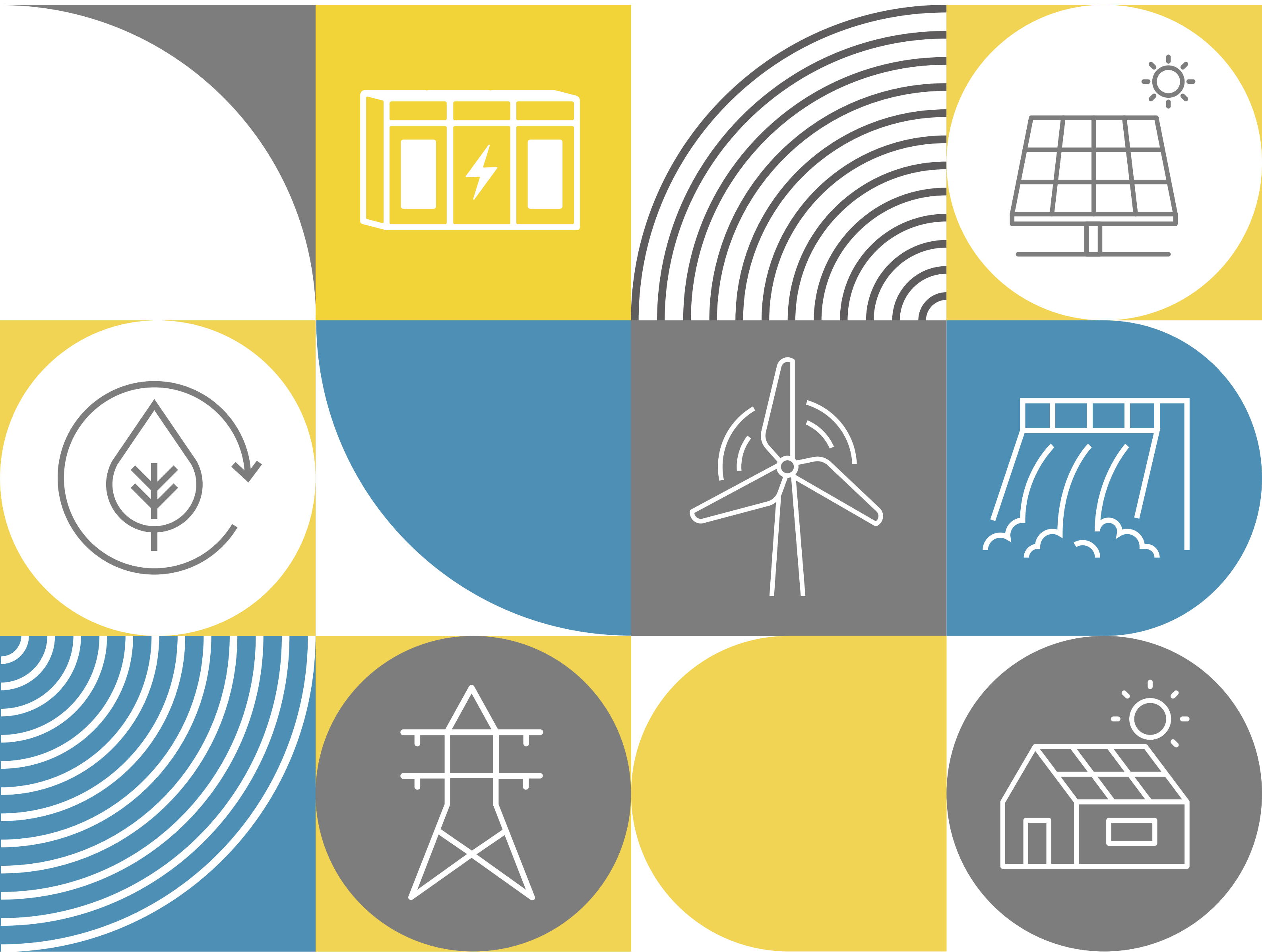
IRENA coalition FOR ACTION

ACHIEVING 100% RENEWABLE ENERGY BY 2050



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About the Coalition

The IRENA Coalition for Action brings together leading renewable energy players from around the world with the common goal of advancing the uptake of renewable energy. The Coalition facilitates global dialogues between public and private sectors to develop actions to increase the share of renewables in the global energy mix and accelerate the energy transition.

About this publication

The Coalition's Towards 100% Renewable System Working Group explores entire energy system needs and end-use sector decarbonisation from the policy, innovation, technology, socioeconomics and institutional perspectives. It develops best practices and policy recommendations for the transition to a 100% renewable energy system enabled by electrification, energy efficiency, grid integration, flexibility and storage solutions.

