TRANSITIONING AWAY FROM FOSSIL FUELS

A roadmap powered by renewables, electrification and grid enhancement

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. www.irena.org

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FOREWORD

Francesco La Camera

Director-General

International Renewable Energy Agency

The global energy transition has entered a decisive new phase. Whilst remarkable progress has been achieved in scaling-up renewable energy capacity, the world remains off track to achieve climate goals. Meanwhile, rising energy demand driven by economic growth, industrialisation, urbanisation and digitalisation, exacerbated by limited advances in energy efficiency, is reshaping the dynamics of energy systems worldwide.

This evolving context is set against a backdrop of heightened geopolitical tension, market volatility, supply chain disruption and energy insecurity, underscoring the urgent need to not only reduce fossil fuel dependency and accelerate the deployment of clean energy technologies, but also to fine-tune the direction of the global energy transition as a whole.

The outcome of the First Global Stocktake at COP28 marked a historic turning point by calling on countries to contribute to global efforts to transition away from fossil fuels in energy systems in a just, orderly and equitable manner. The UAE Consensus established a strong foundation through the global objectives of tripling renewable power capacity and doubling the rate of energy efficiency improvements by 2030. Since then, additional initiatives on sustainable fuels, energy storage and grids have further reinforced the importance of adopting a more integrated and systemic approach to the transition.

This brief contributes to that evolving agenda. It highlights the role of electrification and grid development as key pillars of the next phase of the energy transition and how they can be leveraged to support the COP30 Roadmap for Transitioning Away from Fossil Fuels (TAFF) initiative, whilst also delivering energy security, economic resilience and sustainable development.

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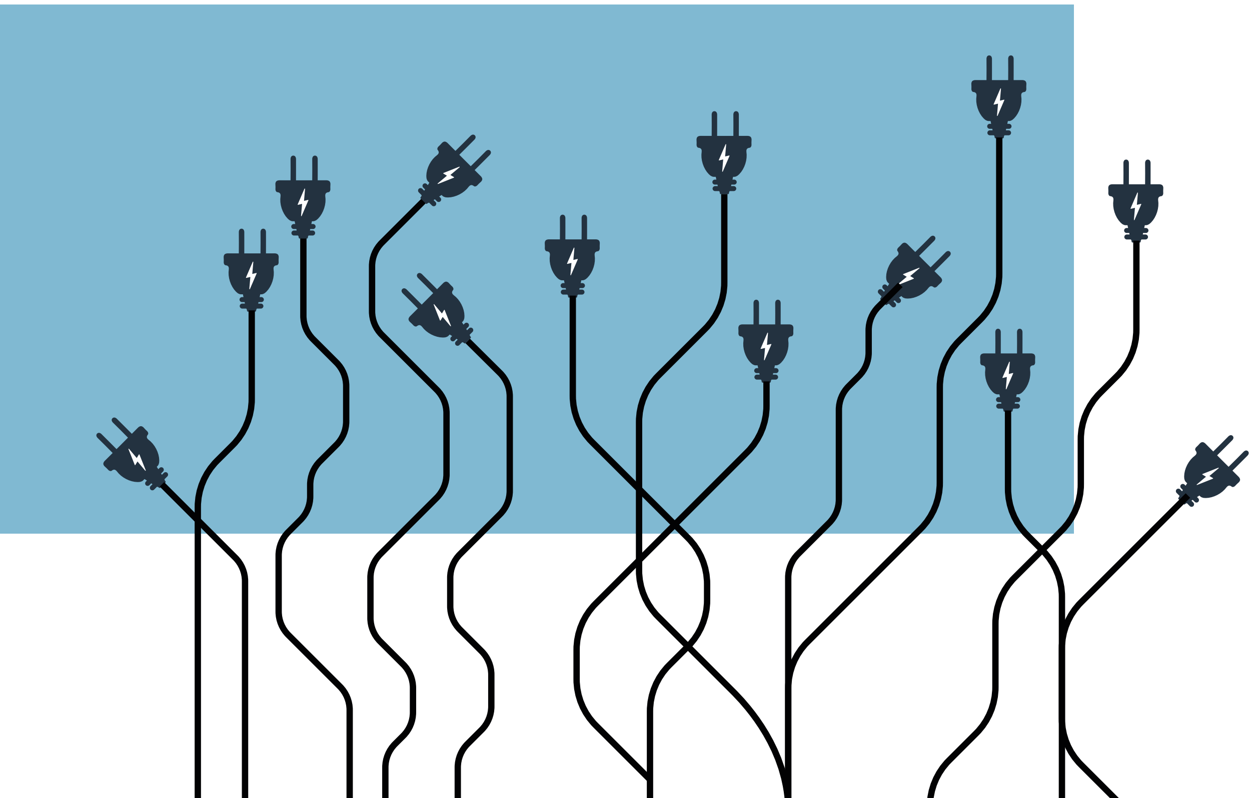
Electrification represents one of the most reliable drivers of structural transformation across energy systems. When combined with renewable energy deployment, modern grids, system flexibility and energy efficiency improvements, it can significantly reduce fossil fuel demand across transport, buildings and industry while improving overall system performance.

This will require unprecedented investments in renewable power generation, electricity networks, storage, digitalisation and enabling infrastructure. International co-operation will also be critical in enabling faster global electrification, particularly in emerging and developing economies where expanding access and supporting economic development remain essential priorities.

IRENA's global membership and partnerships position the Agency to catalyse this co-operation between governments, industry, financial institutions and development partners. This co-ordinated approach can help reinforce alignment between the TAFF, electrification policies, renewable energy deployment, grids and system flexibility, sustainable fuels, and energy efficiency improvements. It can also foster new partnerships with sectors such as transport, buildings, industry and urban development, recognising that the next phase of the transition will increasingly be driven by end-use transformation as much as by renewable power supply.

Therefore, the transition ahead is not simply about adding more clean energy capacity – important as that is; it is also about redesigning energy systems to be more resilient, efficient, secure and inclusive. This will require bold leadership, international solidarity and accelerated action across all sectors of the global economy. The decisions taken during this decade will shape the energy systems of the future and determine whether the world can still deliver on the promise of a sustainable, equitable and prosperous energy future for all.



KEY FINDINGS AND MILESTONES

1.5°C WETO
World Energy Transition Outlook

IRENA
International Renewable Energy Agency

The energy transition is entering a new phase; following the First Global Stocktake and the UAE Consensus at COP28, the challenge is now delivering implementation pathways capable of accelerating the transition away from fossil fuels while supporting energy security, competitiveness and sustainable development. The Roadmap for Transitioning Away from Fossil Fuels (TAFF), launched by the COP 30 Brazilian Presidency and supported by IRENA data and analysis, represents a key platform from which to shape a new pathway consistent with climate, energy security and development challenges.

Achieving a transition away from fossil fuels will require a multi-sector approach that combines policy, regulation, infrastructure, institutional reforms, finance and international co-operation. The world will need to change how it uses energy services as well as how it produces and transports energy. This requires renewable power generation capacity expansion; electrification of key end-use sectors (transport, industry, buildings); energy efficiency improvement; grid and storage expansion; and scaling up sustainable fuels.

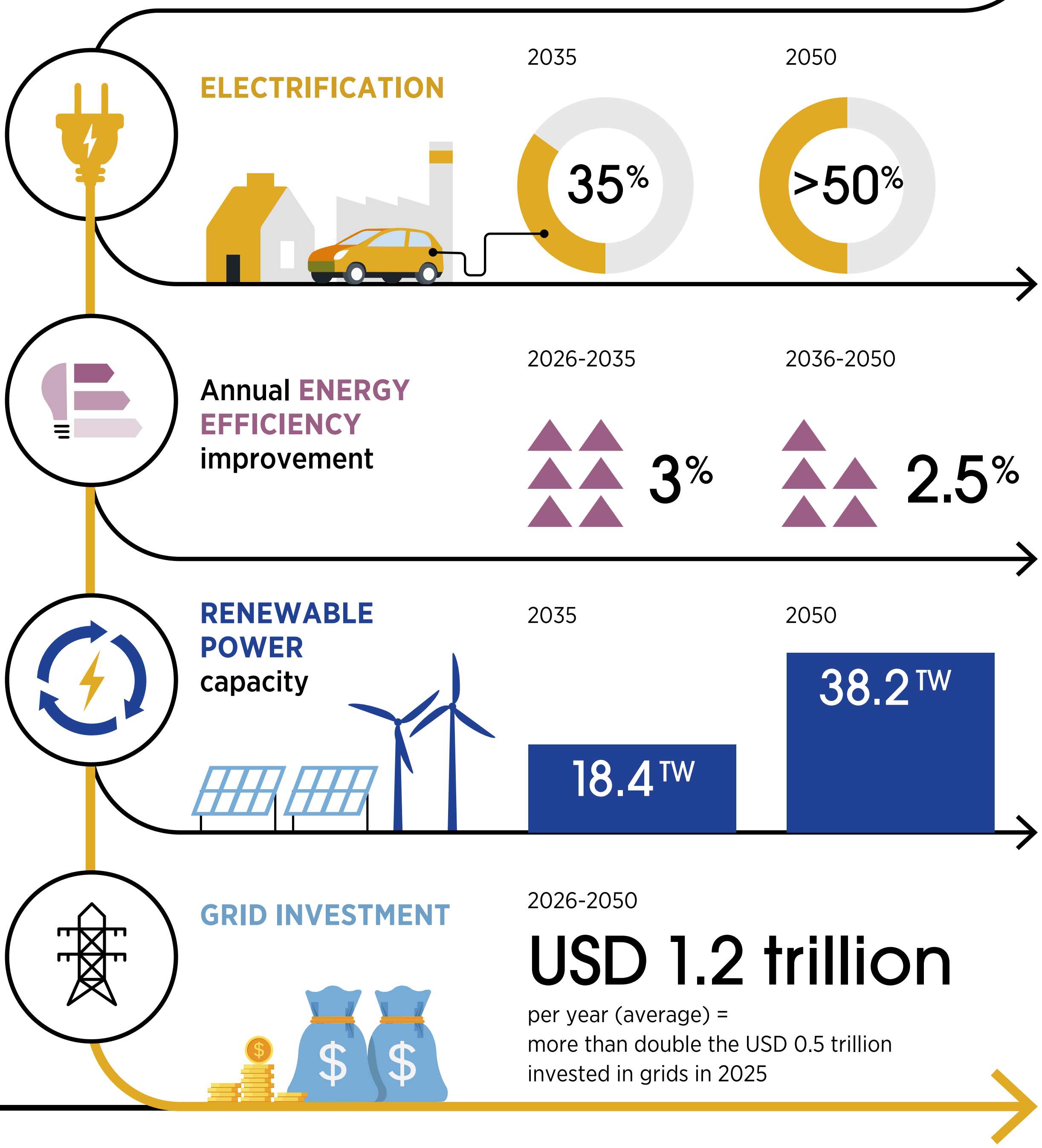
To remain on a 1.5°C-compatible pathway, electricity must account for 35% of global total final energy consumption (TFEC) by 2035 and more than 50% by 2050. Electrification will also foster energy efficiency and will require a global installed renewable power capacity of around 18.4 TW by 2035 and 38.2 TW in 2050.

