UNITED NATIONS DEVELOPMENT PROGRAMME

Charged for change:

The case for renewable energy in climate action

July 2025

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Acknowledgements
This report was authored by United Nations Development Programme (UNDP), the University of Denver's Pardee Institute and Octopus Energy.

From UNDP, Chibulu Luo, Global Energy and Climate Change Advisor at UNDP's Climate Hub, led the development and authorship of the report. Additional review and contributions were provided by the following UNDP colleagues: Amal Aldababseh, Monica Andrade, Meral Mungan Arda, Lisa Baumgartner, Jennifer Baumwell, Rebecca Carman, Aang Darmawan, Catherine Diam-Valla, Elif Duygun, Lorenzo Eguren, Ecem Ersoy, Jordan Fast, Guillermo Fernandez, Yevgen Groza, Stephen Kansuk, Christian Lopez, Fungai Matura, Gianluca Merlo, Maria Moz-Christofoletti, Geoffrey Omedo, Edvard Orlic, Josh Oxby, Alexandra Prodan, Luis Rivera, Mario Rodas, Katya Soegiharto and Ying Zhang. Many thanks are also extended to Riad Meddeb, Director of UNDP's Sustainable Energy Hub, and the Sustainable Energy Hub team for their additional review and feedback. And finally, to Cassie Flynn, Director of UNDP's Climate Hub, for providing guidance on the report's overall development.

At the Pardee Institute, the research team was led by Deva Sahadevan, Mohammod T. Irfan and Jonathan D. Moyer, with contributions from Yutang Xiong, Ethan Sullivan, Collin J. Meisel, Julia Frangul, Taylor Hanna, Omar Aittakalla, José Solórzano, Abdelrahman Ibrahim, Kexin Shang, Norah Shamin and Barry B. Hughes. The Pardee team also led the modelling of the three scenarios discussed in the report, using the International Futures (IFs) tool. From Octopus Energy, Emily Beynon and Charlie Mason provided detailed reviews and contributions.

Finally, we extend our gratitude to the following experts in energy systems, whose peer review and thoughtful feedback further enriched our overall analysis: Shonali Pachauri (Principal Research Scholar, International Institute for Applied Systems Analysis – IIASA) and Steve Pye (Professor of Energy Systems, University College London).

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About this publication

This product was developed by the University of Denver's Pardee Institute, Octopus Energy and UNDP under the Climate Promise by the Pledge to Impact Programme. Delivered in collaboration with a wide variety of partners, the initiative has supported over 120 countries to enhance and implement Nationally Determined Contributions (NDCs) under the Paris Agreement. Pledge to Impact is generously supported by the governments of Germany, Japan, United Kingdom, Sweden, Belgium, Spain, Iceland, The Netherlands, Portugal and other UNDP core contributors. This programme underpins UNDP's contribution to the NDC Partnership.

Citation: Sahadevan, D., Irfan, M. T., Luo, C., Moyer, J. D., Mason, C., & Beynon, E. (2025). Charged for change: The case for renewable energy in climate action. UNDP; Pardee Institute for International Futures; Octopus Energy.

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Contents

Acronyms

CF	capacity factor
CO_2	carbon dioxide
COP	Conference of the Parties
DRE	decentralized renewable energy
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
$GtCO_2$-eq	gigatonnes of carbon dioxide equivalent
HDI	Human Development Index
HIC	high-income country
IAM	integrated assessment model
IEA	International Energy Agency
IFs	International Futures
IRENA	International Renewable Energy Agency
$KtCO_2$-eq	kilotonnes of carbon dioxide equivalent
kWh	kilowatt hour
LCOE	levelized cost of electricity
LIC	low-income country
LT-LEDS	Long-Term Low-Emissions Development Strategy
LMIC	lower middle-income country
MER	market exchange rate
$MtCO_2$-eq	million metric tonnes of carbon dioxide equivalent
MWh	megawatt hour
NDC	Nationally Determined Contribution
NZE	Net Zero Scenario
OECD	Organisation for Economic Co-operation and Development
ppm	parts per million
PPP	purchasing power parity
PV	photovoltaic
RA	Renewable Acceleration scenario
RA+SDG	Renewable Acceleration + SDGs scenario
R&D	research and development
SDG	Sustainable Development Goal
TOE	tonne of oil equivalent
TWh	terawatt hour
UMIC	upper middle-income country
UNDP	United Nations Development Programme
VRE	variable renewable energy

Executive summary

A world powered by renewables is not only possible—it can also be more affordable and better for people and the planet.

Yet today, the world faces a dual challenge: advancing human well-being while mitigating the environmental consequences of fossil fuel-driven development. Decades of dependence on fossil fuels have supported various aspects of human development while also driving significant climate change. Achieving a balance between meeting human needs and preserving the environment requires a new direction—one that aligns development with a just transition that limits global temperature rise to 1.5°C.

Ambitious renewable energy and energy efficiency targets and actions are widely recognized for their development benefits. But what if these targets were made even more ambitious and supported by broader policy measures that facilitate a just transition? What would be the quantifiable benefits for both climate and development?

This report quantifies the benefits of greater ambition, showing how scaling up renewable energy and energy efficiency serves as a fundamental driver of development – supporting critical infrastructure, services and outcomes in key areas such as health, education and agriculture, particularly in societies that have been left behind. Yet as climate change intensifies, energy systems are becoming more vulnerable. Rising temperatures and changing climatic conditions are already disrupting renewable energy generation in many countries, and undermining the reliable delivery of electricity for essential services.

The evidence is clear: when climate commitments are paired with a coordinated and climate-smart policy approach, one that diversifies energy sources, builds resilience and addresses socio-economic needs, clean energy expansion is transformative. We make the case for policymakers to set ambitious and resilient renewable energy and energy efficiency targets in their national climate plans under the Paris agreement, or Nationally Determined Contributions (NDCs) for a more sustainable, resilient and equitable future.

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Our **Base Case** scenario paints a stark picture of the future under current climate policies—a path that is both unsustainable and unjust. This trajectory unfairly burdens those that are least responsible for the climate crisis. By 2060, if we continue this course, only about half of the global energy system will be powered by renewables—an improvement, but not nearly enough to meet global climate goals. At the same time, 400 million people will lack access to electricity, and 700 million will lack access to clean cooking, highlighting persistent energy inequality. The broader human development impacts are equally severe: 380 million people will remain in extreme poverty, 240 million will face undernutrition, and 750 million will still lack access to safe water and sanitation. While these trends show modest progress compared to today, they come at the cost of accelerating climate change, with global temperatures rising by 2.6°C by 2060 under this scenario.

Exploring a different future, we model an alternative scenario with high renewable energy ambition, further impacting climate and development outcomes. Our **Renewable Acceleration (RA)** scenario simulates a world where countries integrate ambitious renewable energy and energy efficiency targets into their climate plans. This allows us to assess what implementation of these commitments means—not just for emissions reductions, but for human well-being, economic growth and climate resilience.

In the **RA** scenario, the global share of renewable energy grows from 7.6 percent in 2024 to 87 percent by 2060, bringing the world closer to a 1.5°C future.[1] Beyond mitigating environmental risks, this transformation delivers modest economic and social benefits, including universal electrification and halving the gap in clean cooking access relative to the **Base Case**. The scenario also projects a US$1.3 trillion increase in gross domestic product

1 **Throughout this analysis, references to the 'share of renewables' or the 'share of a particular source' pertain to its contribution within the primary energy production mix (i.e. the overall energy mix), rather than the electricity generation mix.** This distinction is important because fossil fuel sources often serve multiple end-uses—including electricity generation, heating and transportation—whereas the majority of energy produced from renewable sources (e.g. solar, wind, hydro) is typically in the form of electricity. Since the International Futures (IFs) model does not disaggregate energy use by end-use sector or final energy form, we base our calculations on total primary energy production. The 1.5°C target also refers to limiting the rise in global average temperature to 1.5°C above pre-industrial levels, as set by the Paris Agreement to avoid the most severe impacts of climate change.

(GDP) and 23 million fewer people living in extreme poverty compared to the **Base Case** by 2060. However, despite these gains, 232 million people will still face malnutrition, and 620 million will lack access to safe water and sanitation.

A better and more just world is also within our reach. In the world of **Renewable Acceleration + SDGs (RA+SDG)**, renewable energy expansion catalyses a virtuous cycle of development, where ambitious climate policies align with Paris Agreement targets while simultaneously advancing the Sustainable Development Goals (SDGs). Realizing this scenario requires additional prioritization of policies that improve human development in synergy with renewable energy expansion in the **RA** scenario. In the **RA+SDG** world, an enhanced scenario ensues—universal electricity and clean cooking access is achieved, 193 million fewer people live in extreme poverty, 142 million fewer facing malnutrition and 550 million more gaining access to safe water and sanitation relative to the **Base Case** in 2060.

We present a global pathway that aligns human development with climate action, using the International Futures (IFs) model—a robust, quantitative model—to inform NDC commitments. We underscore the deep interconnections between human and natural systems, emphasizing that renewable energy targets must be complemented by integrated and SDG-aligned policies in health, education and social inclusion. Our acceleration scenarios (**RA** and **RA+SDG**) offer a framework to explore what is needed to rapidly scale up renewable energy production, in line with the sustainable energy priorities outlined in the first global stocktake of the Paris Agreement, which emphasizes the urgent need to phase out unabated fossil fuels and accelerate the global deployment of renewables. Model results show that aligning renewable energy expansion with a 1.5°C pathway accelerates human development.

The share of renewables in the energy mix is forecast to rise to

87-89 percent

in 2060, under acceleration scenarios.

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Purpose and limitations of the work

This report explores potential pathways for integrating renewable energy into national energy mixes, illustrating three scenarios that aim to balance environmental and human development objectives through 2060, as projected relative to the International Futures Model (hereinafter, the "IF model"). The analysis offers decision makers a range of potential futures to inform strategic priorities, rather than prescribing specific policy directions. It models predefined targets, like universal electrification or alignment with global stocktake outcomes. This is achieved by presenting assumptions about what constitutes desirable future outcomes and exploring the potential impacts of achieving them. The scenarios are designed to inform alternative long-term policy directions, evaluating how interventions in energy and environmental systems impact sectors like agriculture and the broader economy. For example, climate change, driven by carbon emissions, is modeled in IFs and assessed for its effects on global temperatures, food security and broader developmental effects. These changes are shown to exacerbate inequality and hinder economic growth, especially in developing countries dependent on climate-sensitive sectors.

This study's focus is limited to renewable technologies (excluding cooling), primarily solar, wind, hydro and geothermal, with an emphasis on solar and wind due to their projected rapid global growth. While socio-economic interventions across scenarios influence population growth, it is not explicitly modeled. Rather, the model dynamically incorporates demographic changes from changing aspects of other sub-models within IFs. For instance, the **Base Case** scenario forecasts continuously rising populations based on demographic changes, particularly in Africa. The analysis acknowledges the role of critical mineral reserves and the importance of international cooperation in supporting infrastructure development, technology transfer and financial mechanisms for accelerating renewable energy deployment. However, due to the IF's predefined assumptions and scope conditions, it does not address the resource curse or the potential impact of renewable energy expansion on mineral availability or environmental externalities in specific resource-rich regions.

It is also important to note that this analysis does not suggest that developing economies should adopt similar energy transition strategies as high-income countries. Strategies around energy transition are a policy matter that must reflect each country's unique context, lived reality, and development priorities. While the model highlights the theoretical potential of regions to achieve specific energy mixes, these outcomes are intentionally generalized, and practical results will vary based on local conditions. The case studies presented reflect these distinctions, acknowledging that no single approach will fit all regions. Further quantitative details of this modeling exercise are provided in the Annex sections.

Key findings

See Table 1 and Figure 1 to explore these scenarios.[2,3]

1. The RA+SDG scenario fosters a virtuous cycle of development that improves outcomes for both people and planet.

By integrating renewable energy investments with holistic policies in agriculture, health, education, governance and infrastructure, this scenario delivers a **triple-win impact**—advancing energy access, human development and climate benefits. Compared to the **Base Case**, this pathway achieves universal electricity and clean cooking access, boosts global GDP by $48 trillion, increases per capita income by $6,000, lifts an additional 193 million people out of extreme poverty and eliminates undernutrition for 142 million individuals by 2060—all within a 1.5°C-aligned future.[4]

Modelled findings from the **RA+SDG** scenario compared to the **Base Case**

900 million
more people gaining access to clean and improved cooking solutions

193 million
fewer people in extreme poverty

142 million
fewer people facing malnutrition

373 million
more people gaining access to electricity, nearing universal access

19% to 40%
increase in agricultural productivity among low and middle income countries

$48 trillion
boost to global GDP

2 Also refer to Annex 1 and 2 for the detailed list of model parameters and scenario assumptions (as modelled in IFs).

3 While scenarios are modelled at the global and regional levels, findings are also presented for Ecuador, Indonesia, Nigeria and Türkiye in Section 5.

4 While the Paris Agreement references net-zero greenhouse gas emissions by or around mid-century, the IFs model primarily focuses on energy/fossil fuel use-related carbon dioxide emissions. The model projects a significant decline in CO_2 emissions, nearing zero by 2060, though it does not fully account for non-CO_2 greenhouse gases.

2. The RA+SDG scenario is particularly transformative for emerging markets, bridging long-standing development gaps.

Compared to the **Base Case**, this scenario drives rapid poverty reduction, reducing extreme poverty rates in low-income countries (LICs) from 42 percent in 2024 to 7 percent by 2060, while ensuring universal electricity access. Structural improvements in governance, infrastructure and targeted climate financing allow these nations to break free from emission-intensive energy systems and transition towards sustainable solutions. Investments in agricultural efficiency, equitable calorie distribution and food security contribute to a 70 percent decline in malnutrition rates in LICs. By 2060, **RA+SDG** delivers real economic and social gains across our country case studies as well (refer to Section 5). Ecuador, Indonesia, Nigeria and Türkiye source 80–94 percent of their energy from renewables, lifting millions out of poverty and positioning these economies closer to achieving the SDGs.

3. Accelerating renewable energy is not only cleaner, but also economically viable—though it requires substantial investment.

Under current policies, renewable investments grow only moderately while fossil fuel spending persists into the 2030s. Our **RA and RA+SDG** scenarios demonstrate that to meet Paris-aligned targets, average annual renewable investments must rise to $2.5–$3.4 trillion between 2024 and 2050, compared to $1.8–$1.9 trillion in the **Base Case**. Front-loaded capital expenditures in these scenarios drive a 30–35 percent boost in renewable power generation investments by the 2040s, while fossil fuel investments decline by nearly 50 percent. By 2060, relative to the **Base Case**, the **RA+SDG** scenario yields an estimated $20.4 trillion in cumulative cost savings (2024–2060), enabled by $8.9 trillion from efficiency improvements and $11.5 trillion from declining renewable costs.[5]

5 These savings are estimated by comparing renewable investments with two alternative **RA+SDG** scenarios: one where economy-wide energy efficiency is held at the **Base Case** level and another where the levelized cost of electricity (LCOE) of renewables remains at the **Base Case** level, while all other factors remain unchanged. In the **RA** scenario, efficiency improvements will result in $8.1 trillion in savings, while declining renewable costs will contribute $10.2 trillion in savings.

4. Achieving ambitious renewable energy targets within climate policies is critical to meeting global climate commitments.

RA and **RA+SDG** scenarios correspond with the global renewables and energy efficiency pledge,[6] in support of the UAE consensus and first global stocktake. Both scenarios project nearly triple the renewable energy capacity from 3,700 GW in 2024 to 10,500 GW in 2030—almost reaching the global target of 11,000 GW (IEA, 2024a; 2024b). Energy intensity declines by 50 percent, and annual energy efficiency improvements double from 1.9 percent in 2024 to 4.1 percent in 2030.[7] These measures limit global warming to below 1.8°C under **RA** and cap it at 1.5°C under **RA+SDG** by 2060.

6 The Global Renewables and Energy Efficiency Pledge, declared at the 28th Conference of Parties (COP 28) in the Dubai in November 2024.

7 IFs assumes baseline reductions in energy intensity based on projected improvements in living standards under existing policies. The **RA** and **RA+SDG** scenarios incorporate additional energy intensity reductions, particularly in high-emission countries, as part of a deliberate policy and technological shift towards more efficient energy consumption. Efficiency improvements in practice stem from various sources, including the adoption of energy-efficient appliances, electrified transportation, industrial process optimization and behavioural shifts in energy use. While IFs does not model sector-specific pathways, literature suggests that these areas are key drivers of energy efficiency gains.

Tripling renewable energy

Renewable capacity additions under the **RA** and **RA+SDG** scenarios increase by **three times** from

3,700 GW in 2024 — to — **10,500 GW** in 2030

This trajectory is in line with the global stocktake, which calls for global renewable capacity to increase to 11,000 GW by 2030 to meet climate goals.

Doubling energy efficiency

Energy efficiency improvements are projected to **double** in both **RA** and **RA+SDG** scenarios, from

1.9% in 2024 — to — **4.1%** in 2030

Global temperature targets

Global warming is limited to **1.5°C** in the RA+SDG scenario meeting the Paris Agreement target.

It is limited to under **1.8°C** in the RA scenario.

5. Assuming key structural barriers, including infrastructure, regulatory and political challenges, are effectively addressed through robust reforms, the RA+SDG scenario further accelerates renewable energy deployment.

Currently, these structural barriers drive up investment risks in most emerging economies, through currency volatility, unreliable grid integration and a shortage of skilled workers, raising the cost of capital and deterring investment. The **RA+SDG** scenario envisions a paradigm shift where governments clear these obstacles via broader economic and institutional reforms, enabling countries to foster a transformative industrialization model that decouples economic growth from fossil fuel dependency in emerging economies.

6. As countries revise their NDCs, setting clear and ambitious renewable energy targets can serve as a catalyst for both climate and development gains.

Embedding these targets within NDCs—alongside supportive policies and investments—can enable countries to fully realize the social and economic benefits of the energy transition. This includes financial mechanisms to support energy access and inclusion, strengthened institutional capacity, investment in workforce skills, and alignment with social and economic development priorities. The **RA+SDG** scenario illustrates how a comprehensive policy approach—embedded in an SDG framework—can chart a path of increased renewable capacity, reduced poverty and undernutrition, and energy system transformation that is aligned with a 1.5°C pathway. Realizing this potential involves coordinated efforts to shift investment from fossil fuels to renewables, mobilize and distribute climate finance equitably, modernize regulatory frameworks, electrify end-use sectors, enhance grid flexibility and strengthen institutions. Without such integrated actions, there is a risk that emissions reductions and economic growth proceed without meaningful progress on poverty alleviation, energy justice or inclusive development.

Table 1: Effects on development indicators across scenarios in 2024, 2035 and 2060

Indicator	Unit	2024	2035			2060		
			Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Renewable production+	TWh	11,800	24,400	44,000	45,400	112,400	148,100	165,800
Renewable capacity*	GW	3,700	8,300	15,100	15,200	45,000	77,000	77,200
GDP at market exchange rate (MER)	Trillion US$	96	130	131	135	229	231	277
GDP per capita, PPP	Thousand US$	17.2	20.2	20.3	20.9	28.2	28.4	33.9
Human Development Index (HDI)	0–1 scale	0.73	0.75	0.75	0.76	0.80	0.81	0.84
Poverty headcount	Millions (%)	720 (8.8)	640 (7.2)	630 (7)	520 (5.9)	380 (3.8)	360 (3.6)	190 (1.9)
Agricultural production	Million metric tonnes	13,000	14,700	14,700	15,100	16,700	16,800	15,900
Malnourished headcount	Millions (%)	620 (7.6)	490 (5.5)	490 (5.4)	330 (3.7)	240 (2.4)	230 (2.3)	95 (0.9)
Access to safely managed water	%	71	75	75	77	84	84	89
Access to safely managed sanitation	%	58	62	62	65	71	71	78
Electricity access	%	91	92	94	96	96	99	100
Population without electricity access	Millions	700	720	530	370	400	90	20
Average education years	Years	8.8	9.3	9.3	9.4	10.3	10.3	10.8
Traditional cookstove use	Billions (% of households)	2 (21.5)	1.5 (16.9)	1.3 (15.5)	0.4 (3.9)	0.9 (8.6)	0.7 (7.1)	0 (0)

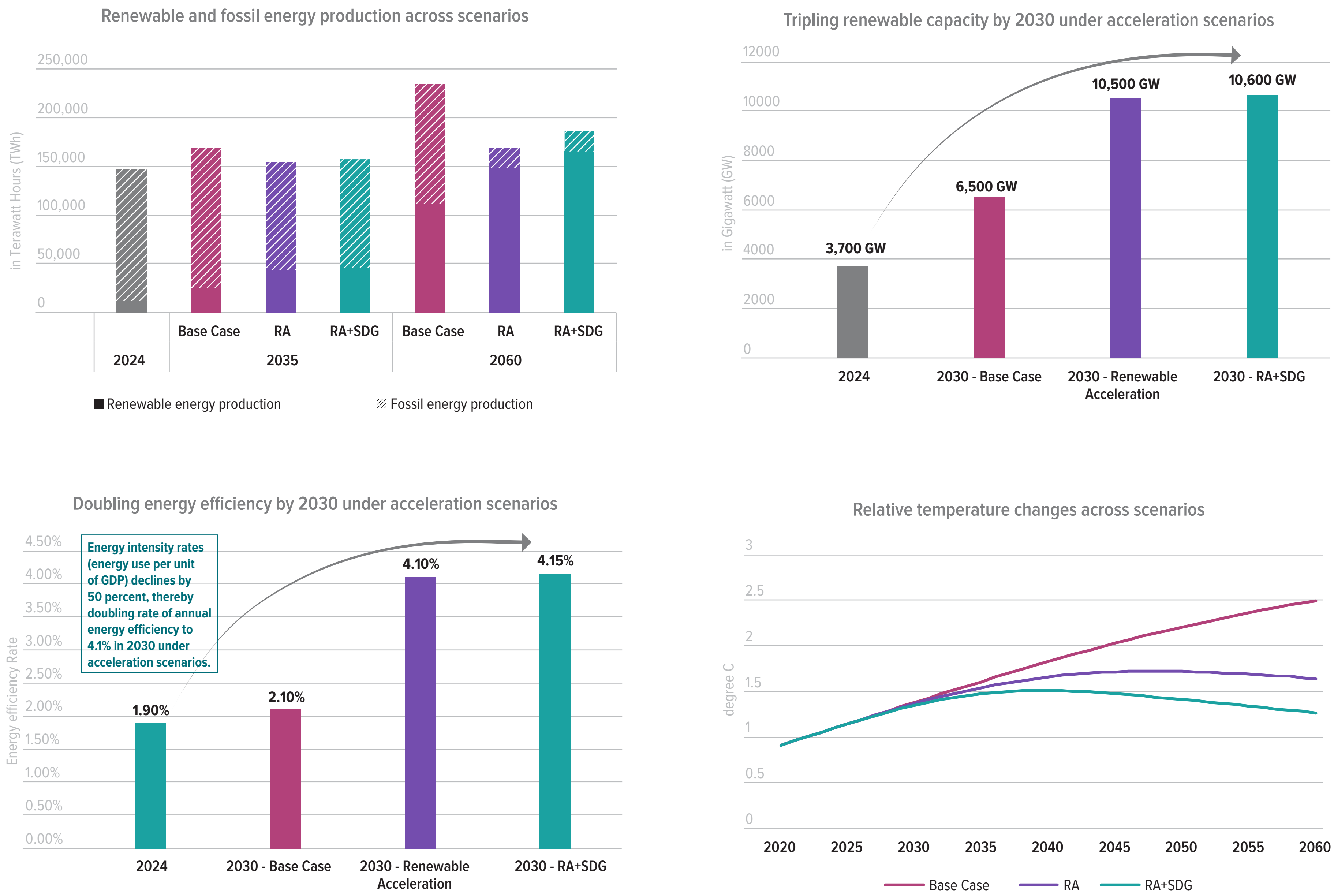
Source: IFs v8.32. Figures have been rounded.

+ Global renewable energy production in IFs is based on the aggregation of primary domestic renenewable energy production across all countries. Also refer to Table 3.

* Since the IFs model does not directly forecast renewable energy capacity, we estimate it by using renewable energy production forecasts in combination with assumed capacity factors for each energy type—based on ranges commonly reported in the literature—and the number of hours in a year. A detailed explanation of this calculation can be found in Annex 3: Methodology notes (Section 3: Computing renewable capacity in IFs).

** The reported figures on traditional cookstove usage are expressed in billions of people rather than households, unless explicitly stated otherwise. While IFs originally computes this measure at the household level, we present it in terms of population to align with baseline data from sources such as UNDP (2025). This approach ensures consistency, as global estimates indicate that approximately 2.1 billion people currently lack access to clean cooking fuels and technologies.

Figure 1. Snapshot of scenario findings, including alignment with outcomes of the first global stocktake



Source: IFs v8.32.

Section 1

Introduction

At the forefront of global climate policy is the urgency to accelerate the rate of renewable energy development to meet climate goals.

The first global stocktake, a landmark decision at the 28th Conference of Parties (COP28) in 2023, sets out the transformative renewable energy pathways needed to achieve the Paris Agreement's goal to limiting global temperature rise to well below 2°C, with efforts to cap warming at 1.5°C (UNFCCC, 2015). The decision calls for tripling global renewable energy capacity and doubling the annual rate of energy efficiency improvements by 2030, while also emphasizing the urgency of a rapid transition away from fossil fuels and the phased elimination of fossil fuel subsidies.[8] Achieving these targets underscores the transformative role of renewable energy as key to decarbonizing the global energy system, keeping the 1.5°C goal within reach and advancing human development.

Such a transformation depends on achieving a just transition—one that carefully balances climate action, human development and economic growth. To ensure no one is left behind, this transition must prioritize fairness, inclusivity and equity across all regions and populations (UNDP, 2022). **In response, this study examines how scaling up renewable energy and energy efficiency within climate policies as well as broader reforms can drive both development and climate progress. It addresses the critical challenge of expanding renewable energy while ensuring economic growth, productivity and human well-being, demonstrating that greater ambition in clean energy can unlock significant gains for both people and the planet.**

8 Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on its fifth session, held in the United Arab Emirates from 30 November to 13 December 2023.

