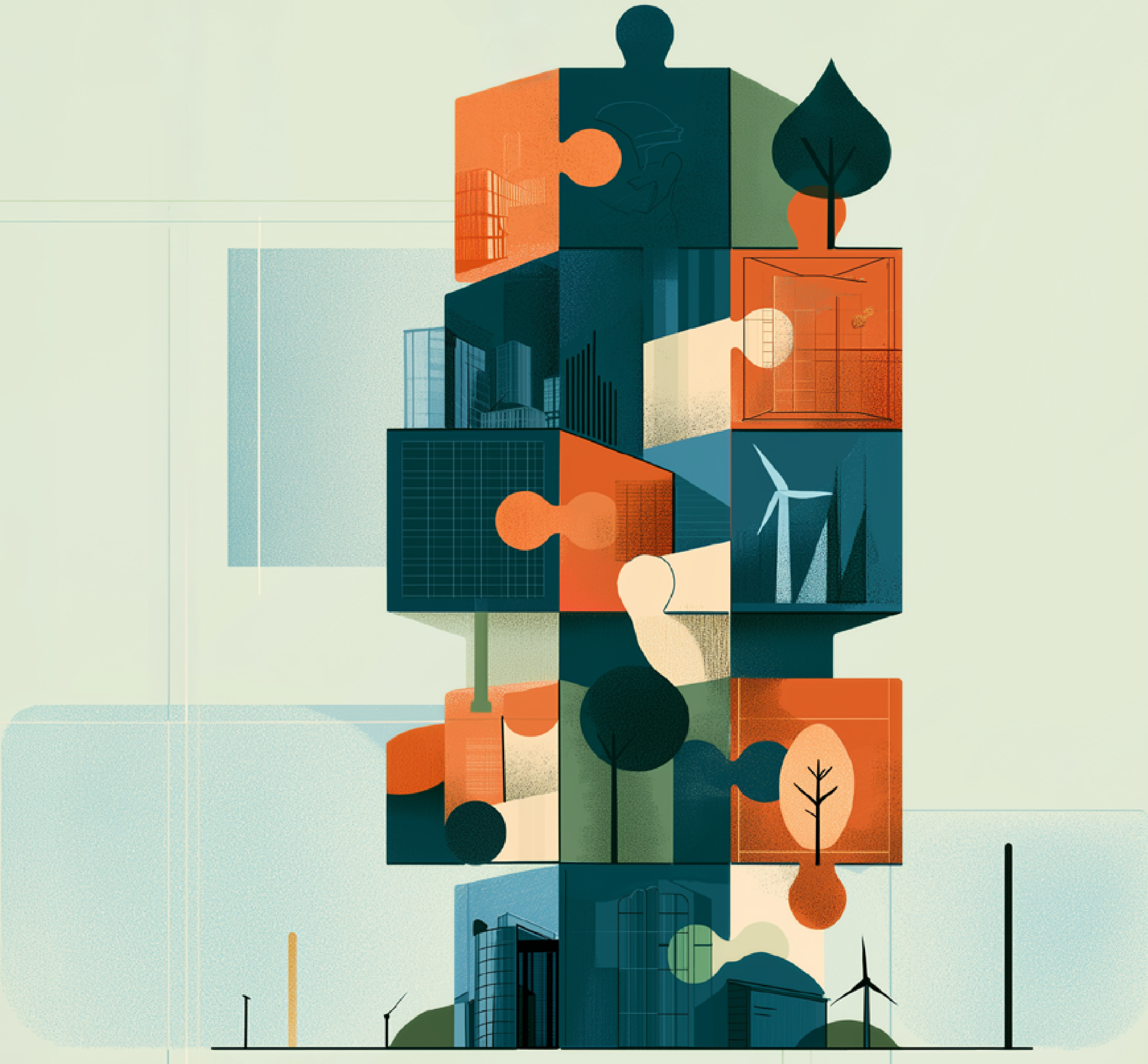
Part II: Financing and pricing the transition



2. Finance

Policymakers increasingly recognise scaling up finance for renewables as a precondition for meeting climate mitigation and development goals. Global investment in the energy transition has risen sharply, with clean energy now attracting almost twice as much capital as fossil fuels. However, current levels remain far below what would be needed to limit the rise in average global temperatures at 1.5°C or even below 2°C, the thresholds identified under the Paris Agreement to avoid catastrophic climate change.[5]

Estimates of the annual investments needed are in the order of USD 5–6 trillion by 2030.[6] Because energy infrastructure is long-lived, delays in redirecting finance can lock economies into a high-emissions pathway, increasing both physical climate risks and the costs of later, more abrupt, energy transition investments.

Fiscal incentives and subsidies are important interventions at the national level, with policymakers in each country shaping the financial conditions for the transition through domestic regulation, fiscal policy, and broader investment policies. Clear, credible long-term decarbonisation targets, combined with predictable support schemes for renewables and energy efficiency, can lower perceived risk and the cost of capital, thereby attracting private investment at scale. Here, reducing off-taker risks also plays an important role.

At the same time, critical segments like grids, storage, industrial decarbonisation and distributed renewables can involve higher upfront costs and less mature business models, which markets underfund. In such cases, public banks, guarantees, concessional credit and blended finance instruments can absorb specific risks and enable local financial institutions to develop expertise in clean energy lending.

In developing countries, international finance is especially important to advance the energy transition. Yet the geography of low-carbon investment flows remains highly uneven. In effect, countries with less historical responsibility for climate change struggle to finance clean energy and development, with global cooperation – particularly on transition financing – offering a way to redress the imbalance.

Presently, climate and renewable energy finance is largely extended on commercial terms, thereby flowing disproportionately to a small number of middle- and high-income countries. Low-income and climate-vulnerable states still receive marginal shares of international climate finance, mostly tied to loans, despite having substantial renewable energy potential and acute energy-access needs.[7]

This leaves high-income and major emitting countries with a dual responsibility: to provide and mobilise international public finance – including concessional and grant-based finance – through development banks, climate funds and export credit agencies; and to help create the policy and institutional conditions that make private investment in emerging markets viable.

Well-designed international finance can support just transition priorities, such as job creation, local value chains, and protection for affected workers and communities. It can also augment donor support for other development objectives, such as energy access and more stable livelihoods in the least developed countries.

[5] IEA, World Energy Investment 2025: www.iea.org/reports/world-energy-investment-2025. IRENA, Global landscape of energy transition finance 2025: www.irena.org/Publications/2025/Nov/Global-landscape-of-energy-transition-finance-2025.

[6] ibid.

[7] IRENA, Global landscape of energy transition finance 2025: www.irena.org/Publications/2025/Nov/Global-landscape-of-energy-transition-finance-2025.

Carbon pricing, crucially, internalises the cost of GHG emissions, making low-carbon technologies more competitive and reducing investment risk for clean energy. Revenues from carbon pricing can be recycled to support renewable energy deployment, grid infrastructure, and social protection measures, accelerating a just and efficient transition.

In sum, making sufficient, affordable and well-targeted finance available – both domestically and across borders – is vital to turn decarbonisation pledges into practical pathways. Only with adequate, accessible financing can the global energy transition proceed at a pace and scale compatible with sustainable development and climate stabilisation.

De-risking investment in developing countries

In developing countries, mobilising international finance for the energy transition depends on heavily on government direction. With stable policies, transparent regulation and a credible long-term transition strategy, a national government can reduce investment risk and strengthen investor confidence. Clear alignment between climate objectives and national development priorities further enhances the effectiveness of international funding, ensuring that external capital supports sustainable growth, energy access and structural transformation.

Investments can be de-risked in a variety of ways:

- **Stable policy and regulatory frameworks:** Predictable energy and climate policies, transparent regulations and credible long-term transition plans reduce regulatory uncertainty and policy-reversal risk. Greater clarity regarding future market conditions lowers the cost of capital and strengthens investor confidence in developing markets.
- **National energy transition and investment plans:** Clearly articulated strategies outlining sectoral priorities, timelines and investment pipelines improve coordination between domestic institutions and international financiers. Well-defined project pipelines enhance visibility, create bankable opportunities, and facilitate alignment between national development objectives and external funding flows.
- **Green public financial institutions:** National development banks and dedicated green funds can act as intermediaries that absorb, structure and blend international climate finance with domestic capital. Their involvement can mitigate perceived country and project risks, provide local market knowledge, and crowd in private investment.
- **Green bonds:** Issuing green bonds can attract long-term capital from institutional investors seeking sustainable assets. Earmarking bond proceeds for renewable energy and climate-resilient infrastructure helps diversify funding sources and potentially lowers financing costs for those assets.
- **Public-private partnerships (PPPs):** Structured collaboration between public authorities and private investors distributes risks based on capacity and expertise. PPP models help governments mobilise private capital and technical know-how while maintaining public oversight of strategic infrastructure development.
- **Blended finance mechanisms:** Concessional public or donor capital, deployed alongside commercial finance, can improve project bankability by absorbing first-loss risk and enhancing returns. Blended structures help crowd in private investment in markets perceived as high-risk.
- **Guarantees and risk mitigation instruments:** Partial risk guarantees, political risk insurance and currency-hedging facilities reduce exposure to regulatory, off-taker and exchange-rate risks. Such instruments can significantly lower financing costs and expand access to international capital.

Case study: Green bonds and renewable energy finance in India

India's green bond market is underpinned by a clear division of roles between public finance institutions and financial regulators. The Indian Renewable Energy Development Agency (IREDA), acting as a government-owned lender, provides dedicated finance to renewable energy and energy-efficiency projects, while the Securities and Exchange Board of India (SEBI) sets the regulatory framework, market rules, and disclosure standards for green bonds. This institutional set-up translates public policy objectives into concrete financing signals while maintaining market integrity and investor protection.

SEBI's green bond framework specifies eligible "green" project categories and effectively excludes activities outside this scope, steering proceeds consistently towards environmentally beneficial investments and reducing the risk of greenwashing.

Since 2022, most Indian green bond proceeds have flowed to renewable energy projects, reflecting stated policy priorities and giving a strong signal for low-carbon investment. Issuers must disclose beforehand how projects are selected and how bond proceeds will be allocated. Then, after issuance, they must provide regular reporting on use of the funds, often supported by external reviews or thirdparty verification. These requirements ultimately improve transparency and boost investor confidence.

Proceeds from green bonds are tracked separately from general corporate funds, typically through dedicated subaccounts or internal tracking systems. Periodic reporting on financial allocations and, where feasible, environmental outcomes – such as emissions reduced or renewable power capacity installed – enhances accountability and supports comparability between bond issuers. Standardised reporting also helps regulators and policymakers assess market integrity and alignment with broader climate and energy goals.

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● *International financial partnerships*

Developed-country governments could unlock considerable finance for the global energy transition by fulfilling existing climate finance commitments. Additionally, they can contribute to multilateral funds and utilise public-finance tools, such as guarantees and blended finance, to help de-risk private investment in developing countries.

Policy priorities for developed countries to advance the global energy transition include:

- **International climate finance commitments:** By contributing to mechanisms like the Green Climate Fund and Just Energy Transition Partnerships (JETPs) and by working with multilateral development banks, developed countries can expand concessional financing pools and help fund the transition in developing countries.
- **Blended finance instruments:** Combining concessional public finance with private capital through mechanisms such as first-loss guarantees, subordinated debt, and risk-sharing facilities can lower financing costs for clean energy projects.
- **Technical assistance and capacity building:** Support for regulatory reform, project preparation, and financial management enhances institutional capacity to design bankable clean energy projects.

Case study: Just energy transition partnerships (JETPs)

JETPs are multi-stakeholder partnerships between developed and developing countries that are designed to accelerate a just and equitable shift away from fossil fuels while mobilising large-scale climate finance for clean energy, social protection, and economic diversification.

The first JETP, announced in 2021, committed USD 8.5 billion from the International Partners Group (EU, France, Germany, UK, and the US) to support South Africa's transition from coal toward renewables, emphasising job creation and community resilience. Similar partnerships have since been launched with Indonesia (USD 20 billion), Vietnam (USD 15.5 billion), and Senegal (USD 2.7 billion), each tailored to national contexts and priorities.

JETPs blend grants, concessional loans, private investment and guarantees, aiming to de-risk clean energy investments while ensuring that finance supports social and economic inclusion. Each JETP is country-led, developed through a national consultation process, and linked to detailed JETP investment plans (JETP-IPs) that outline project pipelines and associated policy reforms.

Another core element of JETPs is ensuring protection for workers and communities through reskilling programmes, social safety nets and community development initiatives.

In practice, however, JETP implementation has faced obstacles, with grant funding falling short of initial pledges and the available finance packages retaining large shares of commercial loans.

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Fiscal incentives and subsidies

Upfront capital costs remain a major barrier to renewable energy deployment, particularly for capital-intensive technologies such as solar PV, wind, and storage. Fiscal incentives and subsidies can reduce the upfront and ongoing costs of renewable energy projects, directly improving project economics and lowering investment risk.

Fiscal incentives and subsidies can include:

- **Tax incentives:** Income tax credits or accelerated depreciation schemes are often available to reduce the tax burden and improve financial returns for renewable energy projects.
- **Accelerated depreciation:** Renewable energy investors may be allowed to deduct capital costs more rapidly than under standard depreciation schedules, reducing taxable income in the early years of a project and improving cash flow when debt service obligations are highest.
- **Grants and rebates:** Renewable energy projects can benefit from grants or rebates structured as an investment subsidy on each kilowatt (kW) installed or through direct financial support to offset initial capital costs.
- **Low-cost capital:** Green credit lines or concessional financing from public banks or international institutions can lower the cost of borrowing for renewable energy investments.
- **Renewable energy subsidies:** Feed-in tariffs or concessional financing (including for off-grid solutions and for power generation by private households or other prosumers) can also lower investment costs, reduce market risk, increase access to community energy solutions, and accelerate the deployment of clean energy technologies.
- **Fossil-fuel subsidy reform:** Phasing out artificially low prices for coal, oil, and gas improves the competitiveness of renewables and frees public resources, both for clean energy investment and targeted income support, while encouraging the shift to low-carbon alternatives.

Case study: Reducing investment risk in India’s renewable energy sector

India has used public finance to reduce risks for investors, improve project economics, and rapidly scale up renewables. Since the early 1990s, the country has provided an accelerated depreciation framework to incentivise investment in renewables.

Assets such as wind and solar equipment were eligible for up to 80% depreciation in the first year, with the rate reduced to 40% from 2017 onwards, still enough to boost earlyyear returns and strengthen cash flow for investors. This tax treatment, alongside other policy tools, has helped attract private capital for clean energy.

India is a member of the International Platform on Sustainable Finance (IPSF), which provides a forum for public authorities to exchange approaches, strengthen alignment, and establish green investment frameworks. Participation in such platforms complements India’s domestic greenfinance regulations and taxonomies, helping to channel more capital into climate and energy transition projects.

In parallel, India channels public capital into renewable energy projects through institutions such as IREDA, a governmentowned specialised lender. IREDA offers longtenor project finance, typically on terms that can improve the weighted average cost of capital relative to standard commercial bank loans, particularly when combined with concessional credit lines or other riskmitigation instruments.

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Off-taker risk mitigation

Renewable energy projects are highly capital-intensive and depend on long asset lifetimes, making investor confidence in revenue stability essential. Effective management of off-taker risk is thus crucial to secure finance for renewables.

Well-structured power purchase agreements (PPAs) provide predictable revenue streams, clarify risk allocation among different parties, and reduce exposure to payment, regulatory and operational uncertainties. By ensuring the credibility of off-takers, robust PPA frameworks lower financing costs, improve the project bankability, and help mobilise private investment in renewables.

Off-taker risks can be addressed in several ways:

- **Ensuring off-taker creditworthiness:** The off-taker, typically an electric utility, might face financial challenges. Audited financial statements or support mechanisms such as government guarantees, letters of credit, or escrow accounts can all improve the off-taker's (and in turn the project's) creditworthiness, particularly if the off-taker is a special-purpose entity formed for the project.
- **Diversification of off-takers:** Corporate PPAs, merchant market participation, and engagement with multiple off-takers all avoid or reduce dependence on a single public utility. Diversification spreads project risk and improves overall system resilience.
- **Inflation and currency risk mitigation:** Tariff indexation or pass-through mechanisms, local-currency financing, and hedging or guarantee facilities can all help address inflation and currency risks, protecting project revenues and debt servicing against macroeconomic volatility.
- **Compensation for curtailment:** PPAs manage curtailment risk through clear compensation rules, often via provisions on deemed generation, which ensure renewable power producers are paid for any energy they would have delivered, assuming any curtailment was beyond their control.
- **Dispute resolution mechanisms:** Clear and transparent arbitration procedures and adherence to international dispute settlement norms reduce legal uncertainties. Predictable enforcement frameworks strengthen contract credibility.

Case study: Managing off-taker risk in India's renewable energy sector

India has reduced renewable energy off-taker risk through a mix of distribution-utility financial reforms, more centralised procurement, and legally enforced paymentsecurity mechanisms. These measures aim to strengthen the creditworthiness of counterparties under PPAs and reduce payment delays for renewable power producers.

The Ujwal DISCOM Assurance Yojana (UDAY), launched in 2015, was designed to restructure debts, improve operational performance, and enhance the ability of financially weak state-level distribution companies (DISCOMs) to honour longterm PPAs. The mechanism has allowed state governments to take over a large share of debt from participating DISCOMs, linking such support to loss-reduction milestones and more costreflective tariffs, thereby improving credit quality for projects with those companies as off-takers.

Under the Jawaharlal Nehru National Solar Mission, the Ministry of New and Renewable Energy (MNRE) introduced Payment Security Mechanism guidelines, with the subsequent Payment Security Fund, managed by the Solar Energy Corporation of India (SECI), backstopping timely PPA payments to solar developers when DISCOMs delay payments.

A 2019 decision by the Ministry of Power, with subsequent clarifications from MNRE, requires distribution licensees to maintain adequate letters of credit or equivalent instruments under PPAs, legally reinforcing payment obligations and reducing liquidity and latepayment risks for renewable power suppliers. The Revamped Distribution Sector Scheme (RDSS), launched in 2021 as a complement to UDAY, aims to create financially sustainable and technologically modern distribution utilities.

The nationwide rollout of smart meters and better energy accounting form another vital component, aimed at ensuring accurate billing, boosting revenues, and building the digital backbone of the modernised power sector.

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• *Tariff design and pricing*

Electricity tariffs are a central part of the policy framework for renewable energy deployment. They influence how much electricity is consumed and when, how costs are shared between consumers, and how predictable revenues are for utilities and investors. Effective pricing frameworks can support cost recovery, encourage efficient and flexible use of electricity, and facilitate the integration of variable renewables while keeping basic consumption affordable.

Tariff and pricing options include:

- **Cost reflective and transparent tariffs:** Tariffs that progressively reflect the costs of efficient generation, transmission and distribution improve the financial sustainability of the power sector and reduce reliance on public subsidies. Transparent and clearly structured tariff components enhance consumer understanding and strengthen investor confidence in revenue stability.
- **Time-of-use and dynamic pricing:** Time-varying tariffs signal the real-time value of electricity, encouraging demand to shift toward periods of high renewable-based generation and away from peak demand. Such pricing structures reduce system stress, limit the need for costly peaking capacity, and improve overall efficiency.
- **Tariffs rewarding flexibility:** Pricing frameworks that recognise demand response, storage and controllable loads support system balancing in grids with high shares of variable renewables. Valuing flexibility services reduces curtailment, lowers integration costs and enhances reliability.
- **Network charges and distributed generation:** Well-designed network tariffs ensure fair cost recovery for grid infrastructure while maintaining incentives for distributed generation, self-consumption and storage. Balanced approaches prevent cost shifting between consumer groups and support continued investment in both centralised and decentralised assets.
- **Equity and affordability:** Lifeline tariffs, connection subsidies for households with new grid access, or increasing block structures can protect access to essential electricity services for low-income households while maintaining cost recovery from higher consumption levels. Such mechanisms help reconcile financial sustainability with social policy objectives.
- **Stable, rules-based regulation:** Clear tariff-setting methodologies and predefined adjustment mechanisms, overseen by an independent regulator, reduce uncertainty. Predictable regulatory processes strengthen investor confidence and give consumers more clarity about future prices.

Case study: Aligning retail tariffs with system needs in California, U.S.

In 2015, the California Public Utilities Commission (CPUC) adopted Decision D.15-07-001, directing the state's major investor-owned utilities (PG&E, Southern California Edison, and San Diego Gas & Electric) to reform residential tariffs and move to default time-of-use (TOU) rates to better reflect costs and support system flexibility.

Follow-up decisions, including D.18-05-011, approved specific default TOU rate designs and rollout plans from 2019 onward, with peak periods shifted into late afternoon and evening to better align prices with net demand amid high solar deployment. The CPUC required customer information campaigns and protections for vulnerable customers, including through CARE discounts, thereby linking tariff reform to equity and affordability objectives.

More recent decisions on net billing, as a successor to net metering, have set highly time-differentiated export rates based on an avoided-cost calculator, reinforcing TOU signals and encouraging consumption when solar output is high and enabling exports to neighbouring states during evening peaks.

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Carbon pricing

Carbon pricing can serve as a powerful enabler of the energy transition, particularly in emissions-intensive sectors such as industry. By assigning a cost to GHG emissions, it internalises the environmental externalities associated with fossil-fuel use and improves the relative competitiveness of renewable energy and low-carbon technologies. When designed to be credible and predictable, carbon pricing provides clear long-term investment signals, reducing policy uncertainty and supporting innovation, energy efficiency and the deployment of clean energy and infrastructure.

Carbon pricing mechanisms include:

- **Emissions trading:** An emissions trading system (ETS) provides environmental certainty through a fixed emissions cap while achieving reductions at less overall cost by allowing firms to trade allowances and respond flexibly to a market-based carbon price.
- **Effective cap-and-trade systems:** An effective ETS sets a clear, enforceable cap that declines over time, ensuring alignment with long-term climate targets. Auctioning of emission allowances, limiting free allocations, and preventing market manipulation all serve to improve efficiency, increase transparency and provide price signals.
- **Carbon taxes:** An alternative to the ETS is a carbon tax. A transparent tax rate that increases over time can give firms and households sufficient certainty to plan investments and reduce emissions efficiently. Applying the tax across sectors and fuel types ensures emission reductions occur where they are cheapest.
- **Revenue recycling for equity and support:** Carbon-tax and allowance-auction revenues under an ETS can help lower other taxes or support compensation for low-income households. Thus, revenue recycling can improve fairness and strengthen public and political acceptance.

Case study: Sweden's dual carbon pricing framework

Sweden was among the first countries in the world to introduce a national tax on carbon dioxide (CO_2), starting in 1991. Since 2005, the country's largest emitters in power and industry have also been regulated under the EU Emissions Trading System (EU ETS). Swedish CO_2 tax is levied mainly on fossil fuels used in end-use demand categories such as heating and transport, with rates and exemptions varying by use and sector.

The EU ETS, as applied in Sweden, covers stationary installations, notably for power, heat and energy-intensive industries, and follows EU cap-and-trade rules requiring regulated entities to surrender allowances for verified emissions. A key design feature is coordination between instruments. Installations covered by the EU ETS are, as a rule, exempt from the Swedish carbon tax, reducing double pricing while keeping incentives elsewhere.

Sweden's ETS is implemented through national law that sets permitting, allocation/registry, reporting and compliance obligations, with detailed application rules set by an implementing ordinance supporting enforceability and market integrity.

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3. Renewable energy procurement mechanisms

Renewable power generation has different characteristics than fossil-based or nuclear generation, one of them being its more limited dispatchability in overall terms. Renewable-based generation technologies can be divided between variable renewables (VRE) with limited dispatchability, such as wind and solar PV, and fully dispatchable renewables, such as concentrated solar power (CSP), biomass, hydropower with reservoirs, and geothermal.