Under IRENA's revised 1.5°C Scenario, electrification will be highest in buildings (reaching 55% of total final consumption in 2035 and more than 75% by 2050) followed by industry (around 35% in 2035 and more than 40% by 2050) and transport (15% by 2035 and over 45% by 2050).

To accommodate this rapid electrification, average annual global investment in grids must rise from USD 0.5 trillion in 2025 to around USD 1 trillion each year in 2026-2035 and USD 1.2 trillion in 2036-2050, to reach USD 29 trillion in cumulative investment. This must be complemented by an equally rapid growth in global installed storage capacity, from 416 GW in 2025 to 2 530 GW in 2035, and 6 859 GW by 2050. Grid expansion must be accompanied by greater demand-side flexibility, with daily flexibility rising from 7% in 2019 to more than 13% by 2035 and 30% by 2050.

The transition requires national and regional planning pathways, resource endowments and development priorities. Whilst electricity will become the dominant energy carrier in all sectors in the 1.5°C Scenario, sustainable fuels will still be needed to decarbonise end-use sectors, particularly in regions with competitive resources.

THE TRANSITION AWAY FROM FOSSIL FUELS



BEYOND CAPACITY: THE NEXT PHASE OF THE GLOBAL ENERGY TRANSITION

The global energy transition is entering a new phase, spurred on by geopolitical uncertainty and structural changes in the global energy landscape.

Lacklustre improvements in energy efficiency, combined with increasing demand for energy services and electricity across key sectors, are ramping up demand. The evolving infrastructure requirements of modern economies and communities – such as space cooling for data centres – have led to a further increase in electricity consumption. Efficiency improvements alone cannot offset this demand growth; and despite the progress achieved in renewable capacity expansion, the energy system remains ill-prepared to meet global climate targets.

The energy transition today also faces an even more turbulent environment, characterised by geopolitical tensions, growing market and price volatility, supply chain disruptions and rising energy security concerns that are influencing policy priorities and investment choices.

The world must adapt to this reality. Beyond the goal of tripling renewable capacity and doubling efficiency improvements lies a wider challenge that requires an integrated approach to address both increasing demand and structural system transformation.

The UAE Consensus – an ambitious negotiated response to the First Global Stocktake charting progress against the Paris Agreement that also called for a tripling of renewable power capacity and a doubling of the rate of energy efficiency improvement by 2030 – has already set a crucial foundation for the transition away from fossil fuels (IRENA *et al.*, 2025) (Box 1).

The Roadmap for Transitioning Away from Fossil Fuels (TAFF), launched by the COP 30 Brazilian Presidency and supported by IRENA data and analysis, represents a key platform from which to shape a new pathway consistent with climate, energy security and development challenges.

BOX 1

Tripling renewable power capacity and doubling energy efficiency improvement

The call to triple renewable energy capacity and double energy efficiency by 2030 is a central outcome of the First Global Stocktake at COP28 in the UAE, and part of the broader UAE Consensus. A total of 133 countries committed to a Pledge to expand global renewable power capacity by three times and double the global average annual rate of energy efficiency improvement by 2030, while all Parties to the United Nations Framework Convention on Climate Change (UNFCCC) were called upon to contribute to this effort in the negotiated outcome text. This dual goal is essential to keep the 1.5°C climate target within reach, while also supporting energy security, reducing exposure to fossil fuel price volatility, improving public health and creating jobs and local economic value (COP28 Presidency *et al.,* 2023).

As the custodian agency for monitoring progress toward these goals, IRENA has found that progress is encouraging, but does not meet the pace required (IRENA *et al.,* 2025). Renewable capacity must reach more than 11 terawatts (TW) by 2030. In 2025, additions reached 692 gigawatts (GW), with solar photovoltaic dominating (around 510 GW), while about 159 GW of wind power capacity was added. However, most other technologies lag far below required growth rates. Moreover, from a geographic perspective, deployment of renewables is also uneven, with more than 79.5% of installed capacity concentrated in China, the United States and the European union (IRENA, 2026a). Energy efficiency improvements are also lagging: global energy intensity improved by only around 1% in 2023–2024, far below the 4% annual target, meaning at least a 5% annual improvement is required each year to 2030 (IRENA *et al.,* 2025).

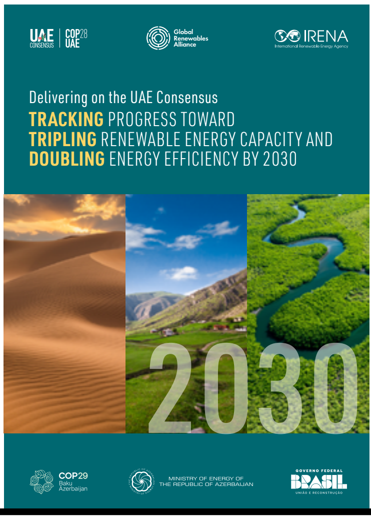
IRENA highlights several priority actions for policy makers: governments should strengthen supply chains through sustainable sourcing, international co-operation and targeted industrial policies, while embedding clear renewable and energy efficiency targets into national climate plans backed by investment strategies. Regulatory frameworks must reduce risk through tools like long-term contracts, transparent standards and simplified permitting, alongside safeguards for social equity and community engagement. Expanding workforce skills – especially through training, education and inclusion of women and underrepresented groups – is critical to sustain growth. Infrastructure must be rapidly upgraded, including grids, storage and system flexibility, supported by faster approval processes and digitalisation. Finally, scaling up international finance is essential: developed countries should deliver and exceed current funding commitments, improve access to concessional finance, and direct more resources toward developing economies to ensure a fair and globally balanced energy transition (IRENA *et al.,* 2025).

BOX 2

Global Energy Storage and Grids pledge

The COP29 Presidency Action Agenda introduced a global pledge to accelerate renewable energy deployment while ensuring systems remain reliable and sustainable. A key initiative on global energy storage and grids set clear, measurable targets: increasing global energy storage capacity to 1500 gigawatts (GW) by 2030 and expanding or refurbishing more than 80 million kilometres (km) of transmission lines by 2040. These goals reflect the growing need to match rapid renewable energy growth with adequate storage and grid infrastructure. Together, they aim to boost energy productivity, strengthen system resilience, and support the transition to low-emission energy systems (COP29, 2024; IRENA *et al.,* 2024).

IRENA's latest report monitoring progress toward the UAE consensus goals showed strong progress, particularly in energy storage. Battery storage costs have dropped dramatically, from US dollars 2 571 per kilowatt-hour (USD/kWh) in 2010 to just USD 192/kWh in 2024, a 93% decline, driving rapid deployment. In 2024 alone, 74 GW of battery storage was added globally, nearly double the previous year, with China, the United States and Europe accounting for about 85% of new capacity, while total investment reached a record of USD 54 billion (+33% year-on-year). However, to align with a 1.5°C pathway, battery capacity must grow from 164 GW in 2024 to between 360–900 GW by 2030, alongside pumped hydro expansion to 320 GW (*i.e.* 28 GW annually). On grids, progress is slower: investment grew only 9% in 2024, far below what is needed, as global grid spending must nearly double by 2030 to support renewable integration and system reliability (IRENA *et al.,* 2024).



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The COP 29 Global Energy Storage and Grids Pledge identified the essential roles of energy storage and grid infrastructure in developing resilient, decarbonised global energy systems (Box 2). Later in 2025, the Belém Commitment for Sustainable Fuels (Belém 4x) was launched by Brazil during Pre-COP in Brasília (Box 3).

Yet the global energy transition will require concerted action to not only transform the supply and consumption of energy worldwide, but also to deliver infrastructure – grids, roads, ports, airports, supply hubs; evolve supply chains; and re-shape market designs and policies.

BOX 3

The Belém Commitment for Sustainable Fuels

The Belém Commitment for Sustainable Fuels (Belém 4x), launched by Brazil during Pre-COP proceedings in Brasília, places sustainable fuels at the centre of the global energy transition. The initiative aims to build strong political momentum to quadruple the production and use of sustainable fuels by 2035. It promotes solutions such as hydrogen and its derivatives, biofuels, biogases and synthetic fuels as practical alternatives to fossil fuels. These fuels can play a key role in reducing emissions, improving energy security and supporting economic development across regions (COP30, 2025).

To inform this effort, IRENA contributed research on Brazil's biofuel industry ahead of the Conference for the COP30 Activation Groups (IRENA, 2025a), showing that under the Agency's World Energy Transition Outlook analysis, sustainable bioenergy should reach at least 15% of global final energy consumption by 2050 – about three times current levels. Brazil has already demonstrated strong progress, with around 25% of its final energy consumption coming from biomass, contributing to the 50% share of renewable energy in the country's primary energy mix, demonstrating that scaling sustainable fuels is achievable with the right environment, policies and investments (IRENA, 2025a).

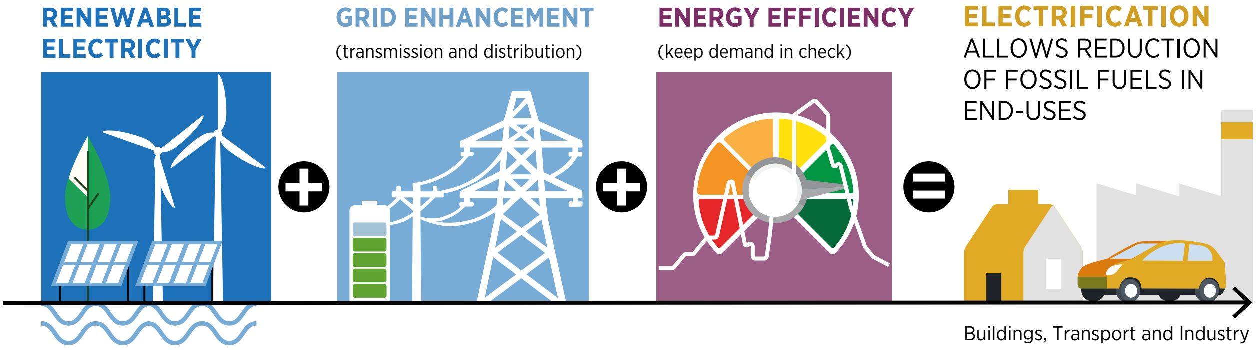
The report concludes that clear and stable policy frameworks are essential to attract investment and guide market growth, supported by co-ordination across energy, transport, agriculture and industry. It also emphasises the need for strong sustainability standards and certification systems to ensure environmental and social integrity. Beyond climate benefits, sustainable fuels can drive job creation, local development and more resilient supply chains. Brazil's experience shows that tools such as blending mandates, tax incentives and carbon markets can be effective, while international co-operation will be key to share knowledge, align standards, and mobilise finance at scale (IRENA, 2025a).