Historically, economic growth in high-income countries (HICs) has been closely linked to the consumption of fossil fuels, thereby worsening climate outcomes. G7 countries—representing the world's largest and the most advanced economies—were responsible for 18 percent of global power sector emissions in 2024.[9] Meanwhile, several low- and middle-income countries face the dual challenge of realizing economic growth and industrialization goals while also addressing climate impacts. These priorities often stand in direct conflict, creating a tension that demands innovative and inclusive strategies to ensure development is both sustainable and equitable. Addressing these competing demands requires transformative frameworks that align climate action with broader human development priorities.

Our analysis addresses two research questions:

1. What effects do ambitious renewable energy targets in climate policies have on long-term development and climate outcomes?
2. What are the relative costs of these scenarios, and how do the benefits of renewable energy compare to the **Base Case**, which represents a more fossil-fuel-intensive development path?

While the relationship between renewable energy and human development is complex and multifaceted, wide-ranging evidence already shows that renewables can positively influence GDP, education and public health (refer to background literature in the Annex 5). Unlike fossil fuels, renewables generate sustained economic dividends by reducing energy price volatility, enhancing domestic energy security and creating jobs in high-growth industries. Expanding renewable energy production can enhance economic productivity, energy access, and contribute to broader social outcomes, including improvements in educational attainment and public health (Nguyen et al. 2023; IEA, 2024c. Also refer to Annex 5 for additional background literature). However, these benefits are not universal and hinge on country-specific policy environments to flourish. Furthermore, United Nations Development Programme (UNDP) analysis shows that all NDCs supported as part of UNDP's Climate Promise include energy-related targets, including renewable energy production, energy efficiency and energy access. However, these targets are often not embedded within a broader development framework that demonstrates their contributions to multiple SDGs.

To analyse these dynamics, we use the International Futures (IFs) modelling tool to explore three potential future scenarios with varying levels of renewable energy ambition and broader ambitions for human development: the **Base Case**, **Renewable Acceleration (RA)** and **Renewable Acceleration + SDGs (RA+SDG)**.

9 Ember Data, accessed May 7th, 2025.

The **Base Case** scenario reflects current climate policies and priorities. Our findings show that such a pathway is unsustainable, pushing global warming towards 2.6°C and threatening progress on energy access, education, safe water, sanitation and nutrition—potentially pushing hundreds of millions into extreme poverty (see Table 3). Relatedly, UNEP's Emissions Gap Report (2024) already indicates that current NDC targets are insufficient to meet the Paris Agreement's goal of limiting global temperature rise to below 2°C. A failure to do so puts the world on track for a temperature increase of 2.6–3.1°C over the course of the century (UNEP, 2024). Authors also state that NDCs for 2035, at minimum, must call for emissions reductions of 37 percent and 57 percent relative to 2019 levels to be compatible with 2°C and 1.5°C, respectively.

In response, **RA** and **RA+SDG** scenarios—that also expand on renewable energy projections from a previous report[10]—show that higher renewable energy ambition in climate commitments can keep the 1.5°C target within reach, while also delivering broader development gains. The **RA+SDG** scenario goes even further, illustrating how ambitious renewable energy targets, with synergistic policy measures in health, education and governance (Table 2), can unlock even greater socio-economic benefits.[11]

10 Published in November 2024, the **Advancing the SDG Push with Equitable Low-Carbon Pathways** report incorporated energy transition strategies into the 'SDG Push', creating the 'SDG Push 3.0' scenario.

11 This scenario structure builds on related studies developed by UNDP and the Pardee Institute (e.g. Abidoye *et al*., 2021, 2024; Hughes *et al*., 2020; Sahadevan *et al*., 2023) that have explored the broad-based implications of various integrated policies on long-term human development outcomes.

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Section 2

Scenarios and narratives

We explore three distinct scenarios to assess the long-term implications of renewable energy development and its interplay with human development and climate goals.

We use the IFs model to project energy production and consumption across 188 countries (including UNDP Climate Promise-supported countries) and the costs and outcomes of both fossil fuel and renewable energy development.

It is important to note that our scenarios do not incorporate specific renewable energy targets in current NDCs, given the variation across countries and limitations in data availability, including differences in how quantitative targets are reported. Instead, the **Base Case** scenario aims to reflect current climate policies. The 'acceleration' scenarios (**RA** and **RA+SDG**) set more ambitious targets to guide countries in shaping future commitments, offering a framework for scaling renewable energy ambition at the national level. We then assess the findings through country case studies in Ecuador, Indonesia, Nigeria and Türkiye.

Box 1 and Table 2 illustrate the narratives of these scenarios. Refer to the Annex 1 for the full list of outcome indicators.

Box 1: Conceptualized scenarios used for analysis and their narratives

The **Base Case** scenario reflects a business-as-usual trajectory of global energy development based on the continuation of existing policies, market dynamics and technological trends. Here, the transition to renewable energy is slow but steady, with fossil fuels continuing to dominate the global energy mix for the following decades. While renewable energy adoption increases gradually, many countries, especially LICs and lower middle-income countries (LMICs)—face challenges due to limited access to clean energy technologies and capital.

By contrast, the **RA** scenario simulates an accelerated expansion of renewable energy relative to the **Base Case**, driven by exogenous policy interventions that increase investments in renewables (see Annex 2). These reflect the falling costs of renewable energy (see section on Investments) and complementary policies to promote the scale-up of solar, wind and hydroelectric power as well more efficient use of energy.[12] The scenario also assumes that substantial financial and technological support is provided to developing countries to ensure they can bypass traditional fossil fuel dependency and directly embrace clean energy solutions. This scenario represents a world where action is primarily focused on addressing climate impacts and is most closely aligned with the ambition of the Paris Agreement, achieving a more sustainable energy future. The **RA** scenario offers a promising outlook towards decarbonizing energy systems through investments in renewables and energy efficiency in an inclusive and equitable manner, but progress towards broader human development outcomes, like economic growth, poverty and undernutrition reduction, and access to health, education and other services, is more moderate.

Addressing this gap, the **RA+SDG** scenario represents a holistic, policy-oriented pathway that balances equity, governance and sustainability to achieve SDGs within planetary boundaries. This scenario includes equitable and just transition measures as the **RA** scenario, while adding development interventions that enable countries to effectively manage the transition, leveraging these strategies as key drivers of human development, especially in historically underserved regions.[13] Consequently, in integrated models like IFs, interventions that improve education, health or governance also raise energy use through broader social and economic activity. These development spillovers help explain modest increases in overall energy production in more ambitious policy scenarios, even as the energy mix continues to shift toward renewables and away from fossil fuels. Refer to Table 3 to explore the differences in energy use and development outcomes across the scenarios.

12 While efficiency improvements can stem from various sources—including energy-efficient appliances, electrified transport, industrial process optimization and behavioural changes—the model does not explicitly attribute gains to any single mechanism.

13 Refer to Annex 1 and 2 for a detailed list of model assumptions and scenario drivers.

Table 2. Conceptualized scenarios used for analysis and their narratives

Parameter	Base Case	Renewable Acceleration (RA)	Renewable Acceleration + SDG (RA+SDG)
Rationale and assumption based on author analysis and IFs model capabilities	A business-as-usual expansion of renewables that assumes no significant advancements in current climate policies. Cost trajectories are assumed to follow business-as-usual trends where technological learning and economies of scale are not assumed.	An inclusive expansion of renewables through additional investments and interventions. Also assumes ambitious renewable energy targets in climate policies. Cost trajectories are assumed to follow technological learning trends, making renewables up to 50–60% cheaper to produce.	An inclusive expansion of renewables through additional investments and interventions. Also assumes ambitious renewable energy targets in climate policies and complementary SDG policies. Cost trajectories are assumed to follow technological learning trends, making renewables up to 50–60% cheaper to produce.
Fossil fuels	Coal, oil and gas production grows through 2040 before declining. Share of fossil fuels in production remains around 51.2% in 2060.	Coal, oil and gas production declines from 2024. Share of fossil fuels declines to 12% in 2060.	Coal, oil and gas production declines from 2024. Share of fossil fuels declines to 11.5% in 2060.
Renewables	Moderate growth in renewable sources like solar, wind, geothermal, hydro and other renewables. Renewable share of production rises to 47.1% by 2060. No changes in renewable technology advancements. Moderate decline in levelized costs of electricity production from renewables.	Solar, wind and geothermal production accelerates through 2060 while hydro remains relatively stable though 2060. Renewable share of production rises to 86.7% by 2060. High-income countries (HIC) lead the charge in technological advancements in renewables. Faster decline in levelized costs of renewables.	Solar, wind and geothermal production accelerates through 2060 while hydro remains relatively stable though 2060. Renewable share of production rises to 87.7% by 2060. High-income countries lead the charge in technological advancements in renewables. Faster decline in levelized costs of renewables.
Energy efficiency	Energy intensity remains high along a business-as-usual trajectory of efficiency improvements. High-income countries continue to consume high levels of energy per capita in 2060.	Energy intensity rates decline by 50%, doubling energy efficiency. Energy use patterns converge as low-income countries increase energy use by 2060.	Energy intensity rates decline by 50%, doubling energy efficiency. Energy use patterns converge as low-income countries increase energy use by 2060.
Energy access	Universal access to electricity is not achieved through 2060. No additional expansion of the power grid. Persistent reliance of traditional cookstoves for cooking.	Universal electricity access achieved by 2050. Power grid expansion allows variable renewable energy (VRE) share to rise to 80% threshold. Clean cooking solutions expand with improved household electricity access.	Universal electricity access achieved by 2050. Power grid expansion allows VRE share to rise to 80% threshold. Elimination of use of traditional cookstoves – full transition to clean cooking solutions.
Development	No exogenous development policy interventions.	No exogenous development policy interventions.	Complementary SDG investments to improve outcomes in infrastructure, education, health, family planning and research and development (R&D). Improved governance reforms. Progressive carbon taxation levied on high-income and upper middle-income countries (UMIC). Reforestation measures to increase carbon sink capacity.

Section 3

Findings and key insights

Finding 1

Current climate policies are falling short of Paris Agreement goals and the SDGs, slowing the shift to renewables and pushing the world towards a 2.6°C future that leaves millions behind.

The **Base Case** scenario, which simulates current climate policies and development trends, projects incremental progress but exposes deep gaps in achieving a sustainable and equitable future. Under this scenario, by 2060, 380 million people will still live in extreme poverty, 240 million will face undernourishment, 400 million will lack access to electricity and 750 million will lack access to safe water and sanitation services. While renewable energy is expected to reach 50 percent of the energy mix, this shift remains insufficient to meet the Paris Agreement goals. Global temperatures are projected to rise to 2.6°C by 2060 and 3°C by the end of the century, with emissions peaking at 10.5 billion tonnes in 2039 before declining to 8.4 billion tonnes by 2060. Despite a reduction in fossil fuel reliance, atmospheric carbon dioxide (CO_2) levels will remain dangerously high, and traditional cookstove use will persist, sustaining health and economic burdens for millions. Explore the **Base Case** and other scenario findings in Tables 3 and 4, which provide a detailed breakdown of results across scenarios (Table 4 includes disaggregation by income and country groupings).

Table 3. Summary of global findings in 2024, 2035 and 2060 across scenarios*

	Indicator	Unit	2024	2035			2060		
				Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Energy**	Fossil fuel production	TWh	135,100	145,000	110,500	111,900	122,300	20,500	20,900
	Renewable production	TWh	11,800	24,400	44,000	45,400	112,400	148,100	165,800
	Share of renewables in energy mix	%	8	14	27	28	47	87	88
	Primary energy demand per capita	KWh/capita	19,000	20,000	18,400	18,700	23,900	16,700	18,700
	Electricity use per capita	KWh/capita	3,300	3,900	3,500	3,600	5,400	3,700	4,300
	Energy demand relative to GDP	MWh/ thousand US$	1.6	1.4	1.2	1.2	1.1	0.8	0.8
Environment	CO_2 in atmosphere	Parts per million	428	468	463	457	554	472	443
	Carbon emissions from fossil fuels	Billion tonnes of carbon***	9.6	10.3	7.6	7.7	8.4	0.7	0.7
	Global temperature relative to 1990	Celsius	1.1	1.6	1.5	1.5	2.6	1.7	1.3
	GDP at MER	Trillion US$	96	130	131	135	229	231	277
Development+	GDP per capita, PPP	Thousand US$	17	20.2	20.3	20.9	28.2	28.4	34
	HDI	0–1 scale	0.73	0.75	0.75	0.76	0.80	0.81	0.84
	Poverty headcount	Millions (%)	720 (8.8)	640 (7.2)	630 (7)	520 (5.9)	380 (3.8)	360 (3.6)	190 (1.9)
	Malnourished headcount	Millions (%)	620 (7.6)	490 (5.5)	490 (5.4)	330 (3.7)	240 (2.4)	230 (2.3)	95 (0.9)
	Agricultural production	Million metric tonnes	13,000	14,700	14,700	15,100	16,700	16,800	15,900
	Access to safely managed water	%	71	75	75	77	84	84	89
	Access to safely managed sanitation	%	58	62	62	65	71	71	78
	Electricity access	%	91	92	94	96	96	99	100
	Population without electricity access	Millions	700	720	530	370	400	90	20
	Average education years	Years	8.8	9.3	9.3	9.4	10.3	10.3	10.8
	Traditional cookstove use	Billions+ (% of households)	2 (21.5)	1.8 (16.9)	1.3 (15.5)	0.4 (3.9)	0.9 (8.6)	0.7 (7.1)	0 (0)

Source: IFs v8.32. Figures have been rounded. As IFs integrates data for these indicators from multiple recognized sources, a full list of sources is provided in Table A1, Annex 1

* IFs model is an integrated assessment tool in which various sub-models are interconnected through a combination of functional relationships and empirically grounded statistical links. The energy sub-model impacts economy by shaping patterns of energy demand and supply, which in turn affect multi-factor productivity and capital accumulation. Renewable energy production, for example, contributes to reduced greenhouse gas emissions and mitigated climate impacts, which then influence environmental and agricultural outcomes. These interconnected effects ripple through to broader development indicators. It is important to note that models like IFs are not designed to establish direct causal chains but rather to explore dynamic relationships and plausible future scenarios based on existing research and data. The development impacts presented in the table above reflect these integrated linkages, including both direct and indirect effects of the global energy transition. Additionally, population-related shifts here are also shaped endogenously through multiple interlinked variables within IFs. While demography is not the primary focus of this analysis, population changes are nonetheless indirectly influenced by scenario-specific interventions - particularly those related to education and socio-economic development.

** In IFs, energy production refers exclusively to primary energy. The model does not further disaggregate energy into secondary energy categories such as residential use, heating, electricity or industrial consumption. As a result, all representations in this analysis reflect final primary energy production.

*** IFs computes carbon emissions in billion tonnes of carbon. However, typically it is expressed in Gigatonnes of CO_2 ($GtCO_2$). Note: 1 billion tonne of carbon = 3.67 $GtCO_2$. Therefore, our baseline estimates of 9.6 billion tonnes is around 35 $GtCO_2$.

\+ The reported figures on traditional cookstove usage are expressed in billions of people rather than households, unless explicitly stated otherwise. While IFs originally computes this measure at the household level, we present it in terms of population to align with baseline data from sources such as UNDP (2025). This approach ensures consistency, as global estimates indicate that approximately 2.1 billion people currently lack access to clean cooking fuels and technologies.

Table 4. Heterogeneity of development outcomes across scenarios and country-groups

Indicator	Unit	Country group*	2024	2060		
			Baseline	Base Case	RA	RA+SDG
Carbon emissions from fossil fuels	Billion tonnes of carbon	OECD	3	1.8	0	0
		LIC	0.1	0.3	0	0
		LMIC	1.3	2.2	0.4	0.4
GDP at MER	Trillion US$	OECD	57	98	98.2	112
		LIC	0.6	5.4	5.7	7
		LMIC	8	42	43	54
GDP per capita, PPP	Thousand US$	OECD	46.3	77.1	77.2	87.8
		LIC	2	5.6	5.8	7
		LMIC	6.9	15.7	15.8	19
HDI	0–1 scale	OECD	0.90	0.95	0.95	0.98
		LIC	0.51	0.66	0.67	0.7
		LMIC	0.65	0.77	0.77	0.80
Poverty	Millions (%)	OECD	10 (0.7)	2.2 (0.2)	2.0 (0.1)	0.5 (0)
		LIC	330 (41.7)	230 (13.5)	210 (12.5)	120 (7.4)
		LMIC	350 (11)	140 (3.3)	138 (3.2)	65 (1.5)
Malnutrition	Millions (%)	OECD	5 (0.4)	1.4 (0.1)	1.4 (0.1)	0.3 (0)
		LIC	200 (25.6)	130 (7.6)	120 (7.5)	60 (3.7)
		LMIC	350 (11.2)	100 (2.2)	90 (2.2)	30 (0.8)

Indicator	Unit	Country group*	2024	2060		
			Baseline	Base Case	RA	RA+SDG
Agricultural production**	Millon metric tonnes	OECD	3000	3100	3000	2700
		LIC	470	990	1000	1200
		LMIC	3500	5100	5200	5500
Access to safely managed water	%	OECD	93	98	98	99
		LIC	25	54	55	64
		LMIC	60	83	83	89
Access to safely managed sanitation	%	OECD	87	95	95	98
		LIC	19	42	42	47
		LMIC	46	64	64	73
Electricity access	%	OECD	100	100	100	100
		LIC	47	84	95	100
		LMIC	92	97	100	100
Average education years	Years	OECD	12.1	13.2	13.2	13.6
		LIC	5.5	7.8	7.8	8.3
		LMIC	7.7	9.7	9.7	10.2
Traditional cookstove use	Million people	OECD	10	4	3	0
		LIC	600	490	370	0
		LMIC	1400	520	460	0

Source: IFs v8.32. Figures have been rounded.

* LICs and LMICs are compared against the OECD's 38 member countries, which primarily consist of HICs and UMICs. The OECD was selected as a reference group to highlight stark contrasts in baseline levels and scenario projections between these economies and LICs/LMICs. As a globally recognized organization, the OECD represents predominantly high-income economies with a very high Human Development Index (HDI).

** Agricultural production in IFs is further categorized by type: crops, meat and fish. As shown in the table, agricultural production in OECD countries remains relatively stable over time, with some decline in overall output across the **Base Case** and **RA/RA+SDG** scenarios. This reduction is primarily driven by decreased meat production, reflecting shifts in dietary consumption patterns and energy use changes in HICs. In contrast, agricultural production in LMICs and LICs increases relative to present levels, aligning with rising demand for these food sources. Higher agricultural productivity in the model helps mitigate food insecurity constraints, which are more pronounced in these country groups.

In the **Base Case** scenario, a slow transition to renewable energy is already taking place, where its share in the overall energy mix improves from 7.6 percent in 2024 to 47 percent in 2060. This is attributable to cost reductions in producing energy from sources like solar, wind and hydro that decline by 23–30 percent in 2060 relative to 2024 estimates.[14] However, fossil fuels remain dominant in many parts of the world. Oil, coal and gas production decline moderately by 2060 but continue to supply 51 percent of the world's energy demands, reflecting a continued reliance on these sources in regions where they are deeply embedded in economic structures.

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Inequitable energy access across regions particularly in the Global South - driven by factors such as inadequate infrastructure, incentives and derisking mechanisms - continues to constrain the prospects of universal electrification. Globally, 700 million people lack access to electricity in 2024,[15] of which 170 million reside in urban areas and 530 million in rural areas. It is projected that by 2060, 400 million people will still lack electricity access—mostly living in LICs and LMICs. While global electricity access rates increase from 91 percent in 2024 to 96 percent by 2060, LICs only see an increase from 47 percent in 2024 to 84 percent in 2060. Access to safely managed water and sanitation services is also projected to remain below 55 percent in LICs. In these countries, the shadow costs of weak governance not only slow down progress but also create bottlenecks that limit access to essential services that sustain human needs.

A persistent reliance on fossil fuels exacerbates climate impacts, driving atmospheric CO_2 concentrations from 428 parts per million (ppm) in 2024 to 554 ppm in 2060. Global carbon emissions continue to be on the rise until 2039, increasing from 9.6 billion tonnes of carbon in 2024 to 10.5 billion tonnes. Even by 2060, carbon emissions from fossil

14 A detailed discussion of levelized cost patterns across scenarios is found in the subsequent sections.

15 Refer to Annex 1 for data sources. Electricity and clean cooking data are based on World Bank development indicators, and model configurations for 2024 estimates will differ only slightly to those reported in the 2024 SDG 7 tracking report.

In the Base Case scenario, while steady growth signals improved living standards overall, it also reflects enduring structural inequalities where HICs continue to benefit disproportionately, reinforcing economic divides with LICs and LMICs. Without addressing these underlying disparities, current trajectories risk perpetuating inequality well into the future, rather than transforming it.

fuels remain around 8.4 billion tonnes—the majority contributed by HICs and UMICs. Temperature rises are also expected to surpass 1.5°C by 2033 and reach 2.6°C by 2060. Current climate policies, therefore, will not suffice to meet the goals outlined in the Paris Agreement. Not only do climate goals remain out of reach, but the continued reliance on solid fuels for cooking, affecting nearly a billion people by 2060, predominantly in LICs and LMICs, exacerbates both environmental and health burdens, highlighting the persistent inequities in access to clean energy solutions.

Global GDP is projected to increase from $96 trillion in 2024 to $229 trillion by 2060. Per capita income in LICs is projected to grow from $2,000 in 2024 to $5,600 in 2060, while HICs see an increase from $51,500 to $85,200 during the same period. While the Human Development Index (HDI) improves across all income groups, LICs are projected to reach only 0.6 by 2060—comparable to the current HDI levels of LMICs—whereas HICs, particularly Organisation for Economic Co-operation and Development (OECD) nations, approach near-perfect HDI scores. In the **Base Case** scenario, while steady growth signals improved living standards overall, it also reflects enduring structural inequalities where HICs continue to benefit disproportionately, reinforcing economic divides with LICs and LMICs shaped by historical and systemic imbalances. Without addressing these underlying disparities, current trajectories risk perpetuating inequality well into the future, rather than transforming it.

Extreme poverty rates also show gradual declines over the forecast horizon, with the number of people living below $2.15/day projected to fall from 720 million (8.8 percent of global population) in 2024 to 380 million (3.8 percent) in 2060—of which 96 percent (370 million) will reside in LICs and LMICs. Among the LICs and LMICs, extreme poverty rates fall from 41.7 percent in 2024 to 13.5 percent and from 11 percent in 2024 to 3.3 percent in 2060, respectively. This translates to 100 million fewer people in poverty in LICs and 210 million fewer in LMICs. Still, extreme poverty remains a persistent issue in 2060, and several countries fall short of eliminating poverty as per **Base Case** forecasts.

While resource access and health improve over time, significant gaps persist, not due to a lack of investment alone, but because of a missed opportunity to align climate, health, gender equity and economic development through a single

intervention. The baseline scenario highlights the broader implications of failing to seize this opportunity. As a result, malnutrition rates decline globally from 7.6 percent in 2024 to 2 percent in 2060, reflecting better food security. Safe water access expands from 71 percent of the global population to 84 percent by 2060, and access to safe sanitation grows from 58 percent to 71 percent. However, these gains are inadequate to meet universal needs. Nearly 950 million people are projected to still rely on traditional cookstoves burning solid fuels or kerosene by 2060 with over 95 percent of them in LICs and LMICs. This persistent reliance carries serious health risks, especially for women and young children, due to heightened exposure to respiratory hazards and associated mortality burdens. By 2060, 240 million people will still face malnutrition and 750 million will lack access to safe water and sanitation. In LICs, an estimated 130 million people, primarily in countries like Afghanistan, the Democratic Republic of the Congo, Ethiopia, Somalia and Yemen, are projected to remain malnourished, while nearly 100 million in LMICs, led by India and Nigeria, will continue to face severe food insecurity under the current policy landscape.[16]

16 While modest improvements in food security are observed globally, **Base Case** projections indicate that agricultural production in key regions—particularly South Asia and sub-Saharan Africa—fails to keep pace with rising demand. As a result, food insecurity persists, disproportionately affecting LICs and LMICs, where limited agricultural growth, supply chain inefficiencies and climate vulnerabilities exacerbate malnutrition. The sustained shortfall in food availability and affordability directly contributes to long-term health consequences, including high rates of stunting, micronutrient deficiencies and increased susceptibility to disease, ultimately undermining broader gains in human development.

Finding 2

Ambitious renewable energy targets in climate policies and NDCs can drive poverty reduction and economic growth, but holistic policies are needed to maximize benefits.

Accelerating renewable energy deployment in the **RA** scenario delivers significant development gains, including expanded electricity and clean cooking access, reduced emissions and economic growth. By 2060, renewables are projected to comprise 87 percent of the energy mix, helping cut carbon emissions, lower atmospheric CO_2 concentrations and limiting global warming to under 1.8°C by 2060. However, although the **RA** scenario achieves significant climate gains, it still falls short in addressing key human development challenges. By 2060, 360 million people remain in poverty, 230 million face malnutrition, and 620 million lack access to safe water and sanitation. The **RA** scenario shows that even though climate policies may set ambitious renewable energy targets, they alone are not enough to limit global warming to 1.5°C. Complementary measures, including financial mechanisms for energy inclusion, institutional capacity-building, skill development and integrated social policies, can help unlock the full socio-economic benefits of accelerated renewable energy deployment.

Driven by rising capital investments and declining levelized costs, renewable energy expansion accelerates rapidly in the **RA** scenario. Under this scenario, the share of renewables in the global energy mix is projected to increase significantly, reaching 87 percent by 2060. Energy production from renewable sources is forecasted to grow from 11,800 terawatt hours (TWh) in 2024 to 148,100 TWh in 2060—35,700 TWh above the **Base Case** projections for the same year. In contrast, the share of fossil fuels in the energy mix is projected to decline sharply, dropping from 87 percent in 2024 to 12 percent by 2060. Table 5 highlights the relative changes in energy production levels across nine sources, including fossil fuels, renewables and nuclear energy, under both the **Base Case** and **RA** scenarios.

The **RA** scenario is firmly grounded in the principles of energy equity and justice. It seeks to address global disparities in energy use by emphasizing the responsibility of high-emitters, particularly in HICs and UMICs, to take the lead. These nations are called upon to make substantial investments in renewable energy technologies and foster multilateral solutions that facilitate the transfer and trade of these advancements, ensuring that the benefits of renewable energy extend to all countries and regions by mid-century.

Globally, by 2060, the share of solar in the energy mix increases to 65 percent (compared to 2 percent in 2024) and wind increases to 17 percent (2 percent in 2024). On the other hand, by 2060 the share of oil declines to 2 percent (31 percent in 2024), gas to 3 percent (26 percent in 2024) and coal to 6 percent (30 percent in 2024). HICs and UMICs, led by China, are projected to dominate the production of renewable energy sources such as solar and wind through the forecast horizon. These countries also demonstrate significant shifts away from the production of fossil fuels, including oil, coal and gas.