VRE technologies dominate current and forecasted generation mixes for the energy transition because of their lower costs in generating electricity. Declining VRE costs entail important consequences for products and services needed, as well as for procurement structures.

The cost structure for renewables is dominated by capital expenditure (CAPEX), whereas fossil-based generation entails higher operating expenditure (OPEX). This radically different cost structure, combined with the limited dispatchability of renewable power, makes procurement structures based on short-term marginal pricing a poor fit for renewable-based power systems.[8]

Long-term procurement mechanisms acknowledge and honour the cost characteristics of renewable energy and specifically VRE technologies, including lower ability to properly respond to short-term price signals. Successful renewable power procurement has always, without exception, been linked to the existence of a long-term procurement mechanism, often by-passing existing electricity procurement structures unsuited to renewable sources and the associated technologies.[9]

Long-term procurement mechanisms for renewable power generation no longer function as traditional subsidies. Still, characterising them as such can prompt political and social resistance that hinders the transition. These mechanisms can form part of either a competitive market-based or a direct regulation process and can operate within both liberalised market systems and publicly managed frameworks.

[8] Garcia-Casals, X., and E. Bianco, Potential limitations of marginal pricing for a power system based on renewables (IRENA Technical Paper 3/2022): www.irena.org/Technical-Papers/Potential-Limitations-of-Marginal-Pricing-for-a-Power-System-Based-on-Renewables.

[9] When the costs of renewable power technologies were higher than those of fossil-fuel technologies, such procurement mechanisms were described as subsidies. Historically, this subsidy aspect helped advance renewable power technologies along an initial learning curve. Even as life-cycle costs for renewable power technologies have fallen below those of fossil-fuel technologies, the crucial need for long-term procurement mechanisms remains.

Long-term procurement of renewables can take different forms, requiring different policies, namely: PPAs, feed-in tariffs (FiTs), feed-in premiums (FiPs), contracts for difference (CfDs), and direct public investment.

Power purchase agreements

A PPA is a long-term contract in which a renewable power producer and an off-taker – such as a utility, government, corporation or energy community – agree on a price for generated electricity, which may be fed into the grid or self-consumed. While the PPA is a contractual arrangement rather than a policy instrument, it depends on an enabling policy framework.

For producers, PPAs provide revenue certainty just as FiTs do, but prices are typically determined through competitive auctions rather than administratively set rates. The resulting market-based price discovery can reduce the risk of overcompensation, though it may also result in prices that challenge project viability or disadvantage smaller market participants.

Aspects to consider in the design of a PPA procurement process include:

- **Delivery structure:** The choice between physical PPAs (direct delivery or utility-sleeved arrangements) and virtual or financial PPAs determines how electricity and price risks are allocated between parties. A well-suited structure enhances revenue stability for generators while aligning with market design and grid access conditions.
- **PPA contract duration and volume:** Clearly defined contract terms – often 10 to 20 years – and agreed supply volumes provide predictable revenue streams that underpin project bankability. Longer tenors and well-calibrated volumes reduce refinancing risk and support access to lower-cost capital.
- **Volume of electricity:** Specifying contracted energy output or capacity clarifies performance obligations and revenue expectations. Clear volume commitments reduce uncertainty for lenders and investors, strengthening the financial viability of renewable energy projects.
- **Standardisation and risk mitigation:** Standardised PPA templates streamline negotiations, lower transaction costs and enhance transparency. Clearly defined provisions on curtailment, force majeure, changes in laws, and termination rights improve risk allocation between parties, increase legal certainty and strengthen overall investor confidence.

Case study: Contract standardisation in South African renewable energy procurement

South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is underpinned by a highly standardised, largely non-negotiable contractual framework. This approach was designed to reduce transaction costs, accelerate project development, and improve bankability by providing clear and consistent risk allocation across projects.

Successful bidders under the REIPPPP enter a standard PPA with Eskom, the state-owned electrical utility, as the single buyer. The PPA is complemented by the standard Implementation Agreement with the government and Direct Agreement involving lenders, together forming a comprehensive contract package that allocates commercial, regulatory, and political risks. PPAs are typically concluded for a 20-year term, denominated in South African rand (ZAR). Tariffs are indexed to inflation, providing long-term revenue stability and protecting investors against currency and inflation risks.

Contracts contain detailed provisions governing the scheduled Commercial Operation Date (COD), a final "Last COD," and the consequences of delays. These include liquidated damages and, in cases of prolonged delay, termination rights, ensuring discipline in project delivery while maintaining clarity for lenders. Standardised clauses allocate the risks associated with regulatory changes and unforeseen events.

Change-in-law provisions define compensation mechanisms, while force majeure clauses allow schedule relief and, where applicable, term extensions, with clear rules for interaction with insurance coverage. Where power generation is curtailed due to defined system events or decisions, the framework allows for "deemed energy" payments as compensation, shielding project revenues against certain system-level risks beyond the control of the producer.

The Direct Agreement establishes clear default and termination procedures and includes step-in rights for lenders, strengthening project bankability and facilitating access to long-term finance. South Africa's use of standardised contracts demonstrates how consistent risk allocation and legal certainty can support large-scale renewable energy deployment in emerging markets.

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• *Direct power purchase agreements*

Direct PPAs enable major electricity consumers, such as corporations, public institutions or large industrial users, to contract directly with renewable energy producers. By providing long-term revenue certainty independent of public support schemes, direct PPAs reduce reliance on government-backed procurement and help diversify the sources of demand for clean electricity. By unlocking private-sector purchasing, they can stimulate additional renewable generation capacity, support corporate decarbonisation and improve project bankability.

Direct PPAs allow for:

- **Moving beyond single-buyer arrangements:** Enabling commercial and industrial consumers to contract directly with power producers reduces reliance on a single utility, diversifies demand and supports additional renewable deployment. Greater buyer choice can enhance competition and strengthen corporate decarbonisation efforts.
- **Wheeling frameworks:** Transparent rules for transporting electricity across the grid, or "wheeling," provide certainty on access rights, charges, losses, and settlement. Clear wheeling frameworks reduce transaction risk, ensure fair cost recovery and improve the bankability of direct PPAs.
- **Direct power lines:** Allowing direct connections between generators and large consumers can reduce grid dependency and congestion risks. Such arrangements can enhance project viability, particularly amid network constraints or regulatory uncertainty.

Case study: Opening the power system to third-party access in South Africa

South Africa's framework for non-discriminatory grid access is anchored in the establishment of the National Energy Regulator of South Africa (NERSA) in 2004 and the Electricity Regulation Act (ERA) of 2006. The ERA explicitly prohibits unfair discrimination in grid access and tariffs while requiring transmission and distribution licensees to provide third-party access on objective and transparent terms. These provisions encourage competition, facilitate private investment in generation, and support the integration of renewable energy by allowing electricity to be transported ("wheeled") across the grid from generators to third-party consumers.

Electricity Regulation Amendment Act 38 of 2024 represents a significant step in operationalising these principles. The act accelerates the transition away from a single-buyer model toward more open and competitive electricity trading arrangements and formally defines institutional roles related to a transmission system operator and future market structures.

A major implementation milestone was reached in May 2025 with the publication of the Regulatory Rules on Network Charges for Third-Party Wheeling of Energy (Version 1) in Government Gazette No. 52781. These rules establish national principles for cost-reflective, transparent, and non-discriminatory use-of-system charges, as well as standardised wheeling credit rates.

Together, these reforms provide greater regulatory certainty for generators, large consumers, and intermediaries engaging in wheeling arrangements. By clarifying access rights and pricing principles, the framework lowers barriers to market entry, supports corporate power purchase agreements, and facilitates higher shares of renewable energy in the power system. South Africa's experience highlights the importance of combining legal access rights with detailed regulatory rules on network charges and institutional roles, thereby translating non-discrimination principles into workable market practice.

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• *Feed-in tariffs*

A FiT policy guarantees renewable energy producers a pre-agreed payment for each unit of electricity generated over an agreed long period of time. It is a market-independent mechanism that provides high degree of revenue certainty to the producer. It is one of the oldest and most successful policies available to support renewable electricity uptake.

Several aspects to consider in the design of a FiT policy are:

- **Duration of tariff payment:** Long-term tariff guarantees – typically 15-20 years – provide revenue certainty and reduce financing costs. Stable payment periods improve project bankability and support sustained renewable energy deployment.
- **Differentiated tariff levels:** Differentiation by technology, plant size, location or other characteristics allows tariffs to better reflect generation costs and system value. Tailored rates can prevent overcompensation while supporting a diverse portfolio of renewable energy technologies and project types.
- **Adjustment mechanisms for new plants:** Gradual tariff digression for newly commissioned plants reflects cost reductions over time and limits excess rents. Clear, pre-defined rules and avoidance of retroactive changes preserve investor confidence and maintain the credibility of the framework.
- **Cost recovery and communication:** Transparent mechanisms for recovering FiT costs – often through electricity tariffs or alternative public funding sources – reduce fiscal uncertainty and distributional concerns. Clear communication around cost recovery and long-term benefits can help support social and political acceptance.
- **Tariff-setting methodology:** Well-defined approaches to determining tariff levels – whether set administratively or informed by competitive processes – help balance adequate investment incentives with cost control. Robust calibration may be necessary to limit windfall profits while ensuring continued deployment.
- **Alignment with system planning:** FiTs are most effective when deployment incentives are aligned with grid expansion, connection procedures, and broader power-system planning.

Case study: Feed-in tariffs and renewable energy in Viet Nam

Viet Nam has used feed-in tariffs as a central policy instrument to accelerate renewable energy deployment and reduce reliance on fossil fuels. FiTs played a catalytic role in initiating market development and rapidly scaling up renewable generation capacity.

The first FiT for onshore wind was introduced in 2011 (Decision 37/2011/QD-TTg), but deployment only picked up after tariffs were increased in 2018 (Decision 39/2018/QD-TTg), underscoring the importance of appropriate tariff calibration. A FiT for solar PV was introduced in 2017 (Decision 11/2017/QD-TTg). Subsequent tariff adjustments, combined with falling technology costs, drove an unprecedented solar boom: capacity rose from around 0.1 GW in 2018 to roughly 16.5–16.7 GW by 2020, far exceeding the original 2020 target of 0.85 GW.

Despite their effectiveness in driving capacity growth, Viet Nam's FiTs have faced challenges. Short application windows and uncertainty about postFiT support initially created pronounced boom-bust investment cycles, constraining the emergence of a stable domestic renewable energy industry. Limited geographic differentiation of tariffs and insufficient coordination with grid expansion and flexibility investments led to grid congestion, curtailment and system stability issues in highpenetration regions.

Viet Nam's experience highlights the need for wellcalibrated tariff levels, policy predictability, and close alignment between deployment incentives, grid planning, and flexibility measures to ensure a sustainable and resilient renewable energy transition.

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• *Feed-in premiums*

FiPs help align renewable energy support with liberalised wholesale markets, specifically by requiring generators to sell electricity at market prices while receiving an additional premium. Compared to FiTs, the FiP approach strengthens market orientation through greater exposure to wholesale price signals and revenue variability.

For VRE projects, price responsiveness remains constrained by weather-dependent generation profiles. Nevertheless, FiPs can still strengthen market participation incentives, forecasting, and system integration.

Revenue stability varies with FiP design: while fixed premiums expose producers fully to market fluctuations, sliding or two-sided premiums can (similarly to FiTs) preserve a degree of long-term certainty. In both FiT and FiP systems, overall support costs are ultimately borne by electricity consumers, although the allocation between regulated payments and market revenues differs – as can associated public perceptions.

In addition to FiT-related aspects, the following design considerations apply to specifically to FiPs:

- **Fixed vs. sliding premium:** The choice between a fixed or sliding premium shapes the balance between market exposure and revenue stability. Fixed premiums fully expose generators to wholesale price volatility, increasing downside risk when prices are low but potentially resulting in windfall gains during price spikes. Sliding premiums, by contrast, reduce uncertainty by stabilising total remuneration, preventing revenues from falling below a minimum while limiting excessive returns. As sliding mechanisms expand, revenue profiles increasingly resemble those under FiTs, although the premium approach maintains a link to market prices.

- **Design options for sliding premiums:** Sliding premiums can include floors and caps, either on the premium or on total remuneration, to reduce downside risk and limit excessive upside gains. In the spot-market gap model, for instance, a minimum remuneration is guaranteed by topping up wholesale prices to a predefined level, with the premium falling to zero when market prices exceed it. These design choices influence revenue predictability, fiscal exposure, and the extent of market integration.

- **Market participation requirements:** FiP schemes are often accompanied by requirements for direct market participation, generation forecasting, and balancing responsibility (making renewable power generators financially and operationally responsible for any difference between their scheduled and actual output to the system), further strengthening the integration of renewable power generators into wholesale electricity markets.

- **Rules for negative price periods:** FiP schemes may also include rules for periods of negative prices, aiming to preserve incentives for efficient market participation and system integration.

Case study: Feed-in premiums in Spain

Spain was an early adopter of FiPs, implementing them between 1998 and 2013 to support renewable energy deployment while encouraging closer integration into wholesale electricity markets. During this period, producers could choose between a FiT and a FiP, subject to limits based on technology and plant size.

In practice, FiPs were often more attractive than FiTs. However, only dispatchable technologies – meaning hydropower with reservoirs, geothermal, bioenergy and CSP – could respond meaningfully to wholesale price signals. To address revenue volatility, Spain introduced caps and floors on total remuneration in 2007, reducing uncertainty for investors while limiting windfall profits during high-price periods.

Rapid renewable power deployment contributed to a growing tariff deficit, reflecting a mismatch between regulated system costs (including renewable energy support payments) and electricity revenues. These pressures were exacerbated by excess capacity in combined-cycle gas turbines (CCGTs) and declining wholesale prices, which reduced revenues for conventional generators and intensified political opposition.

In response to mounting fiscal and political pressure, Spain suspended the FiT/FiP framework in 2008 and introduced retroactive regulatory changes, triggering legal disputes and international arbitration cases, undermining investor confidence. The subsequent "reasonable return" framework substantially reduced project revenues and linked remuneration largely to installed capacity rather than actual generation, weakening operational incentives. Renewable power deployment stalled until new auction-based support schemes were introduced from 2016 onwards.

Spain's experience highlights both the potential and the risks of FiPs, underscoring the importance of fiscal sustainability, policy stability, and careful management of distributional impacts in renewable energy support schemes.

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Contracts for difference

CfDs aim to combine the long-term revenue stability needed for renewable energy investment with exposure to wholesale market prices. Under a CfD, a generator receives or pays the difference between a fixed strike price and a reference market price per unit of electricity. In two-way CfDs, the state compensates the generator when market prices fall below the strike price and receives payments back when prices exceed it.

This mechanism – along with stabilising revenues while limiting windfall gains — can help cushion consumer bills if clawback revenues are redistributed. Although like FiTs in providing predictable remuneration, CfDs remain formally linked to market prices, with overall costs ultimately borne by electricity users.

Key considerations in applying CfDs include:

- **Allocation and strike price determination:** Awarding CfDs through competitive bidding can enhance price discovery and cost efficiency, while administratively set strike prices may provide greater policy control. Hybrid approaches – such as price caps in auctions – can balance competition with budgetary discipline.
- **Contract design parameters:** Contract duration (often 15-20 years), technology neutrality or differentiation, locational requirements, and eligibility criteria can all influence investment certainty, as well as system value and alignment with broader socio-economic objectives. Careful calibration helps avoid excessive price suppression while supporting diverse and timely deployment.
- **One-sided vs. two-way contracts:** One-sided CfDs, like sliding premiums, protect against low prices but allow windfall gains during high-price periods. Two-way CfDs stabilise revenues while clawing back excess returns, reducing volatility for both producers and consumers.
- **Treatment of negative prices:** Limiting top-up payments during periods of negative wholesale prices reduces incentives to generate when electricity has a low or negative system value, encouraging more efficient market behaviour.
- **Reference price design:** The choice between hourly spot prices and average reference prices affects exposure to short-term volatility and the incentives needed to align production with system needs. Alternative reference structures can influence both revenue stability and system integration.

- **Volume definition:** Settling CfDs on actual output provides strong revenue certainty, while applying them to partial volumes or predefined profiles increases market exposure. The further settlements deviate from actual power generation, the greater the residual risk borne by producers.
- **Use of clawback revenues:** Revenues collected when market prices exceed the strike price can offset consumer costs or support broader public spending priorities. Transparent allocation enhances public trust and policy legitimacy.
- **Degree of market exposure:** Mechanisms such as partial volume coverage or price corridors increase responsiveness to market signals but reduce long-term revenue certainty. The balance between stability and exposure shapes financing conditions and overall policy effectiveness.

Case study: Contracts for difference in the United Kingdom

A CfD scheme has been the UK's central mechanism for supporting low-carbon electricity generation since 2014, when it replaced the earlier Renewables Obligation system. CfDs aim for long-term revenue certainty through competitively determined strike prices while exposing generators to market signals. Low-carbon electricity generators compete for CfD contracts in the UK through auctions. Successful projects receive payments based on the difference between a fixed strike price and a reference wholesale market price, conditional on meeting milestones for financial closure and delivery.

To date, seven CfD allocation rounds have been completed. Early support focused on offshore wind and biomass, including bilateral investment contracts awarded in 2014 with a combined capacity of 4.6 GW. The first competitive auction (Allocation Round 1, or AR1) followed in 2015. Over time, eligibility expanded to additional technologies, including solar PV (from AR4 onwards) and floating offshore wind (with dedicated arrangements established in AR4). From 2019, auctions became annual, increasing deployment certainty and pipeline continuity.

AR5, in 2023, resulted in no new offshore wind awards, largely due to an administrative strike price cap – GBP 44 per megawatt-hour (MWh) – that proved commercially unviable amid rising costs. This prompted recalibration in AR6 (2024), which awarded nearly 10 GW of offshore wind. AR7 (2025) shows UK energy-transition ambitions increasing further, with the auction reserving a dedicated offshore wind stream, raising strike price caps, extending contract durations to 20 years, and introducing the Clean Industry Bonus to incentivise sustainable supply chains.

Despite the UK's clear success in scaling up offshore wind, the CfD scheme faces challenges, including negative wholesale price bidding by CfD-backed generators and delayed consumer savings due to higher strike prices and substantial grid investment needs. The UK experience highlights the importance of adaptive auction design, cost realism, and alignment between support schemes, grid development, and industrial policy.

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• *Public investment*

Direct public ownership of power generation or grid assets and other forms of public investment, such as grants, concessional loans, tax incentives, research funding, and support for standards and skills development, can significantly accelerate renewable energy deployment. While private sector participation is often key to achieve scale, government- or state-run institutions continue to influence system development through planning, financing and risk-sharing mechanisms.

When supported by sound governance, public investment can align infrastructure development with long-term social, economic and environmental objectives. However, its effectiveness depends on fiscal capacity, institutional quality, and the design of complementary market frameworks.

Key considerations in planning public investment in renewables include:

- **Scope of public ownership:** Defining the boundaries of public ownership clarifies where state involvement can address market gaps or strategic needs for grids, system flexibility or other capital-intensive assets that may face underinvestment under purely private models. Targeted ownership can enhance system reliability and long-term planning while limiting fiscal exposure.
- **Financing and cost recovery:** Public investment can be supported through budgetary resources, public development banks, bond issuance, commercial debt, or international and regional funding. Recovering costs through electricity tariffs or broader fiscal revenues influences affordability, distributional impacts and public acceptance. Sound financing and cost-recovery arrangements are essential to keep projects financially viable.
- **Human and institutional capacity:** Public ownership entails operational, financial and technical responsibilities that require adequate expertise. Strong institutional capacity reduces inefficiencies and operational risks, whereas limited capacity may constrain the appropriate scope of public involvement.
- **Supply-chain boundaries:** Public participation rarely extends across the full supply chain. Clearly delineating responsibilities – such as by leaving plant construction and operation to competitive engineering, procurement and construction (EPC) contractors or independent power producers (IPPs) can support an effective combination of public strategic control with private-sector efficiency and technical know-how.
- **Governance arrangements:** Transparent power-system governance structures and clear allocation of responsibilities across national and sub-national levels are vital to enhance accountability and reduce corruption risks. Strong oversight mechanisms reinforce public legitimacy and strengthen project performance.

Case study: Uruguay's state-led electricity transition

Uruguay's electricity system is organised around its vertically integrated, state-owned utility UTE (Administración Nacional de Usinas y Trasmisiones Eléctricas), which has operated for more than a century. Electricity supply is treated as a regulated service that must be guaranteed in terms of quality and provided on a non-discriminatory basis.

Today, the power system is almost fully based on renewable sources, which account for 97–99% of annual generation under average hydrological conditions. The mix is dominated by hydropower and wind, with biomass and solar PV playing a secondary role. Fossil fuels account for the remaining 1–3% of electricity generation under such conditions.

Historically, Uruguay relied on state-owned hydropower complemented by fossil fuel-based thermal generation. By the end of the first decade of the 21st century, rising demand and system adequacy concerns required generation capacity expansion. A series of severe droughts, culminating in 2008, sharply increased reliance on costly imported fossil fuels, exposing the system to climate variability and fuel price volatility.

In 2008, Uruguay adopted a long-term energy policy, which was ratified in 2010 through a multiparty political agreement that laid the groundwork for a genuine national energy transition. The policy established strategic objectives, targets, and action plans to promote the expansion of renewable energy, with a strong emphasis on wind power to complement hydropower and reduce fossil fuel imports. By that time, UTE, in coordination with the Secretary of Energy, had already developed in-house technical expertise in wind power generation.

To limit fiscal risk, wind capacity was largely deployed through competitive auctions for independent power producers, with UTE acting as the sole buyer under long-term PPAs. The system is operated through centralised economic dispatch by the Electricity Market Administrator (ADME) and planned by the Ministry of Industry, Energy and Mining (MIEM) in coordination with UTE, maintaining public control over planning and operations. UTE also owns approximately 20% of non-hydro renewable capacity.

Within a few years, wind power reached 35–45% of annual electricity generation, while biomass and solar PV expanded in parallel. Uruguay consequently shifted from being a net electricity importer to an exporter, supported by regional interconnections.

While the transition reduced expected cost variability due to power generation, some stakeholders question whether greater state ownership through EPC-based investment could have delivered lower long-term costs and simpler governance. The case highlights trade-offs between fiscal constraints, ownership models, and long-term value capture, often key considerations for developing countries.

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Part III: Integrating high shares of renewables

4. Grid planning and access

Grid infrastructure is a key ingredient for a successful energy transition, with electricity supply via the grid serving as the physical and operational backbone of a decarbonised energy system. As renewable energy sources increasingly replace fossil fuels, electricity becomes the main vector for delivering clean energy across the economy.

Unlike traditional, centralised power systems, renewable-based generation is often decentralised, variable, and location-specific, which places new demands on grid infrastructure at both the transmission and the distribution levels. A strong, flexible, and well-planned electricity grid is therefore essential to integrate high shares of renewables while maintaining security of supply and affordability.

The power grid, furthermore, is positioned as a technical interface between centralised and distributed renewable power generation. Centralised generation relies on the grid to bring generated electricity to meet demand, while distributed generation uses the grid as a market mechanism, providing an outlet and the means of valuation for surplus generation and enabling flexibility and other services as part of a wider system.

System integration based on the power grid is therefore a key component of the energy transition. The main electricity grid - far from being just an unavoidable consequence of centralised generation – becomes a source of social value that enables resource sharing and facilitates the operation of renewable-dominated power systems.

Long-term grid development planning is crucial to anticipate future energy needs and align infrastructure investments with climate and energy policy objectives. Renewable energy targets and deployment must accommodate long lead times for grid expansion alongside the short-cycle needs of distributed energy resources. System operators that coordinate their grid planning with renewable energy deployment, electrification trends, and expected demand growth can avoid bottlenecks, reduce overall system costs, and ensure timely availability of grid capacity.

Non-discriminatory grid access is a fundamental condition for fair competition and effective renewable energy integration. Non-discrimination means grid planning and operation must treat all market participants equally, regardless of technology, ownership structure, or size and must clearly define access rules as well as curtailment and congestion management principles.