ACCELERATING THE TRANSITION AWAY FROM FOSSIL FUELS

The COP28 UAE Consensus marked a turning point in the global energy transition by calling on Parties to contribute to global efforts to transition away from fossil fuels in energy systems, in a just, orderly and equitable manner, accelerating action in this critical decade (UNFCCC, 2023a, 2023b). This underpins the political basis of the transition away from fossil fuels as a systemic change, not a mitigation measure, requiring deep cuts in emissions, scaled-up finance and increased international co-operation.

Global ambition must translate into practical pathways that reduce fossil fuel use across both energy supply and end-use sectors. This requires aligning trajectories renewable energy expansion, energy efficiency improvements, electrification and sustainable fuels, supported by enabling infrastructure, including grids, storage and system flexibility. It also requires differentiated national and regional roadmaps that reflect countries' development priorities, resource endowments, institutional capacities and economic conditions. In this context, electrification, supported by renewables and efficiency, becomes a central lever to move from negotiated commitments to implementation, enabling a structural decline in fossil fuel demand while strengthening energy security, affordability and shared prosperity.

THE TRANSITION AWAY FROM FOSSIL FUELS

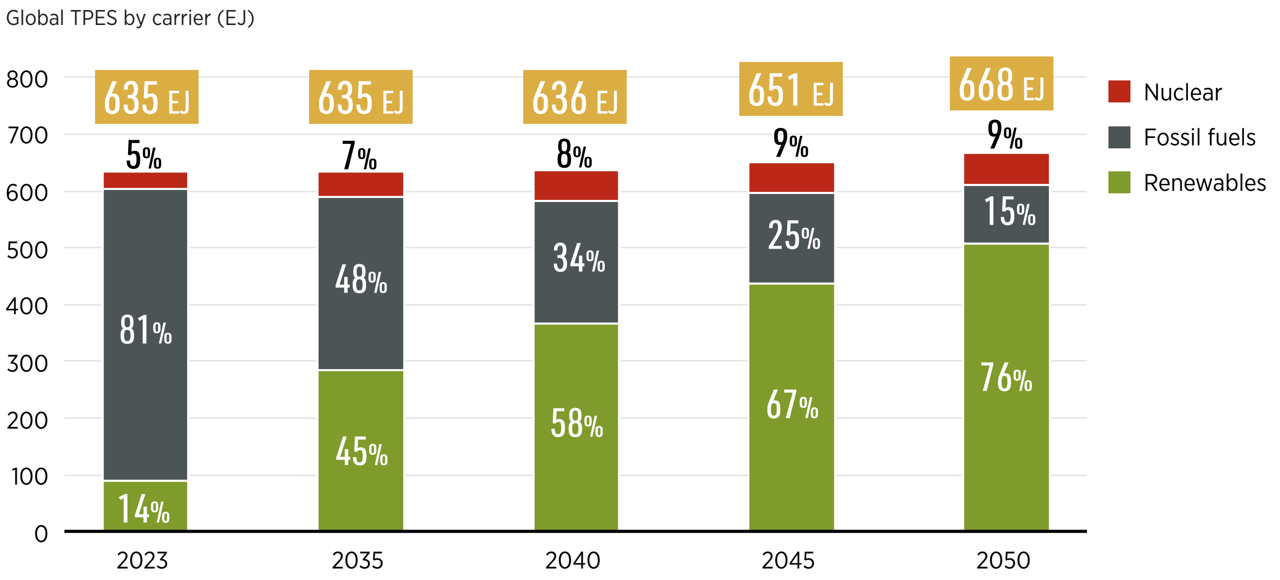


A structural decline in fossil fuel demand across sectors

According to IRENA's analysis in the forthcoming 2026 edition of the World Energy Transition Outlook, fossil fuels accounted for over 80% of total primary energy supply (TPES) in 2023, while renewables accounted only for 14% (Figure 1). Fossil fuels met over 60% of total final energy consumption (TFEC), followed by electricity, at almost 25% (Figure 2).

Following the aggregation of regional studies and a granular modelling of major economies, the revised IRENA 1.5°C Scenario sees the share of fossil fuels decreasing slightly in end-use sectors in the short term (2030), with an increase in electrification and electricity demand growth mostly met by renewables. In the long term, a major reduction in the proportion of fossil fuels is achieved under the revised scenario, with a share of 20% or less in final energy consumption.

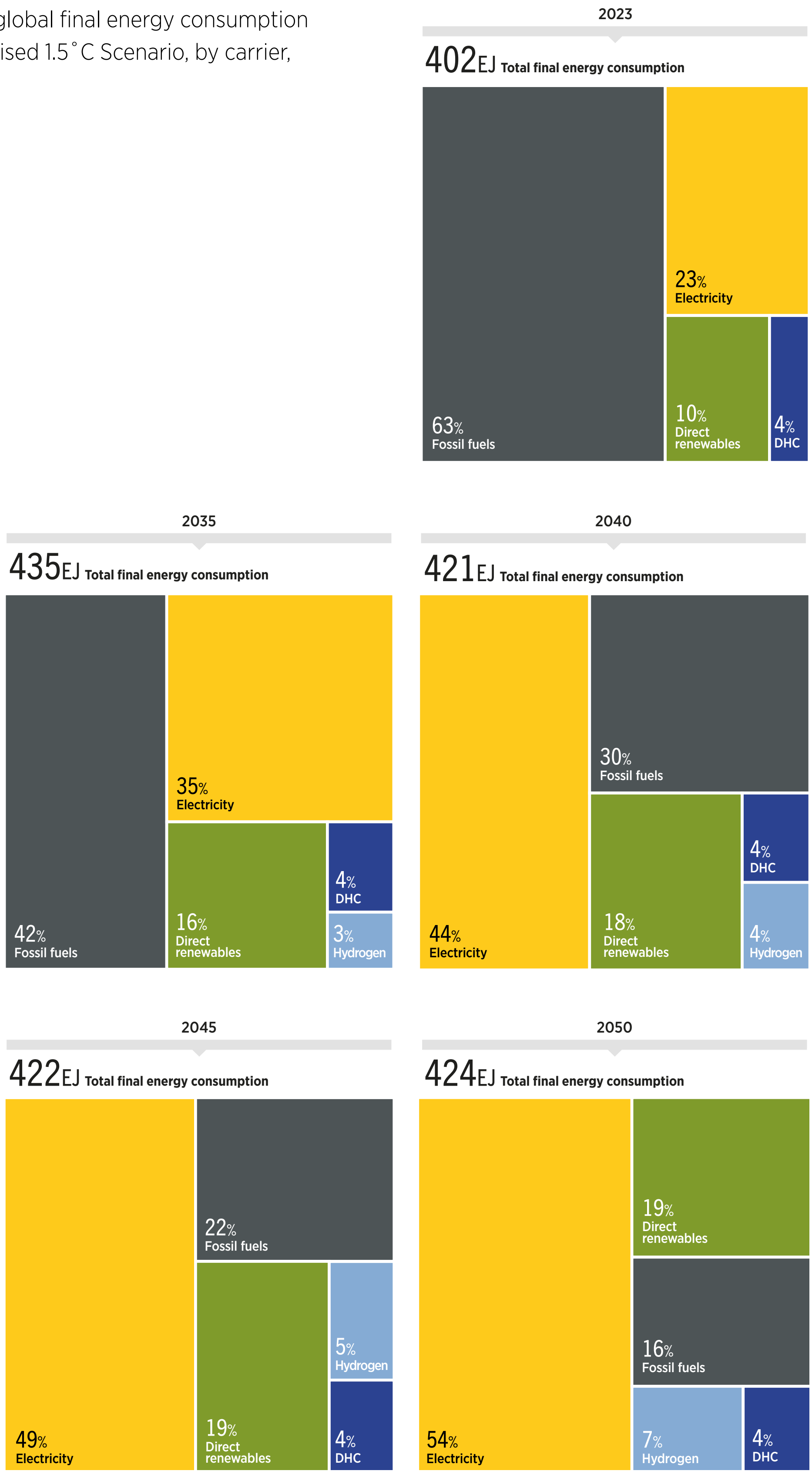
FIGURE 1: Global primary energy supply under the revised 1.5°C Scenario, by carrier, 2023–2050.



Source: (IRENA, Forthcoming a).

Notes: EJ = exajoules; TPES=Total primary energy supply; "renewables" include bioenergy, variable renewables (solar, wind) and others (hydro, geothermal, solar thermal); "fossil fuels" include oil derivatives, coal and natural gas; Maritime and aviation bunkers are included at the global level.

FIGURE 2: Evolution of global final energy consumption under the revised 1.5°C Scenario, by carrier, 2023–2050.



Source: (IRENA, Forthcoming a).

Notes: EJ = exajoules; "fossil fuels" include oil derivatives, coal and natural gas; "direct renewables" = direct uses of renewable energy (solar thermal, geothermal); "DHC" = district heating and cooling; "hydrogen" refers to clean hydrogen (blue, green) and derivatives; Maritime and aviation bunkers are included at the global level; values of "non-energy" uses are not included.

The speed at which this fossil-fuel transition occurs will primarily be dictated by structural changes in energy demand. Electrification speeds up this transition in all major end-use sectors:

- In **transport**, electric vehicle (EV) uptake reduces reliance on oil products and reshapes demand patterns for fuels.
- In **buildings**, electrified heating and appliances reduce the use of gas, coal and traditional biomass.
- In **industry**, low- and medium-temperature processes can be electrified directly or indirectly via green hydrogen, which allows the gradual replacement of fossil fuels.

