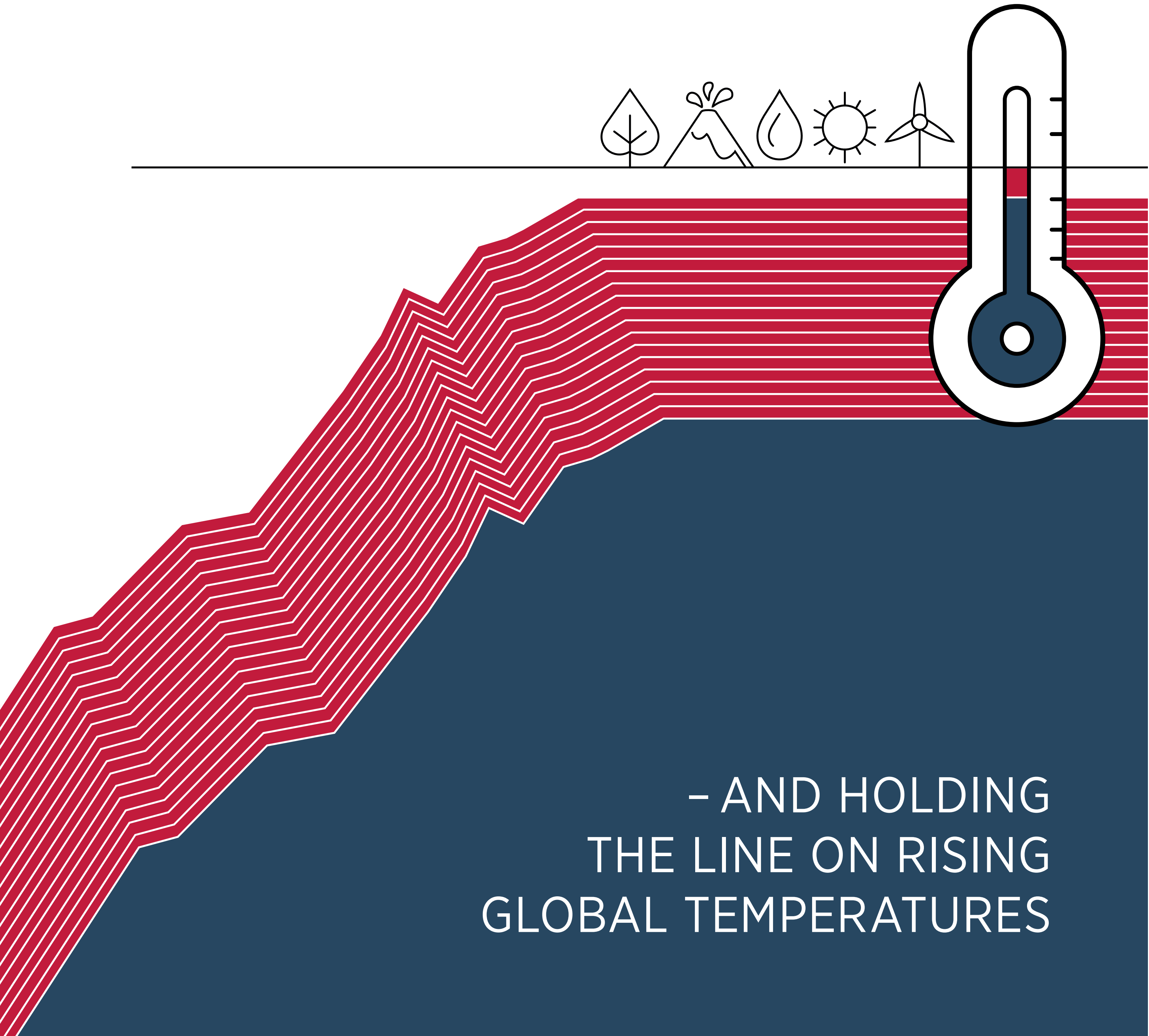
International Renewable Energy Agency

TRANSFORMING THE ENERGY SYSTEM



– AND HOLDING THE LINE ON RISING GLOBAL TEMPERATURES

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that serves as the principal platform for co-operation, a centre of excellence, a repository of policy, technology, resource and financial knowledge, and a driver of action on the ground to advance the transformation of the global energy system. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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FOREWORD