Transparent and technology-neutral planning processes ensure that renewable power producers are not disadvantaged compared to conventional or established fossil-based generators, and that transmission and distribution system operators (TSOs and DSOs) apply consistent rules and standards for all connection requests. This approach prevents incumbent interests from slowing down the energy transition. Non-discriminatory access also strengthens trust in the regulatory framework and helps create a level playing field across the energy market.

Accelerating the rollout of renewable energy projects also depends on efficient, transparent, and predictable grid-connection procedures. Complex, lengthy, or costly connection processes can delay projects and increase investment risks, particularly for smaller developers. Clear rules on connection responsibilities, cost allocation, timelines, and technical requirements help reduce uncertainty and administrative burdens. Streamlined procedures, combined with proactive grid planning, ensure that renewable energy installations can connect to the grid without unnecessary delays, enabling rapid deployment to meet to climate targets.

Smart grids – using digital technologies to monitor, control, and optimise electricity flows in real time – are another key enabler of renewable-based energy systems. By integrating advanced metering, automation, and data analytics, they enhance flexibility and allow deeper VRE integration. Smart grids also enable demand-side management, energy storage, systemic integration of electric vehicles, and active inclusion of distributed generation in the power system. The resulting flexibility improves system-wide efficiency, resilience, and reliability, making smart grids indispensable to manage the complexity of a modern, decarbonised electricity system.

● *Long-term grid development planning*

Long-term grid development planning is essential for effective renewable energy deployment. Often, grid infrastructure plans are not well aligned with expansion plans for power generation or with the emerging needs presented by distributed renewables.

The following planning and policy interventions may be considered:

- **Grid expansion planning:** Long-term national grid expansion plans need to be developed and regularly updated in line with renewable energy objectives and long-term decarbonisation or net-zero targets. Integrated plans can also classify the roles and responsibilities of TSOs and DSOs.
- **Transmission-grid expansion:** To varying degrees, 21st century electricity grids need to reflect renewable energy resource availability. In other words, the transmission grid that was previously planned around conventional power plants and load centres now also needs to reach areas with solar and wind potential, including offshore. In addition, grid planning can incorporate alternative solutions, such as procurement of flexibility services and operational measures to defer or reduce grid reinforcement needs.
- **Distribution network upgrades:** Distribution network infrastructure can be built out to accommodate growing levels of distributed generation. Grid operators can anticipate increasing demand from residential consumers due to e-mobility, heat pumps and other electrification trends, reflecting these demand-side trends explicitly in electrification scenarios and investment prioritisation.
- **Cross-border interconnections:** Grid operators with system linkages to different different jurisdictions need to establish and implement international plans for enhanced regional grid integration and cross-border electricity trading.
- **Flexibility-first planning principles:** Alongside conventional grid reinforcement, flexibility solutions like storage, sector coupling and demand management can be integrated into the planning process to enable more renewables and advance energy transitions.

Case study: The EU's Ten-Year Network Development Plan

The EU's Ten-Year Network Development Plan (TYNDP) provides a non-binding, EU-wide strategic roadmap for the development of electricity infrastructure. It is designed to complement national grid planning processes while improving coordination and consistency among member states, particularly in support of the EU's climate and energy objectives.

The TYNDP assesses future electricity-system needs using a set of harmonised energy and climate scenarios developed at the EU level. These scenarios reflect different pathways for renewable energy deployment, electrification, and decarbonisation, allowing system-wide evaluation of transmission, interconnection, and storage requirements under varying assumptions.

Based on these scenarios, the TYNDP identifies where additional transmission capacity, cross-border interconnections, and storage solutions are likely to be useful and economically feasible. This system-level perspective helps address bottlenecks that would not be resolved through purely national planning.

Projects proposed for inclusion in the TYNDP are subject to a standardised cost-benefit analysis. The methodology for this ensures comparability across projects and countries, taking economic efficiency, security of supply, sustainability, and effects on market integration into account.

Inclusion in the TYNDP is a prerequisite for consideration as a Project of Common Interest (PCI) for EU countries. PCI status facilitates access to EU funding, streamlined permitting procedures, and enhanced cross-border regulatory coordination, making ambitious projects viable and the bloc overcome barriers to infrastructure development.

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Grid access and usage

Access regulation is crucial to make efficient use of grid infrastructure – a natural monopoly for the normally public operator-utility. Efficient and transparent grid-usage rules enable renewables and storage to operate on equal terms, supporting system flexibility, lowering integration costs, and helping maximise renewables and energy efficiency to meet decarbonisation goals.

Important grid access and usage considerations include:

- **Non-discriminatory access:** Open, transparent, and non-discriminatory third-party access to the electricity grid must be ensured through clearly defined principles, as well as protocols for grid congestion and contract or service curtailment.
- **Transparent and cost-reflective tariffs:** Network tariffs must be non-discriminatory (with the same rules in place for comparable users), cost-reflective (based on actual network costs), transparent, and compatible with distributed renewable energy systems.
- **Unbundling of grid network operators:** A legal and functional unbundling (i.e. separation) of grid operation from power generation and supply activities can improve grid access and optimise usage, as long as the operator exercises neutrality while procuring system flexibility and enable participation by distributed renewable power producers.
- **Regulatory oversight:** Independent national regulators (guided, in the EU case, by shared supranational rules) monitor compliance, approve tariffs, and resolve disputes related to grid access. They also set and enforce performance standards for generators, TSOs and DSOs.

Case study: EU rules for third-party access to electricity networks

The European Union's framework for non-discriminatory access to electricity networks builds on successive market liberalisation packages adopted between 1996 and 2009. These rules were consolidated and strengthened in 2019 as part of the Clean Energy for All Europeans package, reflecting the need to scale up renewables and deepen market integration.

Directive 2019/944 lays out common rules for the EU electricity market, establishing legally binding rights for non-discriminatory third-party access to transmission and distribution networks. This ensures grid access for generators, suppliers, and consumers on equal terms. The directive mandates regulated third-party access based on objective, transparent, and cost-reflective tariffs. These tariffs must be approved by independent national regulatory authorities, limiting the scope for preferential treatment or discriminatory practices.

Strong unbundling requirements for TSOs and DSOs have separated network operation from generation and supply activities. Together with enhanced powers for national regulatory authorities, these provisions are important to ensure neutral grid operation and effective enforcement of access rules across the EU market.

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Streamlined and transparent grid connection

Transparent connection procedures give renewable energy project developers clear information and more predictability on available grid capacity, timelines and costs. Without timely and non-discriminatory grid connection, projects can be delayed or stranded due to weak queue management, insufficient hosting capacity, lengthy connection delays, and limited visibility of network constraints.

Crucial policy interventions to facilitate successful grid connection include:

- **Clear timelines and compensation:** Regulations are needed to define clear timelines and ensure compensation to energy producers for connection delays that are attributable to network operators. Streamlined connection procedures that incorporate such provisions can reduce costs and risks for project developers.
- **Simplified grid connection for small-scale systems:** Simplified connection rules – including standardised technical requirements, digitalised applications and approval, and fast-track processes – can reduce connection costs for smaller-scale systems. Small-scale distributed generation (*e.g.* rooftop solar) requires different provisions than large plant set-up.
- **Cost-sharing methods:** Cost-sharing can be shallow, with producers paying only for their immediate connection, or deep, extending to upstream grid upgrades. Policies must also establish how grid reinforcement costs are allocated when such upgrades provide broader system benefits. Transparent cost-sharing increases investment security and clarifies responsibilities in relation to grid connection.
- **Alternative connection agreements:** Grid operators can be authorised to offer alternative connection agreements for providers of renewable energy plus storage, with conditions for firm and non-firm access, curtailment during congestion periods, and flexible or phased connection capacity. Agreements can also offer time-limited access with transparent curtailment and compensation rules.
- **Grid code updates for renewables:** Grid codes normally require updates to include VRE-specific standards and technical requirements, including inverter-based resources, as well as integrated communications and remote controllability wherever needed.

Case study: Accelerating grid connections for clean energy in the European Union

The European Commission's 2025 Guidance on efficient and timely grid connections is a non-binding guidance document that translates existing EU electricity market and renewables law into a practical toolbox. It notes, for example, that the EU's Renewable Energy Directive sets maximum time limits for renewable permit-granting procedures, including grid connection but excluding grid reinforcements, and provides expedited treatment for certain renewable installations, including small-scale solar equipment and heat pumps.

The guidance publication also refers to Article 6a of the Electricity Directive (EU) 2019/944, as amended by Directive (EU) 2024/1711, under which regulators or competent authorities must create a framework for flexible connection agreements in areas with insufficient grid capacity or where grid reinforcement is not efficient. These agreements allow non-firm access, but the system operator may restrict access at certain times, such as peak generation periods.

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Smart grids to integrate renewables

Digital communications technologies have become a key enabler for smart grids, which facilitate grid balancing while integrating renewables. Smart grids allow a dynamic balancing of variable generation with real-time demand across both transmission and distribution networks, helping optimise both distribution and transmission system operations. Advanced monitoring enables the integration of far larger VRE shares into existing grid capacity while also reducing integration costs.

Smart grid deployment involves several key policy considerations:

- **Smart-grid incentives:** Targeted incentives can drive the adoption of smart-grid technologies supporting VRE integration, including automated grid control, digitalised substations, and advanced power distribution and distributed energy resource management.
- **National control centres:** Coordinated system operations architecture through national or regional control centres enables active distribution capabilities based on real-time system operations with clear interfaces between TSO and DSO control functions.
- **Remote generation control:** Grid operators can control the output of renewable power plants and other distributed energy resources remotely, ensuring secure and efficient system operation based on transparent rules, effective technical standards and appropriate safeguards.
- **Real-time data:** Optimising grid performance requires renewable energy producers to provide real-time operational data to grid operators, subject to well-defined data requirements, access rules and cybersecurity standards.
- **Advanced control practices:** Dynamic line rating, grid boosters, high-temperature low-sag (HTLS) conductors, power flow controllers and related technologies can be tested and deployed to modernise operations, improve forecasting, manage congestion and facilitate flexibility procurement.
- **Smart-meter rollout:** Countries aiming to boost smart-grid and VRE uptake need to expand their advanced metering infrastructure and implement programmes and incentives for the deployment of smart meters.

Case study: Japan's Smart Grid and Smart Community framework

Japan's smart-grid policy is grounded in the Basic Act on Energy Policy (2002) and successive Basic Energy Plans, first issued in 2003. These frameworks position smart grids as critical infrastructure to support energy security, decarbonisation, and long-term supply stability in a system facing demographic change and accommodating rising shares of renewables.

Smart grids in Japan are closely linked to the broader "smart communities", concept which integrates energy systems with urban planning, mobility, and digital services. The Ministry of Economy, Trade and Industry (METI) has put this approach forward through the Smart Community Promotion Policy. In 2022, Japan began aligning smart-grid development with the Smart Energy Grid Architecture Model (SGAM) from the International Electrotechnical Commission (IEC), supporting interoperability, system integration, and international standardisation.

Japan's electricity system is operated by ten regional transmission and distribution system operators (TDSOs), known as the General Transmission and Distribution Companies, each managing a control centre. These centres rely on advanced digital technologies, including supervisory control and data acquisition (SCADA) systems, to monitor network conditions and manage power flows. Rising VRE shares have reinforced the need for enhanced coordination between transmission systems and distribution systems, as well as more sophisticated real-time system management.

In tandem with smart-grid development, METI has rolled out smart meters to all electricity customers, aiming to boost demand-side visibility, enable more flexible tariffs, and support future demand response and distributed energy services.

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5. Distributed generation and self-consumption

Rapid and far-reaching transformation of the power system requires broad public support and participation. The distributed nature of many renewable energy technologies creates new opportunities for social involvement, expanding the range of stakeholders involved and the possible scales at which power generation can happen. Decentralisation brings socio-economic challenges, as well as benefits.

Traditional power systems have been largely centralised, with large generation assets – owned by public entities or a limited number of private companies – supplying electricity to predominantly passive consumers. A renewable-based system, by contrast, enables the co-existence of centralised generation with distributed generation at the level of households, businesses and local groupings such as energy communities. This distributed generation can either cover supply to the grid or be used for “self-consumption” by any given producer.

The resulting evolution in how electricity is produced and consumed introduces more complex interactions and technical arrangements. Coherent, well-design policy frameworks are needed to harness the various synergies in distributed generation and minimise barriers to it. Specific self-consumption policies may target different groups – households, SMEs, industry and energy communities – with distinct motivations and constraints that shape the policy approach needed.

Modern self-consumption differs from traditional stand-alone power-generation systems because it maintains a dynamic relationship with the grid. The alignment of self-consumption with grid interaction, furthermore, facilitates the integration of distributed generation and storage into retail market structures, creating economic incentives at the point of demand-side grid parity, or when the levelised cost of self-generated electricity falls below the variable component of retail tariffs. This new power-system paradigm reduces reliance on long-term support schemes for all generated electricity and instead encourages self-reliance for direct power needs and remuneration for surplus generation.

The treatment of surplus electricity is a central design feature for the energy transition. Under net metering, surplus is typically valued at retail prices, while net-billing schemes often value surplus at levels between retail and wholesale prices. As distributed generation expands, surplus valuation may decline, and additional network charges or technical constraints may in some cases limit or discourage injections into the grid.

Localised energy communities dedicated to collective self-consumption are an important emerging factor in the energy landscape, enabling households, SMEs and municipalities to pool resources and share benefits. By aggregating small-scale participants, these models can address space constraints, reduce costs through economies of scale, enhance accessibility and strengthen social inclusion. Their effective integration into the power system requires dedicated regulatory frameworks that clarify community rights, responsibilities and interaction with other market participants.

● *Net metering*

Households or businesses with rooftop solar panels or other distributed generation can interact as prosumers – meaning they produce and consume electricity in concert with the wider power system. This dynamic hinges on net metering, whereby each prosumer receives credit for excess electricity exported to the grid based on a variable component of the retail electricity price.

In effect, the prices paid for electricity drawn from the grid or received for surplus generation are equal. This arrangement allows the grid to function as a virtual storage system, with self-generated electricity that is exported as surplus being offset against consumption, regardless of whether the generation and the demand are simultaneous.

Arrangements to consider for net metering include:

- **Time window for netting:** The length of the netting period – when prosumer bills are balanced – determines the extent to which the grid functions as a virtual storage system. A longer window, such as annual, allows seasonal balancing and maximises the value of surplus generation, while shorter windows limit the duration of implicit storage, better aligning compensation with immediate system costs.
- **Retail tariff structures and cost recovery:** When surplus electricity is credited at retail rates that include network and policy costs, net metering can create cross-subsidisation and weaken cost recovery for grid infrastructure. Aligning tariff design with underlying cost structures helps preserve financial sustainability, avoid unintended subsidies, and reduce the risk of declining utility revenues that could trigger tariff feedback effects.
- **Individual versus collective self-consumption:** Individual net-metering arrangements may disproportionately benefit households with sufficient capital and rooftop space, potentially creating regressive distributional effects. Enabling collective self-consumption and shared facilities broadens access, enhances inclusivity, and increases the social value of distributed generation.
- **Avoiding windfall gains:** As technology costs decline and distributed generation grows, retail-rate compensations may come to exceed the actual value of surplus electricity for the system. Periodic adjustments of valuation mechanisms can help maintain cost efficiency and align compensation with evolving market conditions.
- **System-wide consistency and communication:** Interaction between distributed and utility-scale generation depends on broader market and pricing structures. Clear policy alignment and transparent communication can prevent perceived distortions, lower competitive tensions between different sources of renewable power and support coherent system development.

Case study: Net metering in Pakistan

Pakistan introduced net metering in 2015, with distributed solar PV deployment accelerating rapidly from 2018 onwards. Amid falling PV costs and high overall retail electricity prices, generous surplus valuation under the net-metering scheme proved decisive. Payback periods of around two years, combined with concerns about grid reliability, made self-consumption highly attractive. By 2025, net-metered capacity exceeded 6 GW, out of around 46 GW of total installed generation capacity.

Net metering has succeeded in Pakistan despite regulatory constraints, such as eligibility being limited mainly to three-phase consumers, resulting in the concentration of solar PV among higher-income households and commercial users with sufficient technical and financial capacity.

Pakistan's retail electricity tariffs rely heavily on volumetric charges to recover fixed system costs. As self-consuming users have reduced their grid purchases, utilities have faced declining revenues, prompting tariff increases for the remaining consumers. This has raised concerns about cross-subsidisation and regressive impacts, as traditional users reliant solely on power from the grid bear a growing share of fixed costs.

As of 2026, Pakistani policymakers have sought to reduce surplus-generation subsidies, with the National Electric Power Regulatory Authority (NEPRA) replacing net metering with net billing, adhering to wholesale or avoided-cost rates, to address utility revenue pressures. However, NEPRA's new Prosumer Regulations 2026 (SRO 251(I)/2026) have encountered strong public opposition, reflecting growing appreciation of the economic and reliability benefits of self-consumption for users.

Self-consumption has also served as a channel for expressing dissatisfaction with utility performance and system development plans. Issues such as high technical and non-technical losses, supply interruptions, non-transparent tariffs, and rigid fossil-fuel capacity contracts continue to affect electricity prices and system finances, beyond the influence of distributed generation alone.

Pakistan now faces a critical policy choice over the relationship between distributed and utility-scale power generation. Abrupt or poorly communicated restrictions on self-consumption risk accelerating grid defection, particularly by large consumers with electricity storage capabilities. For an inclusive and sustainable energy transition, the country may need to find a balanced approach combining tariff reform, improved utility governance, and stakeholder engagement to foster synergies between distributed solar and the public grid.

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● *Net billing*

The net-billing approach represents an evolution of net metering, maintaining incentives for self-consumption while aligning compensation for surplus generation more closely with value to the power system. Under net billing, self-generated electricity offsets retail consumption, while excess generation exported to the grid is compensated at a rate typically below retail prices and closer to wholesale market conditions. This approach reduces the risk of overcompensation as distributed generation costs fall and renewable penetration rises.

System values for surplus electricity can fall very low and even become negative during periods of congestion. When they do, the net-billing price deterrent drives higher self-consumption rates and the use of electricity storage to manage excess generation more efficiently.

Several factors come into play in designing a net-billing scheme:

- **Surplus-generation price level:** The compensation rate for exported electricity determines the balance between maintaining investment incentives and avoiding overcompensation. Aligning surplus valuation with actual system value supports cost efficiency while preserving the economic rationale for self-consumption.
- **Time evolution of surplus price:** Adjustment mechanisms that reflect declining technology costs and overall inflation can help align support with market conditions over time. Differentiating between new and existing installations preserves investment certainty, as the cost structure of a project is fixed at the time of investment.
- **Billing and netting period:** The billing cycle defines the effective time window for offsetting consumption and exports. Shorter billing periods reduce implicit storage through the grid, while longer ones increase power-system flexibility but may raise cost allocation concerns.
- **Caps on bill compensation:** Limits on maximum bill credits can prevent excessive seasonal cross-compensation and protect utility cost recovery. Such caps help align compensation with time-dependent system value and infrastructure requirements.
- **Retail tariff alignment:** When retail tariffs embed network and policy costs within variable charges, self-consumption can reduce contributions to fixed grid costs, creating cross-subsidies and revenue imbalances. Cost-reflective tariff structures support financial sustainability and limit unintended distributional effects.
- **Individual versus collective models:** Self-consumption by individual prosumers may disproportionately benefit higher-income households or businesses with access to capital and space. Enabling collective arrangements broadens participation, enhances inclusivity, and increases the social value of distributed generation.

- **Consistency with broader market structures:** The interaction between distributed and utility-scale generation depends on overall market design and pricing rules. Coherent alignment and transparent communication reduce misperceptions and mitigate competitive tensions between larger- and small-scale renewable energy projects.

Case study: Net billing in Poland

Poland introduced net metering in 2016 through amendments to the Renewable Energy Sources Act, supported by substantial investment subsidies co-financed by the European Union. The prosumer framework allowed small-scale renewable electricity producers – primarily rooftop PV owners – to offset electricity injected into the grid against electricity drawn from it.

Combined with rising retail electricity prices after 2019, this framework triggered rapid growth in distributed solar PV. By 2022, self-consumption capacity exceeded 9 GW, accounting for roughly 70% of the country's total installed PV capacity.

However, as deployment accelerated, challenges became increasingly visible. Surplus generation from rooftop PV was weakly aligned with local grid capacity and system needs, contributing to congestion and operational pressures in distribution networks. At the same time, retail electricity tariffs recovered a large share of fixed network and policy costs through volumetric charges. This meant that prosumers avoided paying part of these costs while still relying on the grid. In effect, this led to increasing cross-subsidisation by non-prosumers, raising concerns about equity and long-term grid cost recovery.

To address these issues, Poland replaced net metering with a net-billing scheme in April 2022. The reform shifted surplus compensation from energy-based netting to monetary settlement at market-linked prices, encouraging higher self-consumption, improving alignment with system value, and reducing tariff distortions. The transition required careful political and social balancing, and the initial design – characterised by lower and more variable remuneration – led to a temporary slowdown in distributed PV deployment as households and installers adapted.

Subsequent amendments to restore investment confidence included a move from average to hourly surplus valuation, expanded eligibility for collective and virtual prosumers, and additional subsidies for PV, battery storage and heat pumps. Incentives were also introduced to encourage voluntary migration from legacy net-metering contracts, while energy cooperatives were allowed to remain under net metering.

By 2025, Poland's installed PV capacity had reached approximately 25 GW, of which nearly 60% was linked to self-consumption, illustrating the importance of adaptive policy design when scaling up distributed renewables.

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Collective self-consumption and energy communities

Energy communities have gained renewed institutional attention in recent years, with collective self-consumption emerging as one of their core activities. By enabling groups of citizens, SMEs and municipalities to jointly invest in and share the output of a renewable energy installation, the collective approach expands access to the benefits of self-consumption beyond those with suitable rooftops or upfront capital, helping address the regressive effects of purely individual models.

Aggregation can unlock economies of scale, facilitate innovative financing arrangements and support broader objectives such as energy efficiency, electrification and reducing energy poverty. While expectations should remain realistic, energy communities can strengthen participation, improve local governance, and contribute to a fairer distribution of the benefits of the energy transition, complementing rather than replacing public and private responsibilities.

Energy communities for self-consumption involve various considerations:

- **Policy frameworks for local participation:** Clear and stable legal frameworks for collective self-consumption and energy communities provide certainty for participants and investors, reducing administrative complexity and transaction costs. Provisions that enable community ownership or participation in larger projects can strengthen local acceptance and advance renewable energy investments in targeted areas. Community representatives or managers with well-defined roles can facilitate coordination with authorities and improve operational efficiency.
- **Scope and eligibility conditions:** Flexibility in eligibility criteria – such as geographic proximity requirements – broadens access and enhances the scalability of collective self-consumption models. Removing unnecessary restrictions allows communities to optimise project siting and participation structures while maintaining grid and system integrity.
- **Promotion, support and financing:** Dedicated advisory structures and capacity-building initiatives lower informational and organisational barriers for emerging communities. Targeted financial instruments, such as grants, concessional loans or tax incentives, improve feasibility and inclusivity, particularly for smaller or lower-income participants. Networking platforms and shared resources strengthen knowledge exchange, institutional learning, and the long-term viability of community-based energy initiatives.

Case study: Community energy in Spain

Community energy initiatives have a long tradition in Spain and across Europe. The European Union, recognising the role of citizens in advancing deeper stages of the energy transition and addressing growing challenges around social acceptance of renewables formalised the concept of energy communities through directives adopted in 2018 and 2019 requiring EU member states to actively facilitate and support community energy. Spain partially transposed this framework between 2019 and 2023, creating the national legal basis for energy communities.