Table 5. Projections of energy production by type of source across the Base Case and RA scenarios in 2024, 2030 and 2060 (in TWh)*

Indicator	2024	2030		2060	
		Base Case	RA	Base Case	RA
Oil	50,100	48,900	45,700	26,100	4,000
Gas	42,100	44,900	42,000	46,000	6,000
Coal	48,900	54,600	49,400	55,600	11,500
Hydro	4,800	5,000	4,800	5,700	3,300
Nuclear	8,300	7,900	7,300	4,400	2,300
Solar	2,400	5,400	10,500	78,500	116,000
Wind	2,600	4,900	6,400	29,300	30,200**
Geothermal	1,200	1,500	1,800	2,600	3,900
Other renewables	1,400	1,500	1,600	1,300	1,200***
Total	161,800	174,600	169,500	249,500	178,400

Source: IFs v8.32.

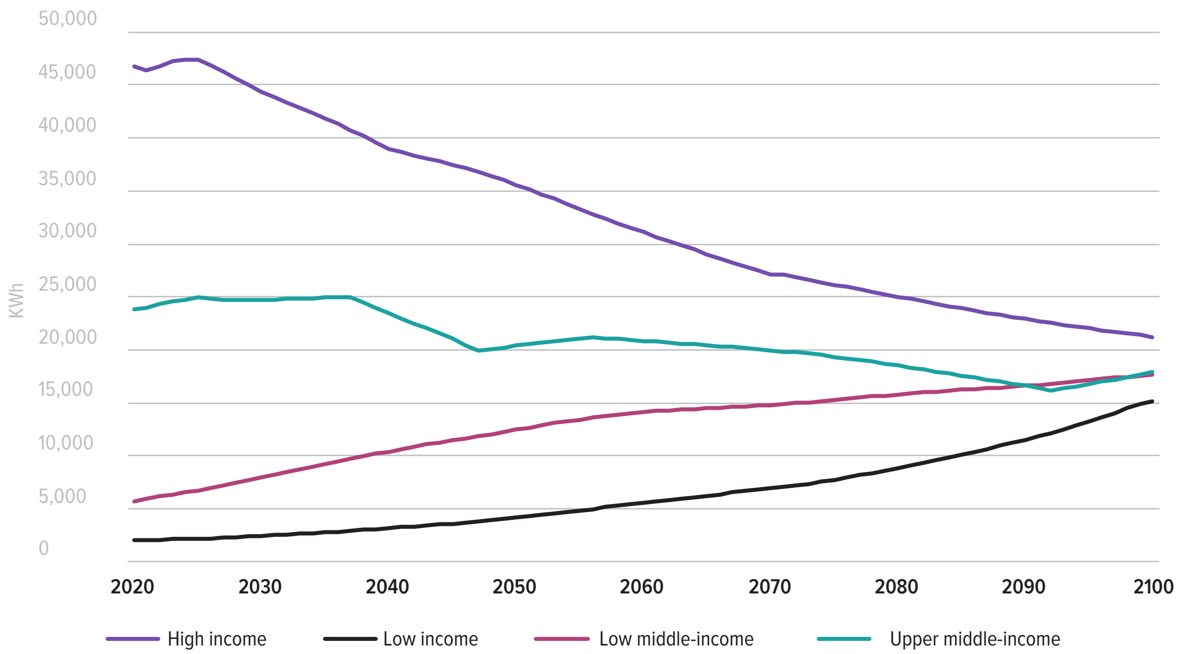
* **In IFs, energy production refers exclusively to primary energy.** The model does not further disaggregate energy into secondary energy categories such as residential use, heating, electricity or industrial consumption. As a result, all representations in this analysis reflect final primary energy production.

** Wind energy projections in IFs do not grow as rapidly as solar due to a combination of economic, geographic and technological factors, as supported by existing literature and other model projections. First, the unit costs of solar energy are expected to decline more rapidly than those of wind, making solar a more cost-effective option over time. Second, wind energy faces greater land-use constraints, requiring specific onshore or offshore developments with extensive infrastructure, such as turbines, to remain economically viable. Third, our projections are informed by the relative potential of each resource, with literature indicating that solar has a broader scalability advantage compared to wind.

*** Other renewables and hydropower production declining below **Base Case** levels are driven by targeted investment interventions across energy sources. The rapid expansion of solar and wind constrains the growth of other renewables and hydro. However, by 2060, their overall share in the energy mix remains higher because the demand-driven assumption also reduces overall energy production in the **RA** scenario.

In LICs and LMICs, fossil fuels are projected to dominate the energy mix in the early part of the forecast horizon, meeting a significant share of energy demand. However, renewable energy production is projected to gradually increase over time. Hydropower emerges as a particularly important source in many LICs, such as those in the Sahel region, where substantial hydropower developments are anticipated to drive growth through the 2040s (UNDP, 2024). By 2060, both these income groups forecast significant advancements in solar and wind energy production, leading to a larger share of renewables in their energy mix. This growth will be spearheaded by countries like India and Nigeria given their significant potential in increasing renewable capacity, reflecting a broader shift towards sustainable energy solutions.

Figure 2. Projections of energy demand per capita across income groups through 2060 in the RA scenario



Source: IFs v8.32.

In the **RA** scenario, energy demand per capita converges over time, reflecting progress towards equity in energy consumption. By the end of the century, near-parity in energy use across HICs and LICs is forecasted (see Figure 2). This is driven by multiple factors, including improved energy efficiency, structural shifts towards less energy-intensive industries, behavioural changes and policy measures aimed at meeting climate targets. It also reflects the principle of differentiated responsibilities, where historically high-emitting nations reduce their consumption in alignment with sustainability goals, allowing LICs to expand energy access and drive development. However, equitable energy use does not necessarily translate into convergence across economic metrics, as energy demand alone may not fully capture broader disparities in wealth, infrastructure and industrial capacity.

Transitioning to renewable energy also alleviates climate pressures by lowering both atmospheric CO_2 concentrations and carbon emissions compared to the **Base Case**. HICs play a leading role in this transformation, projected to close in on net-zero carbon emissions from fossil fuels by 2060. Under the **RA** scenario, atmospheric CO_2 concentrations rise marginally from 428 ppm in 2024 to 472 ppm in 2060, though significantly below the 544 ppm projected in the **Base Case**. Global carbon emissions from fossil fuels decline sharply from 9.6 billion tonnes in 2024 to 0.7 billion tonnes in 2060 under the **RA** scenario, reflecting a significant reduction in emissions over time.

Global temperature projections indicate that the **RA** scenario could limit warming to under 1.8°C by 2060, a significant improvement compared to the **Base Case** projections, which reach 2.6°C. However, this 1.7°C outcome still falls short of the Paris Agreement's goal to keep warming within 1.5°C.

While environmental benefits of such a transition are significant, there is also some progress along human development indicators, including greater access to electricity and shifts away from traditional cooking methods. Globally, electricity access rates increase to 99.1 percent in 2060, relative to 96 percent projected in the **Base Case**. As a result, globally 310 million additional people gain access by 2060, including 190 million in LICs and 40 million in LMICs alone. The use of traditional cookstoves is projected to decline from 400 million households (21.5 percent) in 2024 to 190 million households (7.1 percent) in 2060, compared to 230 million (8.6 percent[17]) in the **Base Case**.

In 2060, the **RA** scenario shows a projected increase in global GDP, relative to the **Base Case**, of $1.3 trillion. Over half of the share of global GDP gains is attributable to LICs and LMICs. GDP in LICs grows by 4 percent by 2060, relative to the **Base Case**, and in LMICs by 1 percent. Extreme poverty outcomes also decline as this scenario pushes 23 million people out of poverty in 2060. Other outcomes like malnutrition also fall from 620 million (7.6 percent) in 2024 to 230 million (2.3 percent) in 2060, relative to 240 million (2.4 percent) projected in the **Base Case**.

While disparities across income groups persist, they are significantly reduced in a renewable energy-centered approach that expands energy services and infrastructure, particularly in underserved regions where millions still lack modern energy access. This transition enhances human capital by creating jobs, fostering skills development and improving health outcomes—key drivers of innovation, technological diffusion and local implementation capacity.

Despite temporal improvements in energy, environment and development outcomes, both **Base Case** and **RA** scenarios show that structural barriers remain a persistent challenge, especially in LICs. Infrastructural inadequacies, lack of governance reforms, persistent socio-economic inequalities, and limited access to de-risked finance and incentives continue to hinder the full realization of sustainable development benefits, leaving vulnerable populations at risk. **Even with increased renewable deployment in the RA scenario, gaps in energy reliability, access and the lack of coherent social protection systems hinder a truly just transition. While the RA scenario may reduce reliance on fossil infrastructure, persistent structural inequities risk creating new forms of exclusion and unequal access without deliberate, inclusive policy action.**

17 This amounts to 0.9 billion people without access to traditional cookstoves in the **Base Case** by 2060, while it remains around 0.7 billion in the **RA** scenario by 2060.

It is important to recognize the broader social and developmental gains that expanded renewable energy, particularly decentralized renewable energy (DRE), can unlock for low- and middle-income countries and small island developing states. Improved renewable energy access can catalyse a cascade of benefits: reducing indoor air pollution and improving public health, expanding digital and educational infrastructure, enabling clean transportation, enhancing skills and digital literacy, creating local jobs, and strengthening economic opportunities. DRE systems, in particular, offer communities greater energy sovereignty, resilience and participation in shaping their own development pathways. While these lived realities and the specific dynamics of DRE are not explicitly modeled in our scenarios (see page 12 on the purpose and limitations of the work), the **RA+SDG** pathway seeks to reflect the broader ambition of a more integrated and inclusive energy transition. These interlinked social gains warrant greater recognition in policy and investment decisions—while placing people at the center of the energy transition to make it both just and transformative.

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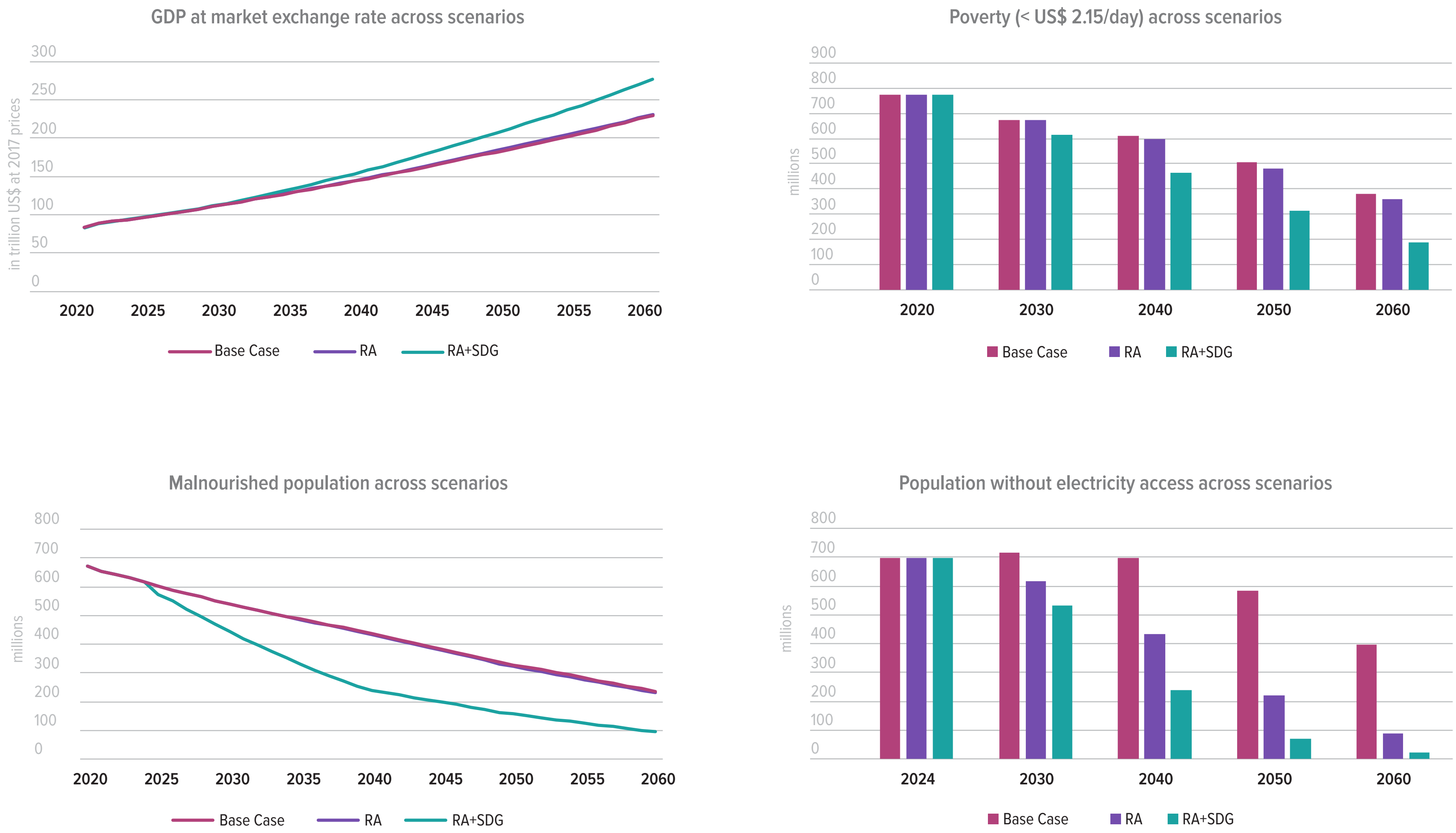
Finding 3

Ambitious renewable energy targets, integrated as part of a broader development framework, can unlock synergistic gains in productivity, health, education and governance, thereby balancing climate action with human development imperatives.

To better balance climate progress with social outcomes, the **RA+SDG** scenario complements renewable energy acceleration with complementary policies to improve governance, enhance agricultural efficiency and increase government spending on key areas of human development, particularly health, education, governance and infrastructure. By 2060, this pathway is projected to add $48 trillion to global GDP, increase per capita GDP by $6,000, lift 193 million people out of extreme poverty and eliminate undernutrition for 142 million individuals relative to the **Base Case** (see Figure 3). It drives substantial progress in critical SDGs, including universal electrification and elimination of poverty, while meeting the Paris Agreement's stated goals of realizing a 1.5°C-aligned energy future.

RA+SDG and **RA** scenarios show comparable trends in the energy mix, given the similar scale and focus of energy policy interventions (Table 6). However, minor differences emerge due to additional investments in the **RA+SDG** scenario aimed at achieving broader SDG objectives, which further enhance the role of renewables. In this scenario, the share of renewables in the energy mix increases significantly from 7.6 percent in 2024 to 88 percent in 2060, compared to 47 percent in the **Base Case** and 87 percent in the **RA** scenario by 2060. Fossil fuel production declines sharply from 135,100 TWh in 2024 to 20,900 TWh in 2060, while renewable energy sees a substantial rise, growing from 11,800 TWh in 2024 to 165,800 TWh in 2060. By 2030, renewable energy capacity additions are projected to triple, reaching four times the current global capacity by 2035. This trajectory aligns with the global goal set under the Paris Agreement to triple renewable energy capacity by 2030, a critical milestone in limiting temperature rise to 1.5°C. **RA** and **RA+SDG** scenarios project an increase in renewable capacity to 10,500 GW by 2030, from over 3,500 GW in 2024.

Figure 3. Projected development outcomes across scenarios



Source: IFs v8.32.

Table 6. Projected energy production in the Base Case, RA and RA+SDG scenarios by 2060*

Energy source (units in TWh)	2024	2060		
		Base Case	RA	RA+SDG
Oil	50,100	26,100	4,000	4,000
Gas	42,100	46,000	6,000	6,100
Coal	48,900	55,600	11,500	11,800
Hydro	4,800	5,700	3,300	3,400
Nuclear	8,300	4,400	2,300	2,300
Solar	2,400	78,500	116,000	131,100
Wind	2,600	29,300	30,200	33,000
Geothermal	1,200	2,600	3,900	4,200
Other renewables	1,400	1,300	1,200	1,300
Total	161,800	249,500	178,400	197,200

Source: IFs v8.32.

* In IFs, energy production refers exclusively to **primary energy**. The model does not further disaggregate energy into secondary energy categories such as residential use, heating, electricity or industrial consumption. As a result, all representations in this analysis reflect final primary energy production.

With declining energy intensity rates, the scenario projects a doubling in energy efficiency rates by 2060, thereby also aligning with the Paris Agreement stipulations and recognizing the role of efficiency in reducing emissions and improving environment. HICs continue to take a leading role in the transition to renewables, reflecting their differentiated responsibility in addressing climate change.

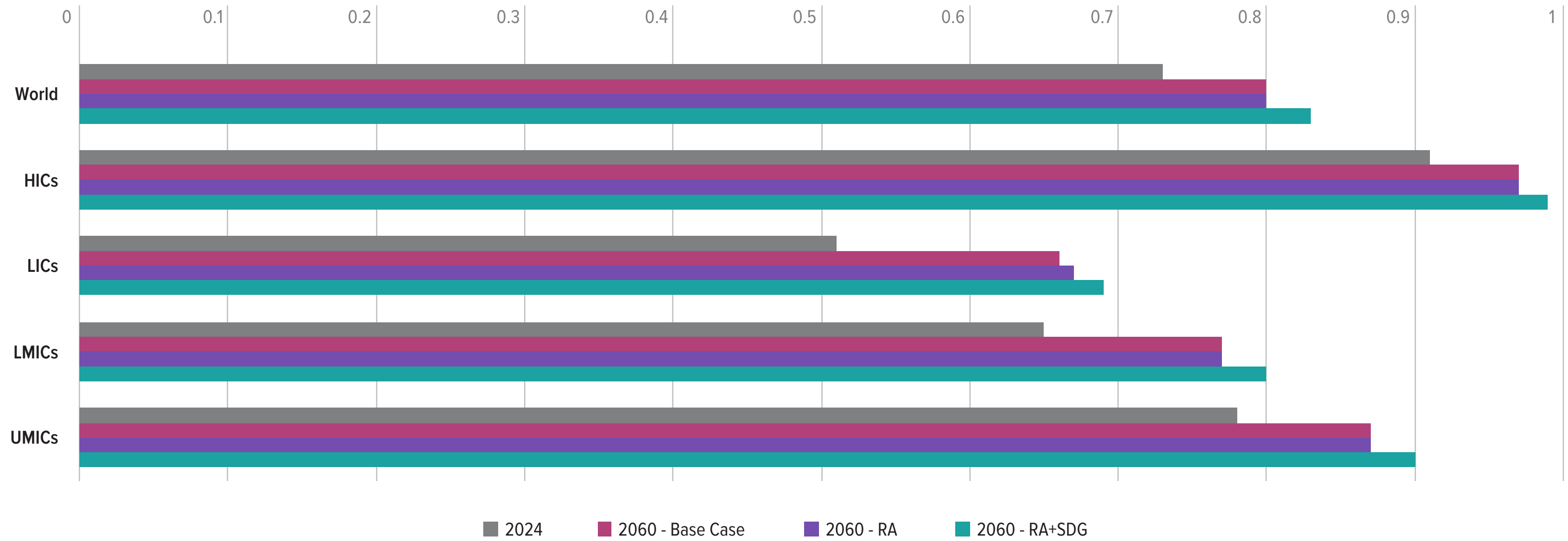
This transition presents an attractive alternative to fossil fuel-driven development (i.e. the **Base Case**), demonstrating a pathway that achieves significant reductions in carbon emissions with a synergistic development–energy nexus. Under this scenario, global carbon emissions peak in 2027 and decline to 0.7 billion tonnes of carbon by 2060, mirroring trends observed in the **RA** scenario. The reduction in carbon emissions leads to a notable impact on global temperature change. In the **RA+SDG** scenario, temperature rise peaks at 1.5°C in 2040 and continues to decline thereafter.[18] Unlike the **RA** scenario, which limits warming to 1.7°C, the **RA+SDG** scenario aligns with the Paris Agreement's goal of limiting global warming to under 1.5°C, highlighting its potential to achieve climate and sustainability targets.

The **RA+SDG** scenario leads to improvements across development outcomes. GDP per capita grows faster across all income groups compared to the **Base Case**, with an additional $6,000 in global GDP per capita. Poverty reduction accelerates markedly, with 193 million fewer people living in poverty by 2060 compared to the **Base Case**. This progress is most pronounced among LICs and LMICs. For LICs, the share of population living in extreme poverty declines from 41.7 percent in 2024 to 7.4 percent in 2060, relative to 13.5 percent projected in the **Base**

18 The effects of climate change are modelled in IFs through a damage function that links temperature increases to reductions in production and capital stock (Hughes *et al.*, 2015). Carbon dioxide concentrations that accumulate in the atmosphere trap heat, thereby raising global temperatures and altering precipitation patterns. In the **RA** and **RA+SDG** scenarios, temperature impacts are mitigated through a combination of greater carbon sequestration and reduced emissions. Expanded adoption of cleaner energy sources, coupled with measures such as reforestation and land-use improvements, leads to lower atmospheric CO_2 concentrations over time.

Differences in HDI trajectories across income groups show varying starting points and sensitivities to intervention. UMICs show steady gains across all scenarios due to broad structural improvements, while LICs and LMICs require more targeted, cross-sectoral interventions—such as those in RA+SDG—to break through developmental plateaus.

Figure 4. HDI across scenarios by income group, in 2024, 2030 and 2060



Source: IFs v8.32.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Case. Similarly, for LMICs, poverty rates fall from 11 percent in 2024 to 1.5 percent in 2060, relative to 3.3 percent in the **Base Case**. With increased agricultural efficiency from limiting production, consumption and distribution losses; improvements to yields; and a more equitable distribution of calories, 142 million fewer people experience malnutrition by 2060 under **RA+SDG** compared to the **Base Case**.

HDI also improves across all income groups over time (Figure 4). While the **Base Case** projects steady progress due to structural development trends, the **RA+SDG** scenario leads to the highest gains, especially in LICs and LMICs. By 2060, HDI increases from 0.51 to 0.69 in LICs and 0.65 to 0.80 in LMICs, surpassing the **Base Case** and **RA** scenarios. In these countries, improvements are particularly significant from present levels as more tailored policy actions yield disproportionately large human development returns in contexts where foundational gaps are still prevalent. HICs, on the other hand, are projected to maximize their HDI to 0.99 under **RA+SDG** by 2060. Global HDI also increases, reaching 0.84 in 2060.

Further disparities across income groups are minimized under the **RA+SDG** scenario, as LICs and LMICs experience accelerated progress through holistic interventions that integrate energy access, economic development and social policies. This scenario fosters convergence by significantly closing the gap between historically high-achieving HICs (particularly OECD countries) and lower-income nations, without implying that wealthier countries must bear the direct financial burden of development in LICs. Instead, it highlights the role of multilateral cooperation, technology transfers, climate finance and capacity-building initiatives as mechanisms that enable developing countries to chart their own sustainable growth pathways.

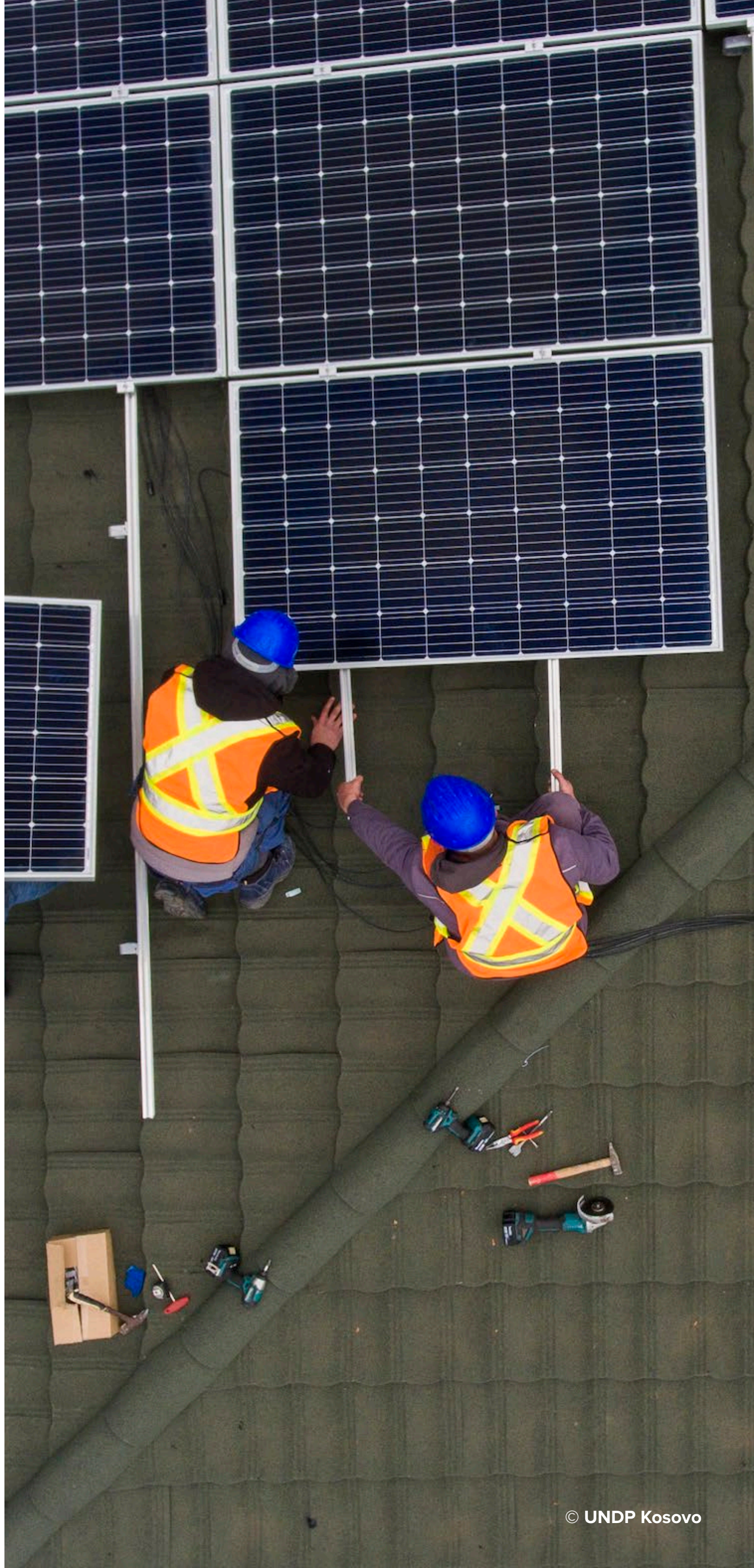
Figure 5. Development gains across the modelled scenarios

Source: IFs v8.32.