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CONTENTS

ABBREVIATIONS

BAU	business as usual
CCUS	carbon capture, utilisation and storage
CER	Consumer Energy Resources
CFD	contracts for difference
COP	Conference of the Parties
EV	electric vehicle
ESCOS	energy service companies
GHG	greenhouse gas
ICE	internal combustion engines
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LUT	Lappeenranta-Lahti University of Technology
NDCs	Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PPA	power purchase agreement
ROCOF	rate of change of frequency
SDGs	Sustainable Development Goals
UNFCCC	United Nations Framework Convention on Climate Change
UTS	The University of Technology Sydney
VPP	virtual power plants
VRE	variable renewable energy
WEO	World Energy Outlook
WWS	Wind-Water-Solar Scenario

INTRODUCTION

In 2024, the IRENA Coalition for Action's Towards 100% Renewable Energy Systems Working Group published a paper (IRENA Coalition for Action, 2024) based on a detailed examination of three studies looking at pathways to 100% renewable energy by 2050: The Lappeenranta-Lahti University of Technology (LUT) Global 100% RE Scenario (Bogdanov *et al*., 2021); The University of Technology Sydney (UTS) 1.5°C Scenario, included in their "Achieving the Paris Climate Goals" Report (Teske, 2019); and Stanford University's 100% Wind-Water-Solar (WWS) Scenario that specifically covered 145 countries (Jacobson *et al*., 2022).

Work continues on all these studies and updates for the three 100% scenarios have been published. In summary, the three studies referenced in the original paper have been expanded to incorporate more current technology innovations in both generation, and grid storage and flexibility, along with sector coupling principles. They show that a range of different solutions are available, with the precise mix of renewables and supporting flexibility solutions determined by local factors, and demonstrate that 100% renewable energy systems will offer the lowest cost options, and provide greater social and environmental benefits for limiting global warming to 1.5°C or less by 2050 (communication with authors).

The studies concluded that a 100% renewable energy system is realistic, being the most cost-effective, socially just and environmentally friendly approach, based on available mature technologies, as a way to achieve the objectives of the Paris Climate Agreement.

Our recent paper (IRENA Coalition for Action, 2024) analysed the aforementioned three 100% renewables scenarios and two net-zero scenarios, and highlighted that all of these scenarios were aimed to achieving the targets of the Paris Agreement (UNFCCC, 2015). The paper concluded with five recommendations for policymakers on how to proceed in developing and implementing 100% renewable energy targets for successful decarbonisation of the entire energy system, including:

1. Embracing 100% renewable energy systems and phasing out fossil fuels.
2. Establishing energy efficiency as a priority (*i.e.* the best energy supplies are those that are not needed).
3. Implementing electrification as a path to a sustainable energy transformation.
4. Upgrading infrastructure for a resilient, decentralised and flexible energy system.
5. Enhancing International co-operation for paving the way for the transformation of the global energy system.

The fundamental premise of the paper published in 2024 is that the energy transformation to 100% renewable energy by 2050 is based on three pillars: 1) technology innovation and infrastructure improvements; 2) access to finance, both from the public as well as the private sectors, and 3) enabling policies at all levels of governance.

These three pillars are interlinked, for example: successful technologies attract financing and successful enterprises; and successful enterprises stimulate policy decisions to further their growth and attract additional financing and vice versa. In addition, the paper focused on policy recommendations that support pathways towards a 100% renewable energy future.

Within the same time frame of the publication of that paper, at COP28 in Dubai in 2023, a pledge was signed by over 130 countries that established two near-term targets to ensure that the world remains on a pathway to limit global warming to no more than 1.5°C: 1) tripling renewable power capacity from 2022 levels by 2030; and 2) doubling the current rate of energy efficiency improvements from 2022 levels by 2030. However, as the official report tracking the targets subsequently adopted in the First Global Stocktake demonstrates, the world is falling far short not only of meeting these near-term targets, but even the 1.5°C target itself (IRENA *et al.*, 2024).

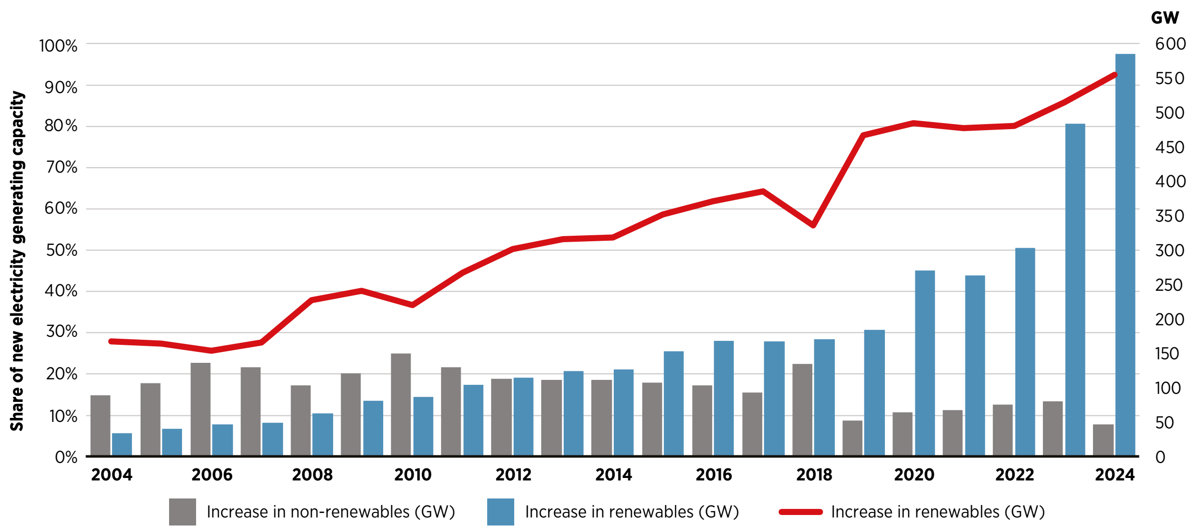
Within this context, the Coalition presents this follow-up paper that takes a deeper dive into recommended actions to bring the world back on track to meet both the short-term tripling target as well as the ultimate 1.5°C target by 2050. Furthermore, the policies are presented within the framework of a future energy system supplied by 100% renewable energy as the means for achieving the target.