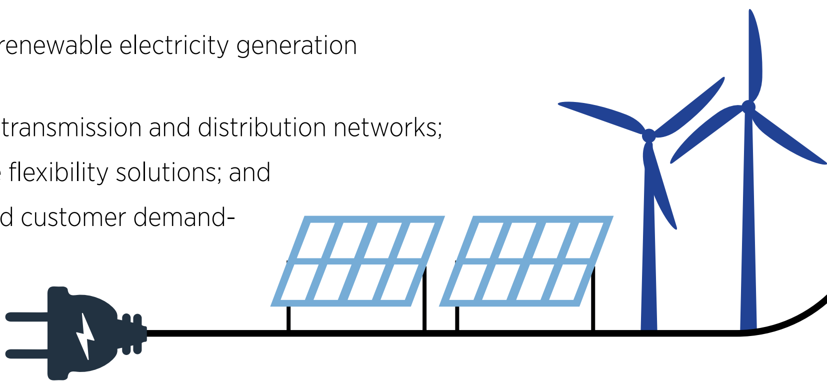
These transitions are amplified by improvements in energy efficiency, which cumulatively lower total energy demand and further limit fossil fuel consumption.

Consequently, electrification represents a crucial demand-side lever that, by gradually replacing direct fossil fuel use, leads to long-term structural decline in their role in the energy system.

Transforming the power sector: From fossil-based generation to renewable-based systems

Electrification is effective for reducing emissions and fossil fuel use only if the power sector undergoes a corresponding transformation. As electricity demand increases, electrical systems must quickly evolve to optimally and reliably schedule renewable resources by combining different flexibility solutions such as storage and interconnections. To avoid simply displacing emissions from end-use sectors to the power sector (rather than eliminating them) will therefore require:

- fast-tracking the deployment of renewable electricity generation technologies;
- modernisation and expansion of transmission and distribution networks;
- scaling up of system and storage flexibility solutions; and
- digital technology integration and customer demand-side management.



Managing residual fossil fuel use and enabling alternative pathways

While both electrification and sustainable fuels will act as accelerators of the energy transition, some fossil fuel use may still continue, particularly where both direct electrification and sustainable fuels cannot be promptly scaled up, such as:

- aviation and shipping;
- some industrial processes such as cement and steel production; and
- some applications in the power system, where dispatchable capacity could still be needed during transitional phases.

In these sectors, the transition away from fossil fuels in each region will require careful calculation of the proportion of renewable generation in the energy mix, reflecting renewable resource availability and economics as well as the availability of sustainable fuels in each region or country – such as sustainable bioenergy or clean hydrogen and its derivatives. The acceleration of these solutions will be crucial for dealing with residual emissions while ensuring continuity of essential economic activities.

Implications for infrastructure, investment and global energy systems

Transitioning away from fossil fuel means a complete restructuring of energy infrastructure and investment allocation. Planning is required for the phasing out, repurposing or retrofitting of existing fossil fuel assets – such as power plants, refineries and transport infrastructure – and significant investments will be needed in key areas, including:

- renewable power generation;
- electricity networks and interconnections;
- storage and system flexibility (Box 2 above);
- electrification of end-use technologies and their enabling infrastructure (*e.g.* EV charging, building retrofits and construction for electric heating, cooling and industrial electrification); and hydrogen and alternative fuels supply chains.

With declining demand for oil and gas, new patterns of trade will emerge around electricity, hydrogen, energy-intensive products, and strategic and critical materials for transition-related technologies. Those nations that rely on fossil fuel exports will face both challenges and opportunities in formulating strategies around economic diversification and engagement in emerging clean energy value chains.

Policy frameworks to enable an orderly and just transition

A transition away from fossil fuels at the necessary speed and scale will be put on the right track with credible, consistent policy signals, but must also be rooted in strategies that adequately reflect national and regional conditions (IRENA, 2022, 2025b, 2025c, Forthcoming b; IRENA and ACE, 2022). These roadmaps need to account for differences in institutional capacities, resource endowments and economic structures, while enabling the transition to be orderly, just, equitable and secure. Therefore, key policy priorities include:

- **Gradually eliminating fossil fuel subsidies** and aligning price signals with transition goals through transparent fuel pricing, and by integrating the cost of carbon and other externalities in energy pricing to ensure socially acceptable transition pathways.
- **Establishing regulatory frameworks and timelines to phase-down fossil fuel use**, strategically and progressively, in order to provide long-term planning certainty while maintaining system reliability and cost-efficiency during the transition.
- **Incentives and standards for electrification**, and the deployment of related technologies, supported by robust supply chains and quality compliance frameworks.
- **Mobilisation of investments in renewable energy, and enabling infrastructure such as grids, storage and system flexibility**, via de-risking instruments to attract private capital at scale, but also concessional finance, grants and innovative financial mechanisms to support developing countries.
- **Ensuring just transition measures and policies** for affected workers, communities and regions, including re-skilling programmes, social protection and economic diversification strategies.
- **Market design improvements** in order to better integrate variable renewable energy (VRE), enable flexibility services and incentivise efficient system operation.
- **Fiscal and tax reforms**, including the redesign of revenue structures and the introduction of transition-aligned taxation mechanisms for long-term sustainability.
- **Strengthening education, skills development and institutional capacity** in order to provide workforce and public institutions with the required capabilities.
- **Research and development, and technology transfer policies** to speed up innovation, reduce costs and support the broader transfer and diffusion of clean energy technologies.

Policy coherence across sectors and the various levels of governance will be key to ensuring harmony between renewable deployment, electrification and the transition away from fossil fuels, and their suitability for national or regional circumstances.

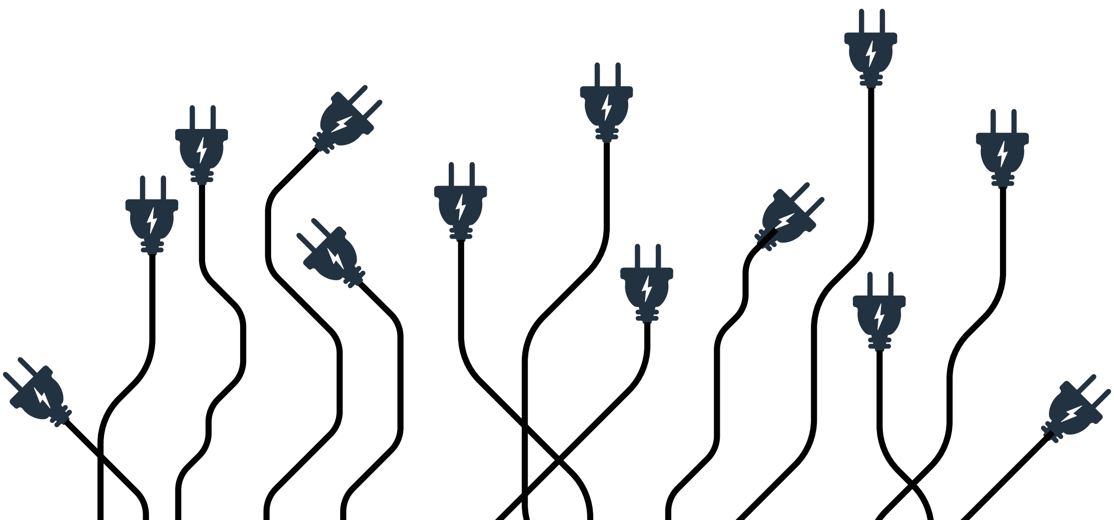
ELECTRIFICATION AND GRID INFRASTRUCTURE IN THE GLOBAL ENERGY TRANSITION

Electrification as a driver of energy security, competitiveness and climate goals

Energy systems exist to deliver energy services such as heating, cooling, mobility, lighting, cooking and power for industrial production and transportation – all of which are critical for economic activity and human welfare. 'Electrification' refers to the provision of these services using technologies powered by electricity, rather than directly by combustion-based fuels.

Electric technologies often provide the same energy service with higher efficiency than their combustion-based counterparts by avoiding conversion losses (Alam et al., 2026; Bisht *et al.*, 2024; Fotiou, Fragkos and Zisarou, 2024; Patel et al., 2026; Rodrigue *et al.*, 2022; Su *et al.*, 2021; Vissa and Sekhar, 2025). This means that, with careful planning, electrification can decrease primary energy demand while lowering emissions and improving system performance.

When powered by renewables, electrification accelerates the reduction of greenhouse gas (GHG) emissions across end-use sectors while increasing energy efficiency and decreasing dependence on fossil fuels. If combined with energy efficiency improvements, electrification could represent about one-third of the cumulative carbon dioxide (CO_2) emissions reduction over the period 2026–2050, avoiding around 110 gigatonnes ($GtCO_2$) according to IRENA's World Energy Transition Outlook analysis.



Electrification represents a reliable long-term solution across a broad set of energy transition scenarios – a "no-regret" option on the path to decarbonisation and enhanced system efficiency that also underpins wider economic and social goals.

The falling costs of renewable energy technologies have significantly increased the viability of clean electricity. Solar and wind power have become two of the most cost-competitive sources of new electricity generation in many regions, with costs declining by more than 88% for solar PV and 56% for onshore wind over the 2010–2025 period, allowing clean electricity to account for a larger share in satisfying final energy demand.

Electrification with renewables serves multiple policy goals simultaneously: it contributes to climate mitigation by cutting emissions; enhances energy security and resilience by boosting independence from imported fossil fuels while improving uptake of renewables and reducing curtailment; and bolsters economic competitiveness through the creation of new industrial value chains and technological innovation. Furthermore, the cost-competitiveness of renewable technologies could guarantee lower and more stable electricity prices, which would improve long-term affordability for households and industry.

Many electric technologies are mature and widely available. Well-established manufacturing ecosystems and fast-growing global markets support electric vehicles, heat pumps, electric cooking technologies and electrified industrial processes.