Since 2022, Spain has opened around 80 Community Transformation Offices (Oficinas de Transformación Comunitaria, OTCs) to provide technical assistance, guidance, and capacity building for emerging initiatives across the country. By 2024, approximately 660 energy communities were operating nationwide, involving citizens, SMEs and municipalities. Growth has accelerated since 2022, with some provinces aiming to establish at least one energy community per municipality by 2027.

While collective self-consumption is the primary activity of Spanish energy communities, many have also expanded into complementary areas, including shared electric mobility, energy efficiency upgrades in buildings, energy storage, electrification, and demand response and flexibility services, as well as responsible consumption and energy education. Several communities also address broader social objectives such as energy poverty reduction and inclusivity.

Access to finance remains a key barrier, particularly for inclusive participation. Energy communities typically rely on a combination of public subsidies (increasingly complemented by fiscal exemptions), member equity contributions, and loans. The non-profit orientation of many communities enables the provision of affordable PPAs once initial investments are recovered.

Beyond financing, successful energy communities depend on effective governance and meaningful citizen participation. Supportive enabling frameworks, including mechanisms such as insurance products tailored to community energy initiatives, have also become an important component as the ecosystem for energy communities in Spain matures.

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6. Power market and flexibility design

Electricity market design is crucial for the integration of renewable energy sources and technologies. The rules governing how electricity is dispatched, traded and remunerated shape investment signals, operational efficiency and system reliability. Well-functioning markets enable substantial shares of renewables, including variable renewables, while maintaining supply security and controlling costs.

Dispatch arrangements influence which power plants operate at any given time and therefore affect how renewables are integrated. Market-based dispatch frameworks help ensure that resources are used efficiently, with curtailment applied only when necessary for system security.

In systems with growing shares of wind and solar power, accurate forecasting becomes increasingly important. Improved forecasts reduce imbalances and associated costs, while aggregators enable smaller generators with distributed resources to participate in wholesale and balancing markets by pooling output.

Intraday markets allow participants to adjust their positions closer to real time as forecasts are updated. Liquid intraday trading with short gate-closure times helps reduce system imbalances and lowers balancing costs, supporting efficient renewable energy integration.

Capacity mechanisms can complement energy markets by ensuring long-term adequacy in systems with high renewable shares. A policy mechanism ensuring payment for availability – when open to renewables, storage, and demand response on equal terms and calibrated to reflect respective contributions to system reliability – supports investments in flexible resources for decarbonisation.

Flexibility in renewable-based power systems can be provided through several channels. Demand-side response and storage technologies – including batteries, pumped hydro and thermal storage – play a direct role. Additional flexibility arises from grid expansion and interconnections, as well as from closer integration between electricity and other sectors, such as electric vehicles, hydrogen production and synthetic fuels.

Together, these elements form the foundation of a resilient and efficient renewable power system.

• *Dispatch regulation*

Dispatch regulation is a core element of electricity market design, as it determines how generating units are scheduled to meet demand at any given time. Depending on the structure of the power system, this function may be carried out by a vertically integrated utility, a single buyer, an independent system operator, or the grid operator.

The rules governing dispatch directly influence how renewable energy is integrated into the system, affecting curtailment levels, market participation and overall efficiency. Clear and transparent dispatch frameworks are essential to ensure that renewable-based generation is accommodated while maintaining system reliability and cost-effectiveness.

Dispatch regulation involves several considerations:

- **Priority dispatch:** In systems where competition is limited or market rules do not yet ensure equal treatment of generators, priority dispatch for renewable energy can safeguard access to the grid. Ensuring that renewable electricity is taken before conventional generation can reduce curtailment risks and support early-stage deployment until more robust market conditions are in place.

- **Economic dispatch:** Dispatch based on short-run marginal costs promotes efficient system operation by ensuring that the lowest-cost generation is used first. Applying this principle consistently across all technologies – including renewables, fossil fuels and nuclear power – supports fair competition, reduces overall system costs, and facilitates the growing integration of renewables as markets mature.

- **Flexibility in legacy fossil-fuel contracts:** Long-term take-or-pay contracts for fossil-fuel power plants can limit operational flexibility and crowd out renewable-based generation. Phasing out such rigid arrangements, or introducing flexibility provisions in remaining contracts, reduces lock-in effects and puts dispatch decisions more in tune with evolving system needs and the priority of decarbonisation.

Case study: Dispatch regulation in Germany

Germany introduced priority dispatch for renewables under the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG), first enacted in April 2000. Priority dispatch required system operators to give precedence to electricity generated from renewable sources over conventional generation, supporting early-stage market entry and rapid capacity expansion.

Priority dispatch reduced curtailment risk and improved revenue certainty for renewable power producers at a time when technologies were less competitive and market structures favoured incumbent generators. This provision played a significant role in enabling large-scale investment in wind and solar generation during the early phases of the Energiewende (energy transition).

Subsequent reforms of the EEG, particularly a 2014 revision, placed greater emphasis on market integration. Renewable power producers were increasingly required to market their electricity directly on the wholesale market and operate under economic dispatch principles, aligning generation decisions more closely with short-run marginal costs and system needs.

In parallel, Germany's electricity market liberalisation in the late 1990s led to the termination of long-term take-or-pay contracts for fossil fuel-based power plants. Conventional generators were required to participate in the wholesale market, eliminating inflexible contractual arrangements that could hinder efficient dispatch.

The combination of market-based dispatch for all generation technologies and the gradual integration of renewables into wholesale markets improved system efficiency and transparency. It has also ensured that curtailments in renewable energy supply are rare and only happen for system-security reasons.

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● *Solar and wind forecasting and aggregation*

Accurate forecasts of power output are critical as higher VRE shares increase system uncertainty, directly affecting dispatch efficiency, balancing costs, and the ability of markets and system operators to maintain reliability. Increasing distribution of power-generation assets around the grid means aggregators are needed to consolidate generation and demand data for reliable forecasts of power supply.

Key considerations in VRE supply forecasts are:

- **Forecasting responsibility and accountability:** Clear responsibility for forecasting and managing imbalances improves forecast accuracy and system reliability. Transparent performance metrics and settlement rules then strengthen accountability and encourage continuous improvement.
- **Forecasting granularity:** The level at which forecasts are assessed – plant-specific or aggregated – shapes the trade-off between accuracy and cost. Aggregation smooths variability and can reduce system costs, while plant-level forecasting better captures local constraints and real operating conditions.
- **Imbalance mechanisms and penalties:** Well-calibrated imbalance frameworks promote accurate forecasting by linking deviations to proportionate charges. Tolerance bands and symmetric treatment of over- and under-forecasting support learning and participation while limiting excessive risk exposure.

Case study: Balancing responsibility for renewables in Spain

Spain began progressively assigning balancing responsibility to renewable power producers in 2007, starting with Royal Decree 661/2007. This marked a shift from treating renewables as fully shielded from market responsibilities toward greater integration into power system operations. Full and explicit imbalance settlement obligations were consolidated through subsequent market and regulatory reforms, notably Royal Decree 413/2014. These reforms aligned renewable generators with the same balancing framework applied to conventional power plants.

Under this framework, renewable power producers are required to submit day-ahead and intraday generation schedules to the wholesale electricity market. Deviations between scheduled and actual generation are financially settled through the imbalance mechanism. Imbalances are priced symmetrically, meaning both over-generation and under-generation are settled at imbalance prices reflecting real-time system conditions. This approach avoids structural bias and ensures that producers face incentives aligned with system-balancing needs.

Exposure to imbalance costs prompted renewable power producers and aggregators to invest in improved forecasting tools and operational capabilities. Enhanced wind and solar forecasting, combined with more active intraday trading, has reduced forecast errors and imbalance volumes over time. Thus, the introduction of balancing responsibility has contributed to improved system efficiency by reducing balancing costs and integrating VRE more smoothly into market operations.

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● *Intraday market design to integrate renewables*

To successfully integrate high shares of wind and solar PV, electricity markets must be designed to accommodate their variability and uncertainty. Intraday markets help manage the variability of wind and solar generation by allowing participants to adjust their positions closer to real-time, typically at hourly intervals or even in 15-minute blocks. The resulting flexibility enables renewable power producers to better match their forecasts with actual generation, thereby reducing imbalance costs.

Key considerations for intraday markets include:

- **Gate-closure timing:** Shorter gate-closure times enable adjustments closer to real time as forecasts improve, reducing imbalances and supporting efficient integration of variable renewables.
- **Market liquidity and access:** Transparent, liquid markets with non-discriminatory access encourage active participation by renewable power producers, aggregators and storage providers, improving price signals and lowering balancing costs.

Case study: Hour-ahead intraday markets in Japan

As part of its post-Fukushima electricity market reforms, Japan introduced shorter intraday trading arrangements to strengthen system balancing. The Japan Electric Power Exchange (JEPX) launched its intraday market in 2009, four years after the introduction of the day-ahead (spot) market in 2005. This initial intraday market allowed market participants to adjust positions after the day-ahead auction, improving flexibility in system operation.

In 2016, the JEPX further enhanced market flexibility by introducing an hour-ahead intraday market. This enabled trading closer to real time, providing market participants with opportunities to respond to updated demand and generation forecasts. Shorter gate-closure times reduced the exposure of wind and solar generators to forecast errors.

By allowing intraday rescheduling, the market has facilitated more accurate alignment between scheduled and actual generation, lowering imbalance volumes and system balancing costs.

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Balancing and ancillary services markets

Beyond renewable-based generation and flexibility, power systems require additional services to ensure secure and reliable operation. Ancillary and balancing services enable system operators to maintain real-time balance between supply and demand and to preserve power quality, including frequency and voltage, even in the face of unexpected disruptions.

As electricity systems shift towards higher shares of renewables, the market has become more technology-neutral, allowing renewable and distributed resources to support those services. Opening balancing and ancillary service markets to renewable energy projects and aggregators can improve system stability while creating additional revenue streams that support the economic viability of renewable-based power systems.

Key considerations for balancing and ancillary services markets include:

- **Market access and eligibility:** Renewable power producers can be allowed to bid directly or via aggregators into balancing markets. This is achieved by relaxing minimum size thresholds, enabling portfolio aggregation, and ensuring non-discriminatory participation rules.
- **Adapted balancing products:** For balancing products to align well with renewables, they require shorter contract durations, options for partial activation, and recognised values for fast ramping and response, rather than firm capacity alone.
- **Risk allocation:** Deviation charges and imbalance settlement mechanisms must be symmetric, transparent, and proportionate by design.

Case study: Procuring balancing services through competitive markets in Japan

Japan established its Supply-Demand Adjustment Market (the Balancing Market) in 2021 as part of broader electricity market reforms. The aim of this national balancing market is to ensure real-time system stability while enabling VRE shares and greater flexibility. The balancing market is operated by the Electric Power Reserve eXchange, EPRX. Transmission and distribution system operators procure balancing services via this platform, ensuring coordinated system operation across regions.

The market is open to a wide range of energy sources, including conventional power generation, VRE portfolios, battery storage, and demand response. Aggregators play a key role by pooling smaller assets to meet minimum participation thresholds.

Distinct reserve products are defined by differentiated performance requirements:

- Primary Reserve (Frequency Containment): minimum capacity of 1 megawatt (MW), response within 10 seconds, and a minimum duration of 5 minutes.
- Secondary Reserve (Frequency Restoration): minimum capacity of 1 MW, response within 5 minutes, and a minimum duration of 30 minutes.
- Tertiary Reserve (Replacement): minimum capacity of 1 MW, response within 15-45 minutes, and a minimum duration of at least 3 hours.

Clear technical specifications and standardised procurement allow system operators to secure appropriate levels of flexibility while encouraging participation by non-traditional providers. The framework supports efficient balancing as renewable penetration increases.

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Capacity-market design to integrate renewables

Well-designed capacity markets can support the energy transition by ensuring system adequacy as VRE shares rise. Designing capacity markets to be technology-neutral and accessible to renewables, storage, and demand response is essential so that any resource package capable of delivering reliability and flexibility can compete fairly and cost-effectively.

Key considerations for capacity markets include:

- **Technology-neutral eligibility:** Open participation for renewables, storage, demand response and hybrid resources supports fair competition and broadens the pool of capacity providers for the power system. Transparent de-rating methods that reflect actual reliability contributions improve adequacy outcomes and strengthen confidence in the capacity mechanism.
- **Contract duration and stability:** Longer, more predictable capacity contracts, particularly for new investments, reduce revenue uncertainty and improve financing conditions. Contract duration is especially important for storage, hybrid projects and other flexibility resources that complement renewable power generation.
- **Flexibility-oriented design:** Capacity mechanisms that focus on performance during scarcity or system stress periods better reflect the value of flexibility. Linking remuneration to availability when it matters most rewards investments that enhance reliability in renewable-based power systems.

Case study: The UK Capacity Market

The United Kingdom established its capacity market under the Energy Act 2013 and implemented through the Electricity Capacity Regulations 2014. The primary objective of the UK Capacity Market is to ensure the long-term security of electricity supply by remunerating capacity providers that commit to availability during periods of system stress, particularly in a power system with growing shares of variable renewables.

Capacity is procured through competitive auctions open to a broad range of resources. Eligible technologies include conventional generation, demand-side response, battery storage, and interconnectors. This technology-neutral approach supports system flexibility and complements energy-only market signals.

Participating capacity providers are subject to de-rating factors that reflect their expected contribution to system adequacy during stress events. For example, storage and demand response are assessed based on their availability and duration, ensuring that capacity payments are aligned with actual reliability value rather than nominal installed capacity.

The Capacity Market uses both T-4 auctions, held four years ahead of delivery, and T-1 auctions, held one year ahead. This dual structure allows the system to secure long-term investment in new capacity while also adjusting for updated demand and supply conditions closer to real time. Contracts of varying lengths provide revenue certainty that can support investment in flexible and low-carbon assets, including storage and demand response, which may face revenue volatility in energy-only markets.

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• *Procurement of energy storage systems*

The procurement of energy storage, particularly battery systems, supports large-scale VRE integration. This trend is driven by rapidly falling costs for storage technologies, primarily battery energy storage. Policymakers need to decide whether they prefer to procure storage separately or in combination with specified renewable energy projects.

Key considerations in procuring storage include:

- **Procurement targets and strategy:** Clear long-term signals on storage needs, eligible services and procurement timelines improve visibility and reduce uncertainty for battery storage developers. Strategic planning supports investment decisions and helps ensure storage capacity is deployed in line with system requirements.
- **Revenue-stacking frameworks:** Transparent rules allowing battery storage to earn revenues from multiple services – such as energy arbitrage, capacity provision and ancillary services – enhance project economics. Clear boundaries prevent double counting while maximising the system value of storage.
- **Technology-neutral procurement:** Competitive, technology-neutral tenders based on performance criteria promote cost efficiency and allow battery storage to compete fairly with other flexibility solutions. Such approaches encourage innovation and reveal the most efficient options for meeting system needs.
- **Co-located storage and renewables:** Dedicated procurement pathways for renewable-based generation paired with battery storage support the delivery of stable low-carbon power. Co-location can improve the usage of grid connections, reduce curtailment, and strengthen the contribution of renewables to system reliability.

Case study: Battery storage procurement in Greece

Greece introduced a dedicated support scheme in 2023 to accelerate the deployment of standalone battery energy storage systems. The initiative aimed to strengthen system flexibility, support renewable energy integration, and enhance security of supply in a power system with growing VRE shares.

Storage capacity was procured through competitive tenders structured in three successive auction rounds. The design included minimum oversubscription requirements to drive competition and limits on bidder concentration to prevent market dominance.

The scheme combined two complementary support elements. First, an upfront, capacity-based investment grant (EUR/MW) reduced capital expenditure and financing barriers. Second, a time-limited (10-year) two-way CfD provided revenue stability, topping up market revenues when prices were low and clawing back excess revenues when prices exceeded the reference level.

Participation was limited to standalone battery storage assets connected to the transmission network. Projects were required to meet minimum thresholds for power output and energy duration that increased across auction rounds – for example, from two-hour to four-hour storage configurations. These requirements were complemented by binding performance and availability obligations.

The combined use of grants and two-way CfDs reduced investment risk while maintaining exposure to market signals. Performance-based eligibility criteria ensured that procured storage delivered meaningful system value in terms of duration and reliability.

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● *Procurement and incentives for demand-side flexibility*

Demand-side flexibility lets electricity systems balance rising VRE shares without relying solely on carbon-intensive, supply-side generation assets. By rewarding consumers and aggregators for shifting or reducing their demand at times of system stress, well-designed flexibility frameworks lower system costs, enhance security of supply, and accelerate the integration of renewables.

Key considerations to achieve demand-side flexibility include:

- **Procurement products:** Flexibility services are defined in standardised products (*e.g.* peak reduction, fast response, locational flexibility) with transparent technical requirements, durations, and performance obligations, allowing providers to assess value and participate at scale.
- **Accessible participation rules:** Market rules should lower entry barriers and explicitly enable aggregators, suppliers, and small consumers to participate, with clear provisions for aggregation, metering, and data access to unlock distributed flexibility.
- **Measurement and verification:** Credible baselining, monitoring, and settlement methodologies help to accurately quantify delivered flexibility, ensure fair payment, and maintain confidence in demand-side resources as system assets.
- **Time-of-use pricing:** Time-of-use tariffs continually send price signals that encourage consumers to shift demand away from peak periods, complementing formal flexibility procurement by triggering both behavioural and automated demand response.

Case study: Demand-side flexibility procurement in the UK

The United Kingdom established its Demand Flexibility Service (DFS) in 2022 to enhance short-term system flexibility and keep electricity supply reliable in periods of peak demand or system stress, particularly with generation from variable renewables on the rise. The DFS enables households and businesses to provide demand-side flexibility through licensed electricity suppliers and aggregators. These intermediaries bundle individual consumers into portfolios, register eligible DFS units, and engage services on behalf of end users, such as small-scale flexibility providers, including residential households with smart thermostats.

Flexibility is procured through predefined DFS activations, including both test and live-system activations. The system operator publishes clear and standardised service terms that define eligibility criteria, bidding and acceptance procedures, performance requirements, and settlement rules. Delivery of flexibility is assessed against agreed consumption baselines. Established verification methodologies are used to quantify actual demand reduction during activation events, ensuring accurate settlement and maintaining system integrity.

The DFS provides a transparent and scalable mechanism for mobilising demand-side response, complementing supply-side flexibility resources and reducing reliance on conventional peaking generation.

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Part IV: Building resilient production, industry and value chains

7. Industrial policies, localisation and selected trade-related measures

Industrial policies and localisation

Industrial policies and supply-chain measures can harness renewables to drive green industries and open broader economic opportunities. Targeted interventions can shape how value is captured along the renewable energy and clean technology supply chains, which of those activities are carried out domestically, and how firms position themselves in regional and global markets.

Governments can identify realistic localisation opportunities and design coherent policy packages that support competitive domestic manufacturing and related services in renewable energy and transition-related industries. At the same time, they need to manage trade-offs linked to costs, speed of deployment, and trade exposure. With all these factors taken together, value-chain diagnostics can inform the choice and sequencing of industrial policy instruments, alignment with localisation requirements, and overall feasibility in terms of trade objectives and market access.

Various elements need to be considered, notably:

- **Value chains and localisation potential:** Sound green industrial strategies begin with a value-chain assessment that clarifies where domestic participation is feasible in the near term, shows where capabilities need to be strengthened, and identifies constraints such as skills, standards and certification, finance, infrastructure and logistics.
- **Industrial policies for localised manufacturing:** Demand-side measures that provide market certainty can be combined with supply-side measures to help address competitiveness barriers to renewable energy and clean technology manufacturing, such as investment costs, technology access, supplier development and clustering.
- **Localisation requirements and long-term market signals:** Local content rules and related requirements can accelerate domestic participation in renewable energy supply chains. The same rules can also stipulate design considerations to avoid inflating project costs, extending timelines, and diminishing long-term market efficiency, with an emphasis on promoting competitiveness and upgrading local capabilities.
- **Strengthening domestic clean energy industries:** Economy-wide foundations, such as skills and training systems, standards, access to finance, innovation support and export promotion can, over time, reduce reliance on mandatory requirements for localisation.
- **Powershoring:** By siting production where renewable resources are abundant, governments can lower production costs, accelerate industrial decarbonisation, and strengthen competitiveness with clean-technology value chains.

• *Value chains and localisation potential*

Assessing the value chain for specific renewable energy technologies (*e.g.* offshore wind) is a key early step in identifying localisation opportunities. Further steps can be determined in line with national skills, industries and strategies.

The typical sequence is:

- **Defining key renewable-based technologies:** Modelling for a decarbonised or net-zero electricity system can help identify the technologies needed and where any part of their manufacturing could be situated based on local competitive advantages.
- **Value-chain assessment:** To provide policy support, the government must understand the specific value chains for identified technologies and which parts or segments could be localised based on existing skills, resources and industries.
- **Industrial policies:** Dedicated industrial policies can assist in localising the manufacturing of the required components for identified technologies.
- **Mining for critical materials:** Domestic manufacturing will require critical raw materials, including transition minerals. Determining the minerals needed, their availability, and how to secure their supply or develop domestic extraction capacity helps build domestic industrial advantages.
- **Building an institutional framework:** A competitive industrial base for clean energy hinges on establishing institutions and mechanisms to conduct regular assessments, consult and communicate with industries and the private sector, and develop effective policies to support the sector.

Case study: Building renewable energy and battery value chains in South Africa

The South African Renewable Energy Master Plan (SAREM) provides a coordinated, long-term framework to scale up deployment while simultaneously driving industrialisation, skills development, and job creation. The plan links energy transition goals closely with local value-chain development.

One key objective of the SAREM is to expand the industrial capacity in the renewable energy and storage value chain. Developing local battery manufacturing – especially for lithium-ion batteries (LIBs) and vanadium redox flow batteries (VRFBs) – could create jobs, increase export earnings, improve energy security, and reduce dependency on imported cells and packs.

A domestic research institute, Trade and Industrial Policy Strategies (TIPs), has flagged significant endowments of critical minerals, such as manganese, vanadium, nickel and cobalt, as a strong foundation for moving upstream in the battery value chain. Currently, local value addition remains largely confined to raw mining, refining, and precursor production.

This nascent battery production capacity requires targeted investment and policy support to capture more economic benefits for the country and local communities.

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• *Industrial policies for localised manufacturing*

Industrial policies that support the localisation of clean energy manufacturing are essential to ensure domestic economic benefits alongside emissions reduction. Supply-side push policies – aimed at stimulating investment, innovation, and capacity expansion – can lower production costs, reduce financial risks, and create supportive industrial ecosystems for manufacturing renewable energy technologies.

Key supply-side push policies include:

- **Offering targeted tax credits:** Cutting investment costs through tax credits for facilities and equipment helps firms scale up production related to renewables.
- **Providing capital grants:** Upfront investment barriers can be overcome with capital grants to offset project risks and ensure financial viability.
- **Funding R&D:** Support for research and development (R&D) accelerates domestic innovation in renewable energy technologies and manufacturing processes.
- **Establishing dedicated economic zones:** The creation of industrial clusters with preferential regulations and dedicated infrastructure can attract manufacturers and strengthen supplier networks for renewable energy development.
- **Expanding concessional finance:** Below-market loan rates and long tenors can ease financing constraints for large-scale renewable energy manufacturing investments.

Case study: Pulling and pushing renewable energy value chains in China

For decades, China has emphasised the need for new energy industries in its Five-Year Plans, with "new energy" mainly referring to wind and solar power. China's National Development and Reform Commission (NDRC) and Ministry of Industry and Information Technology (MIIT) have advanced state-led renewable energy and lowcarbon industrial policies.

New energy has appeared in successive Five-Year Plans from the 7th (1986–1990) to the current 15th (2026–2030) plan, progressing through five broad developmental stages. After an initial recognition of renewables as a supplementary rural energy source, the focus shifted to R&D and then industrialisation. More recently, new energy development has reached to the level of national planning, where it is now positioned as a strategic pillar industry. New energy has become a core element of a Chinese transition aiming for "dual carbon" targets – to achieve peak CO_2 emissions before 2030 and achieve carbon neutrality by 2060.