from the IRENA Director-General

Francesco La Camera
Director-General

International Renewable Energy Agency

In response to the threat of climate change, countries around the world have pledged to invest in low-carbon energy. National plans and investment patterns, however, show a stark mismatch with the pathway to meet the commitments set out in the Paris Agreement, which would keep the rise in global temperatures well below 2 degrees (°C) and ideally hold the line at 1.5°C.

At least USD 95 trillion worth of energy investments are planned worldwide until mid-century. These must rise to USD 110 trillion to climate-proof the energy mix, IRENA analysis shows. At the same time, planned fossil-fuel investments must be substantially redirected, with annual investments in renewables more than doubled for the coming decade.

Renewables and efficiency together offer the most realistic way to cut energy-related carbon-dioxide emissions in the timeframe identified by the Intergovernmental Panel on Climate Change. Combined with rapid electrification, they can achieve over nine-tenths of the reductions needed.

Transforming the energy system is not only about installing renewables. It is about investing in more flexible infrastructure. It is about rethinking current plans to avoid stranding assets in outdated systems. Aligning energy investments with broader socio-economic policies can ensure just and timely changes that leave no one behind.

The renewables-based transformation would grow employment 14% and add 2.5% to global GDP compared to current plans, IRENA's roadmap for 2050 indicates. Every dollar spent delivers returns between three and seven dollars in fuel savings, avoided investments and reduced health and environmental damage. The sooner coal- and oil-burning plants are excluded as new investment options, the more countries can benefit from a modern, fit-for-purpose energy system.

The market has given the signal with cost-competitive technologies. Policy makers must now put the enabling frameworks in place to accelerate climate-proof investments. We must create a low-carbon energy system to hold the line on rising global temperatures. It's possible.

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The Paris Agreement sets a goal of *"[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels"* to significantly reduce the risks and impacts of climate change. The world today has less than two decades to make serious cuts in carbon emissions. If we fail, according to the Intergovernmental Panel on Climate Change (IPCC, 2018), we may cross the tipping point into a future of catastrophic climate change.[1]

Ambitious investments in the energy sector – reshaping power generation, transport and other energy uses on both the supply and demand sides – can provide many of the quick wins needed for a sustainable future. Renewable energy sources, coupled with steadily improving energy efficiency, offer the most practical and readily available solution within the timeframe set by the IPCC. By embarking upon a comprehensive energy transformation today, we can start to create a better energy system – one capable of ensuring that average global temperatures at the end of the century are no more than 1.5°C above pre-industrial levels.

Around the world today, national energy plans and Nationally Determined Contributions (NDCs) fall far short of the emissions reductions needed. Currently, the world may exhaust its "carbon budget" for energy-related emissions until the end of the century in as few as ten years. To hold the line at 1.5°C, cumulative energy-related carbon-dioxide (CO_2) emissions must be 400 gigatons (Gt) lower by 2050 than current policies and plans indicate.

The International Renewable Energy Agency (IRENA) has explored two broad future paths: **Current Plans** (meaning the course set by current and planned policies); and the path for a clean, climate-resilient **Energy Transformation**.[2] Building such a low-carbon, climate-safe future can deliver a broad array of socio-economic benefits, IRENA's analysis shows. But to make this happen, the pace and depth of investments in renewables must be accelerated without delay.

Renewable energy technologies alone are not enough to achieve massive decarbonisation. The future energy system encompasses three inter-related elements: one, renewable energy, would rely on steady improvements to energy efficiency and increased electrification of end-use sectors. The cost equation also matters, with affordable renewable power allowing faster, more viable displacement of conventional coal- and oil-burning systems.