Our analysis shows that the **RA+SDG** scenario is particularly effective in bridging SDG gaps across income groups (Figure 5). Investments in education, healthcare and resilient infrastructure yield substantial improvements, with education indicators in LICs and LMICs advancing by nearly a decade's worth of progress by 2060—a stark contrast to current conditions where millions of children still lack access to primary and secondary education.

Despite the ambitious progress projected under **RA+SDG**, realizing these outcomes requires policymakers to directly address the entrenched barriers that have historically constrained developing nations. With growing opportunities to leapfrog traditional development pathways, many LICs remain constrained by structural inequalities ranging from limited access to dedicated development finance, to the continued export of raw materials without equitable value capture. These challenges, combined with a legacy of underinvestment in infrastructure and institutional capacity as well as limited reinvestment of returns and resource revenues hinder the full realization of inclusive energy transitions. Addressing these barriers requires a macroeconomic lens that connects energy to broader patterns of trade, investment and development. The legacy of underinvestment in infrastructure, weak institutional capacity and financial bottlenecks has long hindered LICs from fully capitalizing on energy transitions. Structural issues such as fragmented electricity grids, high upfront costs of renewable technologies, and unreliable energy markets perpetuate disparities, making it difficult for developing economies to integrate into global supply chains and sustain long-term growth. Without targeted policies, LICs risk remaining locked-in to outdated, high-emission energy systems that reinforce poverty traps and stifle industrial competitiveness.

The **RA+SDG** scenario breaks this cycle by aligning clean energy expansion with pro-development policies that address these barriers at their core. Unlike the **Base Case**, where governance and infrastructure gaps limit progress, **RA+SDG** prioritizes an integrated, cross-sectoral approach that ensures that energy access, economic growth and climate action reinforce one another. The benefits for LICs are particularly pronounced: by 2060, GDP increases by 30 percent, extreme poverty declines by 50 percent, malnutrition drops by 70 percent, and universal electricity access is achieved—all relative to the **Base Case**. These gains underscore the critical role of targeted investments in energy infrastructure, regulatory reforms and technology transfers in transforming development trajectories of vulnerable regions.



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Finding 4

Boosting average annual renewable investments from $1.8 trillion in the Base Case to $2.5–$3.4 trillion in the RA and RA+SDG is needed, ultimately unlocking up to $20.4 trillion in cumulative savings by 2060.

Under current policies, renewable energy investments are projected to grow at a moderate pace, with fossil fuel investments persisting near present levels well into the 2030s. Our acceleration scenarios, **RA** and **RA+SDG**, indicate that to achieve a pathway consistent with the Paris Agreement, annual investments in renewables must increase to $2.5–$3.4 trillion between 2024 and 2050, totaling between $100–$135 trillion over this period. In the **Base Case**, annual renewable investments between 2024 and 2050 are in the range of $1.8–$1.9 trillion. Acceleration scenarios project a 30–35 percent increase in renewable power generation investments relative to the **Base Case** by the 2040s, driven by front-loaded capital expenditures necessary for a sustainable shift to renewables. However, post-2040, renewable power generation investments decline below **Base Case** levels due to projected gains in energy efficiency and decreasing levelized costs (see Tables 9 and 10). By 2060, these translate into $20.4 trillion in cumulative cost savings, calculated from $8.9 trillion from efficiency improvements and $11.5 trillion from declining cost of renewables under **RA+SDG**.[19]

19 To estimate efficiency and cost change-based savings in the **RA+SDG** scenario compared to the **Base Case**, we ran two variations of the **RA+SDG** scenario: (a) one where the LCOE for wind and solar remained the same as in the **Base Case**, and (b) another where energy intensity was held at the **Base Case** level—while all other parameters remain unchanged. By comparing the investment differences between these variations and the **RA+SDG** scenario as modelled, we identified the sources of savings. The estimated savings amount to $11.5 trillion from cost declines, with $8.9 trillion from efficiency improvements. A similar exercise with the **RA** scenario shows that efficiency improvements result in $8.1 trillion in cumulative savings, while declining renewable costs contribute $10.2 trillion in savings.

Global investment trends are shifting decisively towards renewable energy, driven by increasing cost competitiveness and technological advancements.[20] In 2024, global investment in renewable power generation is estimated to stand at $315 billion. However, the broader shift to a low-carbon economy extends beyond power generation, encompassing grid expansion, energy efficiency and end-use electrification, and demand flexibility. When factoring in these components, total investments in the renewable sector amounted to $750–$980 billion in 2024.

While the cost-effectiveness of renewables strengthens the economic case for their acceleration, achieving a 1.5°C-aligned pathway requires immediate and sustained investment beyond current levels. This investment is not only feasible but also beneficial, given the far-reaching economic and environmental advantages of renewables.

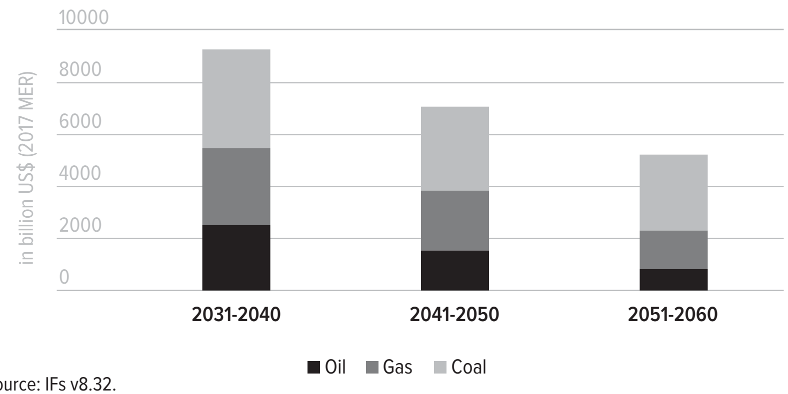
Our analysis reveals a fundamental shift in global energy investments as we move from a fossil fuel-dominated system to a renewable-powered future. Under the **Base Case**, annual renewable power generation investments average around $1.8–$1.9 trillion between 2024 and 2050, while investments in primary fossil fuels account for most early energy-sector spending (Figure 6). Without an accelerated shift towards renewables, fossil fuel energy will continue to attract substantial investment, though its share is expected to decline in the **Base Case** to 30 percent by 2060 (just over $0.5 trillion). In contrast, acceleration scenarios (**RA** and **RA+SDG**) require annual renewable investments to rise to $2.5–$3.4 trillion, while annual fossil fuel spending falls to $10 billion by 2060.

Under the **Base Case**, annual renewable power generation investments average around

$1.8–1.9 trillion

between 2024 and 2050.

Figure 6. Cumulative global investment in fossil fuel (coal, oil and gas) in the Base Case through 2060



Source: IFs v8.32.

20 To ensure consistency with other estimates presented in this report, investments are measured in US$ 2017 market exchange rates. Specifically, IRENA (2023b) uses US$ 2021 prices, while IRENA (2024) uses US$ 2023 prices. Conversion of US$ 2017 prices to US$ 2021 or US$ 2023 can be made using the respective US$ inflation rates for the relevant periods.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Reflecting current climate policies, coal is projected to dominate fossil fuel investments in the **Base Case**, with cumulative investments reaching $13 trillion between 2024 and 2060. Gas follows with approximately $9 trillion in cumulative investments, while oil investments over the same period total slightly over $7.2 trillion. Figure 6 illustrates the cumulative investments in oil, coal and gas across each subsequent decade. The forecasts indicate a declining trend in fossil fuel investments. However, in the absence of a strong push for renewables, more than $9 trillion is expected to be invested in fossil fuel energy production during the decade spanning 2031–2040, with coal receiving 40 percent of that investment.[21]

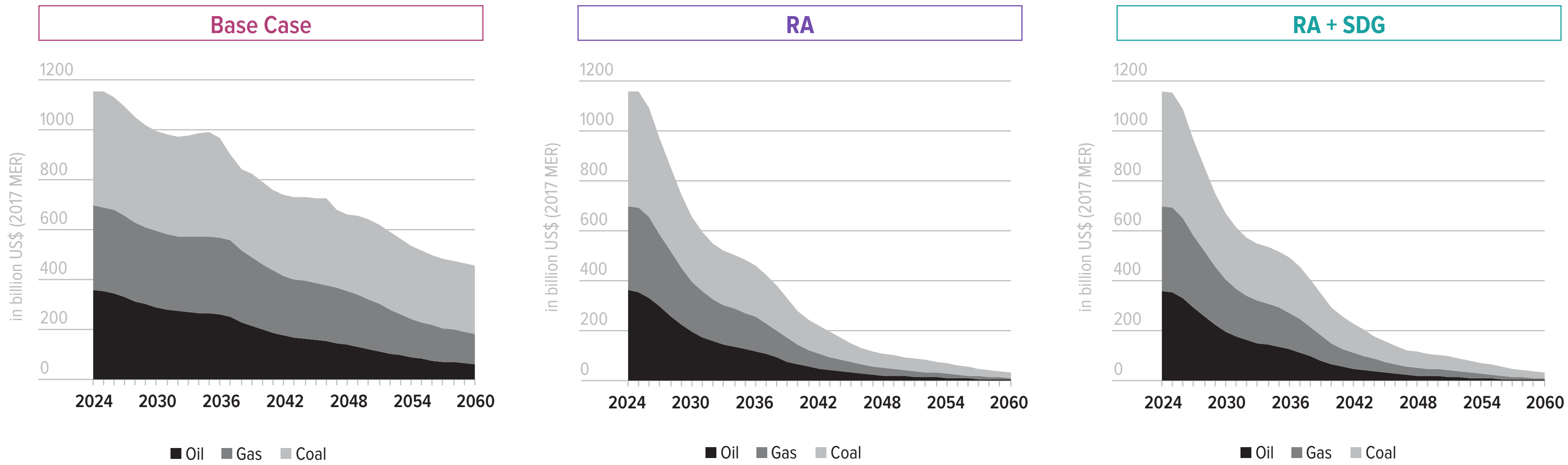
Capital abandonment from fossil fuels accelerates significantly in the acceleration scenarios, with momentum building around the mid-2030s. By 2035, annual fossil fuel energy investments in the **RA** and **RA+SDG** scenarios decline sharply, reaching only 28 percent and 30 percent, respectively, of the investments projected in the **Base Case** scenario. This downward trend continues over the following decades.

By 2060, new fossil fuel investments in the acceleration scenarios decline to $10 billion, making up a mere 3 percent of total production investments. Figure 7 illustrates this steady decline, showing how fossil fuel investments in the **RA** and **RA+SDG** scenarios consistently fall below the **Base Case** projections, reflecting the shift towards renewable energy and a decarbonized economy.

21 IFs estimates of coal investments differ from the IEA—an artefact of different lifetime assumptions of coal plants as well as differences in estimation of coal production growth in some countries.

By 2060, new fossil fuel investments in the acceleration scenarios decline to $10 billion, making up a mere three percent of total production investments. Figure 7 illustrates this steady decline, showing how fossil fuel investments in the RA and RA+SDG scenarios consistently fall below the Base Case projections, reflecting the shift towards renewable energy and a decarbonized economy.

Figure 7. Projected trends of fossil fuel investments across three scenarios



Source: IFs v8.32.

Shifting the landscape of investments from fossil fuels to renewables

Global energy investments, across all components, are shifting rapidly towards renewables, with clean energy now outpacing fossil fuels in a 2:1 ratio (IEA, 2024d). Falling renewable costs—driven by innovation and learning, along with a growing emphasis on transitioning to a greener path, are accelerating this shift despite the significant costs associated with infrastructure and efficiency innovations. However, when considering investment solely in energy production, fossil fuels still dominate. Around 70 percent of global energy production investment in 2024 is still being allocated to fossil fuels based on our methodology. **RA** and **RA+SDG** scenarios on the other hand prioritize early investments in renewables, capitalizing on cost reductions and efficiency improvements.

Table 7 presents energy production investments in renewables and fossil fuels across three scenarios, broken down by decade.[22] Renewable energy investments in this analysis specifically refer to financing for power generation. However, total investments in the renewable energy sector are higher when accounting for additional systemic costs associated with energy transition. Notably, in the early years of the projection horizon, annual renewable power generation investments in transition scenarios exceed those in the **Base Case** by approximately 30 percent between 2025–2030 and 2031–2040. Conversely, fossil fuel energy investments are projected to significantly decline over the same period.[23]

RA and **RA+SDG** scenarios shift the landscape of investments from fossil fuels to renewables. From 2024 to 2060, acceleration scenarios require significantly lower energy production investment compared to the **Base Case**. This reduction is driven by a shift from expensive fossil fuels to lower-cost renewables, faster declines in renewable energy costs, improved efficiency and reduced overall demand. Over this period, global energy production investments in transition scenarios are projected to total between $31.5 trillion and $33.9 trillion (2017 MER), representing 57–62 percent of the $55 trillion projected under the **Base Case** scenario.

Accelerated renewable energy investments also deliver significant economic gains: the **RA** scenario boosts global GDP by $1.7 trillion annually by 2060 and reduces extreme poverty by 23 million compared to the baseline. The **RA+SDG** scenario further amplifies these benefits through integrated investments in energy, environment and development. Moreover, nearly $1 trillion in annual energy sector savings by 2060 within the scenario helps offset public spending on essential services like education and health, especially in countries with high public energy investment, strengthening the economic rationale for swift action.

22 It is important to note that we only represent production investments here, while other systemic costs (particularly those associated with an energy transition) are explicitly detailed later.

23 Unlike our model, other projections from IEA, IRENA and Bloomberg do not consistently disaggregate renewable energy costs into sub-components across these timeframes. If additional data are available, IFs analysis can further break down investments into broader renewable categories within transition scenarios, considering the varying assumptions across models.

Table 7. Average annual investments in US$ billions at 2017 MER in power generation from renewables and fossil fuels for each decade

	Scenario/period*	2024**	2025–2030	2031–2040	2041–2050	2051–2060
Renewable energy	Base Case	315	353	490	707	903
	RA	315	456	641	592	566
	RA+SDG	315	456	693	665	662
Fossil energy	Base Case	1,131	1,075	924	705	523
	RA	1,131	792	264	62	20
	RA+SDG	1,131	791	278	66	21
Total energy	Base Case	1,592	1,551	1,497	1,460	1,453
	RA	1,592	1,339	933	663	590
	RA+SDG	1,592	1,338	999	740	688

* Renewable energy investments in this analysis specifically refer to financial commitments directed towards power generation. However, total investments in the renewable energy sector are higher when accounting for additional systemic costs associated with energy transition. Notably, in the early years of the projection horizon, annual power generation investments in transition scenarios exceed those in the **Base Case** by approximately 30 percent between 2025–2030 and 2031–2040. Conversely, fossil fuel energy investments are projected to significantly decline **over** the same period. Unlike our model, other projections from IEA, IRENA and Bloomberg do not consistently disaggregate renewable energy costs into sub-components across these timeframes. If additional data are available, IFs analysis can further break down investments into broader renewable categories within transition scenarios, considering the varying assumptions across models.

** According to the International Energy Agency (IEA, 2024), global investments in renewable energy surpassed $750 billion in 2024. However, the IFs baseline estimate is approximately $315 billion, reflecting methodological differences in how sectoral investments are defined and allocated as capital shares within the integrated model. These distinctions are further elaborated in Annex 5. Note that nuclear energy investment is not accounted for in our projections.

In all scenarios, renewables account for the most cumulative energy investments, but their share is significantly higher in transition scenarios. In the **RA** and **RA+SDG** scenarios, fossil fuel investments are approximately one-third of those in the **Base Case**. Overall, the **RA+SDG** scenario requires $21.1 trillion less investment than the Base Case over the entire period.

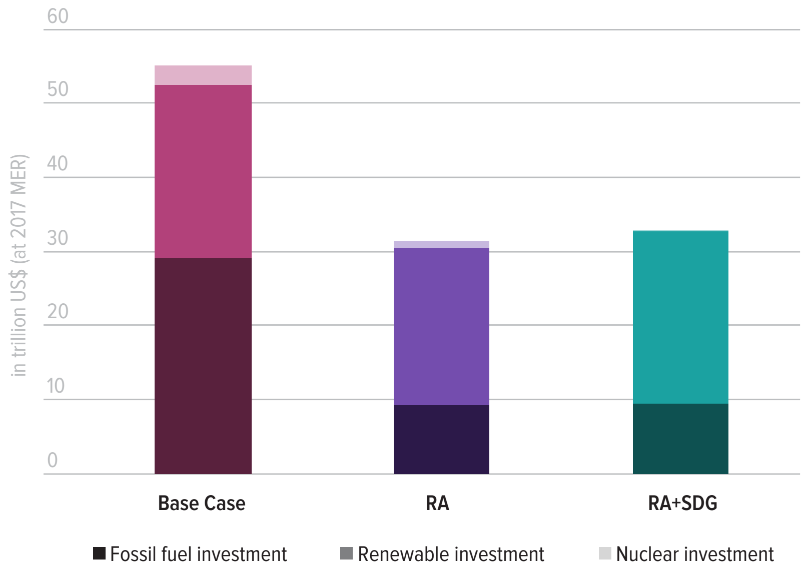
Despite their long-term cost advantages, renewable energy adoption in developing countries faces major financing hurdles, primarily high upfront investment costs and limited access to affordable financing. Ensuring the affordability of renewable energy financing in developing nations requires a multifaceted approach, including blended finance, green bonds, local currency financing with foreign exchange risk mitigation, and public-private partnerships, while leveraging public finance to de-risk projects and attract private investment through supportive policies and innovative financial instruments (IEA, 2021).

Unlike fossil fuels, which spread costs over time through ongoing fuel expenses, renewables require substantial initial capital, leading to higher early debt burdens. This financing disparity significantly impacts competitiveness; for instance, IEA data show that financing costs alone can add up to 40 percent to the levelized cost of electricity (LCOE) generation of wind energy in developing countries, compared to just 6 percent for combined cycle gas (Waissbein *et al.*, 2013). Public derisking measures, such as loan guarantees, insurance and direct financial incentives (e.g. tax breaks, price premiums), can help lower financing costs and attract private investment (ibid). However, post-COVID inflation and rising interest

In all scenarios, renewables account for the most cumulative energy investments, but their share is significantly higher in acceleration scenarios. In the RA and RA+SDG scenarios, fossil fuel investments are approximately one-third of those in the Base Case. Overall, the RA+SDG scenario requires $21.1 trillion less investment than the Base Case over the entire period.

rates have further increased financing costs (IEA, 2024d). In LICs and LMICs, where coal dominates power generation, the incremental financing of fuel costs makes fossil fuels easier to service. In contrast, renewables often require large upfront infrastructure investments – such as grid modernization – with no immediate revenue stream to support repayment, adding to the difficulty and cost of the energy transition.

Figure 8. Cumulative investments across scenarios (fossil fuels, renewables and nuclear energy) by 2060 in US$ trillions (2017 MER)*



Source: IFs v8.32.

* In the figure, energy sector investments in IFs are higher in the **Base Case** compared to the alternative scenarios. This is primarily because the **Base Case** does not assume an asymptotic reduction in the unit costs of energy production, particularly for renewables. Additionally, business-as-usual improvements in energy efficiency contribute to higher estimated investments, as the model aggregates total sectoral energy spending, encompassing both public and private investments.

In acceleration scenarios, renewable power generation investments initially rise above the **Base Case**, driven by upfront capital expenditures for a sustainable transition. Later in the horizon, while renewable generation continues to grow well beyond the **Base Case** in both acceleration scenarios—slightly more in **RA+SDG** due to greater economic activity—renewable power investments decline relative to the **Base Case** as prices fall and efficiency improves. By 2060, these shifts result in substantial long-term savings in both **RA** and **RA+SDG**, which share the same assumptions for renewable energy costs and efficiency gains.

By 2060, integrated action on renewables and energy efficiency can deliver $20.4 trillion in cumulative cost savings—reinforcing the development and climate case. Under the RA+SDG scenario, renewable power generation investments decline below Base Case levels after 2040, driven by transformative gains in energy efficiency and continued reductions in the levelized cost of renewables (see Tables 8 and 9). These shifts yield $8.9 trillion in savings from efficiency improvements and $11.5 trillion from declining renewable costs, underscoring the long-term economic benefits of a sustainable energy transition.

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Table 8. LCOE changes in energy sources across scenarios ($/MWh)

	Scenario	Oil	Gas	Coal	Hydro	Nuclear	Solar	Wind	Geothermal	Other Renewables
2024		25	25	55	125	150	60	70	120	120
	Base Case	25	25	50	130	150	55	70	120	120
2030	RA	25	25	50	130	150	40	60	105	120
	RA+SDG	25	25	50	130	150	40	60	105	120
	Base Case	35	25	50	130	145	50	60	115	120
2040	RA	30	25	50	130	145	35	45	85	120
	RA+SDG	30	25	50	130	145	35	45	85	120
	Base Case	40	30	50	125	140	45	60	110	115
2050	RA	35	30	50	120	140	30	40	65	115
	RA+SDG	35	30	50	120	140	30	40	65	115
	Base Case	40	35	55	120	135	45	55	105	110
2060	RA	35	30	50	120	135	25	30	50	110
	RA+SDG	35	30	50	120	135	25	30	50	110

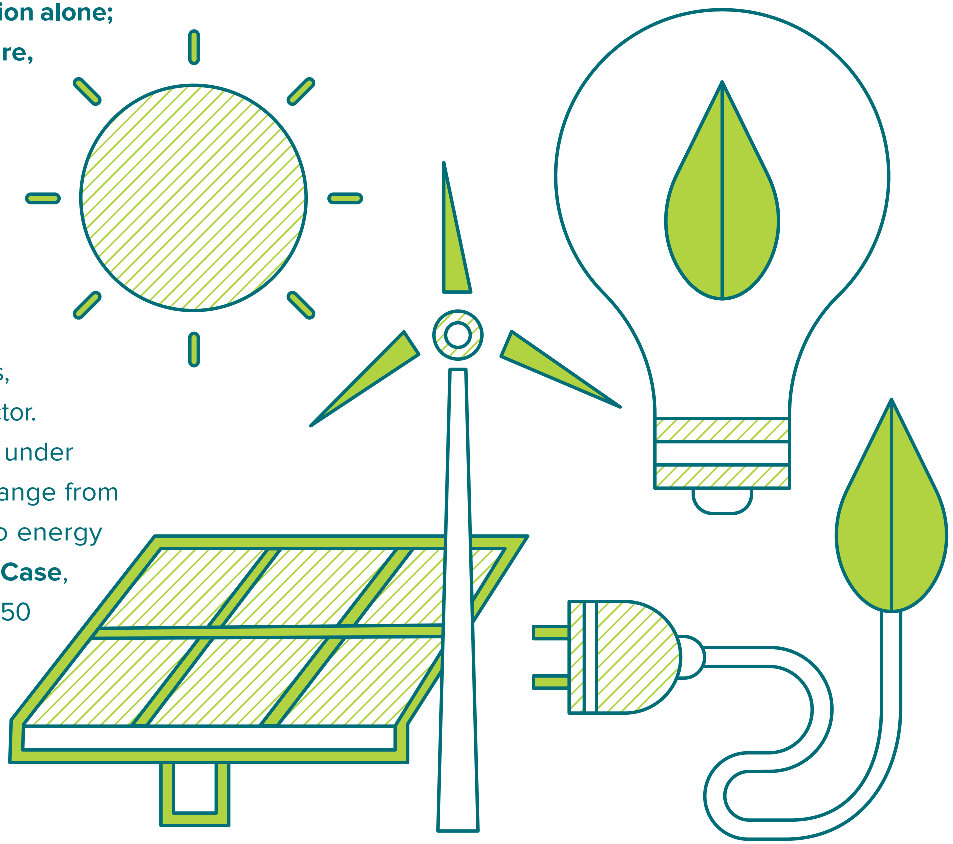
Table 9. Annual savings across RA and RA+SDG scenarios by year 2030, 2040, 2050 and 2060 and cumulative savings between 2024 to 2030, 2040, 2050 and 2060 - in billion US$ at 2017 MER

	RA							
	Savings from cost decline				Efficiency savings			
	2030	2040	2050	2060	2030	2040	2050	2060
Annual	30	270	475	400	140	300	320	210
Cumulative from 2024	60	1910	5310	10180	390	2380	6120	8070

	RA+SDG							
	Savings from cost decline				Efficiency savings			
	2030	2040	2050	2060	2030	2040	2050	2060
Annual	30	290	550	480	140	320	350	260
Cumulative from 2024	60	2080	5920	11530	390	490	6620	8960

Box 2: Scaling renewables requires system-wide investment in infrastructure, energy storage and energy efficiency for long-term sustainability

Renewable expansion requires much more than power generation alone; it demands system-wide investments in modern infrastructure, electrification, grid modernization, energy storage and energy efficiency to create a resilient and inclusive energy landscape. However, a key challenge is that energy efficiency and end-use electrification, particularly in transport and industrial sectors—remain underfunded despite being essential for deep decarbonization. According to IRENA (2024) and Bloomberg (2025), the largest investment gaps exist in energy efficiency improvements, electrification of heat, and transport sector transitions, all of which are necessary to curb emissions beyond the power sector. Our estimates, aligned with IRENA's 1.5°C pathway, project that under the **RA+SDG** scenario, annual energy sector investments will range from $2.4 trillion to $4.5 trillion—with the largest share allocated to energy efficiency and end-use transformation. Compared to the **Base Case**, where cumulative global energy investments between 2024 and 2050 range from $79 trillion to $90 trillion, transition scenarios demand significantly higher cumulative investments from $100 trillion to $135 trillion, underscoring the scale of financial commitment required to meet climate and development goals. Detailed discussion on total system-wide costs of these transitions can be found in the Annex 4.



Section 4

Policy actions:

unlocking climate and development gains through renewables

This report's findings show that accelerating renewable energy deployment is not only essential for climate action but also a powerful driver of economic and human development. However, unlocking the full potential of renewables requires clear targets, supportive policies, more financing and better alignment with development goals.

To realize the benefits outlined in the RA+SDG scenario, we call on policymakers to take the following decisive actions:

1. Establish comprehensive renewable energy targets in climate policies and NDCs and integrate them with development priorities.