On the demand side, the general framework of the Renewable Energy Law of 2005 was complemented by quantitative targets for wind and biomass in the 11th Five-Year Plan, spanning 2006-2011. NDRC later introduced local content requirements (up to 70% for wind equipment) and informal preferences for domestic suppliers, pulling renewables-related manufacturing decisively into China.

On the supply side, concessional finance from state-owned banks was combined with tax incentives, R&D funding through national science programmes, capital grants, incentives via special economic zones, and preferential land use and grid access. These measures enabled firms to invest aggressively in manufacturing capacity, making China the world's largest wind turbine producer and a dominant global supplier of solar PV components by around 2010.

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Localisation requirements and long-term market signals

Localisation requirements for clean energy technologies can boost domestic industrial development and job creation as part of the energy transition. Some governments thus opt to temporarily shield national companies from international competition. This allows the domestic industry to gather expertise and competences for manufacturing specific parts or other components.

Policy options to incentivise local manufacturing include:

- **Local content requirements:** Project developers can be obliged to source a defined share of inputs, labour, or components domestically. The required share to source nationally typically increases over time, strengthening local supply chains and stimulating ongoing national economic development. Local content requirements must be carefully aligned with trade rules and market capacity to avoid raising costs or slowing deployment.
- **Incentives and bonuses for local equipment sourcing:** Projects that incorporate domestically manufactured equipment can be granted advantages in procurement scoring or benefit from lower tariffs.
- **Targets for domestically produced equipment:** Quantitative policy goals (*e.g.* percentages of turbines, panels, or components made locally) can guide industry planning, helping scale up domestic production capacity and reduce reliance on imports.
- **Long-term market signals:** Creating stable and predictable domestic demand for renewable energy products depends on long-term market signals. The procurement framework can provide predictability through multi-year schedules, transparent auction calendars, feed-in tariffs, and long-term deployment targets.

Case study: Strengthening clean energy manufacturing under the EU Net-Zero Industry Act

The NetZero Industry Act (NZIA) calls for EU manufacturing capacity meet at least 40% of the bloc's annual renewable energy deployment needs by 2030. Deployment is set to involve manufacturing plans therefore anticipate demand for solar PV and solar thermal technologies; on-shore and off-shore renewables (primarily wind); battery and storage technologies; heat pumps and geothermal energy; hydrogen technologies (mainly electrolysers and fuel cells); sustainable biogas and biomethane; carbon capture & storage (CCS); and grid technologies infrastructure, among other technologies.

The goal is to strengthen the EU's industrial base and supply-chain resilience, reduce import dependency for clean-tech hardware, accelerate the energy transition and decarbonisation, foster EU competitiveness and job creation, and ensure reliable market access and uptake for clean -energy innovations. The targets are indicative, designed to guide long-term industrial planning and stimulate investment rather than impose a rigid quota.

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Strengthening domestic clean energy industries

Industrial policies promoting renewables can enable domestic firms to participate in relevant value chains. Broader measures to prepare domestic industries for the energy transition can equip firms to respond to new market opportunities shaped by renewable energy deployment, industrial decarbonisation and changing trade patterns. Such measures can boost competitiveness, innovation, and quality in domestic clean energy manufacturing and services, help SMEs participate in the market, and ensure a predictable and supportive business environment.

Policies to strengthen national industry – typically cutting across several ministries and agencies – need to be coordinated with energy transition strategies, industrial decarbonisation policies, and labour and skills measures, so that support for firms, workers, and supply chains is mutually reinforcing. The effectiveness of these policies depends on several factors, such as the maturity of domestic firms, specific technology choices, and existing targets.

Several factors must be considered in building up the domestic clean energy industry:

- **Improving the business environment:** Complex administrative procedures, regulatory uncertainty, and high transaction costs can discourage firms from entering renewable energy value chains. Streamlined registration, licensing and customs processes, along with clear and stable investment rules and dedicated advisory services, can ease investment, lower compliance costs, and improve predictability for domestic and foreign investors.

- **Innovation and technology upgrades:** Domestic firms often struggle to adopt advanced production processes, hindering competitiveness. Applied research programmes, innovation grants and tax incentives can help upgrade technologies and improve productivity, while structured collaboration between industry, universities and technical institutes supports knowledge transfer and workforce reskilling.

- **Standards, certification and quality infrastructure:** Weak or unclear standards and limited testing capacity can prevent domestic producers from meeting international sustainability requirements, limiting access to export markets. Clear standards, robust testing and certification systems, and technical assistance help firms meet quality benchmarks, gain credibility, and integrate into regional and global value chains.

- **Access to finance for domestic producers:** Limited access to long-term, affordable capital can constrain investments in manufacturing capacity and technology upgrades. Financial instruments like green credit lines, guarantees, and concessional loans reduce financing costs and risk exposure, particularly when aligned with renewable energy procurement schemes, corporate PPAs, and industrial decarbonisation initiatives.

- **Cluster development and supplier upgrading:** Fragmented supplier bases and weak linkages between firms can limit economies of scale and exchanges of knowledge. Industrial clusters and supplier development programmes, combined with infrastructure investment and business development services, can strengthen local networks, improve firm capabilities, and enable smaller suppliers to meet the standards and volume requirements of large project developers.
- **Export promotion and value-chain integration:** Even highly competitive firms may face information gaps, trade constraints, limited financial support and other barriers in foreign markets. Trade promotion, export finance, and engagement through international cooperation platforms can facilitate market entry, while alignment with broader trade policy instruments supports long-term integration into regional and global value chains.

Case study: India's solar manufacturing push

To incentivise solar manufacturing, India's early auction rounds under the National Solar Mission included domestic content requirements for certain modules and cells. More recent measures include a USD 2.7 billion (INR 24,000 crore) productionlinked incentive scheme for highefficiency modules, customs duties on imported cells and modules, and the Approved List of Models and Manufacturers, linking project eligibility and support to quality and reliability standards.

Together, these instruments have contributed to the rapid expansion of announced and operational domestic manufacturing capacity for solar modules over the last decade, with Indian firms increasingly present across more of the value chain. Alongside clear gains in capacity, however, concerns remain about longterm competitiveness, trade disputes, and potential overcapacity. Evaluations underline the need for stable demand, coordinated policies, and continued support with technological upgrades.

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Powershoring

The practice of powershoring – relocating energy-intensive production to sites with abundant, clean, and inexpensive energy – links energy access issues to the challenge of attracting and retaining energy-intensive manufacturing. By siting production where renewable resources are abundant, governments can lower production costs, accelerate industrial decarbonisation, and strengthen competitiveness with clean-technology value chains. When aligned with grid planning and localised development strategies, powershoring promotes more balanced economic development and job creation.

Enabling policies for successful powershoring include:

- **Clear roadmaps and strategies:** Aligning renewable energy deployment, grid expansion, and industrial siting decisions ensures that manufacturing facilities are located where clean power supply can be delivered reliably and at scale.
- **Long-term access to affordable clean power:** To build competitive industrial clusters, governments can enable long-term PPAs, CfDs, or regulated tariffs that give industrial users predictable access to low-cost renewable electricity in specific sub-national regions.
- **Grid and infrastructure investment:** Public investment in transmission, distribution, and enabling infrastructure (*e.g.* substations, storage, hydrogen pipelines, roads and ports) reduces connection bottlenecks and de-risks private industrial investment.
- **Targeted location-based incentives:** Tax credits, grants, or concessional finance tied to co-location with renewable energy hubs can encourage firms to site production where clean power is plentiful.
- **Streamlined permitting and land-use planning:** Faster, coordinated permitting for both renewable energy projects and industrial facilities in designated areas on non-contested land reduces delays and helps synchronise project timelines.
- **Workforce and regional development policies:** Skills programmes, housing, and local infrastructure investment help ensure that areas hosting powershored industries can attract workers and build long-term economic benefits.

Case study: Powershoring and renewables in Brazil

Brazil has long-standing experience with industrial clustering and export-oriented manufacturing, supported by 22 export processing zones with differentiated tax regimes. Beyond this institutional framework, the country stands out for its consolidated industrial base in sectors such as steel, aluminium, pulp and paper, and aerospace, positioning it as a potential green industrial platform for energy-intensive industries.

These zones benefit from access to a predominantly renewable electricity system, with around 88% of power generation coming from renewable sources. This creates a structural advantage for energy-intensive industries, particularly in a context of increasing global demand for low-carbon production. The complementarities between hydropower, wind and solar resources enhance system flexibility and reliability, allowing Brazil to mitigate intermittency challenges and provide relatively stable and competitive electricity for industrial operations.

Brazil's extensive port infrastructure supports international trade flows and facilitates the integration of industrial production within global markets, particularly for bulk commodities and intermediate industrial goods. The Northeast region stands out as a strategic hub for powershoring, combining high-quality solar and wind resources (including both onshore and offshore potential) with strong port connectivity. The Northeast region is also emerging as a focal point for green hydrogen development, which could enable the relocation of energy-intensive industrial processes and support the production of low-carbon commodities for export.

Brazil benefits from a relatively well-established institutional framework for energy planning and environmental governance, which supports the formulation and implementation of policies aligned with energy transition objectives and provides a degree of predictability for industrial investment. Recent policy initiatives, including Nova Indústria Brasil and the Ecological Transformation Plan, signal a growing alignment between industrial and climate strategies.

Financial instruments such as ECO Invest, designed to mitigate currency risks for foreign investments in green projects, and platforms aimed at mobilising capital further contribute to improving the investment environment for low-carbon industrial development.

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Selected trade-related measures

Trade-related policies shape how countries acquire renewable energy technologies and participate in clean energy value chains. As renewable energy deployment expands, governments need to balance several objectives: keeping clean technologies affordable; supporting domestic industrial capabilities; maintaining access to regional and global markets; and avoiding unnecessary trade disputes.

These policies are closely linked to industrial policy and localisation choices. They influence whether clean energy supply chains remain open and affordable, whether domestic firms can gradually build capabilities, and whether climate-related measures are seen as credible and fair by trading partners.

The overall policy challenge is to ensure that trade measures are transparent, targeted and time bound, so that they support industrial development without raising costs, slowing deployment or undermining international cooperation.

The following policies are particularly relevant to trade in the energy transition:

- **Border carbon adjustments:** Import taxes can be linked to prior GHG emissions to prevent carbon leakage. Making importers pay for embedded emissions can safeguard the competitiveness domestic firms and reward those in other markets that are advancing in the energy transition.
- **Other trade policies:** Other tools can facilitate the expansion of renewable energy supply chains for domestic and international trade, such as tariff reductions. Trade measures are needed to manage dispute risks without undermining affordability or slowing down the energy transition.

• *Border carbon adjustments*

In markets with existing carbon-pricing mechanisms in place, domestic industries can benefit from a border carbon adjustment (BCA) on imports. This type of trade policy aims to prevent "carbon leakage," whereby costs incurred through carbon accounting drive production to countries without carbon-pricing mechanisms.

The EU's Carbon Border Adjustment Mechanism (CBAM) – the first major instrument of its kind worldwide – makes importers pay for embedded emissions, aiming for systematic cost alignment with EUcarbonpriced goods in key sectors.

Applying a carbon-related charge on imports based their embedded emissions keeps the playing field level for domestic industries that are cutting emissions. In parallel, foreign industries are encouraged to keep pace with emissions cuts of their own.

Several elements need to be in pace for BCAs to work:

- **Robust domestic carbon pricing:** BCA mechanisms build on an existing, well-established, and predictable domestic carbon price, providing the benchmark needed to calculate equivalent border charges.
- **Measurement methodologies:** Standardised rules are needed to assess embedded emissions and ensure that calculations for imported products are consistent, transparent, and verifiable.
- **Revenue use and redistribution policies:** Defined allocation rules for BCA revenues can support climate objectives and channel funds to help decarbonise affected industries, either domestically or in other countries.
- **Industrial policy and transition measures:** Coordinated phase-outs of free allocations and targeted industrial support can help domestic industries adjust to increasingly robust climate policies both at home and abroad.
- **Governance, transparency and review mechanisms:** A dedicated authority and regular review processes can strengthen BCA administration and promote continuous improvement of the mechanism.
- **Trade and WTO-compliance safeguards:** Non-discrimination and equal treatment measures are needed to ensure BCA mechanisms align with international trade law, including provisions of the World Trade Organization (WTO).
- **Engagement with trade partners:** Early dialogues with trading partners before rolling out a BCA mechanism – including on methodologies, interoperability with other carbon-pricing systems, and uses for BCA revenues – can avert misunderstandings, avert subsequent disputes and reduce trade-related tensions.

Case study: The EU Carbon Border Adjustment Mechanism

The European Union's Carbon Border Adjustment Mechanism (CBAM), launched in 2023, represents the world's first major implementation of a BCA policy. CBAM adoption supports EU climate goals, specifically 55% emissions reduction by 2030 and achieving climate neutrality by 2050 under the European Green Deal and "Fit for 55" package.

The EU Emissions Trading System (EU ETS) forms the core of the EU's climate strategy, covering around 40% of emissions from major industrial and transport sectors. A new complementary carbon market, ETS2, will extend carbon pricing to fuel use in buildings, transport, and small industries starting in 2027.

CBAM rules require importers to buy a certificate reflecting embedded emissions, with adjustments allowed for carbon prices already paid abroad. In principle, this aligns imports in designated sectors – initially iron and steel, aluminium, fertiliser, cement, electricity and hydrogen – with EU prices that include carbon costs, with further sectors to follow.

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Other trade policies

Choices of trade policy influence the cost and availability of renewable energy equipment and the way countries participate in global value chains. Beyond the border carbon adjustment mechanisms, instruments such as tariffs, trade facilitation, rules of origin, trade remedies and subsidy disciplines all affect renewable energy deployment and industrial development.

Many trade policy options – when they are transparent, time bound and coordinated with localisation measures – can support renewable energy industrial strategies while avoiding measures that raise costs, slow deployment or trigger unnecessary disputes.

Examples of trade policies and mechanisms that can shape the energy transition include:

- **Tariff reduction for renewable energy goods:** High import duties on key equipment and inputs can raise project costs and slow deployment where domestic production is limited. Reducing tariffs on goods not yet produced at scale lowers costs and supports supply-chain competitiveness. Temporary and targeted protection may be justified where it is tied to a credible, time-bound industrial strategy.
- **Trade facilitation and customs procedures:** Slow and unpredictable customs processes disrupt supply chains and increase costs. Streamlined and digitalised procedures reduce clearance times, improve logistics reliability, and facilitate both imports of components and exports of finished products.
- **Rules of origin and regional trade agreements:** Restrictive rules of origin can constrain regional sourcing and limit value-chain integration. Flexible provisions, including cumulation of inputs among partner countries, can support regional specialisation and the development of integrated renewable energy supply chains.
- **Trade remedies and dispute settlement:** The use of anti-dumping and countervailing duties can protect domestic producers but may also increase costs for renewable energy deployment and slow progress toward climate targets. Careful assessment of system-wide impacts, combined with reliance on multilateral dispute settlement mechanisms, helps balance industrial objectives with affordability and international obligations.
- **Export controls for critical minerals:** Export taxes or restrictions on critical minerals and intermediate goods can support domestic processing and value addition but may also disrupt supply chains and affect downstream industries and trading partners. Their use is most effective when embedded in a broader, coherent strategy for industrial upgrading and resource governance.
- **Subsidies, transparency and cooperation:** Opaque subsidy regimes risk triggering inefficient subsidy competition and trade tensions. Greater transparency and international cooperation can reduce harmful races to the bottom while preserving policy space for well-targeted support to clean energy technologies.

Case study: Tariffs and trade-linked support for renewables in Brazil

Brazil has historically linked access to concessional finance from the National Bank for Economic and Social Development (Banco Nacional de Desenvolvimento Econômico e Social – BNDES) to the use of domestically produced equipment, particularly through local content requirements tied to accreditation with the BNDES-managed Industrial Machinery and Equipment Acquisition Financing Fund (Fundo de Financiamento para Aquisição de Máquinas e Equipamentos Industriais). While effective in fostering a domestic manufacturing base for wind power, these requirements were gradually relaxed, especially for solar PV.

Import tariffs on PV modules and equipment have been adjusted multiple times. Periods of reduced or zero duties under the ex-tarifário regime – a Brazilian special import regime that temporarily reduces the import tax on certain capital goods and technology/telecom equipment when there is no equivalent domestic production – were followed by reinstatement or increases in the Mercosur Common External Tariff to support local industry. Progressive tariff adjustments reflect a shifting balance between cost reduction and industrial policy objectives.

Evidence suggests that this combination of local content-linked finance, tariff adjustments, and auction design contributed to localisation – more strongly in wind than solar – but also increased project costs. These trade-offs led authorities to ease local content requirements over time, particularly where they constrained deployment or competitiveness.

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8. Renewable energy for industry decarbonisation

Policies that support renewable energy use to reduce emissions from industrial processes can be compatible with maintaining industrial competitiveness, reliability and affordability. Along with manufacturing clean energy technologies, countries can decarbonise industrial output by fostering the use of renewable electricity and renewable-based fuels in factories and industrial systems.

Because many industrial assets are long-lived and capital-intensive, progress depends on clear direction and sequencing. Strategic frameworks and roadmaps help translate economy-wide ambition into practical pathways for priority sub-sectors and facilities, with milestones, governance and monitoring to guide investment and infrastructure planning. Turning those pathways into bankable projects often requires targeted measures to address cost premiums and risk. Finance and carbon pricing can mobilise capital, improve investment conditions, and create incentives that reward early action without undermining competitiveness.

Location-based approaches can accelerate delivery by concentrating infrastructure and services. Low-carbon industrial parks and clusters reduce costs through coordination, shared utilities and faster replication across firms. Additionally, industrial decarbonisation depends on reliable access to clean energy at scale. Open-access and corporate PPAs enable large users to procure renewable electricity directly and strengthen long-term price certainty, while green power trading and certification provides credible tracking so renewable energy use can be substantiated and procurement signals are reinforced.

• *Strategic frameworks and decarbonisation roadmaps*

Effective industrial decarbonisation starts with clear strategic direction. Governments can anchor industrial emissions reduction in national energy transition strategies and sector roadmaps, grounded in a robust assessment of where emissions are concentrated. This builds on the broader discussion of net-zero strategies and targets by specifying how energy-intensive industries fit into the overall target hierarchy.

Key elements to drive industrial decarbonisation include:

- **Embedding industrial emission targets in national transition strategies:** Industrial emissions goals need to be integrated into long-term net-zero or energy transition strategies, NDCs and sector plans, with explicit links to renewable energy supply, grids and hydrogen strategies. This ensures that industrial emissions are visible within those frameworks rather than treated separately. It is also consistent with guidance on net-zero strategies and broad energy-sector targets.
- **Identifying the highest-emitting sectors and facilities:** Facility-level emissions and energy-use data must be collected consistently and comprehensively to identify the highest-emitting sectors, sub-sectors and installations. This assessment is crucial to prioritise sectors, areas and clusters for early action and national or international support.
- **Developing sector-specific roadmaps with interim targets:** Priority energy-intensive sectors such as steel, cement, aluminium, fertilisers, chemicals and textiles require roadmaps that define technology pathways, interim-intensity and absolute emissions targets, along with the role of

renewable electricity and fuels in each pathway. These roadmaps give concrete sector-level expression to broader net-zero and renewable energy targets.

- **Aligning industrial, energy and infrastructure planning:** Industrial strategies, grid expansion plans and synthetic-fuel strategies need coordination so that future renewable-based generation, network investments and industrial siting decisions are mutually reinforcing.
- **Creating governance and monitoring arrangements:** Ministries or inter-ministerial bodies can be designated to guide industrial decarbonisation, supported by stakeholder platforms bringing together industry, labour and finance. Roadmaps can be updated in regular review cycles based on the latest emissions data, technology costs and market developments.

Case study: India's "Greening the Steel Sector" roadmap and action plan

India has prepared a dedicated roadmap and action plan to decarbonise its steel sector, which accounts for roughly 12% of the country's GHG emissions and is one of the main industrial sources of CO_2. The sector is expected to grow significantly, as India's per capita steel consumption remains well below the world average and infrastructure needs are rising. The Ministry of Steel's roadmap for "Greening the Steel Sector in India" combines detailed diagnostics of current emissions with a longterm pathway aligned with national netzero objectives.

The roadmap sets out a sequence of actions from 2023 to 2070, underpinned by the work of 14 task forces, with a practical definition and taxonomy for "green steel" and an MRV framework to track emissions at plant level. Actions focus first on improving energy efficiency, increasing the use of scrap, and raising the share of renewable electricity, followed by pilot schemes for hydrogenbased direct reduced iron (DRI), increased use of biomassbased reductants, and carbon capture, utilisation and storage (CCUS) demonstrations, aiming for largescale deployment of breakthrough technologies after 2030.

On the policy side, the plan combines supplyside support with demandside levers. It envisages a policy framework for green public procurement of steel and marketbased incentives that reward lowemission production routes while maintaining international competitiveness. India's roadmap, therefore, illustrates how a government can use diagnostics, longterm sector planning, renewableenergy integration, and procurement policies together to guide a hardtoabate industrial sector toward net zero.

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Finance and carbon pricing for low-carbon industries

Once the strategic direction is set, governments can accelerate industrial decarbonisation by aligning finance and carbon-pricing instruments to support early movers. Hard-to-abate industrial sectors need large upfront investments, long payback periods, and predictable demand for low-carbon products. Targeted public finance and carbon pricing can de-risk early movers, enhance planning certainty, and align private investment with long-term decarbonisation goals.

Notable instruments include:

- **Blended public finance to de-risk first movers:** Combining grants, concessional loans, guarantees, and public equity can reduce financing costs and risks for early low-carbon projects in energy-intensive sectors such as steel, cement, and chemicals. Blended finance, when tied to credible decarbonisation pathways and renewable energy use, helps crowd in private capital and accelerate learning.
- **Long-term contracts to bridge cost gaps:** Carbon CfDs and similar mechanisms provide revenue certainty by covering the cost gap between low-carbon and conventional production, ensuring vital stability while carbon prices and markets for green materials are still maturing.
- **Progressive carbon pricing for industry:** Expanding emissions trading systems or carbon taxes creates durable incentives to cut emissions and improves the competitiveness of low-carbon production. Predictable price paths, safeguards for trade-exposed sectors, and the recycling of revenues into decarbonisation and just-transition measures can enhance investment confidence and political acceptance.
- **Alignment with demand-side policies:** Coordinating carbon pricing and financial support with green public procurement, product standards, and trade measures helps ensure reliable demand for green materials, reducing market risk for early investors.
- **Integration within sectoral roadmaps:** Embedding finance and carbon-pricing choices within sectoral transition roadmaps improves the coherence of investment support, infrastructure planning, and trade policy, strengthening overall policy credibility and effectiveness.

Case study: Germany's carbon contracts for difference and industrial decarbonisation support

Germany has introduced carbon CfDs as a possible instrument to decarbonise energy-intensive industries while preserving competitiveness. Under this scheme, the state signs 15-year contracts with companies in sectors such as steel, cement, glass, paper and chemicals to cover the additional costs of switching from conventional to low-carbon production processes.

In the first round, 15 projects were selected to receive up to EUR 2.8 billion in support over the 15-year contract period, based on competitive auctions that awarded contracts to bidders requesting the lowest subsidy per tonne of CO_2 avoided. Payments depend on the evolving difference between the strike price reflecting low-carbon production costs and reference prices from the EU Emissions Trading System and energy markets, which also allows reverse payments if low-carbon routes become cheaper over time.

Germany is expanding this approach with a larger climate protection contract programme of around EUR 6 billion, which includes projects using green hydrogen, electrification and in some cases CCS. These contracts are embedded in the country's broader industrial and climate policy, which combines EU ETS carbon pricing, innovation funding, and infrastructure planning to support early movers and create leading markets for low-emission industrial products.