Renewables and energy efficiency, enhanced through electrification, can achieve over nine-tenths of the cuts needed in energy-related CO_2 emissions

1 Paris Agreement, Art. 2(1)(a).

2 IRENA's *Global Energy Transformation: A Roadmap to 2050* (IRENA, 2019b) analyses and compares these two investment and development pathways as far as mid-century.

Moreover, falling renewable power costs provide a crucial synergy with electric mobility and heat. Renewables-based heat and transport solutions alone could provide two-thirds of the energy emissions cuts needed to meet agreed international climate goals.

Modern, increasingly "smart" grid infrastructure allows unprecedented flexibility in energy production, distribution and use. But investments are needed to make the most of these gains.

Investment patterns must change

Despite the climate urgency, present investment patterns show a stark mismatch with the pathway to hold the 1.5°C line. Investments in low-carbon energy solutions have stalled over the past three years.

Government plans in place today call for investing at least USD 95 trillion in energy systems over the coming three decades. But those plans and related investments are not always channelled toward climate-proof systems. The investments must be redirected.

To ensure a climate-safe future, they need to flow into an energy system that prioritises renewables, efficiency and associated energy infrastructure. With a different energy investment mix and only USD 15 trillion added to the total investment amount, the global energy system could be largely climate-proof, with cost-effective renewable energy technologies underpinned by efficient use.

USD 3.2 trillion – representing about 2% of gross domestic product (GDP) worldwide – would have to be invested each year to achieve the low-carbon energy transformation. This is about USD 0.5 trillion more than under current plans. While cumulative global energy investments by 2050 would then be 16% higher, their overall composition would shift decisively away from fossil fuels.

> **Transforming the energy system means doubling planned investments in renewable power generation over the next three decades**

Renewables and associated infrastructure account for nearly half of the difference, with energy efficiency and electrified transport and heat applications absorbing the rest:

- Investment to build up renewable power generation capacity needs to be twice as high as currently foreseen, reaching USD 22.5 trillion by 2050.
- Energy efficiency requires investments of USD 1.1 trillion per year, more than four times their present level.
- With solar and wind power on the rise, grid operators need new equipment to make the whole power system operate flexibly. Some of the solutions are market-based, others require investment in modern technology solutions. Quick-ramping thermal generation backups, pumped hydropower, reinforced transmission and distribution grids, digital control equipment, vastly expanded storage capacity, and demand-side management through heat pumps, electric boilers and behind-the-meter batteries are just some of the areas for power system investment.
- The transformed energy system would include more than a billion electric vehicles worldwide by 2050. Combined investments in charging infrastructure and the electrification of railways could reach USD 298 billion yearly.
- Industry and buildings could incorporate more than 300 million highly efficient heat pumps, more than ten times the number in operation today. This means investments of USD 76 billion each year.
- To deepen the system's synergies even more, nearly 19 exajoules of global energy demand could be met by renewable hydrogen – that is, hydrogen produced from renewable sources. But that means adding nearly 1 terawatt of electrolyser capacity by 2050 at an average investment cost of USD 16 billion per year worldwide.
- Investments in renewable heating, fuels and direct uses, which totalled around USD 25 billion last year (IEA, 2019a), must nearly triple to USD 73 billion per year over the coming three decades.

- East Asia would account for the highest annual investments in the energy transformation until 2050, at USD 763 billion, followed by North America at USD 487 billion. Sub Saharan Africa and Oceania would see the lowest, at USD 105 billion and USD 34 billion per year, respectively.

To stay below the IPCC's recommended 1.5°C limit, the world must shift nearly USD 18.6 trillion of its cumulative energy investments until 2050 from fossil fuels to low-carbon technologies. Average annual fossil-fuel investments over the period would then fall to USD 547 billion – about half of what the fossil fuel industry invested in 2017.