The **RA+SDG** scenario demonstrates that scaling renewable energy within broader climate and development strategies maximizes benefits for poverty reduction, health, education and infrastructure. One hundred percent of countries supported under UNDP's Climate Promise include energy as a priority sector, however, many still lack clear, quantifiable renewable energy targets, and therefore miss the opportunity to establish ambitious commitments that drive real impact. With the next round of NDC updates taking place in 2025, countries have a critical opportunity to strengthen renewable energy targets—ensuring that investments in clean energy contribute not only to emissions reduction but also to improved livelihoods, enhanced productivity and inclusive growth. It will also be essential to ensure that renewable energy goals are gender-responsive, inclusive and locally owned, reflecting priorities across health, education and livelihoods as well as climate mitigation.

Policy actions:

- Ensure that NDCs explicitly include quantifiable and time-bound renewable energy targets or measures that support national development priorities.
- Establish cross-sectoral approaches that link renewable energy expansion with complementary investments in gender and social inclusion, health, education and infrastructure to maximize socio-economic benefits.
- Ensure that renewable energy targets are grounded in local priorities and needs, promoting locally owned solutions that enhance inclusive development outcomes.
- Ensure that national development plans explicitly incorporate renewable energy expansion as a driver of economic and human development.

2. Shift energy investment from fossil fuels in favour of renewables.

Despite the falling cost of renewables, fossil fuel investment persists, locking in emissions and delaying the transition. The **RA+SDG** scenario requires a 30–35-percent increase in renewable investment by 2040 while reducing fossil fuel spending to near zero by 2060. Our findings suggest that redirecting investment flows can unlock $20.4 trillion in cumulative savings by 2060, reducing energy costs for consumers and accelerating the transition. However, shifting investment towards renewables must account for the financial realities faced by many LICs and LMICs, where, for example, more than 50 percent of LICs are already in or at risk of debt distress (World Bank, 2024b). Without innovative financing approaches, clean energy investments risk being slowed by fiscal constraints. Debt-smart solutions that ease fiscal pressure while scaling up renewable energy, such as debt-for-energy swaps, are essential to ensuring an equitable and accelerated transition.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Policy actions:

- Phase out fossil fuel subsidies, redirecting savings to renewable deployment, grid resilience and energy access projects, where applicable.
- De-risk private sector renewable investment through a mix of strategies, including blended finance, concessional capital, guarantees and insurance instruments, particularly in emerging markets where capital costs remain high.
- Fast-track project approvals for solar, wind and storage projects, while ensuring that these clean energy investments are tailored to the specific contexts, needs and priorities of the communities they aim to serve.
- Promote debt-smart energy financing for LICs and LMICs, including innovative instruments such as debt-for-energy swaps that redirect debt service towards clean energy without worsening fiscal pressures.


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3. Scale up climate finance commitments, support technology transfer and foster enabling trade environments for LMICs and LICs.

Multilateral institutions can support countries to mitigate the financial and policy risks that deter large-scale renewable investments in LICs and LMICs, ensuring that energy access expansion is not just a possibility but a reality. Our **RA+SDG** scenario makes a compelling case for an integrated, holistic energy transition—one that does not force developing nations to choose between growth and climate action, but instead positions them as drivers of a cleaner, more equitable future that delivers on both the SDGs and long-term climate goals.

Policy actions:

- Support access to public, private and international finance for LICs and LMICs to integrate and scale clean energy as a central pillar of their national development planning.
- Promote the transfer of renewable technologies and strengthen local innovation ecosystems to build domestic renewable energy industries.
- Support trade policies that facilitate technology access, lower costs for renewable deployment and promote the development of local clean energy value chains.

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4. Overhaul regulatory frameworks to unblock the clean energy pipeline.

Permitting delays, outdated grid rules and fossil fuel-friendly market structures slow renewable deployment, especially in LICs and LMICs. Eliminating these structural barriers can cut project timelines by years—an essential step to achieving the call of the global stocktake to triple renewable capacity by 2030.

Policy actions:

- Encourage accelerated permitting for renewables and storage, capping permitting times and consider automatic approvals under certain conditions if these are not met.
- Require utilities to prioritize and fast-track renewable connections to the grid.
- Discourage market bias towards fossil fuels - flexibility solutions (batteries, demand-side response) must be allowed to compete fairly with fossil fuels.

5. Electrify demand—the key driver of energy efficiency.

Improving energy efficiency is critical, and electrification itself (transport, heat, industry) is a primary driver of systemic efficiency gains. Electrification of heat and transport improves energy efficiency and the affordability of public transport (e.g. through the electrification of public transit), reducing energy costs while cutting fossil fuel dependency.

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Policy actions:

- Incentivize 100 percent low-carbon heating in new buildings by 2030. Phase out fossil fuel heating in favour of heat pumps and district heating.
- Phase out new fossil fuel car sales and implement smart EV charging policies to align charging demand with renewable generation.
- Support the deployment of e-mobility through place-based schemes tailored to local transport needs, including EVs, two- and three-wheelers, and shared electric transport options.
- Enhance consumer access to affordable e-mobility financing by creating targeted incentive programmes that accelerate infrastructure rollout and de-risk uptake across diverse mobility segments.
- Expand consumer access to demand-side incentives, so households can save money by shifting electricity use when renewables are abundant.
- Launch industrial electrification roadmaps and fund pilot projects in hard-to-abate industry sectors (including cement, steel and chemicals) to accelerate transition away from fossil fuels.
- Integrate the triptych of digital, data and Artificial Intelligence (AI) as the core infrastructure of energy systems. In doing so, climate intelligence, using forecasts, real-time data and AI, are integrated into every level of electrification planning to optimize demand, reduce costs and future-proof energy systems.

6. Prioritize demand flexibility in grid investments.

High renewable penetration creates integration and balancing challenges, yet grid investment still favours physical expansion over smart, flexible solutions. Unlocking demand flexibility can cut peak energy demand, reduce grid congestion and lower costs, ensuring renewables scale efficiently and affordably.

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Policy actions:

- Prioritize software and AI-driven balancing over new transmission lines.
- Allow grid operators to earn revenue from flexibility, not just infrastructure expansion, so they prioritize innovation over new wires.
- Introduce real-time electricity pricing to consumers that can align demand with renewable supply and reduce curtailment.
- Implement locational pricing to reflect real-time grid constraints and renewable availability.
- Promote place-based grid development policies that enable regional flexibility and innovation in energy system design. Support approaches that can leapfrog conventional grid models where appropriate.
- Ensure that grid developments align with local, gender-sensitive community needs that address energy poverty, inaccessibility and contribute directly to enhancing human development outcomes.

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7. Strengthen institutional capacity to unblock renewable investment in LICs and LMICs.

In many LICs and LMICs, available capital for renewables is not translating into deployment due to weak governance, regulatory inefficiencies and inadequate infrastructure. Without stronger institutions, energy gridlock will persist, delaying investment and increasing project costs. Strengthening governance and infrastructure will accelerate renewable energy deployment, improve investor confidence and ensure that the benefits of clean energy reach all communities, fostering long-term economic stability and equitable access.

Policy actions:

- Reform regulatory frameworks to streamline approval processes and reduce administrative burdens on renewable projects.
- Enhance transparency in energy planning and governance to attract private-sector investment and ensure accountability.
- Invest in foundational infrastructure—roads, digital connectivity and energy transmission networks—to support large-scale renewable deployment.
- Build institutional capacity through training programmes and partnerships to equip policymakers and regulators with the expertise to manage renewable energy development effectively.

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A just and equitable future is within reach, but it needs to happen faster and in a way that delivers economic and social benefits. This report's findings show that the **RA+SDG** scenario offers the best path forward, but it will require a whole-of-society commitment—governments, community, investors and market players—to act now.

A just and sustainable future will not look the same in every country. Each nation must tailor its policies to its own economic conditions, energy mix and development priorities. While the **RA+SDG** scenario provides a global framework, governments must integrate renewable energy expansion with socio-economic development programmes to ensure benefits are equitably distributed across all regions.

With bold action, a 1.5°C-aligned, renewables-powered future is within reach, bringing not just climate benefits, but a fairer, healthier and more prosperous world.

Section 5

Case studies

This section presents the modelled findings for Ecuador, Indonesia, Nigeria and Türkiye.

Methodology note

The analysis in this section is not intended to question or prescribe specific policy decisions or outcomes; rather it explores possible pathways that countries may consider as they work to increase renewable energy in their energy mix. Therefore, the scenarios presented are illustrative and aim to highlight the potential benefits that could be achieved if higher levels of renewable energy ambition—consistent with climate commitments—are realized.

For all case study countries, our analysis shows how countries stand to benefit significantly from higher renewable energy ambition, particularly when efforts are supported by complementary, SDG-aligned policy measures. The most transformative scenario (**RA+SDG**) assumes such policies are in place, including those targeting poverty reduction, health, education and access to services. These assumptions enable the model to capture both environmental and socio-economic impacts of more ambitious renewable energy expansion.

The analysis draws on information available as of December 2024 and does not incorporate new targets from countries' 2025 NDC submission cycle, which were still under development at the time of the research.

Ecuador

Background

Ecuador's energy sector relies heavily on oil production and hydropower. Oil contributes approximately 82 percent of the country's primary energy supply, positioning Ecuador as one of South America's leading oil producers in 2024 (IEA, 2024). This reliance ties Ecuador's economic performance directly to global oil price fluctuations. At the same time, in 2024, hydropower generated 72 percent of the country's electricity. However, seasonal droughts and infrastructure challenges, including recurring issues at the Coca Codo Sinclair hydropower plant, have exposed vulnerabilities in the energy system. These challenges caused energy shortages, forcing Ecuador to import electricity from Colombia, which cost the country $400 million in 2022 (ITA, 2024).

However, Ecuador is taking important steps toward a more sustainable energy future, focused on diversification and growth in renewable energy. While challenges remain, such as the need for stronger regulatory frameworks, reform of fuel subsidies, and increased investment in renewables, the government is

© Villonaco Wind Power Plant, CELEC EP – Electric Corporation of Ecuador, Ministry of Energy and Non-Renewable Natural Resources signaling a clear commitment to change. Through its latest **2025 NDC submission**, Ecuador has pledged an unconditional emissions reduction target of 7 percent, with an additional 8 percent reduction under a conditional scenario, for a total of 15 percent.[24] Although the NDC does not set specific quantified targets for the energy sector, new policies, including tax incentives and the creation of a fund for energy efficiency, demonstrate growing momentum toward renewable energy development and a low-emissions growth trajectory (Icaza *et al.*, 2022; Reuters, 2024). The country is also currently working on a **NDC Implementation Plan**, which will include more detailed sectoral information. Notably, the National Climate Change Mitigation Plan (PLANMICC 2024–2070) lays out long-term mitigation strategies across sectors and reaffirms the government's intention to align national energy policy with decarbonization goals.

Ecuador's energy policy and development trajectory will thus be deeply influenced by its balancing act between oil revenue dependence and a growing commitment to sustainable energy—a tension that is explored further in the following scenario analyses.

By 2060, the **RA** and **RA+SDG** scenarios show a more substantial uptake in renewables in Ecuador,

with the share of renewables forecast to rise to

93–94 percent,

primarily dominated by **solar.**

Scenario findings

The **Base Case** projections indicate a significant shift in Ecuador's energy mix, with renewables increasing from 9 percent in 2024 to 65 percent in 2060, driven by consistent reductions in fossil fuel use. In comparison, **RA** and **RA+SDG** scenarios show a more substantial uptake in renewables, with the share of renewables forecast to rise to 93–94 percent by 2060,[25] primarily dominated by solar (54 percent of the overall energy mix), followed by wind (25 percent) and hydro (13 percent). Oil, on the other hand, is projected to decline from 82 percent in 2024 to 7 percent in 2060.

Human development outcomes advance across all scenarios, with the **RA+SDG** scenario showing the most significant improvements. By 2060, extreme poverty is eliminated, and GDP per capita rises to $19,700, compared to $16,500 in the **Base Case** and $17,000 in the **RA** scenario. Universal access to electricity is achieved by 2030 in all scenarios, alongside increased energy access and a reduction in the use of traditional cookstoves.

Table 10 shows these changes across scenarios and selected development indicators.

24 Ecuador's **2025 NDC submission** was announced after the modeling of these scenarios was completed.
25 **RA** forecasts renewable share to rise to 93 percent, and **RA+SDG** forecasts 93.4 percent in 2060.

Table 10. Projections of key energy, development and environment indicators across scenarios in 2024, 2035 and 2060 for Ecuador

	Indicator	Unit	2024	2035			2060		
			Baseline	Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Energy+	Domestic fossil fuel production	TWh	285	252	183	186	110	17	17
	Domestic renewable production	TWh	28	47	56	57	200	220	240
	Renewables share of domestic energy production	%	9	16	23	24	65	93	93
	Energy demand per capita	KWh/capita	9,200	10,900	9,900	10,100	17,000	9,500	10,500
	Electricity use per capita++	KWh/capita	1,600	1,900	1,800	1,800	3,000	1,700	1,900
	Energy demand relative to GDP	MWh/thousand US$	1.6	1.6	1.5	1.4	1.4	0.8	0.7
Environment	Carbon emissions from fossil fuels+++	Billion tonnes of carbon	0.01	0.01	0.01	0.01	0.01	0.0	0.0
Development	GDP at MER	Billion US$	107	134	136	143	252	262	327
	HDI	0–1 scale	0.76	0.78	0.79	0.79	0.83	0.83	0.86
	GDP per capita at PPP	Thousand US$	10.5	11.5	11.6	12	16.5	17	19.7
	Poverty headcount	Millions (%)	1 (5.3)	0.6 (3.1)	0.6 (2.9)	0.3 (1.6)	0.2 (1)	0.2 (0.9)	0 (0.2)
	Malnourished headcount	Millions (%)	2.2 (12)	1.5 (7.5)	1.5 (7.4)	0.9 (4.7)	0.4 (1.8)	0.4 (1.7)	0.1 (0.6)
	Agricultural production	Million metric tonnes	37	42	42	43	50	50	37
	Access to safely managed water	%	69	74	74	78	87	88	94
	Access to safely managed sanitation	%	43	47	47	53	64	64	77
	Electricity access	%	99.8	100	100	100	100	100	100
	Population without electricity access	Millions	0	0	0	0	0	0	0
	Average education years	Years	9.7	10.4	10.4	10.5	11.6	11.6	12.1
	Traditional cookstove use	Million households (% of households)	0.1 (1.7)	0.1 (1.4)	0.1 (1.4)	0 (0)	0 (0.7)	0 (0.7)	0 (0)

Source: IFs v8.32.

\+ Ecuador's 2025 NDC submission (2026–2035) outlines strategies focused on GHG emissions reduction, adaptation measures and financial commitments. However, it does not specify quantifiable targets for renewable energy, reforestation or energy intensity improvements.

++ Our modeled figure for 2024 is approximately 1,600 kWh per capita, which is slightly higher but still broadly consistent with national statistics. For comparison, Ecuador's electricity regulatory authority, in its **Estadística 2024 report**, estimates average annual electricity consumption at approximately 1,279.75 kWh per capita (rounded to 1,300 kWh/capita). This national average is based on regulated consumer data across provinces, using population projections from INEC (*Instituto Nacional de Estadística y Censos*, Ecuador's national statistics agency).

+++ According to Ecuador's Fifth National Communication and First Biennial Transparency Report, total GHG emissions in 2022 amounted to 88,262.87 ktCO_2-eq (approximately 88 MtCO_2-eq). The IFs model estimates carbon emissions at 0.01 billion tonnes (38 MtCO_2-eq) in 2024. Ecuador has committed to reducing emissions by 8–11 MtCO_2-eq by 2035. In ƒc, emissions decline by 3 MtCO_2-eq relative to current levels and are projected to reach net zero by 2050.

Indonesia

Background

Indonesia, Southeast Asia's largest economy and the world's fourth most populous country, is a key player in the global energy landscape. It also ranks as the world's fourth-largest coal producer, Southeast Asia's leading gas supplier and the largest biofuel producer globally (IEA, 2022; 2025a). As the largest economy in ASEAN, Indonesia's renewable energy expansion has the potential to significantly influence both regional and global clean energy transitions.

Recognizing its renewable energy potential, Indonesia's **enhanced NDC update (2022)**[26] sets the following energy system targets for 2025 and 2050, in line with its national energy policy:

26 Note that this analysis is reflecting on the latest NDC submissions in the UNFCCC database. 2025 NDC submissions are not included as part of this modelling, given that the analysis was conducted in 2024 when new, 2025 NDC submissions for most countries where not yet available.

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- New and renewable energy should be at least 23 percent in 2025 and at least 31 percent in 2050;
- Oil should be at least 25 percent in 2025 and less than 20 percent in 2050;
- Coal should be minimum 30 percent in 2025 and minimum 25 percent in 2050; and
- Gas should be minimum 22 percent in 2025 and minimum 24 percent in 2050.

The Enhanced NDC also raises Indonesia's 2030 climate targets, committing to an unconditional emission reduction of 31.89 percent (up from 29 percent) and a conditional reduction of 43.2 percent (up from 41 percent). The **Low-Carbon Development Strategy (LTS-LCCR)** aims to peak greenhouse gas emissions by 2030, achieve a net sink in the forest and land use sector, and reach net-zero emissions by 2060 or earlier. Notably, these national commitments align with international collaborative efforts such as the ongoing Just Energy Transition Partnership (JETP) process in Indonesia, launched in November 2022.[27] Under the JETP, Indonesia targets on-grid power sector emissions to peak by 2030 with a cap of 250 MT CO_2, achieve a 34 percent share of renewable energy generation by 2030, and reach net-zero emissions in the power sector by 2050. The JETP sets a process to drive Indonesia's sustainable industrialization by accelerating solar, wind and grid development.

The LTS-LCCR also supports Indonesia's long-term development vision, *Visi Indonesia 2045*, by integrating sustainability with economic growth. It aligns climate goals with national and international objectives, such as those embedded in the JETP, while aiming to engage non-party stakeholders, foster innovation and benefit local communities. The strategy emphasizes the following pillars: advancing human resources and technology, promoting sustainable and equitable economic development, and strengthening governance and resilience, positioning Indonesia for a prosperous and sustainable future.

27 **Just Energy Transition Partnership Indonesia: Comprehensive Investment and Policy Plan 2023.**

Scenario findings

By 2060, under the **RA+SDG** scenario,

Indonesia's per capita GDP is projected to be around

$3,500 higher

than in the **Base Case.**

In the **Base Case**, Indonesia's energy sector continues to depend heavily on fossil fuels, which are projected to supply 93 percent of total energy production by 2060 (up from 81 percent in 2024).[28] In contrast, the share of renewables in the energy mix rises only marginally to 7 percent by 2060.[29] Per capita energy demand is projected to grow from 9,000 KWh in 2024 to 20,800 KWh by 2060, in response to a growing population. As a subset of this total demand, electricity consumption per capita is also projected to nearly double from 1,400 KWh in 2024 to 3,200 KWh by 2060. Carbon emissions are projected to rise from 0.22 billion tonnes in 2024 to 0.52 billion tonnes by 2060.

In contrast, **RA** and **RA+SDG** scenarios show a substantial expansion of renewables, with their share of energy production increasing from 3 percent in 2024 to 70 percent and 71 percent, respectively by 2060 (Table 11). Our analysis finds that under these scenarios, Indonesia's renewable energy target of 23 percent is achieved by 2041. **RA** and **RA+SDG** scenarios allow for a significant shift away from fossil fuels, allowing carbon emissions from these sources to subsequently decline to 0.11 billion tonnes by 2060. By 2030, emissions in **RA** and **RA+SDG** scenarios are 15 percent lower than in the **Base Case**, with reductions further rising to 80 percent below **Base Case** levels by 2060 (Table 11).

By 2060, under the **RA+SDG** scenario—the most transformative and closely aligned with the SDGs—Indonesia's per capita GDP is projected to be around $3,500 higher than in the **Base Case**. Poverty is virtually eradicated by 2035, universal access to electricity is achieved by 2030 and 1.6 million fewer people experience malnutrition by 2060. These co-benefits result from the combination of ambitious renewable energy expansion and complementary development policies (additional outcomes are shown in Table 11). Embedding renewable energy strategies within a broader sustainable development framework enables Indonesia to accelerate both climate and development goals, strengthening the case for integrated energy planning aligned with the SDGs.

28 In IFs, domestic energy production data is drawn from the IEA World Energy Balances. Production by energy type is aligned with IEA estimates on installed capacity (for renewables) and reserves (for fossil fuels), which helps ensure the model does not project production beyond feasible limits. According to Indonesia's Ministry of Energy and Mineral Resources (MEMR), the 2023 primary energy mix is dominated by coal (40 percent), followed by petroleum (30 percent) and natural gas (17 percent).

29 The energy mix refers to the share of each energy type in domestic production, whereas total primary energy supply includes both imports and exports. Data differences may arise as IFs uses IEA World Energy Balances, while MEMR relies on BP's Statistical Review of World Energy.

Table 11. Projections of key energy, development and environment indicators across scenarios in 2024, 2035 and 2060 for Indonesia

	Indicator	Unit	2024	2035			2060		
			Baseline	Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Energy+	Domestic fossil fuel production	TWh	5,000	7,200	6,400	6,500	11,900	2,200	2,300
	Domestic renewable production	TWh	150	210	520	530	840	5,300	5,800
	Renewables share of domestic energy production++	%	3+++	3	7	8	7	70	71
	Energy demand per capita	KWh/capita	9,000	12,400	11,400	11,600	20,800	11,800	12,800
	Electricity use per capita	KWh/capita	1,400	2,000	1,800	1,900	3,200	1,800	2,000
	Energy demand relative to GDP*	MWh/thousand US$	1.9	1.8	1.7	1.7	1.6	0.9	0.8
Environment	Carbon emissions from fossil fuels++	Billion tonnes of carbon	0.2	0.3	0.3	0.3	0.5	0.1	0.1
	Country temperature relative to 1990***	Celsius	0.8	1.1	1.1	1	1.8	1.2	**0.9**
Development****	GDP at MER	Billion US$	1,320	2,020	2,040	2,100	4,120	4,230	5,120
	GDP per capita at PPP	Thousand US$	12.4	15.2	15.4	15.7	22.2	22.6	25.7
	HDI	0-1 Scale	0.74	0.77	0.77	0.78	0.82	0.83	0.85
Development****	Poverty headcount	Millions (%)	6.3 (2.2)	2.1 (0.7)	1.9 (0.6)	0.9 (0.3)	0.1 (0)	0.1 (0)	0 (0)
	Malnourished headcount	Millions (%)	13.9 (4.9)	8 (2.7)	7.9 (2.6)	4.4 (1.5)	2.1 (0.7)	2.1 (0.7)	0.5 (0.2)
	Agricultural production	Million metric tonnes	578	694	695	705	850	950	700
	Access to safely managed water	%	70	79	80	83	92	93	97
	Access to safely managed sanitation	%	69	74	74	77	85	86	93
	Electricity access	%	99	99	100	100	100	100	100
	Population without electricity access	Millions	3.7	2.2	0	0	0.4	0	0
	Average education years	Years	9.5	10.2	10.2	10.3	11.3	11.3	11.7
	Traditional cookstove use	Million households (% of households)	27.3 (42.5)	21.5 (27.9)	20.6 (26.7)	6.4 (8.3)	9.7 (10.4)	9.2 (9.9)	0 (0)

Source: IFs v8.32.

+ According to Government Regulation No. 79/2014 on Indonesia's National Energy Policy, oil should account for less than 25 percent of the energy mix by 2025 and less than 20 percent by 2050. Coal should make up 30 percent by 2025 and 25 percent by 2050, while gas should account for 22 percent by 2025 and 24 percent by 2050. In the **Base Case** scenario, fossil fuel production (oil, coal, and gas) reaches 95 percent of the energy mix by 2050, with coal as the dominant source. However, the **RA** and **RA+SDG** scenarios aim to phase out fossil fuels, reducing their share to 45–48 percent by 2050 and further to around 30 percent by 2060 as part of decarbonization efforts.

++ Share of renewables in the energy mix must account for 23 percent in 2025, rising to 31 percent in 2050. In the **RA** and **RA+SDG** scenarios, renewables reach 23 percent by 2041 and expand to 50 percent by 2050, reflecting Indonesia's constraints in rapidly transitioning away from fossil fuels. The model projects a sharp increase in renewables after mid-2030s as fossil fuel reliance declines.

+++ Energy figures for 2024 have also been checked for consistency with MEMR's reported data; the IFs model outputs show close alignment with these figures. However, energy production from biofuels and waste are not include in the calculations for Indonesia. Roughly, they comprise 6 percent of the domestic energy production.

* **Presidential Regulation No. 22/2017** on Indonesia's National Energy General Plan mandates a 1 percent annual reduction in energy intensity. The acceleration scenarios project annual energy intensity reductions of 1–4 percent between 2024 and 2050.

** Indonesia's Long-Term Low-Emission Development Strategies (LT-LEDS) require GHG emission reductions across sectors. The IFs model accounts only for carbon emissions from the energy sector. According to **Indonesia's 3rd Biennial Update Report**, GHG emissions totaled 1.85 Gt CO_2 eq in 2019, with the energy sector contributing 35 percent. In 2024, the IFs model projects energy-related carbon emissions at 0.2 billion tonnes (0.8 Gt CO_2 eq). Under acceleration scenarios, emissions peak in the mid-2030s and decline to 0.1 billion tonnes by 2060, approaching net zero.

*** Indonesia's NDCs commit to preventing global temperatures from exceeding 2°C, with a goal of limiting warming to 1.5°C. Under acceleration scenarios, Indonesia's average temperature increase remains below 1.5°C by 2060. Additionally, forestry sector mitigation strategies target the restoration of 14 million hectares of land. In the **RA+SDG** scenario, forest land expands from 90 million hectares in 2024 to 105 million hectares in 2060.

**** The **RA+SDG** scenario is projected to deliver the greatest long-term benefits for both people across development indicators. It raises Indonesia's HDI to levels currently comparable with UMIC and HIC countries, eliminates extreme poverty, ensures universal access to safe water and electricity, and phases out solid fuels for cooking by 2060. Food security improves as crop production increases to meet the demands of a growing population. However, shifts away from emission-intensive meat consumption reduce total agricultural production compared to the **Base Case** projections. Malnutrition and health burdens linked to food insecurity decline, supported by wider energy access and systemic socio-economic reforms that enhance overall well-being in Indonesia.