This paper is organised around the following chapters: Chapter 2 briefly provides background information on the basis for why the world is shifting towards renewables. It includes definitions of what is meant by a 100% renewable energy system, and why achieving such a goal requires an energy *transformation*, not just a transition. Chapter 3 provides further details on the current status of achieving the tripling target, emphasising how this target accelerates renewable energy deployments, serving as a building block for 100% renewables. Chapter 4 summarises the key financing issues that help to inform policies. Chapter 5 introduces ideas for a fair and just phase out of fossil fuels, an essential component of the energy transformation. Finally, Chapter 6 presents a detailed list of recommendations focusing on achieving 100% renewable energy systems by mid-century at the very latest and achieving the near-term tripling up targets and limiting global warming to no more than 1.5°C.

BACKGROUND AND DEFINITIONS

Over the past two decades, the share of renewables in annual capacity additions has grown significantly, rising from around 27.9% in 2004 to 92.5% in 2024 (IRENA, 2025) [see Figure 1]. Direct uses of renewables are also growing in other end-uses. The increase in renewable energy is occurring in a growing number of countries. Wind and solar power are the fastest growing renewables. These variable sources are complemented by a flexible and dispatchable mix of other mature renewable technologies such as bioenergy, hydropower and geothermal. Additionally, innovative and emerging renewable energy sources including marine (wave and tidal), and a variety of long- and short-term storage (pumped hydro, batteries and renewable-based or "green" hydrogen) can replace fossil sources while enhancing grid flexibility. In turn, dependence on fossil energy imports and vulnerability to global supply chain disruptions will be reduced. Energy security and resilience, as well as local economies, will be strengthened (IRENA, 2024a).

Figure 1 **Annual share of installed capacity additions from renewables**



Source: (IRENA, 2025).

Renewable energy growth is most prominent in a small number of developed countries, and a few emerging markets and developing economies (EMDE), especially China, India and Brazil (IRENA, 2024a). Given the increasing availability, maturity, rapid growth and decreasing costs of renewable energy sources and technologies, and given the growing importance of reducing fossil fuel dependencies and the urgency of mitigating the worsening climate crisis, the critical role of renewables as the key solution cannot be overstated (IRENA, 2024a).

The urgent need to mitigate the climate crisis compels us to phase out global anthropogenic greenhouse gas (GHG) emissions well before 2050. Achieving 100% renewable energy is the most promising pathway to meeting this goal, which is our focus in this paper. Box 1 provides our definition.

Box 1 **The IRENA Coalition for Action has agreed the following definition of 100% Renewable Energy**

Renewable energy encompasses all renewable sources, including bioenergy, geothermal, hydropower, ocean, solar and wind energy. One hundred percent renewable energy means that all sources of energy to meet all end use energy needs in a certain location, region or country are derived from renewable energy resources 24 hours per day, every day of the year. Renewable energy can either be produced locally to meet all local end-use energy needs (power, heating and cooling, and transport) or can be imported using supportive technologies and installations such as electrical grids, hydrogen or heated water. Any storage facilities to help balance the energy supply must also use energy derived only from renewable sources.

Bearing in mind the importance of equity and fairness between and within nations when accelerating the transformation (see Box 2 for our definition) towards renewables-based energy systems, the paper elaborates on policy options including country- or regionally-specific aspects to achieve 100% renewable energy systems in different parts of the world.

Box 2 **The IRENA Coalition for Action has agreed to preferably use the term of Renewable Energy Transformation instead of Transition**