Every dollar spent can bring returns as high as seven dollars in fuel savings, avoided investments and reduced health and environmental damage

By shifting investments, the world can achieve greater gains. Fortunately, transforming the energy system turns out to be less expensive than not doing so. This is true even without factoring in the payoffs of mitigating climate change and achieving long-term sustainability. Through 2050, the amounts saved by reducing net energy subsidies and curtailing environmental health damage would exceed investments by three to seven times.

Investments in the energy transformation could create about 98 trillion in additional GDP gains by 2050 compared to current plans, IRENA's analysis shows.

Jobs in the energy sector would increase by 14% with the transformation. New jobs would outweigh job losses, even with the decline in jobs linked to fossil fuels. Renewable energy jobs would grow an estimated 64% across all technologies by 2050.

While such indicators are highly encouraging, energy investment can no longer be pursued in isolation from its broader socio-economic context. As countries turn increasingly to renewables, they will need a comprehensive policy framework for the ensuing transformation. Plans and investment strategies must be accompanied by a clear, integrated assessment of how the energy system interacts with the broader economy for a just and timely transition.

Countries seeking to stimulate economic growth can simultaneously optimise the effects of renewables and minimise the cost of economic and employment adjustments. Far-sighted energy investment policies, when harnessed to savvy socio-economic policies, can help to ensure a just transformation that leaves no one behind.

Through informed investments starting today, countries and communities can scale up renewables cost-effectively, make steady gains in energy efficiency and achieve extraordinary synergies through electrification. The transformed energy system by 2050 should be able to meet the world's needs for the second half of the century.

If socio-economic needs and aspirations are fulfilled in parallel, such changes are likely to gain acceptance and endure even beyond today's urgent shifts to mitigate climate change. Only then will the global energy transformation be truly sustainable.

A transformed energy system would help to fulfil the Sustainable Development Goals and stimulate benefits across multiple sectors

KEY NUMBERS

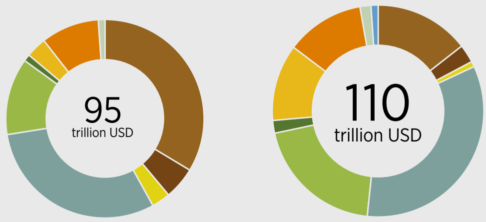
110

110 USD trillion

investments in the sector by 2050 to achieve

ENERGY TRANSFORMATION

+15 USD trillion compared to **CURRENT PLANS**



See **Figure 2.1** for breakdown of energy types in 2050.

Investment in Energy Efficiency:

37 USD trillion

vs. USD 29 trillion

A
B
C

Investment in Renewable Energy:

27 USD trillion vs. USD 12 trillion

Power

22.5 USD trillion

vs. USD 12 trillion

End uses

2.5 USD trillion

vs. USD 1 trillion

Biofuels

2 USD trillion

vs. USD 1 trillion

Changes in **trade**, **spending** and **investment** patterns

See **Figure 3.3** for analysis

2.5% higher GDP

7 million more jobs

A CLIMATE-SAFE ENERGY FUTURE

01

Creating a sustainable, affordable, secure and inclusive energy system is imperative to underpin global development. The need for this wide-ranging transformation, while not entirely new, has taken on a pronounced urgency and immediacy as part of the international response to climate change.

While the future of energy is hard to predict, the contours of the new system are clear enough. Whether in the realm of light, heat or mobility, renewable sources – including bioenergy, solar and wind power, alongside hydropower, geothermal and nascent ocean energy – are at the core of any viable climate solution.

The global energy system is thus on the cusp of unprecedented change—unprecedented in speed, breadth and reach. The transformation is already reshaping economies and societies, creating new linkages between sectors and redefining the relationships between energy producers, consumers, networks and markets.

A strong – and continuously improving – business case for renewables offers an economically attractive response to concerns about the climate. The new paradigm also addresses energy security, sustainable growth and employment, accompanied by solid payoffs for countries and communities in the medium term. Renewables have accounted for more than half of all capacity additions in the global power sector since 2011, with their share in total power generation increasing steadily. Total renewable power capacity in 2018 exceeded 2 300 gigawatts (GW) globally (IRENA, 2019a), with most growth coming from new installations of wind and solar energy.