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● *Industrial clusters and low-carbon industrial parks*

Industrial parks and clusters can concentrate energy-intensive industries in specific locations. This facilitates decarbonising with renewable energy, because governments and firms can plan shared low-carbon infrastructure instead of acting site by site. Well-designed cluster policies can also support local development and just-transition goals.

Key cluster policies include:

- **Targeting priority clusters and industrial hotspots:** Mapping industrial facilities, energy demand, and emissions helps identify where coordinated action can deliver the largest emissions reductions while safeguarding employment. Focusing on clusters or corridors helps address concentrated risks and opportunities more effectively than firm-by-firm approaches.
- **Anchoring clusters in renewable electricity supply:** Linking industrial parks to dedicated or shared power generation from renewables – through direct connections, open access arrangements, or long-term PPAs – supports deep electrification and reduces exposure to volatile fossil-fuel prices. Coordination with power system and grid planning helps ensure that rising industrial demand is matched by new renewable capacity.
- **Shared low-carbon infrastructure development:** Cluster-based approaches enable joint investments for infrastructure – such as reinforced grid connections, energy storage, hydrogen production and storage, CO_2 transport and storage, or shared heat and steam networks – that would be uneconomic for each firm on its own. Investing together lowers costs and accelerates deployment.
- **Planning and incentive alignment:** Coordinated land-use planning, zoning, permitting, and fiscal incentives can steer new or expanding industrial activity toward renewable-anchored clusters, reducing system costs and avoiding fragmented, carbon-intensive development patterns.
- **Skills, employment, and local value creation:** Integrating cluster development with reskilling programmes, training centres, and local supplier development strengthens workforce transitions, embeds economic benefits locally, and supports just-transition objectives.
- **Inclusive cluster governance platforms:** Dedicated coordination bodies that bring together public authorities, industry, workers, and communities can support joint infrastructure planning, emissions monitoring, and alignment between climate, industrial, and regional development goals.

Case study: The zero-carbon industrial park in Ordos, Inner Mongolia, China

China is using zerocarbon industrial parks as pilots for renewableanchored industrial clusters, with a leading example being Inner Mongolia's Ordos NetZero Industrial Park, developed by Envision Group and local authorities from April 2022. The park is widely promoted as the world's first netzero (zerocarbon) industrial park, positioning it as a flagship for China's green industrial transition.

The park operates on 100% zerocarbon energy through an integrated "wind-solar-storage-hydrogen" system, supplying most electricity from onsite wind and solar systems, complemented by battery storage and additional renewable power purchased from the grid. An independent distribution network and 220-kilovolt substation connect an initial wind-solar-storage project of roughly 385 MW directly to the park, delivering several hundred million kilowatthours (kWh) of renewable electricity per year to clustered industries.

Ordos hosts a growing industrial chain that includes battery manufacturing, hydrogen equipment, and upstream and downstream suppliers for renewable energy technologies, supporting job creation, local value addition, and a gradual reduction in coal consumption in the surrounding area. Developers have also established an international standard for netzero industrial parks and a digital carbon and energy management platform, designed to monitor emissions in real time and optimise energy use for the site.

These tools are intended to support replication in other Chinese industrial parks and are informing emerging national guidance on zerocarbon industrial development.

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Open-access and corporate PPAs for industrial users

PPAs allow industrial consumers to buy renewable electricity directly from generators or through the grid, either collectively or at the corporate level, instead of relying only on their local utility mix. When rules are clear and charges are predictable, these tools can cut emissions, hedge electricity costs, and stimulate new investment in renewables, especially in systems where large industry is a dominant consumer.

Key PPA elements include:

- **Eligibility and access thresholds:** Clear eligibility rules for consumers, combined with appropriately low size thresholds, can broaden PPA participation beyond large industrial users and extend renewable electricity access to SMEs.
- **Streamlined and standardised processes:** Simple, digitalised approval procedures based on standard documentation and time-bound decisions reduce administrative risk and transaction costs, improving predictability for both buyers and project developers.
- **Transparent and predictable network charges:** Clearly defined transmission, wheeling, banking, and standby charges, combined with caps on cross-subsidy surcharges, support fair cost recovery while avoiding pricing structures that undermine the economic case for renewable-based open access.
- **Flexible PPA structures:** Physical and virtual corporate PPAs – including on-site, sleeved, or wheeled arrangements – allow industrial users to match contract structures to their risk preferences and market context, as well as clarifying how tariffs, balancing, and settlement rules will apply.
- **Aggregation and credit enhancement:** Allowing the aggregation of demand among smaller consumers and across multiple sites boosts market access and scale, while standardised contracts and targeted credit-enhancement instruments help maintain project bankability.
- **Certification and disclosure alignment:** Linking corporate sourcing for renewables to recognised energy attribute certificates or green labels keeps emissions claims credible and comparable, as well as consistent with national reporting and disclosure frameworks.

Case study: India's Green Energy Open Access Rules and corporate sourcing

India's Green Energy Open Access Rules, published in June 2022, are a prominent example of openaccess regulation to scale up renewable power procurement by industrial and commercial consumers. They reduce the minimum load requirement for green open access from 1 MW to 100 kW, allowing consumers above that threshold to procure renewable power from thirdparty generators or request it from their distribution company. This significantly broadens eligibility for corporate sourcing of renewables.

To encourage uptake, the rules cap crosssubsidy surcharges, waive additional surcharges for green open access, and provide greater clarity on charges for transmission, wheeling, and standby tariffs. India's rules also make provision for surplus energy to be banked with the distribution company. Approvals should be processed within 15 days via a national online portal, with applications deemed approved if technical conditions are met. Subsequent amendments in 2023 enabled aggregation across multiple connections and further clarified banking rules and settlement periods.

By late 2024, a large majority of Indian states had issued or were drafting implementing regulations under the Green Energy Open Access framework, and a growing number of renewable power developers were offering open access and corporate PPA products to industrial clients, particularly in more industrialised states.

This case illustrates how openaccess and corporatesourcing rules can be designed to widen eligibility, reduce regulatory and tariff uncertainty, and create stable conditions for renewable project finance. The same approach can also support emerging policies on green hydrogen and green ammonia, which depend on access to dedicated renewable electricity supply.

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Green power trading and certification for industrial buyers

Green power trading schemes and energy attribute certificates let industrial consumers buy and claim renewable electricity in a traceable way. Robust tracking and certification prevent double counting, strengthen corporate decarbonisation claims and support green procurement and carbon pricing policies. Trading in green power and associated environmental attributes support renewable electricity claims by industrial buyers.

Credible trading and certification depend on several components:

- **Clear certificate schemes and registries:** A single, well-defined energy attribute certificate scheme, supported by a central electronic registry, ensures accurate tracking of issuance, transfer, and retirement, with clearly assigned roles for issuers, traders, and end users, enhancing transparency and trust.
- **Coherent links between power trading and certificates:** Integrating green power trading with certificate issuance and transfer ensures that environmental attributes follow the electricity contract, while clear separation from carbon credits and other instruments prevents double counting and preserves market integrity.
- **Inclusive access for industrial buyers:** Allowing industrial consumers to participate directly or via retailers and aggregators expands demand for renewable electricity, while transparent rules on contract duration, volumes, pricing, and settlement reduce uncertainty and transaction costs.
- **Credible use and retirement rules:** Robust requirements for certificate use – including time matching and mandatory certificate retirement when claims are made – ensure that green power claims are verifiable and meaningful, with increasing temporal and geographic granularity strengthening credibility over time.
- **Alignment with wider policy and reporting frameworks:** Consistency between green power trading, certification systems, national GHG inventories, corporate disclosure rules, and carbon pricing instruments gives industrial buyers clear and coherent signals on how renewable electricity sourcing affects their emissions reporting and compliance.

Case study: China's green power trading and Green Electricity Certificates

China launched a national pilot scheme for green power trading in September 2021, with the Beijing and Guangzhou power exchange centres, backed by State Grid and China Southern Power Grid, organising the trades. The first trading day alone saw about 7.95–10.9 terawatt-hours (TWh) of green electricity traded, signalling strong initial demand. Trading volumes have since expanded rapidly, with annual green power transactions reaching well over 200 TWh by 2024. Inner Mongolia's power grid joined as a third regional green power trading platform in 2024, further extending coverage.

China's Green Electricity Certificate (GEC) system was piloted in 2017 as the domestic energy attribute certificate scheme, with each GEC representing 1 MWh (1,000 kWh) of renewable electricity. In August 2024, the National Energy Administration issued detailed "Rules for the Issuance and Trading of China Green Electricity Certificates," confirming GECs as the sole recognised certificate for renewable electricity generation and consumption in China and the only official proof of green electricity attributes.

Green power trading and GECs now operate as an integrated system: green power can be procured via dedicated sessions on regional power exchanges or via bilateral contracts, with GECs transferred together with the electricity or traded separately. National and regional platforms have linked the former China Green Power Certificate Trading Platform to the Beijing and Guangzhou exchanges, enabling both bundled and unbundled transactions. By the end of 2024, nearly 5 billion GECs had been issued in total, with about 446 million certificates traded in that year alone.

Policy updates in 2024 expanded eligibility beyond onshore wind and utilityscale PV to include hydropower, biomass, geothermal and marine energy. International Renewable Energy Certificate (IREC) issuance in China ceased in 2025, so that domestic GECs now function as the unified instrument for renewable electricity claims. This integrated framework offers industrial buyers a standardised way to source and credibly claim renewable electricity and creates an additional revenue stream for project developers.

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9. Revolutionising industrial operations for net zero

The energy transition changes industrial operations and their interaction with the power system.

Electrifying industrial heat and processes enables the replacement of fossil-based energy in many applications, especially when supported by targeted incentives, standards and enabling infrastructure. As electrification expands, demand response and flexible-load programmes can help industries contribute to system flexibility while protecting production needs and reliability.

For the hardest-to-abate segments, where direct electrification is limited, green hydrogen and green ammonia can serve as renewable-based energy carriers and feedstocks, particularly where industrial processes require high temperature heat or molecular inputs. Finally, biomass and other technologies can play a complementary role in some industries, depending on resource availability, industrial structure and sustainability constraints.

Overall, building the policy chain for renewables to decarbonise industry starts with clear direction, followed by fostering investment and expanding market access, and finally enabling technology adoption and system integration at scale.

• *Targeted incentives to electrify industrial heat and processes*

Industrial heat is a major source of emissions where fossil fuels supply steam and process heat. Targeted incentives such as investment grants, tax credits, accelerated depreciation, concessional loans and competitive "heat auctions" for electrified heat projects can speed up deployment of electric boilers, induction and resistance heating, high temperature heat pumps and electric furnaces. Decarbonisation measures for heat and processes are broadly similar to those in the power sector and the rest of the energy sector.

Key incentives for heat and process electrification include:

- **Prioritised support for suitable temperature ranges and sectors:** A first step is to identify processes where electrification is already technically and economically viable – especially low- and medium-temperature heat in sectors such as food, paper, textiles and some chemicals – and target support to first movers.
- **Targeted capital and fiscal support for electric heat:** CAPEX grants, tax credits or accelerated depreciation, paired with concessional finance and technical assistance, can incentivise the switch from fossil-fuel boilers and furnaces to electric boilers, high efficiency heat pumps, induction and resistance heating and electric arc furnaces.
- **Competitive "heat auctions" and results-based support:** Part of the support budget can be allocated through competitive tenders or dedicated heat auctions that rank projects by tonnes of CO_2 avoided, as was the case in an EU Innovation Fund auction for electrified industrial process heat. This can drive down unit costs, align support with emissions-avoidance, and reveal the most cost-effective projects.
- **Linkage to energy audits and transformation plans:** Applicants can be required to provide energy audits or decarbonisation plans that identify where electrification of heat is preferable to reinvesting in fossil-based technologies and show how project proposals fit into the wider transformation pathway for a given site.
- **Correct relative price signals and coordinate with power system planning:** Authorities need to review energy taxes, levies and network charges so that efficient electric heat is not structurally disadvantaged relative to fossil fuels. Electrification programmes must align with renewable energy deployment and grid planning so that new electric heat demand is met with low-carbon electricity.
- **Innovation windows for higher-temperature applications:** Specific calls or subsidy windows can support demonstrations of higher-temperature electrification and large industrial heat pumps, while subsidy programmes – like Japan's scheme for renewable and industrial waste heat systems – can support learning and cost reductions across multiple technologies.

Case study: Funding to decarbonise industrial process heat in Germany

Germany has created a dedicated funding window for industrial process heat within its Federal Funding for Energy and Resource Efficiency in the Economy (EEW), where. Module 2, "Process heat from renewable energies," offers grants and loan repayment subsidies for systems that supply process heat from renewable sources such as solar thermal, biomass and heat pumps, where as long as more than half of the heat is used for the company's own processes in the company.

The scheme is open to all company sizes, with higher support rates for SMEs. Eligible investments include industrial, including higher-temperature, heat pumps and other renewable process heat supply systems.

Combined with concessional loans from the national development bank and a separate "Decarbonisation in industry" funding line for larger projects, the EEW programme shows how targeted capital support can accelerate the electrification of process heat while keeping industries competitive.

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• *Demand-response and flexible-load programmes*

Demand response and flexible loads improve overall system flexibility and lower the costs of integrating variable renewables and expanding industrial electrification. Well-designed frameworks allow system operators and regulators to treat load flexibility as a reliable resource, alongside storage and flexible generation, while ensuring transparent compensation, credible verification, and fair participation rules for large sites and industrial parks.

Key design elements include:

- **Clear regulations for demand response:** Regulations are needed to define eligible resources, set roles for system operators and utilities, and clarify how operations and markets reflect demand response, including responsibilities for dispatch, settlement, and consumer protection.
- **Bankable products and procurement pathways:** The selected mix of approaches depends on market maturity, taking account of explicit programmes – such as contracted demand response, interruptible load, flexibility tenders – and market-based access to capacity or ancillary services. Standardised products and definitions are needed for response time, duration, availability windows, and performance requirements.
- **Robust measurement and verification rules:** Baseline and verification methodologies must be transparent, auditable, and suited to industrial load patterns, with clear handling of outages, production shutdowns, exceptional days, and rebound effects, so that delivered flexibility is credible and disputes are minimised.
- **Aggregation and scalable participation:** Qualified aggregators can be allowed to pool multiple sites and industrial park loads. Metering and telemetry requirements can be specified to match product risk, and coordination can be required between aggregators, distribution companies and system operators to manage network constraints and avoid double counting.
- **Alignment of incentives with system needs and equity objectives:** Payments can be structured to reward reliable delivery when it matters most, such as during peak hours and congestion periods, while avoiding excessive penalties that deter participation. Where enabling investments are needed, governments can provide targeted support for digitalisation, control systems, and metering, especially for smaller firms.

Case study: China's national action plan to accelerate a new-type power system

China national action plan to accelerate the transformation of its power system in 2024–2027 focuses strongly on flexibility and digitalisation. The plan covers distribution grid development, intelligent dispatch, expansion of EV charging infrastructure, and enhanced demand-side coordination capabilities, among other measures.

Flexibility is placed at the centre of electricity-sector reform and large-scale renewable integration. The plan recognises flexibility as a system-wide requirement and explicitly positions demand-side resources alongside generation- and network-based options. Demand response and other demand-side resources are identified as integral components of the national flexibility toolkit, supporting peak management, balancing of variable renewables, and improved system efficiency while also complementing more conventional flexibility options (*e.g.* spinning reserves and faststart gas plants).

The plan sets a clear national direction for expanding flexibility through more market-based arrangements. It promotes clearer participation rules, improved remuneration mechanisms, and stronger incentives for flexibility providers, aiming to integrate demand-side resources into dispatch, balancing, and ancillary service markets where feasible.

A key enabling pillar is the strengthening of data and digital infrastructure. Enhanced metering, monitoring, and verification systems are emphasised as prerequisites for credible participation with demand-side resources, enabling transparent settlement, robust performance tracking, and greater system-operator confidence at scale.

Implementation follows a national-to-provincial approach: central authorities define strategic direction, broad policy guidance and overarching objectives, while provincial governments and system operators are responsible for delivery. This model allows flexibility measures to be adapted to diverse conditions, resource endowments, and grid constraints around the country.

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● *Green hydrogen and green ammonia for hard-to-abate sectors*

Hydrogen and ammonia produced from renewable electricity can support decarbonisation where direct electrification is limited, especially when they replace fossil-based feedstocks or act as a reductant. Key industrial uses are renewable ammonia for fertilisers and hydrogen use in iron and steelmaking, particularly hydrogen-based DRI as a route toward green steel.

These are capital-intensive value chains that depend on low-cost renewable electricity and new infrastructure, necessitating policy alignment on definitions, demand creation, investment support, and permitting.

Uptake of green hydrogen and green ammonia requires:

- **Clear definitions and certification frameworks:** Robust and harmonised definitions of renewable and low-emission hydrogen and ammonia, supported by credible MRV, underpin market integrity. Clear certification enables contract standardisation, public procurement, cross-border trade, and investor confidence.
- **Targeted demand creation in priority sectors:** Focusing policy support on hard-to-abate applications – such as renewable ammonia for fertilisers or hydrogen use in steelmaking – helps maximise climate impact and avoids inefficient use of limited supply. Standards, mandates, and green public procurement can accelerate early market growth for verified low-emission products, including green steel and chemicals.
- **Time-bound support to address cost gaps:** Temporary support instruments – such as competitive auctions, CfDs, production incentives, tax credits, or concessional finance – can bridge the initial cost differential between green hydrogen or ammonia and fossil-based alternatives, while clear phase-down pathways preserve long-term market discipline.
- **Infrastructure and siting coordination:** Aligning hydrogen strategies with renewable power availability, grid access, storage, transport infrastructure, and end-use demand reduces system costs and development risks. Prioritising industrial clusters, ports, and export hubs can improve economies of scale and drive integration into existing value chains.
- **Competitiveness and integrity safeguards:** Conditioning public support on verified emissions performance discourages greenwashing and helps prevent lock-in with sub-optimal technologies. Predictable policy signals, attention to trade exposure, and interoperable certification systems support international competitiveness while maintaining environmental credibility.

Case study: Hydrogen Bank pilot auction under the EU Innovation Fund

In 2023, the European Union introduced a competitive auction mechanism to provide operating support per kilogram of renewable hydrogen produced. The primary objective is to accelerate early project development, reduce revenue uncertainty for investors, and close the cost gap between renewable hydrogen and fossil-based alternatives.

Auctions award support from the EU Innovation Fund, enabling transparent price discovery and competitive project selection. This approach, which helps contain public expenditure while identifying cost-efficient projects, can be tailored to reflect policy priorities such as scale, timing, or proximity to industrial demand.

The EU Hydrogen Bank auction framework can be adapted to prioritise projects linked to industrial offtake, including hard-to-abate sectors such as steel, chemicals, and fertilisers. This approach strengthens demand certainty, supports the development of green value chains (*e.g.* green steel), and improves the bankability of hydrogen projects.

Eligibility and payments are linked to EU rules on renewable fuels, including requirements on additionality, emissions accounting, and reporting. This reinforces environmental integrity, ensures consistency with EU climate policy, and supports the development of a credible certification system for renewable hydrogen.

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• *Biomass and other renewable fuels*

Strategies based on biomass and other renewable fuels can contribute to industrial decarbonisation, but their climate benefit depends on feedstock choice, land use impacts, and full lifecycle emissions. Because sustainable biomass supply is constrained, good policy design starts with clear allocation logic: where biomass adds the most value, when it should be prioritised over electrification, and how sustainability risks are managed. In practice, this means treating sustainable biomass as a scarce resource and reserving support for applications where alternatives are not yet viable or would be disproportionately costly in the near term.

Key policy approaches for decarbonisation based on biomass and other renewable fuels include:

- **Defining where and when each fuel is used:** Industrial decarbonisation strategies can set priority end uses (*e.g.* high temperature process heat, selected renewable fuels and feedstocks) and explicitly limit support for biomass where energy efficiency and electrification can deliver comparable outcomes.
- **Enforceable sustainability and lifecycle-emissions rules:** Sustainability criteria and lifecycle GHG thresholds, accompanied by traceability, certification, and reporting requirements, can help manage land-use change, biodiversity, and long-lived carbon stock impacts from bioenergy development.
- **Targeted support for fuel switching in priority industries:** Instruments such as carbon pricing, capital grants, CfDs, and green public procurement can enable the switch from coal and oil to sustainable biomass, biogas, or biomethane where the use case is clear.
- **Prioritising residues and wastes through a feedstock hierarchy:** Direct incentives aligned with waste management and circular-economy policies – focusing first on agricultural residues, forestry by-products, and organic waste – can reduce competition with food and material uses.
- **Strengthening supply chains and enabling infrastructure:** Aggregation, logistics, storage and, where relevant, biogas upgrading and grid injection standards can support reliable, cost-effective bioenergy integration into industrial clusters and heat networks.
- **Monitoring and review built into governance:** Tracking of feedstock availability, competing uses, and environmental outcomes enables timely and effective revisions of eligibility and support levels to avoid overuse or lock-in.

Case study: SDE++ support for industrial bioheat in the Netherlands

The SDE++ scheme in the Netherlands provides operating support for CO_2-reducing energy options, including renewable heat from biomass. Support for woody biomass focuses on higher-value industrial heat, with no subsidy for projects producing industrial heat of 100°C or less for the first user.

SDE++ is structured around specific technology categories, each with eligibility rules that steer which types of projects receive support. Support for biomass heat is limited to certain combustion categories, with sustainability verified in accordance with the EU Renewable Energy Directive (RED). In practice, the RED provides EU-wide sustainability criteria for biomass. Producers demonstrate their compliance through approved certification schemes and annual reporting on biomass consumption.

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Part V: Advancing people-centred and inclusive transitions

10. Communities, permitting and planning

Transforming energy systems affects people, the environment and economies, and the necessary changes are often difficult socially and politically. Advancing the energy transition, consequently, can depend on whether the long-term benefits of decarbonising energy systems also translate into short-term benefits for people and communities – even if these differ from long-term climate goals. Either way, decision-making and behaviour changes need to happen without delay.

Many countries recognise inclusivity, equity and justice as fundamental pillars of an effective energy transition. Often, social support and political palatability can hinge on how the transition affects the most vulnerable parts of the population.

As evidence from global transition processes shows, whenever communities perceive a transition as imposed, inequitable, or primarily benefiting others, local and wider opposition will grow, while project deployment slows. Conversely, when people experience tangible improvements – such as lower energy costs, cleaner air and environments, local economic opportunities, or greater control over energy resources – then public support strengthens substantially. Embedding equity and justice into transition planning is therefore not only a normative goal but a pragmatic requirement for accelerating renewable energy deployment at the speed and scale needed.

Socio-economic benefits form a key part of this logic. Renewable energy and supporting infrastructure can diversify local economies, expand access to affordable electricity, and create opportunities for small enterprises and public services. However, these benefits do not materialise automatically: their distribution depends on policy choices, access to finance, and institutional design.

Transitions that reinforce existing inequalities – between rural and urban areas, between wealthy and marginalised groups, or between host communities and external developers – risk eroding trust and hindering future projects. Policies must ensure that communities participate meaningfully in decision-making, have access to information and recourse mechanisms, and capture a tangible share of the economic value generated by new energy investments. These priorities can directly shape how projects are planned, authorised and evaluated.

Robust processes for community engagement – starting early and continuing throughout project lifecycles – are essential to identify concerns, incorporate local knowledge, and strengthen social acceptance. Permitting procedures, as well as environmental and social impact assessments (ESIAs), must extend– beyond narrow biophysical considerations and integrate social equity, cultural impacts, and distributional outcomes. Transparent and inclusive siting and consultation processes can help mediate land-use conflicts, ensure that fragile ecosystems and vulnerable groups are protected, and enable communities to negotiate fairer benefit-sharing arrangements.

Done well, these governance mechanisms reduce risk and uncertainty for developers and authorities alike, ultimately accelerating deployment.