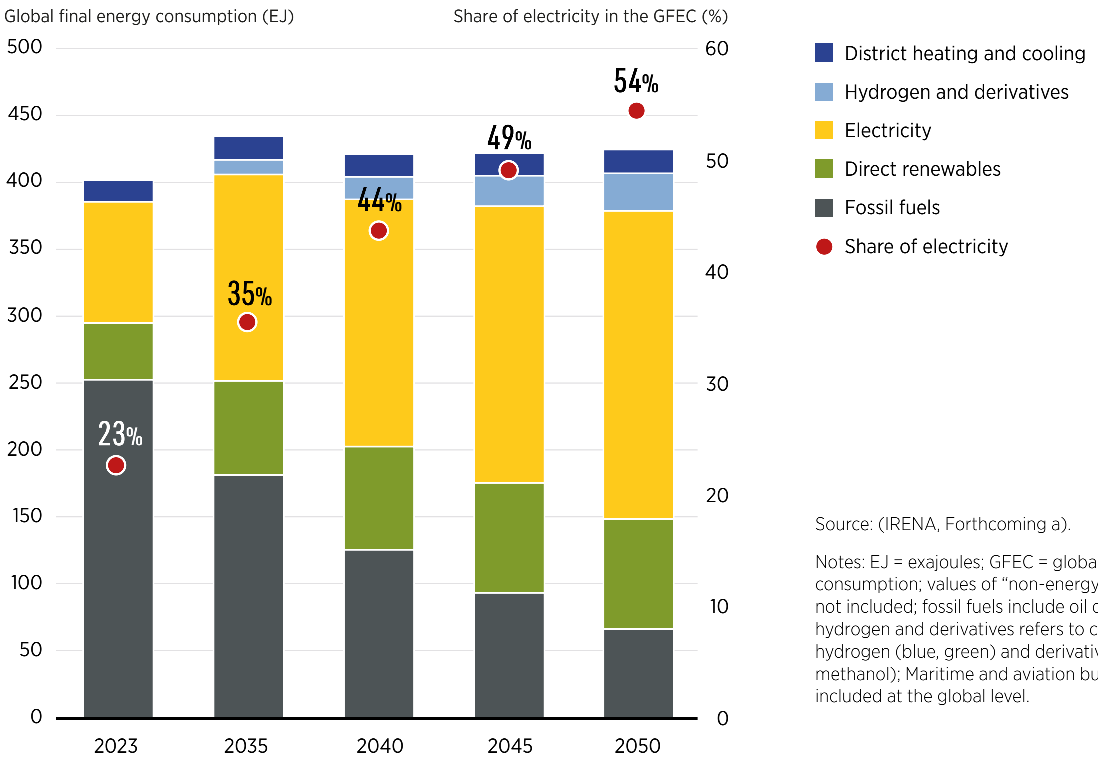
Electrification complements and reinforces renewable energy deployment and energy efficiency improvements. Global efforts to triple renewable power capacity and double the improvement rate of energy efficiency provide a foundation from which to ramp up the electrification of end-use sectors.

Electrification can play an important role in ensuring a just and inclusive energy transition that supports sustainable development. Electrification significantly enhances welfare, quality of life and economic opportunities across advanced, emerging and developing economies. Off-grid electrification with renewables has helped millions of people in remote areas to gain access. In all settings, electrification reduces energy costs while allowing access to modern energy services, making households and cities more sustainable, as well facilitating progressively sustainable industrialisation. Electrification also offers significant environmental and health co-benefits by reducing air pollution, especially in urban areas and those in which traditional cooking methods are prevalent. It also has a role in lowering carbon emissions from inefficient biomass use and methane emissions associated with natural gas systems; and in the transport sector, it has the potential to significantly reduce noise pollution.

ELECTRIFICATION AT THE CORE OF THE GLOBAL ENERGY TRANSITION

IRENA's revised 1.5°C Scenario envisages a significant increase in the role of electricity in the global energy system. Under the scenario, the share of electricity in global final energy consumption[1] would rise from around 23% today to 35% in 2035, and above 50% in 2050, making electricity the dominant energy carrier in the global energy system (Figure 3).

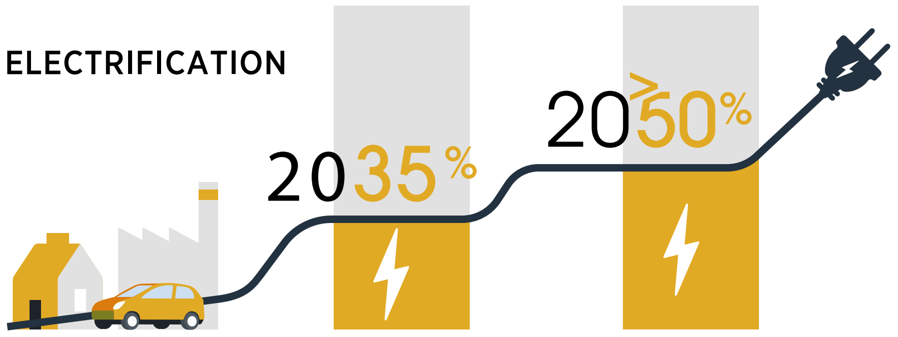
FIGURE 3: Evolution of the global final energy consumption (left axis) and the global electrification rate (in %) (right axis) under the revised 1.5°C Scenario, by carrier, 2023-2050.



Source: (IRENA, Forthcoming a).

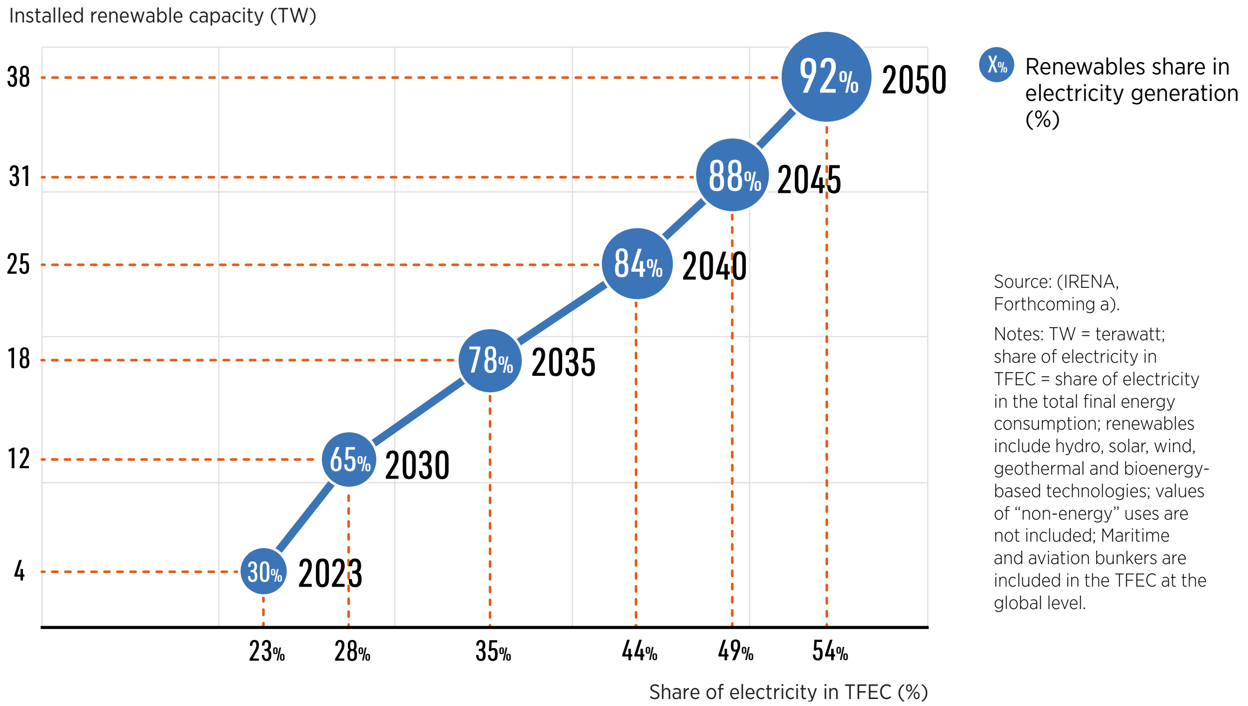
Notes: EJ = exajoules; GFEC = global final energy consumption; values of "non-energy" uses are not included; fossil fuels include oil derivatives, hydrogen and derivatives refers to clean hydrogen (blue, green) and derivatives (ammonia, methanol); Maritime and aviation bunkers are included at the global level.

1 The terms "electrification rate" and "share of electricity in final energy consumption" are used interchangeably throughout this brief.



The trajectory in Figure 4 illustrates the complementary growth needed under IRENA's revised 1.5 °C Scenario in electrification rate, renewable share in electricity generation and renewable power capacity expansion. These dimensions must evolve together – alongside grids, storage and flexibility measures, and planing for the strategic phase-out of fossil fuel infrastructure – to enable a reliable and large-scale transition away from fossil fuels.

FIGURE 4. The energy transition to 2050 under the revised 1.5 °C Scenario, 2023-2050



Source: (IRENA, Forthcoming a).

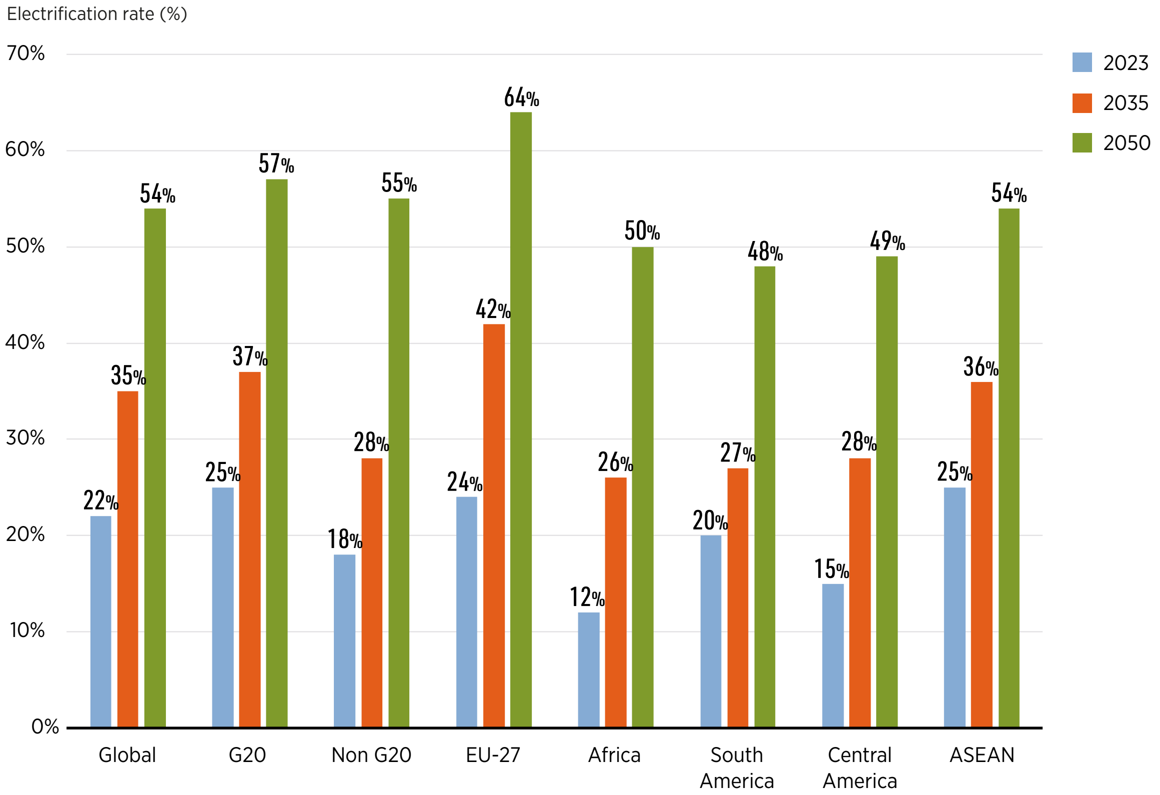
Notes: TW = terawatt; share of electricity in TFEC = share of electricity in the total final energy consumption; renewables include hydro, solar, wind, geothermal and bioenergy-based technologies; values of "non-energy" uses are not included; Maritime and aviation bunkers are included in the TFEC at the global level.