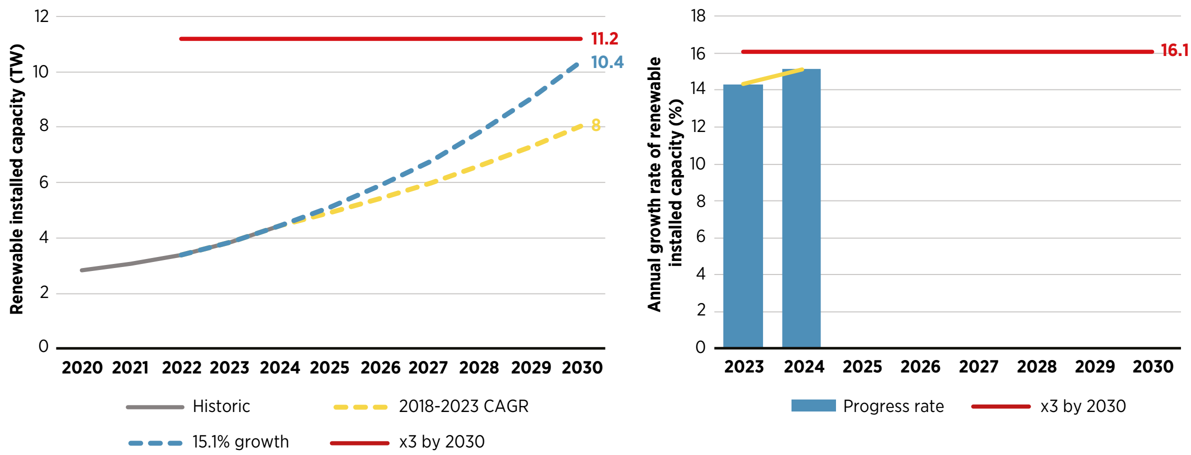
The term ‘energy transition’ implies a gradual **shift** from one form of energy system to another while an ‘energy transformation’ reflects a fundamental **change** in the composition, structure and operation of energy systems and their societal benefits and impacts. For example, in the power sector, the current centralised system, driven primarily by fossil, nuclear and large hydro energy sources, fails to provide reliable and affordable energy for all. Systemic changes are needed not only to address climate change but also to create just and inclusive energy systems based entirely on renewable sources. These changes represent a transformation to more distributed and highly electrified energy systems, based on a rapidly increasing share of a diverse mix of renewable energy sources, some of which are variable in nature and function at the whims of weather patterns and other natural phenomena. This requires significant changes in end-use energy behaviour and in the related infrastructure needed to deliver energy services to all end users safely, reliably and universally. A key driver for referring to an energy **transformation** is the societal aspect of responding to and supporting a system that impacts local economies, the environment, and potentially implies significant changes in energy use practices. The necessary upgrading of infrastructure and market designs to a highly variable and distributed supply and demand, combined with storage and other balancing and flexibility sources and measures, implies a fundamental transformation even where end uses are other than electricity. The new systems must build on a high degree of flexibility through dispatchable renewables such as geothermal, biomass or (small) hydropower, as well as storage, power-to-x and sector coupling, and a much stronger role of demand-side response. Social support and societal engagement will be critically important to ensure the transformation is successful.

Although 2050 is the most common reference year for climate and energy policies related to net-zero emissions and for staying below a 1.5°C global temperature rise, the implementation of the measures safeguarding the 1.5°C limit could and should be achieved earlier in many parts of the world. Efforts to phase out GHG emissions must be accelerated significantly. Reaching 100% renewable energy even before 2050 in both developed and high emitting emerging economies would be our prefered pathway for achieving climate targets.

THE TRIPLING TARGET AS AN ENABLER FOR 100% RENEWABLES

The tripling target agreed upon at COP28 is of primary relevance to this paper. If this target is achieved, a total of 11.2 TW of renewable power will be installed worldwide by 2030. Given that levels were 4.4 TW at the end of 2024, growing by 585 GW at a an annual rate of 15.1%, this still falls short of the required annual renewable capacity growth rate of 16.1%, and would result in a shortfall of 3.1 TW by 2030 (IRENA, 2025). If the historic annual growth rate of renewable capacity of 10% were to continue, only 7.5 TW of renewable capacity would be installed by 2030 - far short of the COP28 tripling target (IRENA, 2024b) [see Figure 2].

Figure 2 **Reaching the global tripling target of 11.174 TW by 2030 (left: historic annual growth rate of renewables; and right: tripling target annual growth rate)**



Source: (IRENA, 2025).

Tripling renewable power capacity by end of this decade is a global target. All countries, including those which have already reached significant renewable energy capacities, should contribute to the tripling and onwards to get to a fully renewables-based systems before 2050. Meeting the short-term tripling target does not necessarily place the world on a 100% renewable energy track by 2050. The growth of renewables and efficiency improvements needs to continue beyond 2030, and therefore the tripling target constitutes an initial building block towards 100% renewable energy systems.

FINANCING A 100% RENEWABLE FUTURE

A key argument for supporting 100% renewable energy scenarios like those analysed in our previous study is their significantly lower costs in comparison to net-zero scenarios. The total costs for financing a 100% renewable energy transformation by 2050 (USD 51 to 72 trillion) are about half of the financing requirements for achieving net-zero GHG emissions over the same period (USD 85 to 140 trillion) (IRENA Coalition for Action, 2024a). The cost advantages of 100% renewable energy scenarios result from the lower cost of renewable energy technologies and supporting infrastructure as compared with ongoing fossil, nuclear and CCUS technologies requires under net-zero. Additional savings can be found in reduced externalities associated with healthcare and other pollution-related costs, as well as improved efficiencies and demand side management practices.

Adequate financing for the transformation, such as access to grants-based public, affordable concessional, and private-sector financing, are key for a successful transformation. Here we provide a short summary of requirements and the current state of financing the energy transformation as a background for the recommendations presented in Chapter 6.

4.1 FINANCING AT THE GRID SCALE

In 2024, estimated global energy financing amounted to USD 2.8 trillion. The single largest share was USD 1.1 trillion for financing upstream and downstream coal, oil, and fossil gas development and use (IEA, 2024a). Financing for the renewable power sector, mainly solar and wind, grew to USD 750 billion, with energy efficiency and infrastructure (storage and grids) investments, each totalled almost USD 400 billion in 2023 (IEA, 2024b). About 85% of the renewable energy financing is currently directed towards a number of developed countries, and to China (IEA, 2024b). Despite the renewable energy growth stimulated by these investments, the world is still not on track to limit global warming to 1.5°C, nor to achieve the tripling target or even 100% renewable energy by mid-century (IEA, 2024a; IRENA, 2024c).