Nigeria

Background

Nigeria, sub-Saharan Africa's largest economy in purchasing power parity (PPP) terms and a leading oil producer, relies heavily on fossil fuels to power its economy. Oil and natural gas account for more than half of Nigeria's energy supply, with nearly 80 percent of its electricity generated from gas-fired power plants (IEA, 2025b). However, grid electricity reaches only about 40 percent of the population (Nigerian Electricity Regulatory Commission, 2023), with frequent disruptions forcing reliance on costly and polluting petrol and diesel generators. Even more concerning, over 180 million Nigerians lack access to clean cooking, contributing to 77,600 annual fatalities, 67 percent of which are children (Federal Republic of Nigeria, 2024).

Renewable energy contributes approximately 25 percent of Nigeria's electricity, with around 24 percent coming from hydropower and less than 1 percent from solar photovoltaic (PV) (IEA, 2025b; Nigerian Electricity Regulation Commission, 2023). However, when considering the broader primary energy supply, the share of renewables falls to under 2 percent—excluding traditional biomass,

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which is primarily used for unsustainable burning of wood, and charcoal for cooking and heating. Despite these challenges, Nigeria's abundant solar and wind resources position the country well for a renewable energy transition, provided that policy, capacity and financing challenges are systematically addressed (Obada *et al.*, 2024).

A new transformative opportunity has emerged through **Nigeria's Electricity Act 2023,** which ushers in a new era of electricity market deregulation. Under this Act, State Governments now have a clear mandate to undertake electricity generation, transmission and distribution, with a new National Integrated Electricity Policy set to be unveiled. Complementing this legislative reform, the **Nigeria Integrated Resource Plan 2024** provides a comprehensive framework for national power system planning. The Resource Plan adopts a least-cost approach, assessing both supply-side energy resources and demand-side efficiency opportunities to meet national objectives such as energy security, social equity, decarbonization and environmental sustainability. While the plan emphasizes meeting current and future electricity demand, it also aligns with Nigeria's energy transition goals by prioritizing the integration of renewable energy sources and phasing out self-generation practices.

Nigeria's 2021 NDC update and **Energy Transition Plan** further underscore a strong focus on increasing renewables in the energy mix and achieving carbon neutrality (net-zero emissions) by the year 2060, through transformations across the power, transport, oil and gas, cooking and industry sectors. Specifically, Nigeria's NDC outlines targets including 30 percent on-grid electricity generation from renewables, zero gas flaring, a 60 percent reduction in methane emissions, and the elimination of diesel and gasoline generators for electricity generation by 2030.

Consistent with these targets, **Nigeria's Renewable Energy Master Plan** and the **Energy Transition Plan** aim to increase renewables' share to 36 percent by 2030. The government's **Vision 30:30:30 strategy** seeks to add 30 GW of renewable energy by 2030, contributing to at least 30 percent of the energy mix. This strategy, detailed in the National Integrated Electricity Policy, emphasizes the need for stronger private sector involvement, clearer regulations and expanded infrastructure, particularly in underserved rural areas. Achieving these objectives will be critical for transitioning to a sustainable energy future.

Meanwhile, **Nigeria's Energy Compact** as part of the Africa-wide Mission 300 effort, sets even more ambitious targets: increasing the share of renewables in electricity generation to 50 percent by 2030 and achieving universal access to electricity and clean cooking.

Scenario findings

The acceleration scenarios present a promising outlook for Nigeria's energy sector. Remaining on the **Base Case** pathway, however, sets a dangerous precedent for the national environment, as renewables' share of primary energy production only rises from 2 percent in 2024 to 2.4 percent in 2035, and to just 38 percent in 2060. In contrast, the **RA** and **RA+SDG** scenarios


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demonstrate that Nigeria's stated targets of a renewable share of 30 percent are attained by 2045; and by 2060, the share rises further to 83 percent—effectively meeting Nigeria's NDC pledges.

In the acceleration scenarios, renewable adoption faces an initial delay as Nigeria works to transition away from dominant fossil fuel sources such as oil and gas. By 2060, the share of oil production declines from 64 percent in 2024 to 4 percent and the share of gas from 34 percent in 2024 to 6 percent.

Comparing our scenario results with Nigeria's Integrated Resource Plan, it is important to note that the **RA** and **RA+SDG** scenarios presented here are globally oriented and illustrative, designed to explore broad policy pathways without delving into country-specific interventions.[30] The Integrated Resource Plan is anchored in the Delayed Electrification and Self-Generation phase-out (DESG) scenario, which emphasizes meeting national electricity demand through least-cost solutions while aligning with Renewable Energy Supply (RES) penetration and Energy Transition Plan (ETP) emission targets. A key objective of the DESG scenario is the complete phase-out of self-generation by 2035.[31]

In terms of economic growth, the **RA+SDG** scenario projects an increase in GDP per capita from $4,800 in 2024 to $9,100 in 2060, which is approximately $2,000 higher than the **Base Case** projection for 2060. The **RA** scenario shows moderate improvements, with GDP per capita reaching $7,700 in 2060. Poverty alleviation also sees marked progress, particularly in the **RA+SDG** scenario, which lifts an estimated 47 million people out of extreme poverty by 2060, compared to 0.5 million people in the **RA** scenario. Both acceleration scenarios achieve universal access to electricity by the end of the projection horizon, underscoring their potential to address Nigeria's energy poverty. The population relying on traditional fuels for cooking is also projected to decline sharply, from 24 million people in 2024 to zero in 2060. Additionally, carbon emissions in the **RA** and **RA+SDG** scenarios decline significantly, with reductions exceeding 60 percent relative to the **Base Case** by 2060.

By 2060, under the **RA** and **RA+SDG** scenarios, **carbon emisions** decline significantly in Nigeria, **with reductions exceeding**

60 percent

relative to the **Base Case**.

Table 12 below summarizes these results, highlighting Nigeria's potential to make substantial progress across key development indicators through targeted energy transition strategies.

30 In contrast, Nigeria's Integrated Resource Plan (NIRP) adopts a more granular, engineering-focused approach using the PLEXOS model to conceptualize its scenarios.

31 Consequently, the sensitivities analysed within the NIRP are based on the DESG scenario rather than a **Base Case**. Our **RA** and **RA+SDG** scenarios, developed using the IFs model, are conceptual (relative to IFs Base Case) and do not incorporate the specific demand projections or policy levers detailed in the NIRP scenarios.

Table 12. Projections of key energy, development and environment indicators across scenarios in 2024, 2035 and 2060 for Nigeria

	Indicator	Unit	2024	2035			2060		
			Baseline	Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Energy	Domestic fossil fuel production+	TWh	1,400	1,300	1,100	1,100	700	230	240
	Domestic renewable production	TWh	15	30	40	40	390	1100	1250
	Renewables share of domestic energy production++	%	1	2	4	4	38	83	84
	Energy demand per capita	KWh/capita	4,100	5,100	5,300	5,400	8,600	9,800	11,000
	Electricity use per capita	KWh/capita	170	240	260	270	530	630	730
	Energy demand relative to GDP+++	MWh/thousand US$	2.2	2.5	2.6	2.5	2.3	2.5	2.2
Environment	Carbon emissions from fossil fuels*	Billion tonnes of carbon	0.05	0.09	0.09	0.09	0.22	0.05	0.05
Development**	GDP at MER	Billion US$	437	641	645	666	2,075	2,165	2,660
	GDP per capita at PPP	Thousand US$	4.8	5.1	5.1	5.2	7.5	7.7	9.1
	HDI	0–1 scale	0.59	0.61	0.61	0.62	0.68	0.69	0.71
	Poverty headcount	Millions (%)	72 (30.8)	80 (25.2)	78 (24.6)	71 (22.4)	96 (17)	95 (16.9)	49 (9)
	Malnourished headcount	Millions (%)	30 (12.9)	31 (9.8)	31 (9.8)	22 (6.9)	25 (4.4)	24 (4.3)	10 (1.8)
	Agricultural production	Million metric tonnes	228	260	260	270	360	365	385
	Access to safely managed water	%	24	32	32	35	55	56	66
	Access to safely managed sanitation	%	32	36	36	37	48	49	52
	Electricity access	%	58	67	77	84	88	100	100
	Population without electricity access	Millions	98	106	72	49	69	0	0
	Average education years	Years	7.2	7.4	7.4	7.5	8.1	8.2	8.5
	Traditional cookstove use***	Million households (% of households)	24.7 (66.1)	29.3 (53.2)	22.6 (41.1)	5.2 (9.5)	26.1 (22.3)	17.2 (14.7)	0 (0)

Source: IFs v8.32.

\+ Nigeria's 2021 NDC Update outlines plans to phase out fossil fuels, particularly oil and natural gas. The mitigation strategy sets targets for zero gas flaring and the elimination of diesel and gasoline generators for electricity generation by 2030. While the acceleration scenarios do not forecast such a drastic shift—given that 95 percent of Nigeria's energy in 2024 relies on oil and gas—reliance on these sources declines to 10 percent by 2060.

++ Nigeria's Renewable Energy Master Plan and Energy Transition Plan aim to increase renewables' share to 36 percent by 2030, while the 2021 NDC Update sets a target of 30 percent of on-grid electricity from renewables. In the **Base Case**, these targets are only met by 2060. However, in the **RA** and **RA+SDG** scenarios, renewables reach 30 percent of total energy consumption 15 years earlier. By 2060, renewables are projected to account for 83–84 percent of total energy consumption.

+++ Nigeria's mitigation measures mandate a 2.5 percent annual reduction in energy intensity across all sectors. Since the IFs model does not differentiate between sectors, the acceleration scenarios project energy intensity reductions of 1–2 percent annually throughout the study period.

* The 2021 NDC Update covers emissions from four GHGs, including CO_2. In 2018, the energy sector alone contributed 209 $MtCO_2eq$. In 2024, the IFs model estimates Nigeria's carbon emissions at 0.05 billion tonnes (183 $MtCO_2eq$). The 2015 NDC projected GHG emissions reaching 898 $MtCO_2eq$ by 2030 under a business-as-usual scenario. This was later revised to 453 $MtCO_2eq$ in their 2021 NDC Update. The IFs **Base Case** projects a similar trend, with carbon emissions rising to 310 $MtCO_2eq$ by 2030 and reaching 820 $MtCO_2eq$ by 2060. Under acceleration scenarios, emissions decline significantly to 190–200 $MtCO_2eq$ by 2060.

** The **RA+SDG** scenario presents significant opportunities for Nigeria to improve economic and social outcomes. In this scenario, extreme poverty declines substantially, lifting 50 million people out of poverty compared to the **Base Case** in 2060. While the Energy Transition Plan aims to lift 100 million people out of poverty, the **RA+SDG** scenario still achieves substantial progress. Universal access to safe water, sanitation and the elimination of undernutrition remains unlikely by 2060 under this scenario. However, it drives broad-based improvements that enhance overall well-being compared to the **Base Case**, indicating a better quality of life for the population.

*** Nigeria's residential sector mitigation targets set a goal for 13 percent of households to transition to improved cookstoves by 2030. In the IFs **Base Case**, only 4 percent of households are projected to achieve this transition by 2030. In contrast, the **RA+SDG** scenario projects 12 percent of households using improved cookstoves by the same year. By 2060, traditional cookstove use is fully eliminated, contributing to reduced indoor air pollution, lower health risks and improved energy efficiency in Nigerian households.

Türkiye

Background

Türkiye, Europe's sixth-largest electricity market and the 14th-largest globally, is undergoing significant energy transition. To meet its commitments and strengthen clean energy capacity, Türkiye has adopted national strategies and action plans that outline clear pathways to enhance the role of renewables and reduce energy intensity.

Türkiye's climate commitments, outlined in its **2023 NDC update** and Long-Term Low Emissions Development Strategy, include emissions caps across sectors including energy, industry, agriculture and waste. These efforts are further complemented by investments in nuclear power and smart-grid development to bolster energy diversification and enhance overall efficiency.

Energy is identified as a top priority in the **Twelfth Development Plan (2024-2028)**, which focuses on maximizing a sustainable, reliable and affordable energy supply while also enhancing energy efficiency across all sectors. In line with the Twelfth Development Plan, Türkiye's updated **National Energy Plan (2020-2035)** sets

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ambitious goals, targeting a total installed capacity of 189.7 GW by 2035, with renewables representing 64.7 percent of this amount (up from 54 percent in 2022) and reaching an installed capacity of nuclear power plants of 7.2 GW by 2035. The plan also aims to reduce energy intensity by 35.3 percent.

Türkiye has also further demonstrated its commitment to energy efficiency by publishing the **Energy Efficiency 2030 Strategy and Second National Energy Efficiency Action Plan (NEEAP)** for 2024–2030. These documents align Türkiye's' core strategies to address climate change targets, ensure energy security and support the European Green Deal. The NEEAP anticipates reducing emissions equivalent to 100 million tonnes of CO_2 alongside an energy savings target of 37.1 million tonnes of oil equivalent (MTOE).

Most recently, Türkiye's **2053 Long-Term Climate Strategy** aims to significantly increase the use of renewable energy sources and enhance their share in the energy supply in line with key national documents. Total electricity demand is projected to reach 1,271.39 TWh by 2053, with the share of renewable energy sources expected to rise from 42.4 percent in 2020 to 69.1 percent in 2053 to meet this demand. In the medium term, Türkiye aims to quadruple its existing renewable energy capacity, reduce energy intensity by 35 percent and integrate renewable energy technologies into the national energy system as part of its short- and medium-term targets set for 2030 and 2035.

In conclusion, Türkiye's energy goals are shaped by a multidimensional strategy that focuses on enhancing energy efficiency in the short term, expanding renewable capacity in the medium term and achieving net-zero emissions in the long term.

Scenario findings

In our scenario analysis, Türkiye's energy and development landscape stands out as more advanced compared to the other case study countries (Ecuador, Indonesia and Nigeria), with minimal poverty (0.2 percent in 2024) and universal access to electricity. In the **Base Case** scenario, renewables are projected to dominate Türkiye's energy production, rising to 94 percent by 2060, driven by substantial growth in solar, wind and hydroelectric capacity. While development indicators show incremental progress, rising energy demand—fueled by population and economic growth poses challenges to sustaining economic growth and achieving environmental goals without additional interventions.

Acceleration scenarios (**RA** and **RA+SDG**) are consistent with the ambitions outlined in Türkiye's Long-Term Low Emissions Development Strategy and NDC; however, they push beyond currently articulated targets to demonstrate the potential benefits of a more accelerated and integrated approach. The **RA** scenario accelerates Türkiye's renewable energy transition while emphasizing energy efficiency to manage rising demand. However, this rapid shift towards renewables does not significantly improve development outcomes.

The **RA+SDG** scenario further integrates renewables acceleration with social and economic development goals, resulting in a higher GDP per capita (PPP) of $70,000 by 2060—above the $59,000 projected in both the **Base Case** and **RA** scenarios.

This integrated approach highlights the potential to maximize both economic and environmental outcomes, underscoring the importance of coupling Türkiye's energy transition with sustained social progress. Table 13 shows these changes across scenarios and selected human development indicators.

By 2060, **RA+SDG** scenario further integrates renewables acceleration with social and economic development goals,

resulting in a higher GDP per capita of

$70,000

for Türkiye above the **$59,000 projected** in both the **Base Case** and **RA** scenarios.

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Table 13. Projections of primary energy production, development and environment indicators across scenarios in 2024, 2035 and 2060 for Türkiye

	Indicator	Unit	2024	2035			2060		
			Baseline	Base Case	RA	RA+SDG	Base Case	RA	RA+SDG
Energy	Domestic fossil fuel production	TWh	240	210	140	141	134	25	25
	Domestic renewable production	TWh	340	680	690	700	1,800	2000	2000
	Renewables share of domestic energy production+	%	60	77	83	83	94	99	99
	Energy demand per capita	KWh/capita	22,100	28,500	25,800	26,000	44,600	24,200	27,000
	Electricity use per capita	KWh/capita	3,700	5,400	4,900	4,900	10,500	5,700	6,500
	Energy demand relative to GDP++	MWh/thousand US$	1.7	1.4	1.3	1.3	1.1	0.6	0.6
Environment	Carbon emissions from fossil fuels+++	Billion tonnes of carbon	0.13	0.15	0.12	0.12	0.13	0.02	0.02
Development*	GDP at MER	Billion US$	1,100	1,800	1,800	1,900	3,800	3,800	4,500
	GDP per capita at PPP	Thousand US$	31.7	39.6	39.7	40.5	58.8	58.4	70.4
	HDI	0–1 scale	0.83	0.87	0.87	0.87	0.93	0.93	0.95
	Poverty headcount	Millions (%)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)
	Malnourished headcount	Millions (%)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Agricultural production	Million metric tonnes	175	189	189	195	210	210	195
	Access to safely managed water	%	96	98	98	98	99	99	100
	Access to safely managed sanitation	%	82	89	89	93	97	97	100
	Electricity access	%	100	100	100	100	100	100	100
	Population without electricity access	Millions	0	0	0	0	0	0	0
	Average education years	Years	9.5	10.3	10.3	10.3	11.8	11.8	12.3
	Traditional cookstove use	Millions households (% of households)	0.1 (0.4)	0 (0.2)	0 (0.2)	0 (0)	0 (0)	0 (0)	0 (0)

Source: IFs v8.32.

+ As of September 2022, Türkiye's Updated 2023 NDC reports a total installed capacity of 102,281 MW, with renewable energy sources contributing 55,630 MW, accounting for 54 percent of total electricity generation. For 2024, our model estimates that renewable energy production accounts for 60 percent of Türkiye's energy needs. According to Türkiye's LT-LEDS, the share of renewables is expected to rise from 42.4 percent in 2020 to 69.1 percent by 2053. In acceleration scenarios, renewables reach 75 percent much earlier by 2030. Over the study period, renewable production capacity nearly quadruples, aligning with Türkiye's long-term energy strategies.

++ To achieve its renewable energy targets, Türkiye projects that primary energy intensity must decline to 0.08 TOE per thousand US$ (at 2015 prices) by 2030. In acceleration scenarios, primary energy intensity declines to 1.2 MWh per thousand US$ at 2017 prices, equivalent to 0.1 TOE per thousand US$ (at 2017 prices) by 2030. By 2060, it further declines to 0.08 TOE per thousand US$.

+++ According to Türkiye's National Inventory Report (2022), GHG emissions across all sectors stood at 523.9 $MtCO_2eq$ in 2020. The IFs model estimates that carbon emissions from the energy sector will reach 0.13 billion tonnes (460 $MtCO_2eq$) in 2024. In the **Base Case**, emissions grow until the 2050s before declining. In acceleration scenarios, carbon emissions fall to 60 $MtCO_2eq$ by 2060.

* Türkiye achieves nearly all SDGs under the **RA+SDG** scenario. Even in the **Base Case**, development outcomes improve steadily over the study period.

Section 6

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Section 7

Annexes

Annex 1: Outcome indicators

We examine the long-term impacts of these scenarios on a range of outcome indicators through 2060, with focus not only on the feasibility of achieving global energy and climate goals but also their alignment with the broader objectives of the SDGs. A 2060-time horizon provides sufficient time to account for the complex, systemic transitions required to address energy challenges, mitigate climate change and evaluate their ripple effects on development outcomes. Table A1 reports the list of outcome indicators we situate our analysis on. It shows these indicators, followed by their definition, data source and baseline value in IFs.

Table A1. List of outcome indicators, including their definitions, data sources and baseline values with corresponding years in the IFs model

	Indicator	Definition	Source	Global baseline value (Year)
Energy	Energy production	Energy production by type, in billion barrels of oil equivalent (BBOE)	International Energy Agency (IEA) World Energy Balances	89.2 BBOE (2020)
	Energy demand	Total energy use that accounts for both production and trade in energy	International Energy Agency (IEA) World Energy Balances	96.5 BBOE (2023)
Environment	CO_2 in atmosphere	Concentration of CO_2 in the atmosphere, in ppm	Carbon Dioxide Information Analysis Center (CDIAC)	414.7 ppm (2020)
	Carbon emissions	Carbon emissions from fossil fuels in billion tonnes of carbon	Carbon Dioxide Information Analysis Center (CDIAC)	9 billion tonnes (2020)
	Global temperature relative to 1990	Annual average temperature change from 1990, in degrees Celsius	Carbon Dioxide Information Analysis Center (CDIAC)	0.9 (2020)
Development	GDP at MER	Gross domestic product at market exchange rate, in constant 2017 US$	History – World Bank World Development Indicators (WDI); Short-term forecasts – International Monetary Fund World Economic Outlook (IMF WEO – 2023 October)	88.4 (2021)
	GDP per capita at PPP	Gross domestic product per capita at purchasing power parity per capita, in constant thousands 2017 US$	World Bank World Development Indicators (WB WDI)	17.04 (2021)
	HDI	Human Development Index	UNDP Human Development Review (HDR)	0.73
	Poverty	Percentage of the population living on less than $2.15 a day in 2017 international prices; estimation by World Bank, Poverty and Inequality Platform	WB WDI	9.3% or 738.6 million (2021)
	Malnutrition	Share of population whose weight for height is more than three standard deviations below the median for the international reference population aged 0–59 months	WB WDI	8.9% or 708.6 million (2021)
	Agricultural production	Total agricultural domestic production, by type: crop, meat and fish	Food and Agricultural Organization (FAO) Food Balances	13,000 million metric tonnes
	Water access	Share of population with access to 'safely managed' water services	Joint Monitoring Programme (JMP) – World Health Organization and UNICEF	68.6% (2020)
	Sanitation access	Share of population with access to 'safely managed' sanitation services	Joint Monitoring Programme (JMP) – World Health Organization and UNICEF	55.9% (2020)
	Electricity access	Share of population with access to electricity	World Bank WDI	91.4% (2021)
	Average education years	Average years of schooling for those 15 years or older	Estimations from Wittgenstein Centre Human Capital Data Explorer	8.2 (2015)
	Cookstove use	Households using traditional cookstoves for cooking, in millions	World Health Organization (WHO) Air Pollution Data	425.3 million households or 24.2% (2020)
	Population	Number of people, in billions	United Nations World Population Prospects	7.9 billion (2021)

Source: IFs v8.32.

Annex 2: Scenario assumptions

Table A2. Detailed scenario assumptions as modelled in IFs Scenario

	Impact area	Scenario assumption	Model structure – Impact pathways
Base Case	-	Most likely development path that involves a dynamic unfolding of current development patterns	The model estimates the current path trajectory by assuming that the current trends and policies continue unchanged into the future. This involves no additional parameterization of variables in the model.
The interventions described below are simulated in the model relative to its Base Case projections.			
Renewable Acceleration (RA)	Hydro investment	An increase in hydro investment for upper middle-income countries of 75% by 2030	Energy investment by type multiplier in IFs allows greater/lower capital allocation for a particular type of energy source. Here, we assume no exogenous intervention on fossil fuels, but higher investment levels for non-fossil fuels that eventually impacts stocks and flows of energy. Energy production/supply therefore increases based on the nature of intervention.
		An increase in hydro investment for low-income and low middle-income countries of 100% by 2050	
		An increase in hydro investment for high-income countries of 9% by 2035	
	Solar investment	An increase in solar investment for low-income countries of 200% by 2030	
		An increase in solar investment for upper middle-income countries of 300% by 2030	
		An increase in solar investment for high-income countries of 200% by 2030	
		An increase in solar investment for low middle-income countries of 100% by 2030	
		An increase in solar investment for China of 300% by 2028	
	Wind investment	An increase in wind investment for low-income countries of 200% by 2030	
		An increase in wind investment for upper middle-income countries of 300% by 2030	
		An increase in wind investment for high-income countries of 200% by 2030	
		An increase in wind investment for low middle-income countries of 100% by 2030	
		An increase in wind investment for China of 300% by 2035	
	Geothermal investment	An increase in geothermal investment for low-income countries of 200% by 2030	
		An increase in geothermal investment for upper middle-income countries of 300% by 2030	
		An increase in geothermal investment for high-income countries of 200% by 2030	
		An increase in geothermal investment for low middle-income countries of 100% by 2030	
		An increase in geothermal investment for China of 300% by 2034	

Impact area	Scenario assumption	Model structure – Impact pathways
Other renewables investment	An increase in other renewables investment for low-income countries of 200% by 2030 An increase in other renewables investment for upper middle-income countries of 300% by 2030 An increase in other renewables investment for high-income countries of 200% by 2030 An increase in other renewables investment for low middle-income countries of 100% by 2030 An increase in other renewables	
Nuclear investment	An increase in nuclear investment for low-income countries of 100% by 2035 An increase in nuclear investment for low middle-income countries of 150% by 2040 An increase in nuclear investment for upper middle-income countries of 50% by 2030 An increase in nuclear investment for high-income countries of 15% by 2035	
Ratio of energy demand to GDP	Held constant for high-income countries from 2025 until 2057 Held constant for upper middle-income countries from 2025 until 2040 Held constant for low-income countries from 2060 until 2075 Held constant for low middle-income countries from 2080 onwards	
Capital-output costs of solar	A decrease in the capital cost to output ratio of solar for the world to 20% by 2035 A decrease in the capital cost to output ratio of solar for China to 50% by 2040	Decreasing capital-output costs for VRE sources like solar and wind are based on literature findings and improvements arising from technological learning and economies of scale. This impacts energy production directly, as cheaper sources gain an economic advantage over capital-intensive sources of fuel.
Capital-output costs of wind	A decrease in the capital cost to output ratio of wind for the world to 20% by 2030 A decrease in the capital cost to output ratio of wind for China to 50% by 2040	
Energy demand	A decrease in energy demand for high-income countries of 20% by 2040 A decrease in energy demand for upper middle-income countries of 15% by 2038 An increase in energy demand for low-income countries of 15% by 2060	Energy demand affects overall spending as well as production patterns in IFs. This intervention is designed to keep equity in mind, allowing countries to get to near-parity in per capita consumption of energy.
Electricity access	An increase in electricity access for the world of 50% by 2050	Increasing electricity access has direct links to multi-factor productivity, thereby moderately affecting growth.
Rate of discovery of coal	An increase in the rate of discovery of coal for Indonesia by 500% An increase in the rate of discovery of coal for Nigeria by 500%	An increase in this parameter leads to higher reserves of a particular type (in this case, coal for Indonesia and Nigeria) based on available resources. This allows un-capped growth in a particular type of energy source.
Maximum coal production	A maximum level of coal production for China at 200% of current production A maximum level of coal production for India at 150% of current production	Sets the maximum production limit on coal production for China and India, allowing for capped growth in these sources.
VRE share threshold	VRE threshold is set to 0.8, i.e. 80% generation of total energy demand	Variable qevrethr is parameterized to 0.8 (default value, 1), meaning that system cost impacts start only after the share of VRE sources reach 80% of total energy demand.
Clean cooking	Faster adoption of modern-fuel and other improved technologies for indoor cooking—an additional 200% rise by 2030, and thereafter for the world	Variable cookstoves add is parameterized in the model to reflect an increase in adoption of modern cookstoves of over 200% by 2030. The model also computes this transition accounting for an increased availability of electricity in homes under this scenario.