Finally, policies that empower communities directly – such as special incentives for community-owned projects, support for cooperatives, and models that allow local communities to invest in and profit from renewable energy assets – can substantially broaden the constituency of the energy transition. Community ownership also anchors economic value locally, reinforcing social and political resilience. However, the work needed to ensure communities benefit from the transition must start at a higher policy level.

No single instrument is sufficient on its own. Permitting rules, impact assessments, spatial planning, consultation requirements, and ownership models operate as an interconnected policy ecosystem, with weaknesses or omissions in one area undermining critical outcomes in others. Embedding equity, participation, and benefit-sharing consistently across complementary policy levers helps reduce conflict, build trust, and accelerate renewable energy deployment at scale.

● *Permitting and impact assessments*

Permitting processes and ESIAs help drive people-centred energy transitions through early, meaningful community engagement, transparency, and mitigation of negative impacts from projects. When well designed and enforced, these tools can give affected people a forum to shape project design, protect their rights and livelihoods, and ensure that benefits and burdens are more fairly distributed across communities.

Governments must ensure that ESIAs for renewable energy projects are transparent, effective, and grounded in respect for nature and the well-being of people, including rural and indigenous communities. Robust regulatory frameworks and clear assessment procedures enable governments to balance the urgency of expanding clean energy with the responsibility to safeguard ecosystems, biodiversity, and local communities. Government leadership in the process – supported by early and meaningful stakeholder engagement – helps build public trust, prevent harm, and ensure that renewable energy development contributes to a just and sustainable future.

While robust permitting and impact assessments are essential at the project level, they are most effective when embedded within broader spatial planning frameworks that guide where renewable energy development should occur in the first place.

Permitting and ESIAs require:

- **Clear legal frameworks:** Effective impact assessments are grounded in well-defined national legislation that outlines the scope, process, and criteria for environmental and social review, ensuring consistency and accountability across projects.
- **Early integration in project planning:** Planning and impact assessments must include vulnerable communities – with a particular focus on indigenous peoples – at the earliest stages of project development, allowing potential environmental and social risks to be identified and mitigated before major siting or financing decisions are made.
- **Public participation and consultation:** Meaningful engagement with affected communities, including indigenous peoples, enhances legitimacy, limits damage to local livelihoods, and helps projects secure free, prior, and informed consent where relevant.
- **Social and cumulative impact assessments:** Evaluating effects on livelihoods, cultural heritage, health, and gender relations ensures that social dimensions are reflected alongside environmental factors. Assessing cumulative effects within a designated geographic area can capture the broader environmental and social footprint of multiple projects, reducing the risk of overexploitation or ecosystem strain.
- **Mitigation and benefit-sharing plans:** Strong ESIAs include actionable strategies to minimise negative impacts and create tangible local benefits, such as employment or community investments.
- **Monitoring and compliance mechanisms:** Ongoing monitoring and reporting help verify that mitigation measures are implemented and that unforeseen impacts are promptly addressed. Credible and transparent outcomes depend on assessments being conducted or validated by independent experts with recognised technical and socio-economic expertise.

- **Transparency and data accessibility:** Public access to ESIA findings, decisions, and the data from monitoring promotes trust and enables informed community participation in project oversight.
- **Capacity building and institutional support:** Local authorities and communities often need training, information and practical toolkits to engage meaningfully in assessment and monitoring processes.

Case study: Socially inclusive solar development at Ouarzazate, Morocco

Morocco's Noor Ouarzazate solar complex, developed from the early 2010s, was the world's largest CSP complex at the time, with 510 MW of CSP capacity or around 580 MW including PV.

Although costly by today's standards, it was built amid international hopes for CSP to become a major utilityscale option, because of the technology's thermal storage and ability to deliver dispatchable electricity after sunset. The complex was developed by the Moroccan Agency for Sustainable Energy (MASEN) using a publicprivate partnership model that has since become to the norm for structuring renewable energy investments in Morocco.

Extensive environmental and social impact assessments were conducted in cooperation with international financiers, examining local employment, community development, land acquisition, water use and ecological impacts. Based on those assessments, project plans incorporated measures to maximise local job creation, support social infrastructure, and mitigate adverse impacts on vulnerable groups.

Water use emerged as a critical concern in the arid Ouarzazate region. Noor I was built with wet cooling, which is more waterintensive, but experience from this first phase prompted a shift in technology for subsequent stages. Noor II and Noor III were required to employ dry cooling systems, significantly reducing water consumption while maintaining plant performance.

This phased approach illustrates how large flagship projects can provide technical and social lessons that inform later investment decisions and improve the environmental performance of subsequent phases.

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● *Spatial planning for renewables*

Spatial planning for renewable energy helps decide where projects go, aiming to maximise resource potential while avoiding conflicts with communities, land uses, and ecosystems. Socially accepted, people-centred transitions are grounded in clear permitting processes and rigorous ESIAs, which ensure that projects anticipate and manage any impact on livelihoods, health, and local environments rather than shifting such burdens onto vulnerable groups.

Together, these tools ensure transparency, enable early community participation, and build trust, making the transition not just faster but fairer and more responsive to local needs and rights. Robust spatial planning, by coordinating renewable energy deployment with other activities and sectors (*e.g.* transport, agriculture), reduces conflicts, shortens permitting processes, and lowers investment risk.

Even where suitable areas for renewable energy development are identified through spatial planning, project siting decisions ultimately intersect with local land rights and livelihoods, necessitating community consent. Early inclusion and consultations can help avoid later conflict and project delays, as well as reducing investment risk. Similar considerations may apply for offshore projects, which affect maritime ecosystems and can also damage related community livelihoods.

Key elements of spatial planning include:

- **Geospatial planning:** National geospatial planning frameworks and geospatial mapping allow planners to identify and zone the most suitable areas for renewable energy resource development.
- **National land-use, planning and zoning laws:** Land-use and zoning laws – drafted collaboratively by relevant national, sub-national and local government departments in consultation with local communities and indigenous peoples – can designate priority or "acceleration" areas for renewables, based on coordinated spatial mapping that considers resource quality, environmental impacts and constraints, priority areas for conservation, and social impacts.
- **Siting and permitting:** Clear, streamlined permitting and environmental assessment procedures can ensure alignment with spatial plans, set time limits, and use digital one-stop shops to reduce uncertainty while maintaining robust environmental and social safeguards.
- **Requirements for early public participation and consultation:** Spatial planning processes can enable affected communities to influence where and how renewable projects are developed from the outset.
- **Priority on dual-use areas:** Spatial planning policies can prioritise the use of artificial, degraded, or dual-use areas (*e.g.* rooftops, brownfields, agrivoltaics) for renewable energy deployment, thereby reducing land-use conflicts and protecting sensitive ecosystems and livelihoods.

Case study: Spatial planning for renewables in Denmark

Denmark has established a robust spatial planning regime that supports renewable energy deployment through clear marine and landuse planning frameworks.

For landbased projects, renewable energy development is guided by Denmark's Planning Act (Planloven), which governs national and municipal planning, requires municipalities to preselect areas for technical installations (such as wind turbines), and typically requires local plans before major projects proceed.

For offshore wind, the Act on Maritime Spatial Planning provides the framework for spatial planning in Danish marine areas. It was implemented through Denmark's first national Maritime Spatial Plan in 2021, later amended in 2023, which designates areas for offshore renewable energy alongside other marine uses and serves as the basis for coordination among various relevant authorities.

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• *Siting and consultation*

Policymakers need to ensure that land-use and siting decisions for renewable energy projects are grounded in meaningful community consultation and in the principle of Free, Prior, and Informed Consent (FPIC). This entails laws and procedures requiring developers to engage early and openly with affected communities, especially indigenous peoples, whose rights, lands, and livelihoods are often directly impacted by energy infrastructure.

Inclusive, culturally appropriate consultation processes are crucial to convey accessible information and enable communities to make legitimate decisions. Beyond consultation and consent, long-term social acceptance is further strengthened when communities can participate economically and share in the benefits of renewable energy projects.

Key elements to strengthen consultations on project siting include:

- **Embedding FPIC in national legislation:** By integrating FPIC and participatory land-use planning into renewable energy policies, governments can prevent conflict, build public trust, reduce legal risks, and promote equitable outcomes in which the benefits of the energy transition are shared with those most affected.
- **Ratifying and implementing UNDRIP principles:** Only people whose existence is recognised by law can be included in legally required consultations. Committing to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and incorporating its principles – especially FPIC – into national laws and renewable energy governance frameworks is a key step to strengthen inclusion and legitimacy.
- **Participatory land-use planning:** Inclusive project planning involves local communities and indigenous peoples in mapping, zoning, and land allocation decisions for renewable energy projects, with communities retaining the right to reject project proposals. Establishing regulations that require early-stage consultation during planning and site selection can help to achieve socially accepted and economically effective siting.
- **Independent grievance and redress systems:** Affected communities need a channel to raise their concerns and seek remedies related to land use, with independent mechanisms in place to mediate disputes, facilitate ongoing consultations and help mitigate conflict.
- **Benefit-sharing requirements:** Requiring renewable energy developers to negotiate benefit-sharing agreements – such as community investment funds or co-ownership models, as well as affordable electricity access for vulnerable local communities – can further cement support for projects.

Case study: Utility-scale solar on tribal lands in Nevada, U.S.

The Moapa Southern Paiute Solar Project is a 250 MW photovoltaic plant located on tribal land of the Moapa Band of Paiutes in Nevada, in the southwestern United States.

The project developer engaged with the tribal government and community over a period of seven years, ensuring that the site, construction, and operations aligned with tribal interests and land-use preferences.

During construction, the project directly employed 115 indigenous Americans, including about 50 local tribe members on the Moapa River Indian Reservation, and engaged 485 local subcontractors, demonstrating real employment benefits for the community.

As the first utility-scale solar power project sited on North American tribal lands, the Moapa project showed how major renewable energy deployment could align with indigenous land rights and participation.

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• *Special incentives for community-owned projects*

Governments can create specific incentives to support community-owned renewable energy projects. Targeted policies like tax credits, low-interest loans, feed-in tariffs, and grant programmes can lower financial barriers and encourage local ownership and participation. These measures help ensure that the economic and social benefits of clean energy – such as job creation, income generation, and energy access – flow directly to communities, fostering equity, resilience, and long-term public support for the transition.

Examples of policies that incentivise community energy include:

- **Dedicated feed-in tariffs and PPAs:** Designated community-level FiTs or PPAs can guarantee fair and predictable prices for electricity generated by community-owned renewable energy projects, providing financial stability and encouraging investment.
- **Grant and loan schemes:** The availability of grants and loans can make capital more accessible to cooperatives, municipalities and local groups, helping them plan, finance and operate renewable energy installations.
- **Tax incentives and rebates:** Individuals and cooperatives can be rewarded through incentives and rebates for investing in community energy, reducing upfront costs and improving project viability.
- **Publicly funded technical assistance and training:** Local capacity-building programmes can provide the skills and knowledge needed to develop, manage, and maintain renewable energy projects.
- **Dedicated legal frameworks:** Laws and regulations that enable energy cooperatives and shared ownership can formalise community participation, enabling groups of citizens to jointly own and benefit from clean energy infrastructure.
- **Priority grid access and simplified permits:** Access rules and permitting processes can remove administrative and technical barriers that often hinder small-scale, community-owned renewable energy projects.

Case study: Indigenous-led renewable energy development in British Columbia, Canada

More than 200 indigenous-led renewable energy projects exist across Canada, with 79 grid-tied projects in British Columbia alone supplying about 13% of the province's electricity from small hydro, wind, solar, and biomass.

In 2025, a federal ministry, Environment and Climate Change Canada, announced over CAD 40 million (about USD 29-30 million) in funding through the Low Carbon Economy Indigenous Leadership Fund to support 13 Indigenous-owned and -led clean energy projects across Canada.

The expansion of indigenous participation in energy development throughout Canada is supported by the Declaration on the Rights of Indigenous Peoples Act, which aligns provincial law with UNDRIP principles and enshrines FPIC in national law. This framework ensures that indigenous communities are consulted on – and gain a meaningful stake in – projects developed on their traditional territories.

Many indigenous-led projects adopt joint-venture or full-ownership models, resulting in stable income that supports housing, education, health, and local employment. Indigenous-owned utilities and corporations train local community members in technical and managerial roles, ensuring that skills, profits, and knowledge remain in the community.

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11. Labour and skills development

The global energy transition has rapidly expanded employment in renewables – to an estimated 16.2 million jobs worldwide by 2025 – while simultaneously displacing fossil-fuel workforces.[10] This entails a massive, yet delicate, social and economic shift that necessitates policies to reskill workers and promote equitable access to new green jobs.

As energy systems change, labour markets will undergo significant structural shifts, requiring proactive planning to manage job creation, job displacement, and evolving skill demands. With labour safeguards and timely skills upgrades, the shift to low-carbon energy systems can deliver inclusive economic outcomes alongside environmental benefits.

Labour and employment interventions require long-term strategies and coherent plans, supported by cross-ministerial coordination and public-private cooperation. Embedding labour and employment considerations into renewable energy planning can enhance the ability of institutions and training programmes to respond effectively to changing labour-market needs. Coordinated planning also improves policy consistency and bolsters long-term workforce readiness.

Skills gaps must be identified and future needs assessed to anticipate how the energy transition will reshape labour markets. Informed decision-making can then reduce the risks of unemployment and skill mismatches as fossil-fuel industries contract, particularly in areas and sectors heavily dependent on carbon-intensive activities.

Deliberate skills-transfer initiatives can support some retention of experienced workers through the energy transition. Policymakers can facilitate this process by identifying competencies from

[10] IRENA and ILO, Renewable energy and jobs: Annual review 2025: www.irena.org/Publications/2026/Jan/Renewable-energy-and-jobs-Annual-review-2025.

fossil-fuel industries that are applicable to renewable energy and other low-carbon sectors. Targeted reskilling and upskilling can then help reduce job losses while maintaining industrial productivity.

Effective training and reskilling programmes are essential as countries pursue net-zero emissions pathways. Declining consumption of coal, oil, and natural gas – and the inevitable job losses that follow – put communities that depend on those industries under growing pressure. Job creation requirements woven into renewable energy procurement can soften the impact for fossil-fuel workforces and improve overall employment outcomes during the transition.

By linking public investment in renewables with local employment requirements, governments can help offset fossil-fuel job losses. This approach supports local economic stability while fostering public support for clean energy development. Aligning procurement with labour objectives ensures that the energy transition delivers tangible social and economic benefits alongside emissions reduction.

Planning labour and employment interventions

Preparing the labour force to meet future requirements requires long-term planning, involving close coordination between different government ministries and departments, as well as cooperation between the public and private sectors. As renewable energy deployment accelerates, targeted workforce planning can help address skills shortages and smooth the transition for workers from declining sectors. Embedding labour and employment considerations into renewable energy planning helps inform training and strengthen institutional readiness to respond to changing labour-market needs.

Key requirements to ease the labour transition include:

- **Policy coherence:** Policymaking is key to coordinate skills development, energy plans, and employment policies. Effective communication is vital to maximise impact and avoid duplication between government ministries and different levels of government. Local government involvement is key to effectively assess sub-national needs and impacts.
- **More and better data:** Investing in comprehensive data collection and analysis helps governments and the education sector anticipate skills demand and guide targeted interventions, such as adapting school and university programmes and continually updating training programmes.
- **Partnerships with the private sector:** Public-private partnerships enable collaborative planning, facilitate investment mobilisation, and support more efficient, targeted delivery of transition policies. Industries are best placed to assess their skills needs, while policymakers steer labour-market adjustments – including for groups with traditionally limited employment access, such as women.
- **Social dialogue:** Continuous dialogue among governments, employers, workers, civil society, and training institutions ensures that transition strategies align with social and economic realities, helping make key government decisions more effective.

Case study: Employment and skills impact of the energy transition in Viet Nam

Extensive studies by COBENEFITS and the World Bank have analysed the value chains for solar PV and wind power in Viet Nam and estimated associated employment effects, confirming that renewables offer significant opportunities for job creation. The studies show "green jobs" in renewable energy, agriculture and forestry to be more skillintensive, indicating that Viet Nam could expand them in line with the energy transition. For now, green jobs account for a relatively modest portion of total employment.

Complementary modelling suggests that the electricity-sector workforce in Viet Nam could grow from roughly 300,000 to around 500,000 fulltime jobs by 2035 under an ambitious transition scenario, driven by rapid uptake of renewables and grid investments.

While renewable energy offers considerable potential to create new jobs and enhance local skills, Viet Nam faces structural challenges: limited domestic manufacturing of renewable-related components, comparatively low local content in many projects, and the need to align local training and education with emerging labourmarket opportunities.

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● *Identifying skills gaps and assessing needs*

Identifying skills gaps and assessing future skills needs helps anticipate how the energy transition will reshape labour markets, reduce employment shocks, and minimise skill mismatches as fossil-fuel industries decline. Gaps at high skill levels constitute a fundamental challenge for low-income countries. By aligning workforce capabilities with emerging renewable energy opportunities, such assessments ensure a smoother, more inclusive, more economically resilient transition.

Effective skills assessments involve:

- **Mapping existing skills and qualifications:** Skills mapping establishes a baseline of workforce capacities across sectors, clarifying where current competencies could already support renewable energy deployment.
- **Estimating future workforce demand:** Demand projections can link employment to long-term energy and climate scenarios, helping anticipate essential qualifications and occupations and thereby supporting targeted training as technologies and national energy priorities evolve.
- **Analysing skills gaps:** Skills-gap analyses can reveal mismatches between current and future needs, providing evidence for the design of education and labour-market responses.
- **National stakeholder engagement:** Government, industry, labour, and training providers can work together to strengthen labour-market monitoring and coordination.
- **Accounting for gender and inclusion:** Integrating gender and inclusion perspectives helps identify and address barriers that prevent women, youth, and under represented groups from obtaining green jobs.
- **Regular reviews:** Skills assessments require regular reviews to allow for adaptive planning as technologies, markets, and policies continue to evolve.

Case study: Addressing energy transition skills gaps in South Africa

South Africa's Energy & Water Sector Education and Training Authority (EWSETA), in collaboration with GreenCape, launched the PowerUp initiative in 2025 to help bridge skills gaps in the energy transition.

PowerUp is a digital skills facilitation hub connecting industry, educational institutions (including for post-school education and training), and other stakeholders to align workforce development with the needs of the renewable energy sector. It aims to bridge the gap between industry needs and educational offerings, so that training and curricula align with the evolving requirements of the green economy.

The initiative emphasises three core objectives: providing industry-ready skills; fostering stronger collaboration between academia and industry; and promoting inclusive growth by creating job pathways for youth and for workers facing redundancy in other sectors.

PowerUp continues seeking industry partners to help shape future skills development and has invited post-school education and training institutions to embrace a demand-driven approach that matches evolving market needs.

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● *Assessing options for skills transfer*

Skills from fossil-fuel industries can be transferred to emerging green sectors, helping retain experienced workers and reduce job losses during the energy transition. By identifying transferable competencies and supporting targeted reskilling, policymakers can ensure a smoother and more inclusive transition to a low-carbon economy while maintaining industrial productivity.

Key considerations for skills-transfer initiatives include:

- **Prioritising clean energy technologies:** Skills-transfer plans can focus on skills for solar PV, wind, green hydrogen, or bioenergy, depending on each country's planned energy mix, industrial strategy, and comparative advantages.
- **Mapping transferable skills and occupations:** Key skills from the oil and gas sector (*e.g.* mechanical, electrical, and safety competencies) can transfer smoothly, particularly to offshore wind or hydrogen projects, with mapping exercises helping identify specific overlaps in technical and managerial capabilities.
- **Conducting targeted sectoral assessments:** Transition planning requires an understanding of which fossil-fuel job roles can continue with renewables and where skills gaps remain that require additional training or certification.
- **Learning and labour-transition measures:** Integrating lifelong learning and active labour-market measures – including career guidance, job matching, and social protection – can help affected workers move smoothly into green industries.
- **Reskilling and upskilling:** Skills programmes can build on people's existing technical expertise, particularly through short, modular training programmes linked to newly introduced renewable energy technologies.
- **Industry co-investment in training:** Public-private partnerships, fiscal incentives, and project requirements can mandate local skills development and content plans.
- **Alignment with just-transition frameworks:** Skills transfer initiatives can ensure that communities dependent on fossil-fuel industries benefit from alternative employment options and economic diversification.
- **Monitoring labour-market outcomes:** Data on employment transitions, wages, and local impacts can help refine and continually update training and policy interventions.

Case study: Workforce transition pathways in Australia's hydrogen economy

An analysis of skills and job types for the hydrogen economy in Australia shows extensive continuity from fossil-based jobs that are set to be displaced. For most roles, workers coming from the oil and gas industry will experience minimal changes in day-to-day tasks, responsibilities, and skill or knowledge requirements.

The study places different jobs and skills on an "augmentation scale" indicating relative continuity with the energy transition. For some job types, only "insignificant" reskilling is necessary, whereas others fall into the "low," "moderate" or "high" augmentation categories.

Most engineers – including those in chemical, civil, electrical, electronic, mechanical, and marine engineering – will experience only minor or low-level changes in their job roles. More substantial changes are likely in the logistics chain, where workers will need to learn how to handle hydrogen, a highly flammable material that is more hazardous than most petroleum products.

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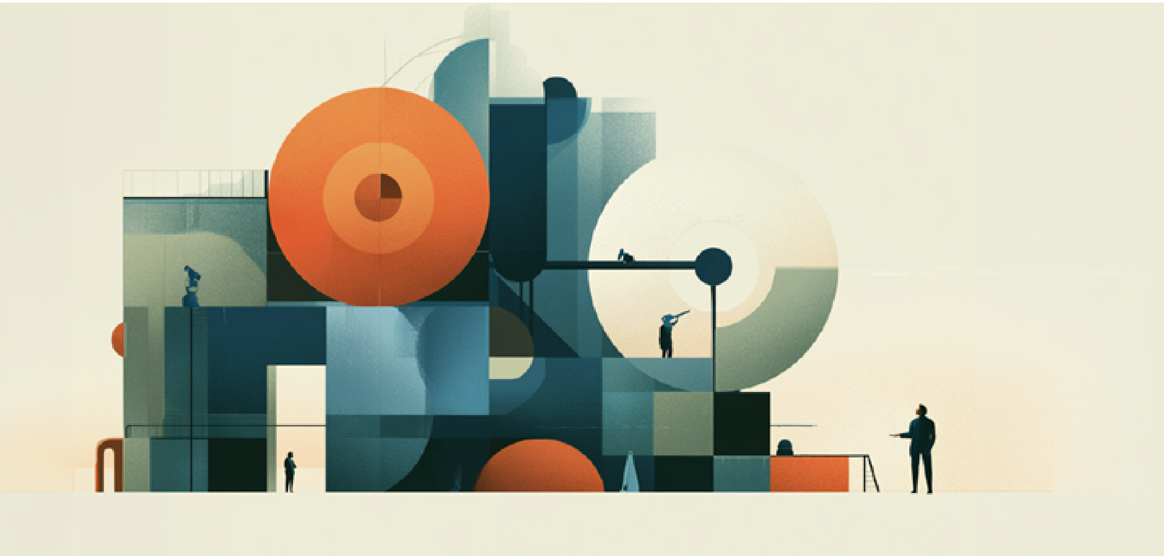

• *Designing training and re-skilling programmes*

As countries pursue net-zero emissions, the decline of fossil-fuels will inevitably result in job losses and economic disruptions, particularly in communities that rely directly on coal, oil and gas extraction or processing. Governments can respond with reskilling and transition programmes to help affected workers shift into clean energy and electric vehicle industries, helping ensure a just and sustainable transition.