In advanced economies, electrification is mainly a function of the substitution of fossil-based technologies, as well as efficient use of energy in buildings, industry and transport. In emerging and developing economies, electrification is closely associated with expanding access to modern energy services, sustainable industrialisation, and meeting the growing demand for energy for infrastructure development and the expansion of modern urban habitats (Box 4).

BOX 4 Regional disparities in electrification

Electrification pathways will differ between regions, reflecting disparities in the structures of their respective economies and patterns of energy demand, as well as in their development, resource availability and level of energy access.

FIGURE 5: Evolution of the electrification rate in selected regions, 2023, 2035 and 2050



Source: (IRENA, Forthcoming a).

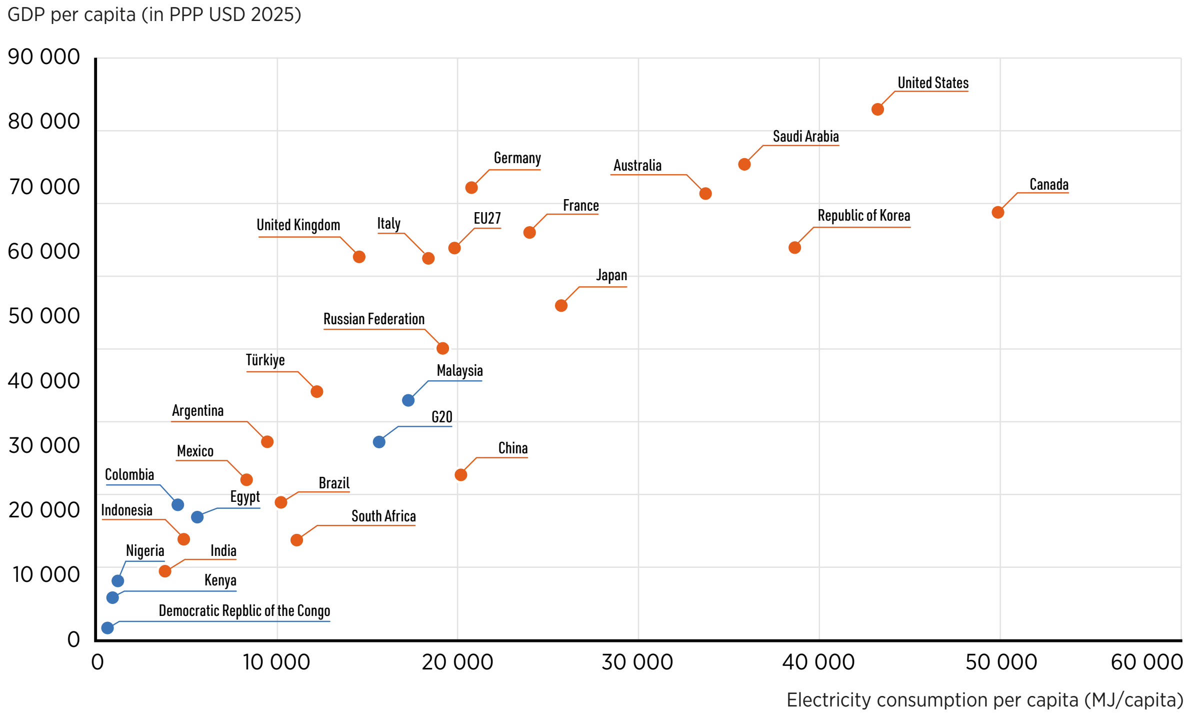
Notes: ASEAN = the Association of Southeast Asian Nations; EU = European Union; G20 = the Group of 20, excluding the African Union; Total final energy consumption excludes international marine and aviation bunkers, except at global level.

Electrification comprises 25–30% of TFEC in advanced economies today but rises to 40% or more by 2035 in the revised 1.5°C Scenario (IRENA, Forthcoming a). In several developing regions, however, the rate may well remain below 30%, owing to a variety of factors including lower levels of electricity access; infrastructure limitations; other direct use of renewables including biomass fuelling the energy mix, *etc.* Indeed, the goal of low fossil-fuel use and high electrification powered by renewables may not be achievable everywhere – it will depend on resource endowment, system size, grid status, investment capacity, *etc.* In such cases, regional electricity trade and stronger interconnections can provide a crucial enabler by allowing countries to overcome structural constraints, deploy resources in the most efficient way possible, use renewable resources optimally, enhance system efficiency and thereby enabling higher electrification levels at the regional level.

Nevertheless, electricity is projected to become a central energy carrier in all regions by 2050, meeting around 55% of final energy consumption in both G20 and non-G20 countries (IRENA, Forthcoming a). The 1.5°C Scenario sees electricity constituting the predominant energy vector in the EU-27, meeting 64% of final consumption. In Africa, the share increases to almost 50%, as access grows and economies expand, supported by a progressive transition away from traditional biomass use toward modern and cleaner bioenergy. South and Central America would also reach similar levels through further electrification of end-uses, including transport and new demand from green hydrogen. In the ASEAN, electricity will represent around 53% of final energy use, as electrification expands across cooling, transport and industry. In North Africa, electrification grows to meet around 30% of TFEC, as momentum gains in the buildings sector, propelled by growing demand for space cooling and urbanisation.

Countries must tailor their electrification strategies to align with their own economic structures, energy resources and policy goals. For those within clusters characterised by comparable levels of electricity consumption per capita or GDP per capita may benefit from common policy action and collaboration (Figure 6).

FIGURE 6: Per capita electricity consumption versus GDP per capita; selected countries and regions, 2023

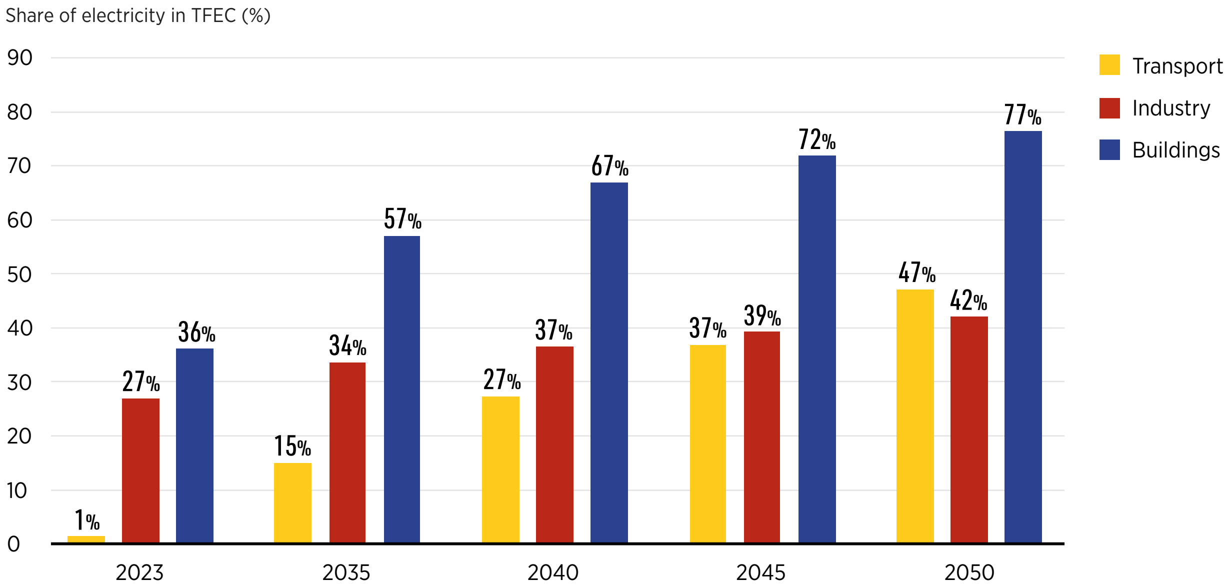


Sources: (UN, 2024; World Bank, n.d.).

Notes: GDP = gross domestic product; MJ = megajoules; PPP = purchasing power parity.

Electrification is highest in **buildings**, reaching 55% in 2035 and more than 75% by 2050 (Figure 7) owing to the use of electric heat pumps and appliances instead of fossil-based heating in new buildings, as well as the rapid growth in electricity demand for space cooling, data centres, and the electrification of cooking and water heating, all coupled with efficiency improvements. Under the Scenario, **industry** experiences a growth in electrification to reach around 35% in 2035 and more than 40% by 2050 for the provision of low- and medium-temperature heat, alongside indirect electrification through use of green hydrogen in hard-to-abate sub-sectors that require stronger incentives and investment. The fastest relative growth would be observed in **transport**, increasing from 1% today to 15% in 2035 and over 45% by 2050 through transport electrification across light-duty vehicles and buses. Electrification would become the dominant energy carrier in all sectors, but sustainable fuels will still be needed for as yet hard-to-electrify applications such as aviation.

FIGURE 7: Evolution of global electrification rate in the revised 1.5°C Scenario, by sector, 2023–2050



Source: (IRENA, Forthcoming a)

Notes: TFEC = total final energy consumption; Maritime and aviation bunkers are included in the total final energy consumption at the global level.

Electrification therefore presents a win-win opportunity for countries and regions across the development spectrum. The multiple electrification pathways available will enable broad international exchanges of best practices – an outcome that can be encouraged by global action to support differentiated approaches to electrification as a pillar of a just, inclusive and sustainable energy transition.