	Impact area	Scenario assumption	Model structure – Impact pathways
The interventions described below are in addition to the RA scenario interventions described above.			
Renewable Acceleration + SDGs (RA+SDG)	**Electricity transmission**	A reduction in electricity transmission loss of 20% by 2054	Additional electricity-relevant parameterization includes reduction in electricity transmission loss (infraelectranlossm) by 20% over **Base Case** forecasts by 2054. This brings in no additional cost implication but simply allows for a greater availability of electricity for common household use.
	Agricultural loss	A reduction in agricultural losses in all stages of production, distribution and consumption of 30% by the year 2055 for the world	Improves agricultural efficiency practices, also ensuring minimal deviation in coefficient of variation in calories. This has health and nutritional implications in the model.
	Agricultural yields	An increase in agricultural yields for high and upper-middle income countries of 20% by 2040 An increase in agricultural yields for low middle-income countries of 50% by 2074 An increase in agricultural yields for low-income countries of 100% by 2074	Increased yields reflect greater food security and greater production to meet local and national dietary demands.
	Environment	A reduction in residential PM 2.5 levels of 30% for the world by 2060	envpm2pt5m or the residential particulate matter levels is simulated to reduce by 30% by 2060. This compensates for policies that are suited to mitigation measures for increased growth in the region thereby curtailing the environmental footprint.
		An increase in the world's forest area of 1% by 2040	Increases the carbon sink capacity of the world contributing to a reduction in emissions directly.
	Governance and spending	An increase in government effectiveness for the world by 30% by 2037	goveffectm or the government effectiveness parameter is increased by 30% by 2037 over **Base Case** projections. This improves the state of governance and allows for a larger share of public funding for the core sectors that may have been lost due to implicit and explicit costs.
		An increase in government spending towards household welfare transfers to unskilled labour force by 50% by 2038 for the world, barring low-income countries where we simulate a 100% increase by 2037	govhhtrnwelm or government spending towards household welfare transfers is increased by 50% globally and 100% for low-income countries over **Base Case** forecasts by 2038. This is indicative of greater allocation towards public consumption spending in different forms as they may exist around the world, like cash transfers, public subsidies, minimum support prices (MSPs), etc.
		An increase in fiscal expenditures towards health, education, infrastructure, and research and development (R&D) sectors of 100% by 2037	gdsm (Education, Health and R&D) is simulated to increase by an additional 100% over **Base Case** projections by 2037, which has labour and capital productivity effects leading to a higher growth in the economy. This allows the model to identify that existing government resources may be constrained and thus requiring additional expenditure to support core sectors.
		An increase in the level of democracy of 30% by 2037 for the world	democm or the democracy multiplier in IFs is employed to bring about changes in the democracy indices and it is increased by 30% over **Base Case** projections by 2037 globally.

	Impact area	Scenario assumption	Model structure – Impact pathways
	Expenditure on R&D	An increase in the world expenditure on R&D of 20% by 2037	Increasing government expenditure on R&D brings about improvements in technological choices and greater ability to learn-by-doing. It also affects government spending across other sectors of the economy.
	Fish catch	A reduction in fish catching for China, Indonesia, Japan, Myanmar, Peru, Russia, Thailand and the United States of America of 15% by 2075	These interventions indicate a shift to more sustainable practices, allowing the environment to be cleaner, safer and less-consumption intensive, all the while maintaining greater equity. These interventions also are closely linked to health and nutritional outcomes in the model.
	Nutrition	A decrease in the demand for calories coming from meat of 20% by 2054 An increase in the demand for calories coming from plants of 11% by 2037 Coefficient of variation in caloric availability—an alternate, distributional measure for food insecurity is reduced by 25% by 2040 for the world	
	Contraception use	An increase in contraception by 15% by 2050 for the world	Better family planning allows low-income and lower middle-income countries to reap benefits of a demographic dividend, thereby also improving the productive sectors of the economy.
	Education	An increase in the share of total science and engineering graduates of 15% for the world An increase in the tertiary graduation rate of 50% by 2050 for the world An increase in the lower secondary graduation rate of 200% through 2050 for the world	Revitalized revenue mobilization in education with greater share of budget devoted to the sector. This has human productivity effects, thereby affecting overall stock and flow of education outcomes.
	Broadband	An increase in users of fixed and mobile broadband of 50% by 2044 for the world	Infrastructural gaps are lessened to proxy for structural barriers often found in the developing world. Better infrastructure also allows for further development of other sectors that rely on these resources.
	Water and sanitation access	An increase in the provision of piped water and improved sanitation access of 100% by 2050 for the world	

Annex 3: Methodology notes

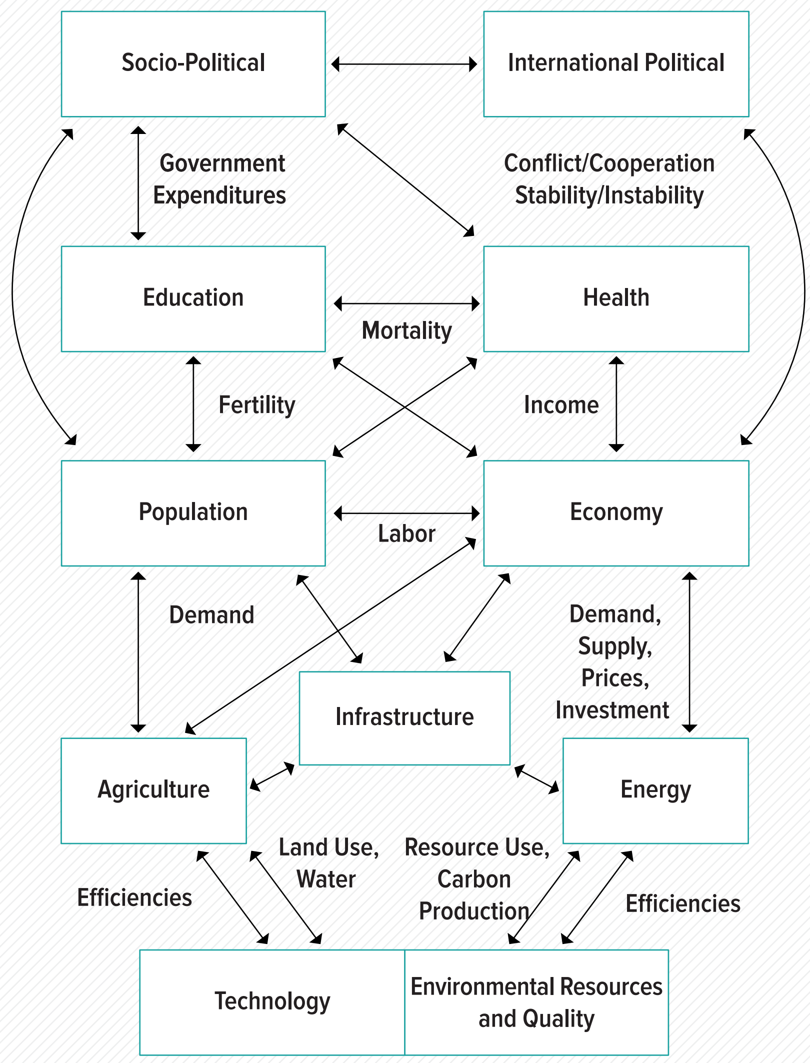
1: Overview of International Futures

The study uses the IFs model for forecasting and scenario analysis. IFs is an integrated assessment modelling platform with representation of 188 countries and incorporates a vast database of over 5,000 series of data spanning from 1960 with a capacity to forecast out to 2100 (Hughes, 2019). It features numerous endogenized and interconnected sub-modules with coverage of the following systems that interact dynamically: agriculture (Verhagen *et al.*, 2023), economics, education (Dickson *et al.*, 2015), energy, environment (Moyer, 2023b), demographics, governance (Hughes *et al.*, 2015a; Moyer, 2023a), health (Hughes *et al.*, 2015b), infrastructure (Rothman *et al.*, 2015), international relations (Moyer *et al.*, 2023) and human development (Hanna *et al.*, 2024).

IFs can be used to analyse country-specific, regional and global futures across multiple domains such as human development, social change and environmental sustainability. It facilitates understanding of development pathways and enables creation of empirically grounded alternative scenarios. While IFs focuses on macro-level strategies, it highlights the need for context-specific policies to implement key interventions. It is intended to inform, rather than dictate policy strategies by providing a broad and prospective perspective on developmental outcomes. Figure A1 (adjacent) provides an overview of the major models incorporated within the IFs system.

For this project, we heavily emphasize and draw insights from the energy model in IFs that projects long-term energy production, costs and investment needs

Figure A1. Overview of the International Futures (IFs) model.



Links shown are examples from much larger set for a renewable energy transition. The IFs model provides a comprehensive view of the energy sector by projecting overall energy demand for the economy while simultaneously disaggregating energy production by source. This detailed breakdown encompasses three fossil fuels (oil, gas and coal), four renewable energy types (hydropower, solar, wind and geothermal) and nuclear power, enabling a nuanced analysis of energy trends and interactions within the model.

A detailed explanation of the energy model documentation can be found **here**.

2: Energy model in IFs

IFs originally comprised six energy production categories: oil, natural gas, coal, hydroelectric, nuclear and other renewables (Hughes, 2019; Rothman *et al.*, 2015). Here, oil, coal and natural gas form fossil fuels, while the hydro and other renewables form the renewables. IFs computes only aggregated regional or national energy demands and prices, however, on the assumption of high levels of long-term substitutability across energy types and a highly integrated market. The model also conducts energy trade only in a single, combined energy category. Presently, there is not a full connection between the energy model and access to electricity and electricity production (see the IFs **Infrastructure Model Documentation** for a description of the electricity aspects of IFs).

The dominant relations in the model are governed by two key variables: Energy demand (ENDEM) and energy production (ENP). Energy demand is a function of GDP and the energy demand per unit of GDP (ENRGDP). On the other hand, energy production is a function of capital stock in each energy type, the capital/output ratio (QE) for that energy type and a capacity utilization factor (CPUTF).

The following key dynamics are linked to these dominant relations:

1. Demand: Energy demand per unit of GDP depends on GDP per capita, energy prices and an autonomous trend in energy efficiency. The first two of these are computed endogenously, the latter exogenously. The user can control the price elasticity of energy demand and the autonomous trend in efficiency of energy use. The user can also use an energy demand multiplier to directly modify energy demand.

$$ENDEM_{r,t=1}=\sum_e ENP_{r,e,t=1}+ENM_{r,t=1}-ENX_{r,t=1}-ENST_{r,t=1}*AVEPR_{r,t=1}$$

   Here, ENP, ENM, ENX, ENST and AVEPR are energy production, energy imports, energy exports, energy stocks and an average of the expected growth in production across all energy types.

2. Production: For fossil fuels and hydro, there are upper bounds on production. For fossil fuels, these are based on reserve production ratios, as well as user-specified upper bounds for oil, gas and coal. For hydro, the upper bound relates to hydropower potential.

   Here, only capital is considered important as a factor of production (not labour, land or even weather). Energy production is initially estimated by dividing the quotient of capital in each energy category (ken) and the appropriate capital-to-output ratio (QE). A multiplier, enpm, can be used to increase or decrease production. This yields:

$$\mathrm{ENP1}_{r,e}=\frac{ken_{r,e}}{QE_{r,e}}*\mathbf{enpm}_{r,e}$$

3. The capital/output ratio for each fuel type decreases over time due to technological improvements, but factors may increase the ratio as remaining resources decrease. Users can further modify capital/output ratios with multipliers.

4. Energy capital is initialized based on initial production and capital/output ratios, depreciates at a rate determined by energy capital lifetime and grows with investment. Users can influence desired investment by energy type using various factors, including expected profits, reserve production factors and exogenous restrictions on maximum production.

5. Resources and reserves are separately represented in IFs, with reserves declining with production and increasing with discoveries. Users can modify ultimate resources directly or through multipliers. Discovery rates depend on remaining resources, current production and world energy prices, which users can control.

6. Domestic energy prices are influenced by world and domestic stocks and the global capital/production ratio. Users have control over various factors affecting energy prices, such as domestic stocks, ‘cartel premium’, carbon tax and setting exogenous domestic prices for the first year or multiple years.

7. The energy model also incorporates energy trade, with imports and exports depending on production, demand and past trade propensities. Users can set maximum limits on energy imports and exports, as well as general trade limits.

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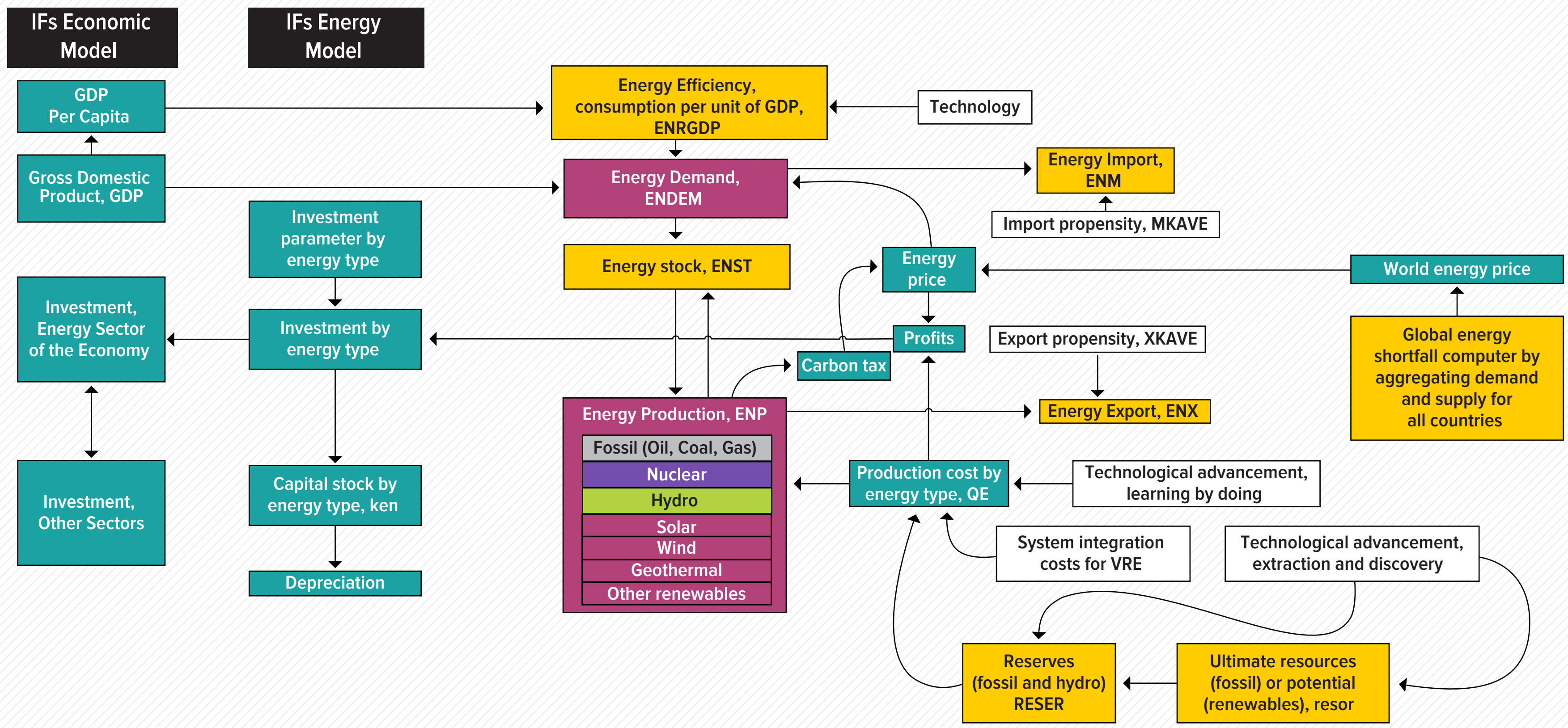
The current version of IFs projects energy, energy trade and electricity in three sub-models: a physical energy model, an economic model and an infrastructure (electricity) model. The modelling work for the project is focused on the physical energy model, only on the supply side of the model: production, cost and investment.

The network diagram below shows the existing linkages between IFs energy model and other sub-models. As a part of the model extension, we highlight the additional linkages with the newly created variables and parameters with yellow lines and boxes.

Figure A2. Block diagram of the energy model including extensions



3: Computing renewable capacity in IFs

In the International Futures (IFs) model, renewable capacity is not a variable that is explicitly available in its interface. Therefore, we compute it externally using renewable production estimates from our projections and capacity factors broadly understood from literature. The capacity factor (CF) is a crucial metric that represents the actual output of a power plant over a given period compared to its theoretical maximum output if it operated at full capacity 24/7. It is calculated as:

$$CF = \frac{Actual\ Energy\ Output}{Maximul\ Possible\ Output}$$

A higher capacity factor means a power source is more consistently producing energy. For example, nuclear power has a high CF (~90 percent) due to its baseload operation, whereas solar PV has a low CF (~15–25 percent) due to daily and seasonal variations in sunlight.

Table A3 compares CFs across different energy types. For this modelling exercise, we assume a single representative value for each energy type, even though CFs can vary significantly by region and technology. This assumption simplifies the analysis but inherently introduces some uncertainty, as real-world CFs are influenced by factors such as geographic location, infrastructure and technological advancements.

Renewable capacity in IFs is calculated as:

$$\text{Renewable Capacity} = \sum_{i}^{5} \frac{ENP_i}{8760 \times CF_i}$$

Table A3. Global average capacity factor across different energy types

Energy type	Global average capacity factor (CF)	Regional/technology variations
Coal	50%–70%	Lower in aging plants and developing countries, higher in modern ultra-supercritical plants
Oil	10%–30%	Often used as peaking plants, so highly variable
Gas	40%–60%	Combined cycle gas turbine (CCGT) plants are more efficient (up to 60%)
Solar PV	15%–25%	Higher in desert regions (e.g. Chile, Southwest U.S.), lower in cloudy regions
Solar CSP	25%–45%	Concentrated solar power (CSP) with thermal storage has higher CF
Nuclear	80%–93%	France and U.S. operate at >90% due to baseload role
Hydro	30%–60%	Highly variable; seasonal variations impact CF
Geothermal	70%–90%	High reliability in places like California, Iceland
Wind (onshore)	30%–45%	Lower in some inland areas, higher in wind corridors
Wind (offshore)	45%–55%	Higher due to consistent wind speeds
Other renewables	20%–50%	Biomass, tidal and wave energy vary widely

Here, ***i*** represents the type of energy (solar, wind, geothermal, hydro and other renewables), ***ENP*** is energy production and ***8760*** represents the number of hours in a given year.

4: Computing energy investments in IFs

The IFs economic model computes energy investments using data on gross fixed capital formation (GFCF) from the World Bank's World Development Indicators (World Bank, 2024a). Economy-wide GFCF is allocated across IFs economic sectors based on the capital share of value added in each sector, using value added data from the Global Trade Analysis Project (GTAP) database (Aguiar *et al.*, 2019). Within the energy sector, total investment is further disaggregated by energy type: coal, oil, gas, solar, wind, hydro, nuclear, geothermal and other renewables. For each type, production data from the IEA and cost estimates from literature are integrated with replacement capital—calculated based on the expected lifespan of each technology—to determine initial investment values. This bottom-up approach is aligned with the overarching top-down economic model to maintain consistency across the IFs tool's modelling of dynamic interactions across a suite of human, natural and social systems.

Investment decisions in the IFs energy model are influenced by total energy demand and the relative costs of different technologies. While energy demand is covered elsewhere in this report, this section discusses the role of energy efficiency in shaping investment patterns. The model accounts for fossil fuel production costs using the capital-output ratio as a measure of unit production cost. For renewables, which are primarily electricity-based, the LCOE generation is used as the key cost metric.

While the IFs estimates power generation costs for renewable energy, additional costs associated with transitioning from fossil fuels to renewables are not explicitly represented. To provide a more comprehensive assessment in this report, assumptions from external models are incorporated to estimate these systemic costs, which include:

- **Electricity network costs** – Expanding and modernizing transmission and distribution networks to support geographically dispersed renewable energy sources.
- **System flexibility costs** – Investments in energy storage, grid balancing mechanisms and demand-response solutions to manage the variability of renewable generation.
- **End-use and efficiency costs** – Enhancing energy efficiency through improvements in appliances, industrial processes and electrification of transport and heating.

Unit cost assumptions in scenario conceptualization

The LCOE serves as a key metric in our scenario analysis, informing both investment projections and comparative cost dynamics across different energy sources. In 2024, fossil fuel-based power generation exhibited higher costs, with oil at 7.6 cents/kWh, gas at 6.8 cents/kWh and coal at 15.7 cents/kWh. In contrast, renewable sources, particularly solar and wind, were more cost-competitive, with LCOEs of 5.9 cents/kWh and 7.0 cents/kWh, respectively. Other renewables, including hydro, geothermal and nuclear, ranged between 11.4 cents/kWh and 14.6 cents/kWh.

In the **Base Case** scenario, unit costs for fossil fuels are assumed to increase due to resource depletion and rising extraction costs, coupled with environmental mitigation expenses such as carbon capture and storage (IEA, 2023a). By 2060, oil is projected to reach 11.3 cents/kWh, gas 9.5 cents/kWh and coal 15.6 cents/kWh.

Conversely, renewable energy costs are expected to decline over time, though at a slowing rate as technological learning plateaus and system integration costs increase. By 2060, solar and wind costs are projected to decrease by 30 percent and 23 percent, respectively. Hydropower costs are expected to remain relatively stable, with a marginal decline to 11.7 cents/kWh, constrained by environmental concerns such as ecosystem disruptions and displacement effects (WWF, 2022).

In the acceleration scenarios (**RA** and **RA+SDG**), the cost reductions for renewables are more pronounced due to systemic efficiency improvements and accelerated technology diffusion. By 2060, solar and wind LCOEs are expected to decline significantly to 2.4 cents/kWh and 3.2 cents/kWh, representing a 73 percent reduction from 2024 levels. Other renewable sources, including geothermal, hydro, tidal and biofuels, are projected to range between 4 and 11 cents/kWh. Meanwhile, fossil fuel costs under these scenarios are assumed to be lower than in the **Base Case**, with oil at 10.2 cents/kWh, gas at 7.8 cents/kWh and coal at 14.5 cents/kWh by 2060 because of lower corresponding demand of fossil fuels.

Variable renewable energy costs and demand flexibility

While our analysis has primarily focused on investment needs, an equally critical aspect of the energy transition is the integration of variable renewable energy (VRE) sources into power systems. Although renewables such as solar and wind are essential for reducing GHG emissions and driving a low-carbon future, their widespread deployment introduces new challenges due to their variability and intermittency.

The IFs model accounts for these integration challenges by incorporating VRE shares in power systems and assessing the impact on costs and grid stability. As VRE penetration increases, power grids must address issues such as supply-demand mismatches, grid congestion and the need for large-scale storage. Solar generation is inherently limited to daylight hours, while wind power fluctuates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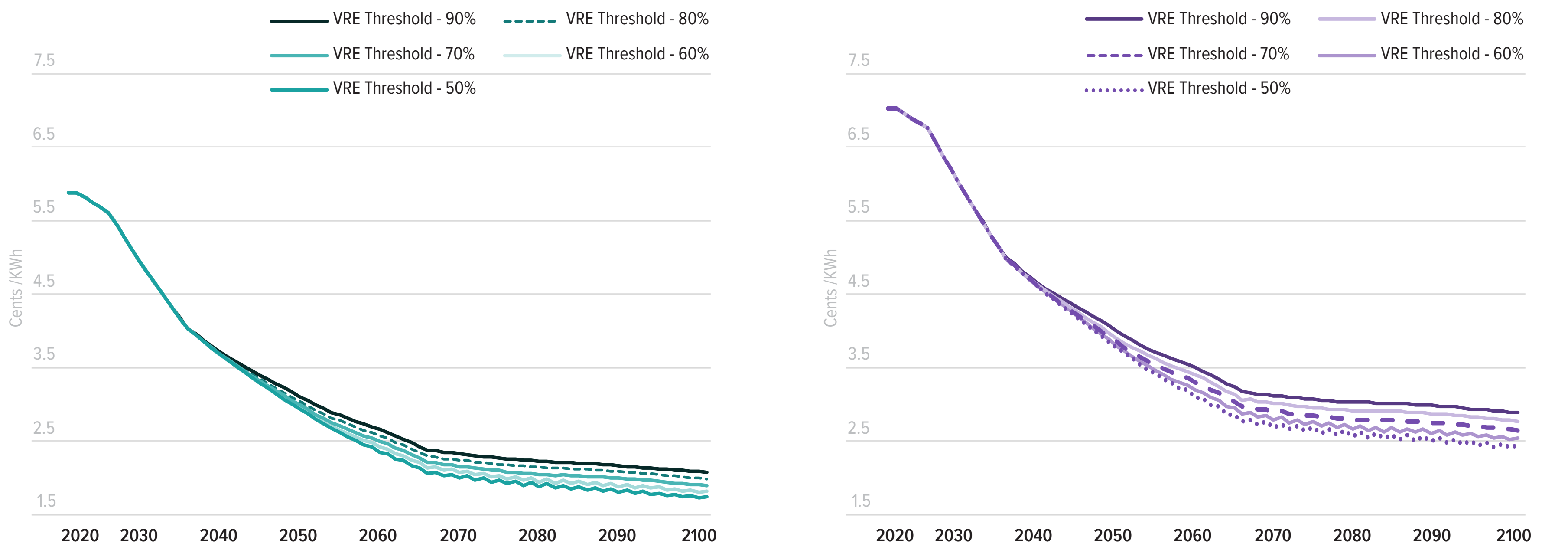
based on meteorological conditions, requiring enhanced grid flexibility to ensure stability.