Renewable energy, coupled with energy efficiency, is the key to a world energy system capable of ensuring that the global average temperature by the end of the century is no more than 1.5°C above the pre-industrial level, as recommended by the Intergovernmental Panel on Climate Change (IPCC). Limiting warming to 1.5°C, the IPCC notes, implies reaching net zero CO_2 emissions globally around 2050, with concurrent deep reductions in emissions of methane, ozone and other climate-impacting emissions.

The IPCC also stresses that a world adhering to the 1.5°C pathway would see greenhouse gas emissions fall rapidly in the coming decade. But getting there will require action on many fronts: reductions in energy demand, decarbonisation of electricity and other fuels (notably by ambitious deployment of renewables), and electrification of energy end use, among other measures. The success of this pathway must be underpinned by very ambitious, internationally co-operative policy environments that transform both energy supply and demand (IPCC, 2018).

The decisive shift in the energy mix necessary to ensure the planet's survival is not an accomplished fact. Renewable energy has yet to make sufficient inroads into the so-called end-use sectors, such as direct heat, buildings and transport. The next wave of cost reductions in renewable energy technologies (notably in system design and construction), along with further technological breakthroughs, may well determine whether the decisive shift occurs in time to to stay on a 1.5°C pathway.

Ultimately, investment in a comprehensive transformation – involving not just a mix of technologies but equally the policy package to put them in place and optimise their economic and social impact – will be the key to a climate-safe future.

1.1. Current plans – or a real energy transformation?

The International Renewable Energy Agency (IRENA) has explored the levels of effort demanded by two energy pathways—the first being the course charted by current plans and policies; the second, a climate-resilient course based on a level of investment sufficient to ensure that the ongoing energy transformation achieves the 1.5°C goal.[3]

The genesis of the two pathways is explored in Box 1.1.

Current national plans around the world fall far short of the emissions reductions needed to reach either the goal articulated in the Paris Agreement on climate change or the 1.5°C IPCC recommendation. Analyses of current and planned policies show that the world will exhaust its "budget" of energy-related carbon dioxide (CO_2) emissions in 10–18 years. To limit the global temperature rise to 1.5°C, cumulative emissions must be reduced from those specified in current and planned policies by at least a further 400 gigatons (Gt) by 2050.

Figure 1.1 shows the path of annual energy-related CO_2 emissions and reductions in both the Current Plans (indicated by the yellow line) and Energy Transformation (indicated by the green line) scenarios. In Current Plans, energy-related CO_2 emissions are expected to increase each year until 2030, before dipping slightly by 2050 to just below today's level.

However, to limit warming to 1.5°C, annual energy-related CO_2 emissions would need to fall by more than 70% between now and 2050, from 34 Gt to at least 9.8 Gt. A large-scale shift to renewable energy and electrification could deliver three-quarters of the needed reduction, or as much as 90% with ramped-up energy efficiency.[4]