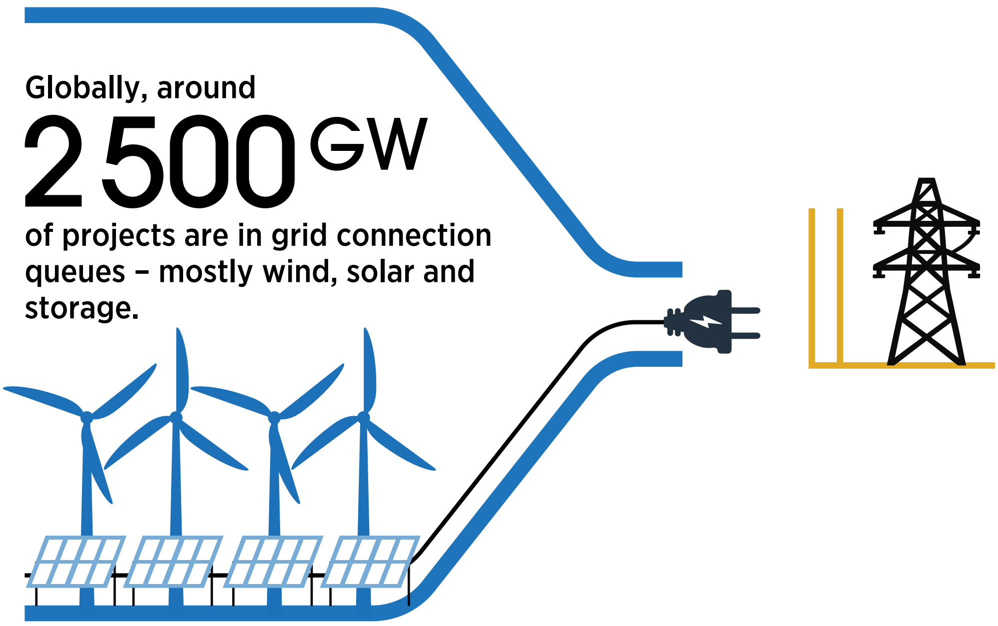
As energy systems continue to be electrified, the transition from fuel-based systems will demand resilient grid infrastructure as well as flexibility solutions to ensure system reliability and efficiency. This electrification must be planned strategically; new electric loads should be as flexible as possible to respond to system needs, thereby also helping to accommodate higher shares of variable renewables rather than adding to peak stress.

Grids

Increasing electrification will raise electricity demand, which in turn will require more infrastructure. Electricity demand and generation will also become more variable and more weather dependent. Addressing these challenges requires a structural transformation of power systems, centred on enhanced flexibility of supply and demand, and stronger grid infrastructure. Co-ordinated planning, advanced digital monitoring and AI-driven analytics (albeit their application is nuanced) are required.

In many regions, grid infrastructure and flexibility has already become a critical bottleneck. Globally, around 2 500 gigawatts (GW) of projects are currently in grid connection queues, consisting mostly of wind, solar and storage capacity (IEA, 2026). The pace and scale of grid expansion by 2035 and 2050 will require consistent long-term planning and will not be achieved without fast-tracked permitting and scaled-up investment.

Conditions and priorities differ sharply across regions: in the European Union, where power markets are deeply connected, demand growth and renewables expansion are critically dependent on accelerated grid buildout to absorb almost double the current installed capacity of wind and solar by 2030 (IRENA, 2025b). In South America, strengthened cross-border grid integration and interconnection are identified as essential enablers for the region's potential to reach 90+% renewable electricity by 2050 (IRENA, 2025c). In small islands developing states (SIDS) and across much of Africa and Asia, the priority is not simply grid



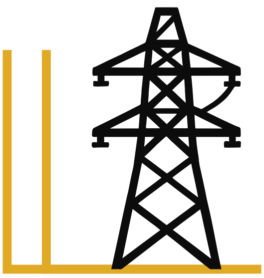
enhancement but integrated planning from the outset, combining centralised generation expansion with distributed solutions to leapfrog legacy infrastructure and deliver resilient, low carbon power systems.

Without proportional grid investment, electrification risks increased curtailment, network congestion, and higher costs or reliability problems. Grids need to simultaneously accommodate rising demand and new renewable connections, and the costs of poor co-ordination will only grow as electrification deepens across daily life and economic activity. Grid expansion and reinforcement is therefore an essential prerequisite, and must keep pace with renewables growth.

A key structural challenge lies in the mismatch between deployment timelines: renewable generation projects can be developed relatively quickly, whereas grid infrastructure typically requires significantly longer planning, permitting and construction periods. This necessitates different approaches to address the mismatch across different time horizons. In the long term, grid infrastructure should be planned and deployed in a more integrated way, aligning timelines of generation and electrification targets with network development. Anticipatory investments will also help system operators navigate associated challenges.

Alongside accelerating grid infrastructure expansion, it is equally critical to optimise the use of existing grids. Technology and operational measures such as grid-forming solutions and grid enhancing technologies,[2] are some of the solutions that can contribute to unlocking untapped grid capacity and reliability, mitigating at least some of the immediate need for expansion.

Recent international initiatives reflect the growing focus on grids and flexibility. The COP 29 Presidency's Global Energy Storage and Grids Pledge called for an additional 25 million km of grids, coupled with a target to reach 1500 GW of storage capacity, both by 2030. To remain on the 1.5°C pathway, IRENA estimates a total of USD 5.5 trillion in investments for power grids and energy flexibility is required between 2026 and 2030. In parallel, power system flexibility needs (the amount of electricity that will need to be delivered by flexible sources) are projected to increase significantly – global daily flexibility needs are projected to increase by up to ten times by 2050 compared to current levels (Table 1) (IRENA, 2026b).



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2 As well as battery storage, dynamic aline rating, reconductoring, virtual power plants (VPPs), smart charging technologies and digitalisation with enhanced use of data and data sharing.

TABLE 1: Evolution of global grids, storage and flexibility indicators in the revised 1.5°C Scenario

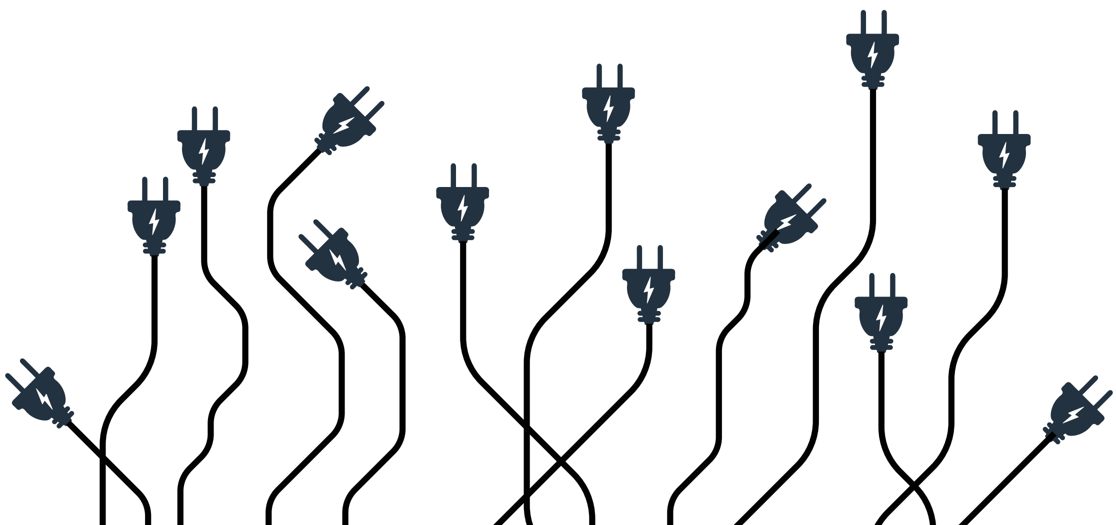
	Recent years	2035	2050
Annual average grid investments	**USD 0.5 trillion per year** [1]	**USD 1 trillion per year** [2]	**USD 1.2 trillion per year** [2]
Installed storage capacity[3]	**416 GW** [4]	**2 530 GW**	**6 859 GW**
Approximate flexibility needs (% of overall electricity demand)			
Daily	**7%** [5]	**13%** [6]	**30%**
Weekly	**2%** [5]	**4%** [6]	**6%**
Monthly	**2%** [5]	**2%** [6]	**4%**

Sources: (BNEF, 2025, 2026; IRENA, 2026a, 2026b, Forthcoming a).

Notes: GW = gigawatt; [1] Data refer to recent year available, 2025; [2] annual average investments required under the revised 1.5°C Scenario during the periods 2026-2035 and 2036-2050 are shown in the investments row under 2035 and 2050, respectively; [3] including battery, pumped hydropower and long-duration energy storage (LDES); [4] data refer to recent year available, 2025; [5] data correspond to 2019; [6] for the approximate flexibility needs, the value shown under 2035 reflects 2030.

Delivering resilient and robust grids to support the energy transition is a monumental undertaking. To support the rapid electrification of transport, heating and industry, transmission and distribution grids must become dynamic, flexible, intelligent/smart and significantly larger. They will need to manage complex, multi-directional energy flows across vast areas, in addition to monitoring and controlling high shares of distributed energy resources.

Grids are the essential link between new clean generation and electrified energy users, enabling low-carbon electricity to be delivered reliably and cost efficiently. Without a robust grid, the clean energy generated cannot reach end-users. This expansion needs to go hand-in-hand with demand flexibility, electrification that is not designed to be flexible risks undermining the system it depends on. Consequently, the sheer scale of this physical transformation demands a radical shift in capital allocation, elevating grids to the very centre of global climate finance, with up to USD 29 trillion of investment being needed by 2050.



TARGETS FOR GLOBAL ELECTRIFICATION AND GRID ENHANCEMENT

Despite the relevance and growing awareness of the positive impact of electrification and grids enhancements, efforts remain fragmented across sectors, regions and institutional frameworks. In the absence of integrated energy planning approaches, most actions, policies and measures are focused on individual technologies.

Electrification at scale and speed will require co-ordinated action across the energy system to ensure growth in electricity demand is coupled with new renewable power generation, grid enhancement and expansion, and improvements in energy efficiency. With the electrification of different end-use sectors, demand for electricity will grow significantly. Simultaneously, electricity systems will evolve with rapid deployment of renewable generation, grid infrastructure and system flexibility. These components were already reflected in the Outcome of the First Global Stocktake, that called on all parties to work towards tripling global installed renewable power capacity to over 11 000 GW and doubling the global pace of energy efficiency improvement by 2030 (UNFCCC, 2023a).

The electrification and grid enhancement agenda should therefore focus on accelerating end-use electrification of buildings, transport and industry, whilst remaining aligned with broader system developments. Whilst the past decade has been marked by extensive policy support for renewable energy, the coming phase of the transition will see a shift to demand-side policies, as electrification creates new sources of electricity demand and increasingly provides market pull for renewable generation and system investments. Accelerated electrification of key sectors would need appropriate policy frameworks, infrastructure and market mechanisms to allow adoption of electric technologies. These involve scaling up electric mobility and charging infrastructure, deploying heat pumps and efficient electric appliances in buildings at pace, and increasing electrified industrial processes for low- and medium-temperature heat, as well as in manufacturing.