Key training and re-skilling components include:

- **Just-transition training strategies:** Governments, unions, and companies must coordinate to ensure fair retraining and support for displaced fossil-fuel workers, with national and sub-national frameworks in place to channel funds where needed.
- **Skills assessments:** Mapping existing worker skills and training needs is critical to design targeted vocational programmes for renewable energy jobs. Local authorities can provide critical support to national governments in this regard.
- **Regional training centres:** Dedicated academies in coal, oil and gas regions can provide hands-on training and certification for green energy employment.
- **Financial and employment support:** Social safety nets, income aid, relocation assistance, and policies encouraging companies to hire locally – both for fossil-fuel decommissioning and renewables-based projects – can help communities find a secure place in the transition.
- **Economic diversification:** Green energy presents opportunities in new industries, entrepreneurship, and digital infrastructure, which government investment and incentive schemes can promote to create alternative jobs, particularly in coal-dependent regions.
- **Oversight and monitoring bodies:** Reskilling initiatives need dedicated institutions to oversee worker retraining, track outcomes, and maintain ongoing dialogue with investors, local governments, civil-society groups and affected workers.

Case study: Worker retraining and re-employment in China's coal transition

In 2016, China launched a major initiative to cut excess coal and steel capacity while prioritising worker redeployment and retraining. The central government established the CNY 100 billion (USD 15.1 billion) Industrial Special Fund over two years and allocated CNY 10 billion (USD 1.5 billion) specifically to support worker resettlement and training.

Shanxi Province, China's largest coal-producing region, committed CNY 2.2 billion (USD 330 million) from employment and unemployment funds to finance retraining, job transfers, and early retirement.

The Shanxi Coking Coal Group set up an innovation centre that created 26 new businesses, led mainly by former employees, providing alternative livelihoods and fostering local entrepreneurship. By the end of 2016, around 31,600 workers in Shanxi and 726,000 nationwide had been successfully re-employed following down-sizing in the coal and steel sectors.

Shanxi has also pursued tourism development projects to diversify its economy and create additional employment opportunities for former coal workers.

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Integrating job creation into procurement policies

Procurement policies that advance specific job-creation objectives can help offset job losses in the fossil-fuel sector and ensure that new clean energy projects create local employment opportunities. This approach allows governments to directly link public investment in renewables with workforce transition goals, fostering economic stability and social acceptance of the energy transition.

Policies to offset local job losses include:

- **Local content requirements:** Renewable energy projects can be required to source a percentage of their components and services locally to stimulate domestic job creation.
- **Employment-linked bidding criteria:** Job creation and workforce transition plans can be requested in renewable energy tender evaluations to reward companies that invest in local hiring and training.
- **Retraining incentives:** Tax credits or subsidies can be offered to renewable energy firms that hire and retrain displaced fossil-fuel workers.
- **Community-benefit agreements:** Developers can be required to collaborate with local authorities and labour unions in establishing job guarantees and apprenticeship programmes for affected communities.
- **Public procurement targets:** Government procurement quotas for clean energy projects can also prioritise inclusive employment, gender equity, and fair wages.
- **Monitoring and reporting mechanisms:** Systems can be established to track job creation outcomes for renewable energy projects, strengthening compliance and supporting continuous improvement in labour standards.

Case study: Public procurement as a tool for local content and job creation in India

The Indian government's public procurement policy includes a "purchase preference" for goods and services that meet a minimum local content requirement, thereby embedding local industry and employment objectives into the procurement process. This policy helps channel public-funded demand toward domestic manufacturers and service providers, thereby stimulating job creation and economic diversification in sectors aligned with the energy transition.

When governments procure renewable energy infrastructure or related services, they can deliberately require local job creation, skills development, and supply chain development as part of the tender criteria.

As India's case illustrates, procurement is not just about selecting the lowest cost. It can also be leveraged as a strategic tool for job creation and industrial development in the clean energy transition.

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12. Energy access and rural electrification

Ensuring access to affordable, reliable, sustainable and modern energy for all – Sustainable Development Goal 7 in the United Nations Agenda for 2030 – remains a critical challenge in countries with incomplete grid coverage, particularly in rural and remote areas. The energy transition holds vast potential to benefit communities that continue relying on rudimentary, and often highly polluting energy sources, including kerosene (for lighting and cooking) and diesel generators.

Renewable energy solutions can significantly improve people's livelihoods in previously underserved communities, particularly in isolated areas not connected to a national power grid. Off-grid renewables can also contribute to uninterrupted electricity for health, education and agriculture in remote regions.

Rural electrification increasingly relies on a combination of grid extension, mini-grids, and stand-alone off-grid systems, with each solution tailored to local demand, geography, and socio-economic conditions. The success of these efforts depends on effective planning that integrates least-cost electrification modelling, geospatial data, and community needs into coherent national strategies. As countries pursue both decarbonisation and development objectives, rural electrification has become a cornerstone of inclusive energy transitions, linking climate goals to human well-being, economic opportunities, and overall socio-economic resilience.

Off-grid systems – especially mini-grids and solar home systems – help deliver rapid, affordable and scalable access to electricity. Their deployment hinges on enabling policies, including streamlined licensing regimes, cost-reflective tariff structures that protect vulnerable households, and clear rules for interoperability and potential future grid integration.

Financing mechanisms are equally essential: concessional funds, results-based financing, guarantee schemes, and local financial sector engagement help reduce risks and bring down upfront costs that typically impede rural consumers and small-scale operators. When enabling policies and financing are in place, off-grid solutions can deliver reliable electricity more quickly than traditional grid expansion while complementing longer-term grid plans.

The value of rural electrification extends well beyond household lighting. Productive energy uses – such as agro-processing, cold storage, irrigation, and digital services – strengthen livelihoods, enhance food security, and enable rural communities to participate more fully in local and wider economies. Designing electrification programmes with productive uses in mind ensures that energy investments generate sustained economic and social returns.

Clean cooking technologies also remain a central component of energy-access initiatives, reducing indoor air pollution, improving health, and mitigating environmental degradation. Integrated policies that address both electricity and clean cooking needs are therefore essential to achieve universal energy access in a holistic and sustainable manner.

Effective, equitable, and economically viable rural electrification depends on specific policy architecture, with an interplay between grid and off-grid planning, dedicated financing, and well-designed regulatory frameworks for mini-grids and stand-alone systems. Productive uses and clean cooking must also be addressed to ensure that rural energy access translates into meaningful development gains. Together, these elements form the foundation of rural energy transitions that are robust, inclusive, and aligned with national development priorities.

• *Planning and tracking energy access*

Governments can advance off-grid planning and measurement by establishing enabling policies, regulatory frameworks, and standards for sustainable, decentralised renewable energy systems. Governments must also coordinate data collection, monitor energy access, and track off-grid progress, along with promoting environmental sustainability and supporting local economic development.

Key mechanisms for energy-access planning and tracking include:

- **Integrated electrification planning:** Coordinated decision-making on grid extension, mini-grids, and off-grid solutions within a single national framework helps to optimise investment decisions, avoid duplication, and ensure that different delivery models contribute coherently to universal and inclusive energy access.
- **Data-driven decision-making:** Geospatial analysis, demand assessments, and regularly updated datasets enable governments to identify priority areas, match technologies to local conditions, and track implementation. Open data platforms and outcome-based indicators also strengthen transparency, accountability and investor confidence.
- **Time-bound access pathways:** Clearly articulated connection milestones and timelines provide a shared reference for governments, utilities and development partners, helping to align implementation efforts and signal long-term commitment to universal energy access.
- **Multi-tier frameworks for access measurement:** Using a multi-tier framework allows energy access to be assessed beyond simple connection rates, capturing dimensions such as reliability, affordability, quality and duration of electrical supply, enabling more nuanced policy evaluation.
- **National electrification data platforms:** Centralised systems for collecting and reporting data on connections, service quality, and system performance support consistent monitoring across technologies and localities, improving accuracy in planning while enhancing coordination among institutions.
- **Local capacity and institutional development:** Strengthening local entrepreneurship, technical skills, and institutional capacity – particularly within local governments and with attention to gender inclusion – supports sustainable operation for off-grid systems and ensures that energy access contributes to broader social and economic development.

Case study: Universal electrification in the Philippines

The Department of Energy of the Philippines has adopted the 2024–2033 National Total Electrification Roadmap (NTER) as the country's central strategy to achieve universal access, combining grid extension, off-grid solutions, and renewable-based minigrids to reach underserved and remote communities.

The roadmap integrates geospatial mapping and leastcost electrification planning tools to identify where grid extension, mini-grids, or standalone systems offer the most cost-effective and reliable solutions, with a particular focus on islands and hardtoreach areas. Implementation is underpinned by regular monitoring and data collection, including offgrid energy access surveys and reporting from electric cooperatives (ECs), which track connections, service quality, and reliability to inform adjustments to the programme.

The Renewable Energy Act of 2008 (RA 9513) provides the broader regulatory and incentive framework, including feedin tariffs and a package of fiscal and nonfiscal incentives, which. This supports private and communitydriven renewable energy projects in remote and underserved areas, including so-called "missionary areas" being newly electrified or stabilised under a special initiative by the National Power Corporation.

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Mini-grid policies

Renewable mini-grid deployment requires governments to ensure regulatory clarity and provide tariff frameworks and financing mechanisms that make projects bankable and feasible for private developers. Mini-grid policies give communities and private developers essential information, technology quality standards, and regulatory certainty, including transparency about future grid expansion.

Key features of mini-grid policies include:

- **Integrated planning:** National electrification and energy transition plans can set quantitative deployment targets, ensuring mini-grids are treated as a core pillar rather than a niche add-on. Such targets strengthen planning, regulation and financing for renewable-based mini-grids.
- **Clear legal and regulatory frameworks:** Legal and regulatory frameworks for mini-grids must clarify the respective roles and responsibilities of developers and operators, setting out simple, proportional licensing rules so projects can move forward with regulatory certainty. Mini-grid laws and regulations also provide planning certainty for developers and communities.
- **Clear governance structures:** A clear division of responsibilities is needed among government offices for procurement, permitting, planning and community engagement at both national and sub-national levels to send clear investment signals to the private sector.
- **Quality, safety, and reliability standards:** Technical and service standards for equipment, installation, and operations – including regulations on operator maintenance – help ensure a reliable supply, protect consumers, and build trust in mini-grids as a long-term solution.
- **Dedicated tariff regimes:** A predictable, transparent tariff framework that allows cost-reflective or partially subsidised tariffs – tailored to mini-grid realities – can support community-benefit models that ensure financial viability while protecting consumers.
- **Clear rules for interconnection:** Policies should specify technical standards and commercial arrangements for mini-grid interconnection with the national power system, including what happens when the main grid arrives and under what terms power can be bought or sold.
- **Community engagement and consumer protection:** Participatory planning, transparent information on tariffs and service levels, and dedicated finance for community-owned projects ensure that mini-grids respond to local needs and remain socially and politically robust.
- Guidelines and regulations for e-waste disposal. Clear guidelines and regulations are also needed for the disposal of electronic waste, such as disused batteries, inverters or panels, to uphold environmental protection amid the development and operation of mini-grids.

Case study: Mini-grid deployment in Nepal

Nepal has long faced gaps in national grid expansion, with access to electricity in remote and mountainous regions remaining limited. To address this, the government has promoted off-grid electrification through village-based mini-grids led by the Alternative Energy Promotion Centre (AEPC). The programme and related initiatives have supported more than 3,000 community-managed micro-hydro plants and close to one million solar home systems nationwide, significantly expanding access in hard-to-reach areas.

Democratically elected Electricity User Committees and similar bodies take responsibility for project planning, financing, operation, and management, helping to ensure transparency and local ownership. Nepal's approach also integrates gender and social inclusion, with an AEPC framework promoting participation by women and marginalised groups in the governance and management of local energy systems, even if implementation varies by in different areas.

Supported by non-governmental organisations and cooperatives, these decentralised renewable energy projects have enhanced equity, resilience and livelihoods, creating new income opportunities, made affordable electricity more accessible to remote communities, and improving health outcomes through clean lighting and reductions ined indoor air pollution, and making affordable electricity more accessible to remote communities.

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● *Off-grid solar home systems and solar energy kits*

Solar home systems (SHS) and solar energy kits provide a cost-effective and rapidly deployable solution for electrifying remote and sparsely populated areas where grid extension is not viable. These distributed energy solutions have become a key component of rural electrification strategies in the past decade, as roll-out can advance local communities rapidly from basic or limited access to more robust, higherquality service.

Key considerations for off-grid SHS and solar energy kits include:

- **Integration into national electrification planning:** Embedding SHS and solar energy kits within national and rural electrification strategies helps ensure that off-grid solutions complement grid expansion, reach remote populations efficiently, and contribute coherently to universal access goals.
- **Innovative and inclusive financing models:** Flexible payment mechanisms such as mobile money, pay-as-you-go, and pay-as-you-use arrangements lower affordability barriers, expand access for low-income households, and support sustainable market growth for off-grid solutions.
- **Quality and performance standards:** Minimum technical standards for equipment, combined with warranty and after-sales service requirements, protect consumers from low-quality products, build trust in off-grid technologies, and safeguard long-term system performance.
- **Targeted fiscal incentives:** Exemptions from value-added tax (VAT) and import duties for off-grid components and appliances can reduce system costs, improve affordability, and stimulate private investment across the off-grid value chain.
- **Support mechanisms for vulnerable groups:** Dedicated programmes for low-income households and other vulnerable users enhance equity in energy access and ensure that off-grid solutions contribute to poverty reduction and social inclusion.
- **Workforce development and local capacity:** Vocational training and skills development for installation, maintenance and repair strengthen local service ecosystems, create jobs, and improve the reliability and longevity of solar energy systems.
- **E-waste management and environmental safeguards:** Clear guidelines for the collection, recycling, and disposal of batteries, panels, and electronic components help mitigate environmental risks and ensure that off-grid electrification remains environmentally sustainable over time.

Case study: Solar home systems in Cameroon

Solar home systems, or SHS, have emerged as a key electrification solution in Cameroon, driven by frequent load shedding, limited grid reliability, and a dispersed population. In rural and peri-urban areas, grid extension is often technically complex and economically unviable, making decentralised solar solutions a practical alternative for improving household energy access.

Cameroon has adopted a series of fiscal measures to reduce the upfront cost of SHS and accelerate market uptake. Since January 2012, solar products – including photovoltaic cells and modules, inverters, transformers, and batteries – have been exempt from VAT, lowering consumer prices and supporting market development.

The 2024 Finance Law introduced a temporary exemption from customs duties and certain taxes on solar products for an initial period of around 24 months starting in 2024, aiming to further reduce import costs, improve affordability, and stimulate short-term deployment of solar technologies.

More recent policy measures include direct tax incentives and installation subsidies for households adopting solar energy systems, such as a 30% tax break on installation costs and an additional 15% direct financial subsidy, significantly reducing the initial investment required for SHS adoption.

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● *Productive energy uses*

Productive uses of electricity – such as agro-processing, irrigation, cold storage, and rural enterprise activities – enable households and communities to generate income, add value to local resources, and improve local livelihoods. By anchoring demand and improving the financial viability of energy systems, productive uses make rural electrification sustainable and scalable while helping drive social and economic development.

Key policy considerations to promote productive energy uses include:

- **Identification of productive-use opportunities:** Integrating an assessment of potential productive uses into mini-grid and rural electrification planning helps align system size and service design with local economic activities, socio-economic conditions, and community needs, increasing electricity uptake and local value creation.
- **Affordability of productive appliances:** Reducing upfront costs for productive-use equipment – through measures such as VAT or import-duty exemptions for certified appliances – lowers an entry barrier for small businesses and farmers, accelerating adoption and improving the economic viability of electrification.
- **Targeted financing instruments:** Concessional loans, grants, and results-based financing can address capital constraints faced by micro-enterprises and rural users, enabling investment in productive technologies that would otherwise remain out of reach.
- **Market access and value-chain integration:** Ensuring access to input and output markets for businesses and farmers using electricity in productive activities can strengthen the business case for electrification, increase income and boost local employment.
- **Skills development and capacity building:** Training and technical support for users and local service providers can enhance the establishment, maintenance and expansion of productive energy uses, supporting longer-term economic sustainability and resilience.

Case study: Productive uses of solar energy in Kenya

Kenya's energy policy framework explicitly recognises Productive Use of Energy (PUE), with a strong emphasis on solar energy, as a lever for rural economic development. In 2021, the Ministry of Energy established the National Roadmap for Scaling up Productive Uses of Renewable Energy (PURE) in Kenya. Additionally, the Inter-Governmental Committee on PURE was established in 2024 to lower barriers and create opportunities for scaling up PURE.

The framework targets productive applications such as agricultural processing, irrigation, cold storage and refrigeration, as well as energy-enabled services for small businesses. By linking energy access to economic activities, the policy seeks to increase demand for electricity, improve the financial viability of rural energy systems, and strengthen local economies.

Regulatory interventions have facilitated business models suited to productive uses, including pay-as-you-go solar systems, tax incentives (import duties and VAT) on solar PV products, and community mini-grids, as well as mini-grids anchored by productive loads. These approaches reduce upfront costs for users, improve affordability, and create more predictable revenue streams for energy providers.

Productive-use assessments are incorporated into mini-grid planning and design, ensuring that generation capacity, network sizing, and service offerings reflect both household and productive demand. The resulting integration supports more efficient system design and reduces the risk of underutilised infrastructure.

Kenya has developed roadmaps for scaling up productive uses in rural areas through inter-ministerial coordination and public-private dialogue. Complementary measures include improving tax conditions for productive technologies, enforcing quality standards, and aligning energy policy with agriculture, water, and industrial development strategies.

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Clean cooking

Clean cooking is an important component of energy access, with an estimated 2.1 billion people worldwide lacking access to clean cooking solutions. Cooking on three-stone fires is a major source of indoor air pollution in many countries and contributes to deforestation. It also perpetuates gender inequality, as women and children usually collect the firewood for cooking.

Various clean cooking solutions are available in the market. Improved cookstoves are a step up from the traditional three-stone fire and can achieve thermal efficiencies of up to 30%. Briquettes (from sustainable materials) and pellets offer better energy efficiency than firewood as cooking fuels. Liquefied petroleum gas (LPG) and biogas are cleaner, but they depend on supply chains.

Biogas also depends on substrate, i.e. a steady supply of organic feedstock such as animal manure, crop residues, or food waste, which must be collected, fed into digesters, and maintained over time. Some cultures also reject biogas in principle due to reservations about cooking with animal or human waste.

Electricity use remains expensive for cooking, especially in off-grid areas, where clean solutions compete with firewood that is readily available at no cost. However, e-cooking is becoming a viable option in urban and peri-urban areas.

Clean cooking policy should consider:

- **National strategy:** Clean cooking strategies must take account of a range of technological solutions, such as LPG and biomethane fuels, e-cooking, more efficient cookstoves and other options.
- **Financial incentives:** Subsidies, tax incentives, result-based finance, pay-as-you-go, bulk procurement programmes and other financial incentives can all support clean cooking.
- **E-cooking strategy:** Dedicated strategies can promote cooking with electricity in peri-urban and rural areas.
- **Quality standards:** Clean cooking appliances require effective and enforceable quality standards.
- **Local manufacturers and distributors:** Support for local stove manufacturers can strengthen their supply chains, reduce costs, and create local jobs.

Case study: Expanding access to clean cooking in Tanzania

In 2021, only 6.9% of Tanzanians had access to clean cooking solutions, with most of the population relaying on firewood and charcoal for cooking. The Tanzanian National Clean Cooking Strategy and Action Plan (2021-2031) laid out strategies to promote clean cooking solutions, aiming to safeguard health as well as the environment, including by improving kiln efficiency, expanding community-based forest management, formalising markets, and promoting alternative livelihoods.

The updated Tanzanian National Clean Cooking Strategy (2024-2034) lays out strategies to promote clean cooking solutions with an aim to safeguard health as well as the environment and achieve 80% adoption of clean cooking solutions by 2034. It positions electric cooking as a key solution for grid-connected households.

The strategy outlines eight objectives, namely: increasing public and institutional awareness of clean cooking; enhancing access to raw materials and infrastructure for clean cooking; reducing costs for clean cooking solutions; developing enabling policies and guidelines; promoting investment; fostering research and innovation; providing capacity development for project implementers; and incorporating gender equality considerations.

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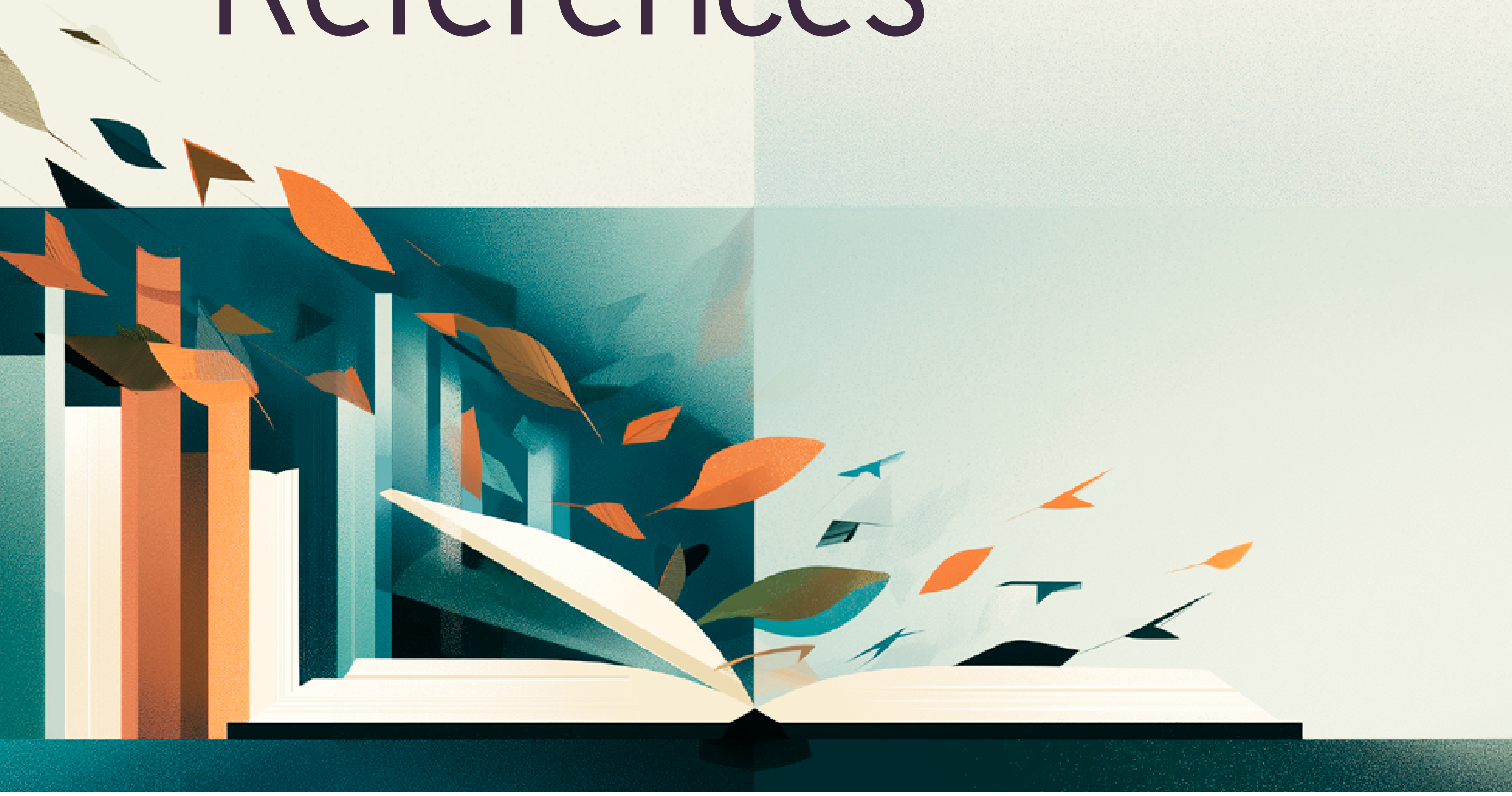

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