The three 100% renewable energy scenario studies that formed the basis for this paper all conclude that global fossil fuel investments need to be ended and diverted to renewable energies. Given the current levels of clean energy financing, annual global financing levels must increase to nearly USD 5 trillion as soon as possible and by 2035 at the latest. Since renewable electricity will be the main energy source for a net-zero and 100% renewable energy world, three quarters of that investment are needed for the combined financing of renewable energy supply, mainly solar and wind, storage, and grid infrastructure[1] (IEA, 2024b; IRENA, 2024c).

For countries to reach their national climate goals, modernising or updating a total of over 80 million kilometres of grids by 2040 will be required (IEA, 2024). Additionally, the world's current grid capacity needs to double by this time. These infrastructure upgrades will require a substantial investment. For context, in 2023, global grid investments reached USD 391 billion, short of the USD 717 billion needed annually to 2030 (IRENA, 2024b).

[1] The remaining quarter of annual global clean energy financing is needed for enhanced energy efficiency in all economic sectors (IEA, 2024a).

The United States, Europe and China attracted the most grid investments in 2022 and 2023 (IRENA, 2024b). Many emerging economies lag behind, constrained by financial limitations that hinder their energy transformations (REN21, 2024). Effective strategies for financing the required energy infrastructure in emerging and developing economies are essential to advance a swift and equitable energy transformation. These strategies must involve stronger global and regional collaboration, and a variety of financial instruments aimed at overcoming investment challenges to ensure they are successfully secured. Innovative financial tools and supportive policies to accelerate grid development, particularly in underserved regions, where traditional methods have fallen short, will be needed. Grid infrastructure development is particularly dependent on specific regional contexts, which must be reflected in the financing strategies.

4.2 MINI-GRID AND OFF-GRID FINANCING

Large-scale national infrastructure cannot always reach or serve the last mile of energy needs efficiently. Mini- and off-grid solutions can reach remote and underserved areas including underserved urban areas. These solutions provide electricity generation and distribution services that typically operate independently from the main power grid.

The economic and social benefits of mini- and off-grid solutions and can help outweigh the higher upfront costs, especially in comparison to the longer lead times and large-scale investments required for expanding centralised grid infrastructure. They improve access to essential services, help stimulate local economic development, contribute to community development, enable improvements to gender equity, reduce reliance on more costly fossil fuels, and improve the environment – particularly if a community had previously used diesel generators, kerosene and/or unsustainable biomass (IRENA Coalition for Action, 2024b).

Despite these positive benefits, the financial challenges to mini- and off-grid deployments remain a hurdle. Although smaller in scale and size, mini-grids still require reliable, mid- to long-term funding, offered at low interest rates. Local financing options are not necessarily easy, as financial institutions in emerging and developing economies are often reluctant or unable to offer these types of loans, either because they lack funds or cannot afford losses due to inflationary pressures. Financial institutions often charge very high interest rates, which make smaller scale projects unaffordable (USAID Energy, 2024).

4.3 DEMAND-SIDE FINANCING

Implementing 100% renewable energy targets also require demand-side management strategies, notably energy efficiency improvements, time-of-day electricity tariffs, and efforts to reduce energy intensity per capita. These components require their own financing strategies. Demand-side infrastructure and equipment can be financed both by public and private money depending on the context. These products can benefit from support mechanisms such as lower interest rates, loan guarantees, and longer maturity of loans. Energy service companies (ESCOs) can also offer additional services such as energy management and equipment retrofits.

4.4 UNIQUE CHALLENGES FOR DEVELOPING COUNTRIES AND EMERGING ECONOMIES

Affordable energy access can be particularly challenging for developing countries and emerging economies. Budgetary limitations and high interest rates constitute prohibitive barriers for universal access to energy and for a transformation away from existing fossil fuel-based systems. This is why governments from emerging economies, supported by non-state actors around the globe, are demanding significant financial contributions from the industrialised and other richer countries.

Nevertheless, achieving universal energy access by 2030 is a major requirement of the Sustainable Development Goals (SDGs). Despite significant progress 685 million people, mostly in developing countries, still lack any access to electricity (IEA, *et al.*, 2024). Also, about 2.1 billion people, mainly in lower income rural areas, rely on inefficient and highly polluting biomass for their indoor cooking needs, resulting in the premature death of more than 3 million people annually (IEA, *et al.*, 2024). The IEA projects that global annual investments will need to reach USD 45 billion for access to electricity, and USD 10 billion to meet the SDG clean cooking goals by 2030. Although these investments represent a mere 2% of all global energy expenditure, present support for universal energy access is only USD 10 billion per year (IEA, 2024a).

One key mechanism to overcome the projected renewable energy gap in developing countries would be a binding commitment by developed and wealthier nations to start to pay back their long-time climate debt. This would achieve equity and fairness in climate change mitigation responsibility. This could start with a commitment, well prior to 2030, to assist developing countries with grants-based financing in the range of USD 300 billion annually for clean renewable energy development. These financing levels would be in line with the request of many developing countries in the context of new commitments discussed (but not agreed to) at COP29 in Baku in 2024. Their goal was to seek USD 1.3 trillion annually of grant-based funding and support, including climate adaptation and loss and damage financing (UNFCCC, 2024). However, the final agreement, was only to encourage industrialised countries to increase total climate financing (mitigation and adaptation) from USD 100 to 300 billion annually by 2035 (UNFCCC, 2024). This reduced level of support was strongly criticised by many developing countries (Carbon Brief, 2024).