Higher electrification rates will also be enabled by sustained progress in the deployment of renewable power and improvements in energy efficiency. Achieving an electrification rate of 35% by 2035 and over 50% by 2050, when combined with annual efficiency improvements of around 3% through 2035 and continued annual gains of 2.5% until 2050, will require a global installed renewable power capacity of around 18 400 GW in 2035 and circa 38 200 GW in 2050 under the revised 1.5°C Scenario (IRENA, Forthcoming a).

Meeting this level of electricity demand growth will require electricity grids capable of operating with these new loads, as well as more geographically dispersed generation sources. Scaling this infrastructure relies on unlocking unprecedented levels of capital. Starting from today's investment levels, to build a grid fit for a decarbonised world, global investment in grids will need to more than double, to reach a cumulative total of USD 10 trillion by 2035, and scale further to cumulatively reach USD 29 trillion by 2050 (both figures are calculated from 2026, averaging USD 1.2 trillion/to 2050 – more than double the USD 0.5 trillion invested in grids in 2025). Mobilising these funds requires a co-ordinated global effort to de-risk projects and attract private finance, particularly in developing economies, where the infrastructure gap remains most acute. Delaying this capital injection risks turning the grid into the primary bottleneck of the entire energy transition.

To this end, this analysis indicates the need for **a global electrification target for 2035, complemented by a corresponding grid development target**, to guide co-ordinated action across demand and supply. **These targets would provide a clear direction of travel, while allowing countries to determine nationally appropriate pathways and levels of ambition through international dialogue and negotiation.**

Electrification and grid enhancements should thus be framed as part of a broader transition: renewable electricity establishes the foundation; grid enhancement allows for transmission and distribution of electricity; energy efficiency helps to keep overall demand in check; and electrification allows for the displacement of fossil fuel use throughout end-use sectors.

A system-integrated approach to electrification can turn growing electricity demand into an opportunity to increase system efficiency, unlock demand-side flexibility, generate new revenue streams for financing renewable energy deployment and optimise infrastructure planning, while being closely aligned with international efforts already underway to accelerate renewable energy deployment to strengthen power system infrastructure.

DELIVERING GLOBAL PROGRESS ON ELECTRIFICATION, GRIDS AND THE TRANSITION FROM FOSSIL FUELS

These global electrification and grid enhancement targets would help translate global energy transition objectives into actionable implementation pathways, providing a clear and measurable direction to guide national and international action.

Successful implementation will require strategic planning, progress tracking and international cooperation.

Planning: Electrification and grid enhancement

Countries will require electrification and grid enhancement pathways that align end-use deployment with renewable electricity expansion, as well as energy efficiency improvements. Such pathways would allow countries to set priority sectors, infrastructure requirements and policy measures necessary to catalyse accelerated adoption of electric technologies, as well finance programs to support end-use sectors and infrastructure adjustments.

IRENA's analytical work – including the World Energy Transition Outlook, regional energy transition outlooks and country assessments – offers a strong intellectual foundation for this planning process. Flagship reports from these series have already analysed trends in electrification and grids enhancement by regions and sectors, and can guide governments in identifying feasible and cost-effective trajectories for electrification.

Tracking implementation and progress

Monitoring of progress on electrification and grid enhancement will be key to inform policy and track implementation. An appropriate monitoring framework could include a set of complementary indicators that capture both system transformation and sectoral progress, including:

Share of electricity in total final energy consumption (TFEC) (%), as a core global electrification indicator.

Sector-specific (buildings, transport, industry) growth in electricity demand (TWh).

Electricity consumption per capita (in petajoules [PJ]), an indicator of the uptake of modern energy services.

Deployment indicators (in number of units) for key electric technologies, like electric vehicles and heat pumps and electrified industrial processes.

Annual capital investment in transmission and distribution grids (in USD), as a primary indicator of grid infrastructure scaling.

Socio-economic impacts[3] (on GDP, employment and welfare) and required investment (USD).

Policies and regulatory frameworks that enable electrification, such as standards, incentives , technology transfer, capacity building and infrastructure deployment.

Finance and support mechanisms for end-use sectors and infrastructure adjustments, including access to low-cost financing and investments in grid infrastructure, particularly in developing countries.

3 IRENA analysis examines the macroeconomic implications of the transition, highlighting overall GDP, employment impacts and growth trends, underlying drivers of economic and employment trends. The analysis builds on identifying the key drivers (investment, trade, household consumption and government spending), providing an evidence-based foundation for policy makers to leverage the socio-economic benefits of the transition, while anticipating and managing its associated risks.

These indicators would enable countries and international bodies to track electrification trends and demand-side progress within the context of the broader energy transition agenda.

The monitoring of electrification must also remain linked to global efforts to expand the supply of clean electricity. Specifically, the initiative should support the goals of the UAE Consensus to triple renewable power capacity and double the rate of energy efficiency improvement by 2030, as well as the global pledge to scale up energy storage. In conjunction with renewable deployment, storage expansion and efficiency gains, tracking electrification and grids enhancement will give a more complete picture of the overall transformation in energy systems.

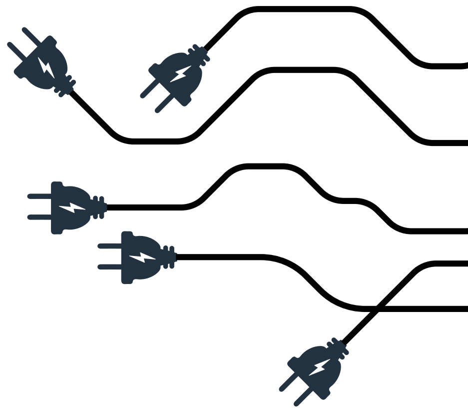
The IRENA World Energy Transition Outlook (IRENA, 2024, Forthcoming a); regional energy transition outlooks (IRENA, 2025b, 2025c, Forthcoming b; IRENA *et al.,* 2022); as well as the reports tracking progress on the UAE Consensus (COP28 Presidency *et al.,* 2023; IRENA *et al.,* 2024, 2025); complemented by private sector engagement through partnerships such as the Utilities for Net Zero Alliance (UNEZA) for power systems and grid infrastructure and the Alliance for Industry Decarbonization (AFID) for industrial transformation; and Electrification Plans-to-Accelerate-Solutions (PAS) under the Global Climate Action Agenda at COP30 (UNFCCC, 2025), all represent existing instruments that can support this tracking process.

Governance and co-ordination

Building a space for co-ordinated action on planning and monitoring efforts can be highly effective. A regional approach can also facilitate governments in sharing best practices and designing electrification roadmaps while measuring progress over time through its analytical frameworks and country engagement activities.

Such initiatives and platforms are well established by IRENA, encompassing the regional energy transition outlook assessment process, national-level assessments and IRENA's collaborative frameworks and regional initiatives such as APRA, APRESA, PARLAC and APRECA,[4] could be leveraged to enable knowledge sharing, policy dialogue and peer-learning among countries.

A more holistic and co-ordinated governance approach will be needed in order to ensure actions are not fragmented or misaligned across sectors and institutions. Electrification strategies will need to be co-ordinated across multiple ministries and agencies – including energy, transport, industry, buildings, finance and planning authorities – to ensure coherence between demand-side measures and supply-side developments.



In particular, the alignment of electrification policies with planning and deployment of electricity grids and system flexibility solutions will be critical to avoid mismatches between increasing electricity demand and infrastructure readiness. This also entails matching workforce skills and training systems with developing electrification needs, ensuring that fiscal frameworks and public finance strategies are aligned with the scale of investment necessary, whilst also maintaining macroeconomic stability.

IRENA can play an important role in supporting this integrated approach, through its analytical workstreams, country engagement and partnerships to facilitate cross-sectoral co-ordination, strengthen planning capacities and support the alignment of electrification, grid development and broader energy transition strategies.

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4 APRA = Accelerated Partnership for Renewables in Africa; APRESA = Accelerated Partnership for Renewable Energy in Southeast Asia; PARLAC = Partnership for the Advancement of Renewable Energy in Latin America and the Caribbean; APRECA = Accelerated Partnership for Renewable Energy in Central Asia.

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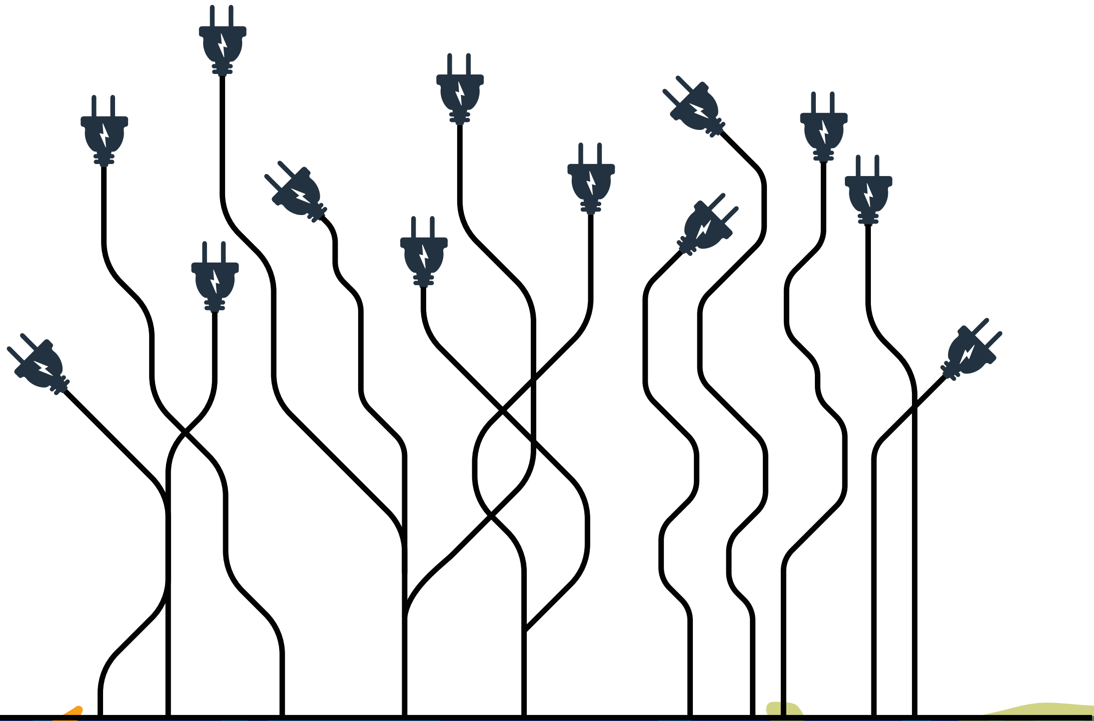

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