System integration costs, reflected in the LCOE, rise as VRE penetration increases.[32] Literature supports this trend, showing that at low penetration levels, existing grid infrastructure can accommodate variability with minimal cost increases (IEA, 2021). However, when VRE penetration exceeds 50 percent, costs escalate due to the need for advanced storage solutions, expanded transmission capacity and grid modernization (Hirth *et al.*, 2015). At penetration levels near 90 percent, integration costs become a dominant factor in total electricity costs, driven by higher curtailment rates and the need for backup generation.

Figure A3. Sensitivity of solar (left) and wind (right) unit costs (LCOE) to VRE penetration threshold



Source: IFs v8.32.

32 Here, we model system integration costs that assume additional markup over baseline unit costs. The IFs model does not represent the additional investment requirements to factor these integration costs associated with renewables.

The IFs model does not perform real-time load modelling but applies a cost-impact threshold approach to account for the financial implications of rising VRE shares. This method introduces a multiplier that adjusts solar and wind costs upward once penetration surpasses a predefined threshold. In the **Base Case**, this threshold is set at 50 percent while in transition scenarios, it is raised to 80 percent reflecting advancements in storage, grid flexibility and demand-side management. If transition scenarios maintained the same cost thresholds as the **Base Case**, renewable power generation investment would incur an additional cumulative cost of $1.5 trillion over the entire projection period.

To ensure a cost-effective and reliable transition, infrastructure investments must prioritize grid modernization, real-time monitoring systems and decentralized energy resources. Demand flexibility—through smart appliances, time-of-use pricing and responsive demand-side programmes—will also be crucial for aligning consumption with VRE availability. Policymakers must set optimal VRE penetration thresholds to balance economic feasibility with system stability, ensuring that the energy transition remains sustainable and equitable.

Computation of efficiency investments

Energy efficiency expenditure or investments for **RA** and **RA+SDG** scenarios are computed by comparing the energy savings with the **Base Case** projections. Energy use in the scenario, had the efficiency gain not been attained, can be computed by multiplying the GDP projected in the scenario with the energy efficiency projected in the **Base Case**. The difference between this and the projected energy use in the scenario will give the energy savings in the scenario.

$$Energy\ Savings_{RA} = (GDP_{RA} \times Energy\ use\ per\ unit\ of\ GDP_{\text{Base Case}}) - Energy\ Use_{RA}$$

$$Energy\ Savings_{RASDG} = (GDP_{RASDG} \times Energy\ use\ per\ unit\ of\ GDP_{\text{Base Case}}) - Energy\ Use_{RASDG}$$

These energy savings are then multiplied by the cost of energy efficiency expenditure KWh. Literature suggests these costs to be in the range of 2 to 8 cents per kWh.[33]

$$Energy\ Efficiency\ Investment_{RA} = Energy\ Savings_{RA} \times \frac{Efficiency\ Cost}{Lifetime}$$

$$Energy\ Efficiency\ Investment_{RASDG} = Energy\ Savings_{RASDG} \times \frac{Efficiency\ Cost}{Lifetime}$$

5: Income groupings

IFs uses World Bank income groupings based on their gross national income per capita. These are updated annually and are dynamic, reflecting changes in GDP overall and GDP per capita.

1. **Low-income countries**
   Afghanistan, Burkina Faso, Burundi, Central African Republic, Chad, Democratic People's Republic of Korea, Democratic Republic of the Congo, Eritrea, Ethiopia, The Gambia, Guinea-Bissau, Haiti, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, Somalia, South Sudan, Sudan, Syria, Togo, Uganda and Yemen.

33 For estimates on the cost of energy efficiency, see ACEEE (2016), How Much Does Energy Efficiency Cost?, and Knight *et al.* (2022), The cost of energy efficiency programs: Estimates from utility-reported datasets, Energy, 239, 122448.

2. **Lower middle-income countries**
   Algeria, Angola, Bangladesh, Benin, Bhutan, Bolivia, Cape Verde, Cambodia, Cameroon, Comoros, Congo, Côte d'Ivoire, Djibouti, Egypt, El Salvador, Eswatini, Ghana, Guinea, Honduras, India, Iran, Jordan, Kenya, Kiribati, Kyrgyz Republic, Lao People's Republic, Lebanon, Lesotho, Mauritania, Micronesia, Mongolia, Morocco, Myanmar, Nepal, Nicaragua, Nigeria, Pakistan, Palestine, Papua New Guinea, Philippines, São Tomé and Principe, Samoa, Senegal, Solomon Islands, Sri Lanka, Tajikistan, Tanzania, Timor-Leste, Tunisia, Ukraine, Uzbekistan, Vanuatu, Vietnam, Western Sahara, Zambia and Zimbabwe.

3. **Upper middle-income countries**
   Albania, Argentina, Armenia, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Equatorial Guinea, Fiji, Gabon, Georgia, Grenada, Guatemala, Indonesia, Iraq, Jamaica, Kazakhstan, Kosovo, Libya, Malaysia, Maldives, Mauritius, Mexico, Moldova, Montenegro, Namibia, North Macedonia, Paraguay, Peru, Russian Federation, Serbia, South Africa, St. Lucia, St. Vincent and the Grenadines, Suriname, Thailand, Tonga, Türkiye, Turkmenistan and Venezuela.

4. **High-income countries**
   These IFs countries include Australia, Austria, The Bahamas, Bahrain, Barbados, Belgium, Brunei, Canada, Chile, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Guyana, Hong Kong, Hungary, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, New Zealand, Norway, Oman, Panama, Poland, Portugal, Puerto Rico, Qatar, Republic of Korea, Romania, Saudi Arabia, Seychelles, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Taiwan (Republic of China), Trinidad and Tobago, United Arab Emirates, United Kingdom, United States and Uruguay.

6: Limitations

The IFs model's notable strengths lie in its comprehensive representation of a wide array of fundamental structures within global issue systems and long-term scenario analysis. However, like many other integrated assessment models (IAMs) of its kind, there are certain limitations that need to be acknowledged. Chief among these is the substantial uncertainty surrounding crucial data, such as estimates of ultimately recoverable energy resources, which can impact the accuracy of projections. Furthermore, uncertainties surround fundamentally important relationships, including the drivers of economic productivity, which can influence the outcomes of the model's forecasts. Additionally, some crucial key dynamic forces, such as technological advancements, may also exhibit uncertainties that can affect the reliability of long-term projections.

This study explores three scenarios with underlying assumptions designed to simulate a climate action pathway. However, it does not include a dedicated NDC scenario to explicitly identify gaps between the pledges and commitments of countries. Given that NDCs often lack clearly articulated, quantitative energy targets, the just energy transition scenarios provide a framework for ambitiously addressing NDC goals while recognizing these limitations.

The IFs model is historically validated and calibrated, often by running simulations from 1995 to 2015 to assess its performance across key indicators at global, regional and country levels. At the global level, the model demonstrates strong validation,

with deviations in GDP and population projections over 20 years typically within 10 percent of measured data. However, historical biases emerge in certain regions, particularly in large economies such as China, India and the United States, and in countries with small populations or high conflict propensity. These limitations suggest that long-term forecasts should not be interpreted as precise predictions, but rather as indicative projections characterized by significant uncertainty.

Furthermore, the scenarios and interventions presented are not designed to reflect narrow, context-specific public policy concerns. Instead, the modelling work aims to inform broader policy strategies, charting a multi-decadal course for development priorities. These strategies provide a high-level framework to guide more specific policy interventions, which can subsequently address narrower public policy questions.

Annex 4: Total system-wide costs, including infrastructure, electrification, grid modernization, energy storage and energy efficiency

Renewable energy expansion demands far more than investments in power generation alone—it requires robust spending on system-wide infrastructure. This means investments to modernize power grids and deploy advanced energy storage and efficiency measures to seamlessly integrate renewables and ensure resilient, reliable power systems.

According to Bloomberg (2025) and IRENA (2024), a substantial portion of the immediate investment gap lies in energy efficiency and end-use electrification, particularly in transport through the adoption of EVs and electrification of heat. These investments are critical for ensuring that the transition not only decarbonizes electricity production but also reduces emissions from transport, industry and residential energy use. We estimate various infrastructure, efficiency and end-use transition costs using cost estimates from existing literature. To do so, we apply the ratio of generation to non-generation costs from external computations to the generation costs in our scenarios, aligning with the time periods and comparable scenarios for which these external computations are available.[34]

Projections of total energy transition investments vary depending on the modelling approach and underlying assumptions. The IEA (2023b) projects annual global energy investments of approximately $5 trillion by 2030 and $4.5 trillion by 2050 (in 2024 $MER) under its Net Zero Scenario. Similarly, IRENA (2024) estimates that achieving a 1.5°C pathway requires an annualized average investment of $4.5 trillion from 2024 to 2050, which is more than double the investment projected in their Planned Energy Scenario (PES). McKinsey (Krishnan *et al.*, 2022) places these costs even higher, estimating that annualized spending on energy and land-use systems in a net-zero scenario would reach $9.2 trillion over the period 2021–2050.

First, we estimate the significant front-loaded investments required during the initial years of the projection horizon between 2024 to 2030 using IRENA (2024),[35] and then discuss these investments, both annual and cumulative, over the 2024 to 2050 period using IRENA (2023a; 2023b).[36]

Using IRENA's (2024) 1.5°C pathway computation as the reference, we find the annualized investments in the energy sector in the **RA+SDG** scenario to be

34 To address the uncertainty introduced by this ratio-based approach, we use two additional estimation methods: (1) applying the absolute values of non-generation costs from external sources, adjusting their dollar units to match ours, and (2) using an across-scenario ratio, where the ratio of a specific cost category between two scenarios in the external computations is applied to similar scenarios in our computations. These approaches produce a range of estimates rather than a single fixed value, which we report in this section.

35 IRENA's *World Energy Transitions Outlook 2024*: 1.5 °C provides reference estimates for the period 2024–2030 but does not provide these specific costs beyond 2030.

36 IRENA's *World Energy Transitions Outlook 2023*: 1.5 °C provides reference estimates for the period 2024–2050.

in the range of $2.4 to $4.5 trillion, the largest share of which goes towards energy use and efficiency. Table A4 shows the annual average investment requirements including fossil fuel supply between the 2024–2030 period across IFs' **RA+SDG** scenario and IRENA's 1.5 °C scenario.

Figure A4 shows the average annual investment projected across three scenarios between 2024–2050. Here, we estimate these investments using IRENA (2023a; 2023b). Our estimates indicate that in the **Base Case** scenario, overall energy sector investments are projected to be in the range of $1.8 trillion to $1.9 trillion per year from 2024 to 2050. In contrast, under transition scenarios, annual investments are expected to rise significantly, ranging from $2.5 trillion to $3.4 trillion per year over the same period. In transition scenarios, total annual investment will continue to grow, increasing from $2.1–$3.7 trillion per year during the 2025–2030 period to $3.1–$5.2 trillion per year between 2036 and 2050.

Between 2024 and 2050, cumulative energy sector investments are projected to range between $100 trillion and $135 trillion under transition scenarios, compared to $79–$90 trillion in the **Base Case**. The largest investment requirements are in energy efficiency and end-use, which is estimated to total between $25 trillion and $40 trillion over this period.

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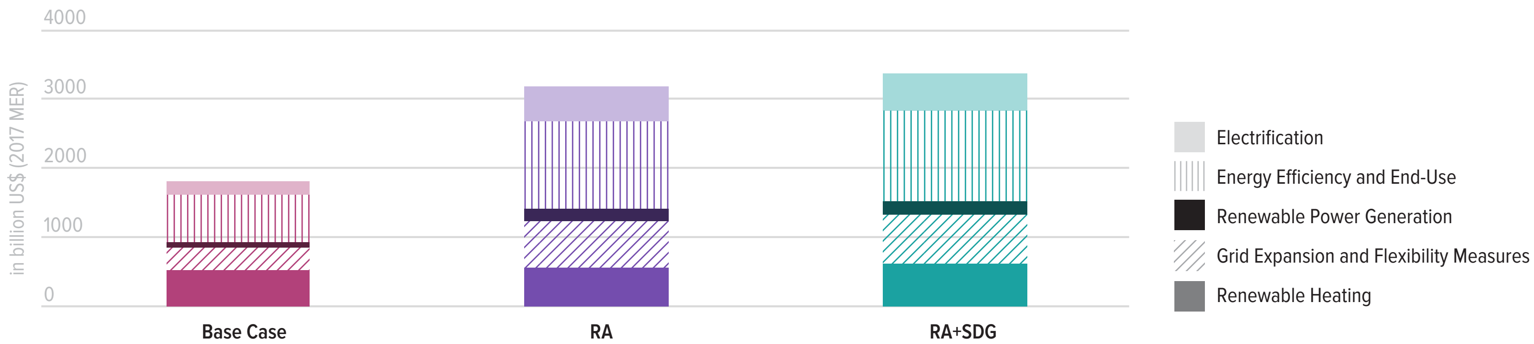
Table A4. Annual average investments across energy sector between 2024 and 2030, comparing IRENA (2024) and IFs analysis

Investment area	**Annual average, 2024–2030 in US$ billions**	
	IRENA 1.5 °C (2023 US$)	IFs **RA+SDG** (2017 US$)
Renewable power generation capacity	1550	440
Power grids and energy flexibility	720	200–560
Renewable heating and direct use	330	100–300
Energy efficiency	2260	650–1800
Electrification	490	150–400
Fossil fuels and nuclear power generation	240	70–200
Fossil fuel supply	1000	850
Total	**6,800**	**2,400–4,500**

Source: IFs v8.32 and author's estimates.

Figure A4. Average annual investments in the renewable sector across scenarios, accounting for total system wide costs, in US$ billions (2017 MER)



Source: IFs v8.32.

Table A5. Comparison of cumulative investments in US$ trillion (2017 MER) 2024–2050 across scenarios in IFs and IRENA

Investment/scenario	IFs			IRENA	
	Base Case	RA	RA+SDG	PES[37]	1.5[38]
Fossil fuels	24	9	9	35	12
Renewable power generation	14	15	17	18	39
Grids and flexibility	8–9	10–20	10–20	10	23
Energy efficiency and end-use	19–21	20–40	25–40	24	44
Electrification	5	7–15	7–15	5	17
Overall energy sector	79–90	90–135	100–135	103	150

Source: IFs v8.32, author's estimates and IRENA's World Energy Transitions Outlook 2023. All IFs values in 2017 US$ and IRENA values in 2021 US$.

37 PES is the Planned Energy Scenario used by IRENA as the primary reference case, providing a perspective on energy system developments based on governments' energy plans and other policies. We use this as a benchmark against IFs' **Base Case** scenario.

38 1.5 is the 1.5°C scenario used by IRENA to describe an energy transition pathway aligned with the 1.5°C climate goal to limit global average temperature increase to 1.5°C. **RA+SDG** is used as a comparable scenario that outlines similar policy targets albeit with additional interventions that go beyond the energy sector.

Differences in investment between IFs and IEA's Net Zero Scenario

Investment estimates for global renewable power generation investment figures derived in IFs are about 60 percent lower than those reported by the International Energy Agency (IEA, 2024d) due to methodological differences in how investments are accounted for.[39] IFs computes energy investments by splitting economy-wide investment according to sectoral capital shares and further disaggregating energy investment by type using production data and cost estimates, whereas IEA estimates are based on project financing data, leading to variations in reported figures.

Table A6 compares average annual investments in renewable energy production between the **RA+SDG** scenario from this report and the IEA's Net Zero Scenario for the periods 2031–2035 and 2036–2050. While both scenarios share similar targets for a low-carbon transition, they differ in how efficiency gains and cost declines are modelled.

In the **RA+SDG** scenario, greater investment in energy efficiency reduces overall energy demand, lowering global energy consumption to 80 percent of the **Base Case** level by 2060. Additionally, faster cost declines—driven by innovation, improved technology adoption and economies of scale—further enhance the cost-effectiveness of the transition. Between 2024 and 2060, the costs of solar and wind energy declined by 60 percent and 55 percent, respectively, in the **RA+SDG** scenario, compared to 27 percent and 20 percent in the **Base Case**.

These combined effects result in a more efficient and economically viable energy transition.

Table A6. Annual average investments in renewable energy generation across IFs RA+SDG and IEA NZE scenarios

	Average annual investment in renewables*	
Period	**IFs, RA+SDG** (Billion $2017 MER)	**IEA, NZE** (Billion $2022 MER)
2031–2035	621	1185
2036–2050	698	875

* Differences arising from varying assumptions in the scenario design and methodological differences in accounting for renewable power generation investments. Discussed in Box 1.

Source: IFs v8.32 and IEA's World Energy Outlook (2024c).

Existing literature (IEA 2024d; IEA, 2024e; IRENA, 2024; BNEF, 2024) frequently highlights the high costs associated with the energy transition, particularly when factoring in expenditures beyond the energy sector. These include investments in electrifying transport, upgrading appliances and improving building efficiency—components essential for achieving a sustainable transition. Within the energy sector, investment needs for power generation increase and eventually decline over time, particularly in acceleration scenarios where efficiency gains and falling renewable energy costs contribute to substantial savings. To provide clarity, we distinguish between production costs within the energy sector and broader transition costs related to end-use electrification and infrastructure improvements.

39 IEA (IEA 2024d) tracks direct financial flows to energy projects, making it particularly useful for short-term planning. Their computation spreads capital expenditures over multiple years, from financial close (final investment decision, FID) to the asset's operational launch, tracking real-time capital flows. The IFs model records investment expenditures when new production capacity comes online, making it more sensitive to long-term dynamics like energy efficiency gain and cost declines, especially in renewables. As solar and wind experience rapid cost reductions, the IFs methodology ensures that new investments reflect these trends rather than relying on past expenditure patterns. IFs also uses LCOE to estimate renewable energy investments, incorporating capital costs, operations and maintenance over a plant's lifetime. For fossil fuels, the model applies capital-output ratios at the primary energy production stage, linking investment directly to production levels rather than construction timelines. This macro-level approach helps capture long-term structural shifts in energy investment, such as the transition from fossil fuels to renewables. While the IFs is designed for long-term energy and economic planning, the IEA's cash flow-based methodology is better suited for short-term financial decision-making. The IEA's focus on actual capital flows provides precise insights for tracking annual investment spending, while the IFs offers a broader perspective on how investment patterns evolve alongside economic activity and sectoral transitions. Both approaches have distinct strengths, with the IFs excelling in long-term scenario analysis, including analysis of broader impacts on human development, and the IEA providing real-time investment tracking.

Annex 5: Background literature

The global energy transition is at a critical juncture, gaining momentum towards renewable energy adoption despite persistent challenges. While fossil fuels continue to dominate the energy landscape, substantial progress in clean energy has been achieved through advancements in technology, declining costs of renewables and enhanced policy measures. This progress, however, is not sufficient to meet the urgency of the 1.5°C pathway or to achieve the SDGs. Global reports such as the **World Energy Outlook 2024** (IEA, 2024c) and the **World Energy Transitions Outlook 2024** (IRENA, 2024) emphasize the business case for accelerating clean energy transition through increased investments, market innovation and the adoption of inclusive and gender-responsive strategies.

Adopted in 2015, the Paris Agreement is central to global climate action, aiming to limit temperature increases to well below 2°C, with efforts to cap warming at 1.5°C (UNFCCC, 2015). According to the IPCC (2023), achieving these targets required global emissions to peak before 2025, decline by 43 percent by 2030 and reach net zero by mid-century. NDCs and long-term climate strategies serve as roadmaps for countries to align with these goals, considering common but differentiated responsibilities. Article 4 of the Paris Agreement emphasizes the necessity of net-zero emissions in the second half of this century while urging parties to submit and update "long-term low greenhouse gas emission development strategies." The first global stocktake has reiterated the urgency for nations to act promptly in this regard.

However, the UNEP's **Emissions Gap Report** (2024) already indicates that the current NDCs are insufficient to meet the Paris Agreement's goal of limiting global temperature rise to below 2°C. A failure to do so puts the world on course for a temperature increase of 2.6–3.1°C over the course of the century (UNEP, 2024). They state that NDCs for 2035, at minimum, must call for emissions reductions of 37 percent and 57 percent relative to 2019 levels to be compatible with 2°C and 1.5°C, respectively.

From an investment perspective, the IEA's **World Energy Investment 2024** estimates that $2 trillion was invested in clean energy in 2024, with $1.9 trillion directed towards renewable energy, energy efficiency and clean energy grids and storage. While this represents double the investments in fossil fuels (estimated at $1.1 trillion), only 15 percent of these investments flowed into emerging and developing economies. Furthermore, the IEA's Net Zero Scenario projects that investments to achieve a net-zero emissions energy system need to more than double to $4.5 trillion annually between now and 2030 (IEA, 2024). These needs can be compared to the 2024 COP29 decision to triple climate finance to developing countries, from the previous goal of $100 billion annually, to $300 billion annually by 2035 (which represents less than one percent of global clean energy investment needs) (UN Climate Change News, 2024).

Analysis from IRENA (2023a; 2023b) and Pourasl *et al.* (2023) further show the centrality of renewable energy technologies, particularly wind and solar, in achieving decarbonization. By 2050, the authors show that solar power is projected to provide approximately 25 percent of global electricity needs, with the combined share of renewable energy sources potentially reaching 60–90 percent of the energy mix. Comparison of IFs projections against others can be found in Annex 4. These projections are driven by significant technological advancements that have reduced the cost of renewables. Since 2010, the cost of solar has fallen by 82 percent, and wind energy costs have similarly decreased due to innovations in turbine design and manufacturing (IRENA, 2020).

Despite these advancements, fossil fuels remain a dominant energy source, particularly in countries with limited financial resources and infrastructural support for renewable energy integration (IEA, 2023a). These countries must navigate challenging trade-offs between fostering economic and human development and managing the costs of transitioning to cleaner energy sources. To accelerate the energy transition, it is essential to strengthen the alignment between renewable energy investments and their socio-economic and environmental benefits, ensuring that investments are equitably distributed and targeted to areas with the highest impact potential.

Despite inherent costs, transitioning to renewables also presents profound environmental and socio-economic benefits. For example, IRENA (2023b) shows that the renewable energy sector is highly labour intensive and can potentially generate millions of jobs globally, particularly in regions with high unemployment, thereby contributing to economic growth and poverty alleviation. Ellis & Ferraro (2016) examine the impact of renewable energy adoption on GHG emissions and air quality. Using meta-analysis, they show that a 10-percent increase in renewable capacity reduces CO_2 emissions by 0.8 metric tonnes per megawatt hour (MWh) generated and PM2.5 decline in the range of 1–5 percent. Several studies point to amplified benefits of renewables for a cleaner environment (Waris, 2023; Dutta, 2023).

Increasing the share of renewables in the global energy mix has been shown to positively impact global GDP, economic sector output and human welfare, although these effects vary across regions. IRENA (2018) shows these benefits using macroeconomic modelling that links renewable energy deployment to job creation, higher economic productivity and improved energy access. Nguyen *et al.* (2023) uses panel data analysis covering multiple countries and finds that increased renewable energy capacity correlates with higher GDP per capita and higher average years of education, suggesting direct and indirect benefits to human development. Similarly, IEA (2023) reports that clean energy investments accounted for 10 percent of global GDP growth in 2023, emphasizing renewable energy as a key driver of economic progress and energy security.

However, conflicting findings have emerged regarding the broader human development outcomes of renewable energy adoption in developing countries. Adekoya *et al.* (2021) examine the distributional effects of renewable energy adoption in low-income regions using household-level data and find that unequal access, high consumption costs and limited production exacerbate inequalities, particularly when renewable energy technologies remain accessible only to wealthier populations. This highlights the need for targeted policies to reduce the cost barriers and enhance access to renewables in developing countries, ensuring equitable distribution of benefits and mitigating potential socio-economic disparities.

Therefore, equity in energy access is another critical dimension of this renewable energy transition. High initial capital costs, limited access to financing and inadequate infrastructure are significant barriers that prevent widespread adoption of renewable technologies in these regions (IRENA, 2023). Beyond these direct hurdles, structural barriers and shadow costs, such as entrenched fossil fuel subsidies, political inertia and misaligned market incentives, further slow progress (UNDP, 2024). Thus, systemic shifts require not just technical solutions but also governance reforms and financial mechanisms to drive equitable energy transitions. NDCs reflect varied approaches to addressing these challenges based on levels of economic development and resource availability. For instance, Nigeria targets multiple sectors, including power, cooking and transport, to achieve carbon neutrality by 2060. Indonesia mandates a 23 percent renewable energy share by 2025 and a 1 percent annual reduction in energy intensity but lacks sector-specific targets. Ecuador prioritizes hydropower, with a goal to produce 90 percent of electricity from clean energy, already reaching 79 percent by 2021 (U.S. Energy Information Administration, 2023).

IAMs play a crucial role in analysing the complexities of renewable energy transitions. IAMs have evolved to incorporate the challenges of VRE integration, including system flexibility, grid stability and broader economic impacts (Pietzcker *et al.*, 2017). For example, the ADVANCE project explores how VRE integration affects global low-carbon energy pathways, emphasizing that assumptions about integration costs and system constraints significantly shape renewable energy adoption more than changes in technology costs (Carrara & Marigoni, 2017; Dai *et al.*, 2017). Similarly, models like the IFs framework adopt assumptions from similar IAMs, such as setting thresholds for VRE sources before accounting for additional systemic costs in the power grid. These thresholds ensure that the broader impacts of renewables on electricity systems are realistically captured.

The relationship between renewable energy and human development is complex and multifaceted, with evidence suggesting that renewables can positively influence GDP, education and public health. However, these benefits are not universal and hinge on country-specific policy environments to flourish. A holistic approach that integrates energy policies with broader development objectives is necessary to maximize the impact of renewable energy on making progress towards the SDGs. Thus, in this study we explore the implications of a just energy transition scenario that evolves alongside synergistic policy measures in health, education and governance—what we term a 'Renewables Acceleration plus SDGs' (**RA+SDG**). In related studies (Abidoye *et al.*, 2021, 2024; Hughes *et al.*, 2020; Sahadevan *et al.*, 2023), the Pardee Institute has collaborated with UNDP on the broad-based implications of various integrated policies on long-term human development outcomes.

In summary, while literature underscores the potential of renewable energy to address interconnected challenges of climate change, energy access and human development, key gaps remain. First, there is a scarcity of long-term studies examining how renewable energy interacts with broader development outcomes over time. Second, the construction of alternative scenarios in long-term planning remains underexplored, particularly scenarios that strategize policies to balance environmental constraints with growing human development needs. **This study addresses these gaps by emphasizing holistic, integrated policy approaches that guide pathways to a just energy transition—one that ensures equitable outcomes and leaves no one behind.**

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