A FOSSIL FUEL EXIT STRATEGY

Despite unprecedented growth of renewable power capacity in the last decade, administrative barriers and unnecessary and prohibitive costs are continuing to hamper smooth integration of renewable energy in markets and grids which were originally designed for large and centralised fossil and nuclear baseload and fossil gas powered peaking plants. Societal and environmental costs of this system are borne by all taxpayers. Adjusting policy frameworks and financial flows to disincentivise the use of fossil fuels, and support more decentralised deployment and use of energy from a broad mix of renewable sources should be prioritised.

Introducing solutions such as carbon pricing in the form of levies and taxes, but also cap-and-trade emissions trading systems, should result in the phase-out of the competitive advantages of carbon-emitting technologies in favour of clean renewable sources. In economies and regions that rely heavily on fossil fuels for their electricity supply and for their heating and cooling demand as well as for most transportation and industrial applications, carbon pricing and other policies aimed at internalising the costs of negative health or environmental impacts are often perceived as an unbearable or unjustified burden placed on marginalised and lower-income sectors of the population.

Transparent and effective strategies with ambitious and realistic targets and milestones require the early engagement and support of those who are most impacted by cost and price increases. Otherwise the transformation may be met with resistance. A just transformation should always be among the key objectives of policies aiming at renewables-based energy systems.

Technically, a system based on VRE sources is incompatible with the incumbent concept of baseload provided by inflexible power plants running 24/7 (mostly coal and nuclear), complemented with expensive fossil-fired peak load plants for balancing and flexibility. Coal and nuclear power plants are widely incompatible with the flexibility requirements of a renewables-based energy system. A more distributed deployment and use of renewable energy requires smarter and more decentralised grids and energy markets. Thus, when exiting from a fossil-based system, flexibility through storage, smart grids, solar and wind forecasts, dispatchable renewables and other measures will enable a reliable 100% renewable energy system. To support this, the necessary price signals and affordable pricing strucutures for system flexibility and reliability must be established.

Fossil fuel exit strategies are important for accelerating the deployment of renewable energy with little curtailment and lower costs. The gradual transformation from inflexible traditional baseload to smart and flexible energy systems benefitting from digitalisation, decentralisation and consumers participation needs to be well planned and designed. With wide ranging support by all stakeholders, the transformation can be implemented smoothly. Creating level playing fields and removing unfair cost advantages for coal, oil, fossil gas and nuclear by implementing the “polluter pays” principle is another important pillar for an exit strategy and should go hand in hand with targets and milestones to create and maintain a stable and reliable framework for the transformation. This overall approach will enhance investment security and bankability of projects. In general offering financial incentives for renewables and disincentives for polluting sources has proven to be very effective. Ambitious and transparent milestones towards targets and enabling frameworks also help avoid stranded investment and wait-and-see positions, which delay investment decisions and deployment.

Good exit strategies begin with early involvement of stakeholders and affected citizens. By highlighting opportunities without denying challenges and offering a high level of transparency and credibility through social dialogue, social protection to affected workers, information, round tables, or living labs, a successful transformation of the energy system can be achieved (IRENA Coalition for Action, 2023). The perception of reliable processes and steps is supported by setting targets and interim milestones as mentioned earlier. Anticipating skill needs, reskilling of the existing workforce as well as providing opportunities to youth, women, and minorities are important building blocks for a smooth, successful and widely supported transformation of the economy. The need for involving and integrating local communities, people and workforce also applies to countries and regions, where broad, and ultimately universal access to energy services still needs to be established.

Another important element of a successful fossil fuel exit strategy is avoiding ambiguity in target setting and inconsistency in incentives. A sustainable, reliable renewables-driven system with clear targets and incentives is much easier to implement. Targeting new fossil or nuclear capacity is incompatable with full decarbonisation by 2050. Even if all radiation and security risks and the disposal of nuclear waste were solved, new nuclear capacity would still be too costly and definitely too late for keeping the 1.5°C limit within reach. Relying on strategies such as CCUS to offset carbon emissions is highly uncertain and would require technology developments and cost decreases which are nowhere in sight and would delay renewables deployment.

South Australia offers a compelling example of how rich natural resources, strong government leadership and ambitious renewable energy targets can drive fast transition. South Australia has transitioned **from around 1% renewable electricity generation in 2007 to 75% in 2024**, with a target to reach net 100% renewable generation by 2027.

The state's renewable journey began in 2003 with construction of one of Australia's earliest wind farms located 100 km from the State capital, Adelaide. Then in 2008 came Australia's first legislated solar feed-in tariff. By 2025 this resulted in 51% of households having rooftop solar with a combined installed capacity of about 2 GW - almost double that of utility scale solar capacity. Additionally, farmers gained a new revenue stream from hosting renewable projects

The journey to transition to 100% renewable electricity has faced challenges such as:

- **System strength and inertia:** Declining system strength and inertia as variable renewable inverter-based technology replaced traditional generators, reducing the grid's ability to manage frequency and voltage changes.
- **Minimum demand:** South Australia became the first GW scale power system in the world to achieve negative operational demand, as rooftop solar output exceeded total consumption. If electrically 'islanded' (*i.e.* with the South Australian grid operating in isolation), there must be sufficient demand to keep synchronous generators online, as they provide essential system security services (inertia, frequency control and voltage support) in the case of generator or transmission faults.
- **Equity:** Changing the distribution network to two-way power flows risks the burden falling heaviest on consumers with insufficient financial means to invest in prosumer resources.

The following solutions were undertaken:

- **Grid-scale batteries:** Grid scale battery installations demonstrated significantly improved fast-frequency response, emergency response to system events and synthetic inertia (Virtual Machine Mode) in a grid scale application.
- **Synchronous condensers:** four high inertia synchronous condensers were installed in strategic parts of the network to stabilise the frequency and voltage.
- **Distributed energy integration:** staged roll-out of smart solar inverter technology enabled solar exports to automatically adjust, matching available capacity of the network.
- **Distributed energy projects:** innovative use of Consumer Energy Resources (CER) through a range of trials including aggregated small battery Virtual Power Plants (VPP) in 6,000+ social housing homes, utility scale microgrids, home and community battery programs as well as Electric Vehicle (EV) smart charging trials and statewide charging network.
- **Transmission infrastructure:** Strengthened transmission network by constructing new high voltage links.
- **Green hydrogen development:** Legislated the Hydrogen and Renewable Energy Act 2023 for large scale development. Including the co-ordinated development of a multi-user hydrogen precinct for export and domestic markets. Hydrogen demonstration projects including Australia's first 1MW electrolyser supplying hydrogen to fuel cell buses, to industry, and the gas network.

Courtesy of the South Australian Department of Energy and Mining

RECOMMENDATIONS FOR PATHWAYS TO 100% RENEWABLES

In our previous policy brief, we analysed global energy scenarios aimed at implementing the objectives of the Paris Agreement and in particular staying below 1.5°C temperature rise compared to pre-industrial levels (IRENA Coalition for Action, 2024a). The 100% renewable energy scenarios elaborated that aiming at 100% renewable energy by 2050 at the very latest will be the safest, fastest and most cost-effective pathways to achieve this target. The previous policy brief provided recommendations for enabling policies and frameworks to successfully strive for fully renewables-based energy systems.

Tripling global renewable power capacity and doubling energy efficiency improvements by 2030 is a stepping stone to 100% renewable energy. However, further accelerated growth of renewables has to continue beyond 2030. Here are our recommendations to accelerate the transformation, which can be applied to all countries, including fossil fuel exporting nations. The recommendations are categorised into 4 focus areas, as follows:

1. TARGETS, INCENTIVES AND REGULATORY FRAMEWORKS:

a. Set ambitious targets for the different technologies to scale up capacities ultimately leading to 100% renewable energy systems.

   - Accelerate wind and solar installations as the fastest growing renewable sources with the most significant cost decreases in an increasing number of markets.
   - For supply security and grid stability, complement these variable sources with dispatchable renewables such as hydropower, biomass and geothermal as along with innovative technologies such as wave and tidal energy and incentivising flexibility and different types of storage solutions and smart grid enhancement.
   - Highlight the important contribution of renewables in reducing import dependencies, and facilitating energy security, affordability and universal access to energy.
   - Promote the socio-economic benefits of domestic renewable sources as opposed to imported fossil and nuclear energy sources. Renewable sources are locally available and therefore the obvious alternative to high levels of import, supply chain dependencies, and price volatility. Where doubts about the availability of renewable sources and the reliability of a renewables-based energy system or associated costs prevail as major reasons for opposing the transformation, engage in focused and credible dialogue about the potentials of renewable energy to overcome these concerns. Practical and replicable examples of successful projects will help broaden understanding and grow support (see Box above).

b. Create an enabling policy environment as well as legally binding frameworks for national, regional and local targets for accelerated deployment of all available renewable energy sources, empowering large-scale electrification and enabling technologies for all end-uses.

c. Include all domestic renewable energy targets and policies, short-, mid- and long-term, in the processes of reviewing and enhancing national renewable energy, energy efficiency and infrastructural support in Nationally Determined Contributions (NDCs) for 2025 and beyond under the United Nations Framework Convention on Climate Change (UNFCCC).

2. FOSSIL AND NUCLEAR PHASE-OUT STRATEGIES:

a. Strive for 100% renewable energy by 2050 at the latest. Accept that developed and high emitting countries have to achieve that objective earlier, and renounce new fossil or nuclear projects or related infrastructure. This includes phasing out inflexible baseload (particularly coal and nuclear) to avoid costly delays and deviations.

b. Phase out all direct and indirect fossil fuel subsidies in a socially just manner and implement comprehensive fossil-fuel exit strategies to boost public support for the transformation towards 100% renewable energy systems and accompanying structural changes in line with a participatory, equitable, transparent process for a just transition in society.

c. Let targeted fossil fuel exit strategies guide policy decisions so that the structural changes accompanying the transformation are avoided or mitigated. Introduce programmes to attract new industries and jobs, roll out reskilling programmes for those whose jobs will change and provide incentives and compensations for those who need them to cope with the changes until the benefits of the transformation are tangible for all.

3. INFRASTRUCTURE AND TECHNOLOGY ENHANCEMENTS AND INNOVATIONS:

Transforming energy systems towards renewables and renewables-based electrification as well as direct use of renewable thermal energy will be the fundamental driver for decarbonising economies.

a. Renewables, such as solar thermal and geothermal should be promoted for providing heating and cooling to individual homes and buildings, district heating systems, and industrial processes. The growing need for higher levels of electrification can be supported by direct use of thermal renewables combined with thermal storage.

b. Promulgate measures such as time-variable tariffs, market signals for system serving feed-in vs. storage, targeted infrastructure development and market signals for providing and managing the significantly growing electricity demand from much higher levels of electrification across end-uses. Electricity will be the main energy carrier for any clean, efficient and renewable-based economy of the future. And direct electrification usually goes hand in hand with higher energy efficiency and less wasted energy, thus reducing energy demand. For example, electric Vehicles use less primary energy than internal combustion engines (ICE) powered cars, and heat pumps are more efficient than conventional heating systems.

c. Introduce sector coupling and power-to-x as important parts of the solution, where direct electrification is not feasible such as in some hard-to-abate industrial processes. This is where renewable-based hydrogen comes in as an energy carrier, in addition to batteries, pumped storage and other short, medium, and long duration energy storage technologies.

d. Develop and deploy the necessary infrastructure for the transformation towards resilient, flexible, and more distributed energy systems that are fully driven by renewables.

- Prioritise the planning and building of the infrastructure required to accommodate an electricity supply and demand based on very high shares of VRE complemented by other mature and innovative renewable sources and balanced by flexible renewables, as well as smart grids, sector coupling, regional balancing and various types of storage. This includes high-voltage long distance transmission lines as well as distribution grids and more distributed mini- and microgrids or off-grid installations. This also entails infrastructure for batteries and other storage applications, including pipelines for renewable-based hydrogen and other green gases. Flexibility and digitalisation should be the guiding principles of an infrastructure fit for 100% renewables.

4. PUBLIC AND PRIVATE FINANCING AND CAPACITY BUILDING:

Markets and networks designed for fossil and nuclear baseload combined with gas-fired balancing power as well as fossil-based heating and cooling systems and internal combustion engine (ICE) for transport purposes are significant obstacles and hindering renewables to compete on a level playing field.

a. Remove unnecessary administrative and regulatory barriers for renewables deployment, as well as direct and indirect subsidies for fossil and nuclear sources.

   - Introduce carbon taxes, cap and trade emissions trading systems or similarly effective instruments to internalise externality costs.

b. Develop and implement market mechanisms which are fit for renewable energies as the dominant sources. This would include adapting market designs and regulatory frameworks to create a level playing field for renewable energy. Here the cost of capital, in industrialised countries for example, is less of a problem, but in distorted or dysfunctional fossil or nuclear dominated markets, the bankability of renewable energy projects is at risk. This is due to a lack of stable framework conditions and/or continued subsidies for unsustainable energy. Increasingly, low, or even negative electricity prices put the economic viability of renewable power at risk. Negative electricity prices occur when wind and solar in particular produce high amounts of electricity, while the grids are insufficient and storage is lacking, or where inflexible coal or nuclear powerplants cannot be ramped up and down to the extent needed to cope with flexible supply and demand.

c. Create and maintain frameworks which support rapid deployment of large and small installations of mainstream as well as innovative renewable energy technologies. Although wind and solar (and traditionally also hydropower) are mature and low-cost technologies, they need appropriate frameworks and regulation fit for renewables to be economically viable.

   - Establish smooth and fast permitting procedures which include citizen and stakeholder involvement so that project developers can reasonably place bids in auctions and/or contract the installation of turbines or panels (also applies for private customers and smaller projects).
   - Establish targeted revenue support, such as feed-in tariffs or premiums, tax exemptions or credits and/or investment support or capacity payments for those dispatchable sources and innovative technologies, including battery and other storage technologies, which need them to support their economic viability and market introduction. Contracts for Difference (CfD) and public or private Power Purchase Agreements (PPA) are other options for accelerating renewables growth. PPAs are becoming more important tools for private off-takers to provide the necessary financing for new renewable energy projects, including for industrial self-consumption. Long term revenue visibility is important to incentivise investment.

d. Create an enabling environment for ensuring adequate private and public financing for diverse types and sizes of renewable energy projects and enabling infrastructure.

- Develop mechanisms and funds for developing countries to drastically improve access to small and large project financing. Act to mitigate country or project risks for large and small projects and facilitate access to financing. The availability of public and increasingly on private money depends largely on the costs of capital. Interest rates for loans differ significantly between countries and regions, and they are particularly high in developing countries.
- Traditionally public finance is lacking in developing countries often as a result of their colonial heritage, which adds to project costs that must be borne by private financing. It has recently been suggested by civil society stakeholders and through the Brazilian Presidency of the G20 that high capital costs could be overcome by debt relief or by increasing the availability of public finance through an annual 2% wealth tax on the world's 3 000 wealthiest individuals (Zucman, 2024). This could generate up to USD 250 billion annually.
- International and bilateral development banks have a role to play by facilitating access to cheaper capital. Providing grants instead of loans for developing countries will serve as additional accelerators.

e. Involve citizens, local businesses and stakeholders at an early phase of project development and siting and let the local population directly benefit from the projects.

- Renewable energy projects as well as related infrastructure such as power lines are often subject to opposition from local governments, citizens, or businesses, because they expect noise, odor, visual disturbance, or other negative impact like cost increases or job losses. Most of these concerns can be mitigated by early and proactive information and participation. And where positive impacts such as cleaner air or less noise in the neighborhood or newly created jobs are visible or where personal or community-focused benefits are tangible, support will usually grow.

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