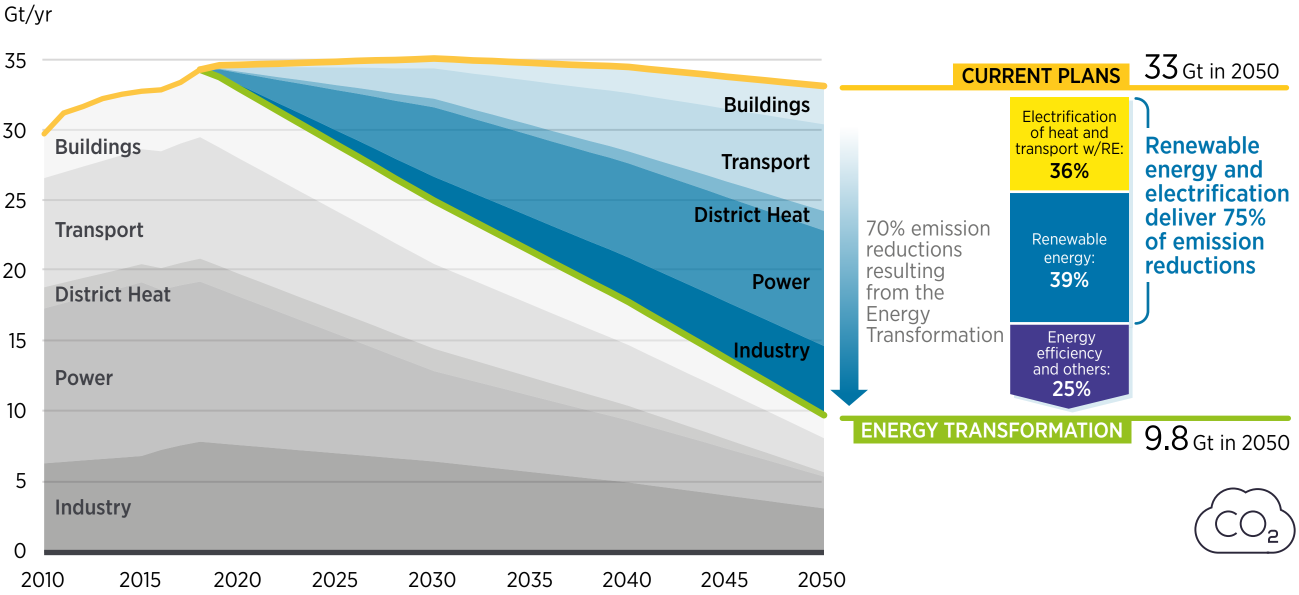
CO_2 emission trends over the past five years show annual growth in emissions of 1.3%. If this pace were maintained, the planet's carbon budget would be largely exhausted by 2030, setting the planet on track for a temperature increase of more than 3°C above pre-industrial levels. This case cannot be considered as a baseline scenario, as many governments, by signing the Paris Agreement in 2015, committed to reducing their emissions. Under current plans and policies, therefore, CO_2 emissions should drop from the historical trend. However, those plans are not nearly ambitious enough to meet the 1.5°C goal by 2050.

Thus, the need to accelerate the pace of the world's energy transformation. As shown in Figure 1.1, such acceleration is needed across a range of sectors and technologies, ranging from deeper end-use electrification of transport and heat powered by renewables, to direct renewable use, energy efficiency and infrastructure investment.

3 The investment needs estimated here are based on the roadmap laid out in IRENA's *Global Energy Transformation: A Roadmap to 2050* (IRENA, 2019b).

4 The Energy Transformation scenario focuses on deployment of low-carbon technologies, based largely on renewable energy and energy efficiency, to generate a transformation of the global energy system consistent with a 1.5°C carbon budget, which would be within the envelope of scenarios presented in the IPCC Special Report on Global Warming of 1.5°C (IPCC, 2018).

Figure 1.1: Annual energy-related CO_2 emissions and reductions, 2010–2050



Based on IRENA, 2019b.

Note: "Renewables" in the caption denotes deployment of renewable technologies in the power sector (wind, solar photovoltaic, etc.) and in direct end-use applications (solar thermal, geothermal, biomass). "Energy efficiency" denotes efficiency measures in industry, buildings and transport (e.g., improving insulation of buildings or installing more efficient appliances and equipment). "Electrification" denotes electrification of heat and transport applications, such as heat pumps and electric vehicles. Gt = gigaton; RE = renewable energy.

Box 1.1 Practical options for global energy decarbonisation

IRENA has explored global energy development options from two main perspectives: the course set by current and planned policies; and a cleaner, climate-resilient pathway based on more ambitious uptake of renewables and associated technologies. Throughout this report the first, or **Current Plans**, provides a comparative baseline for a more ambitious **Energy Transformation**.

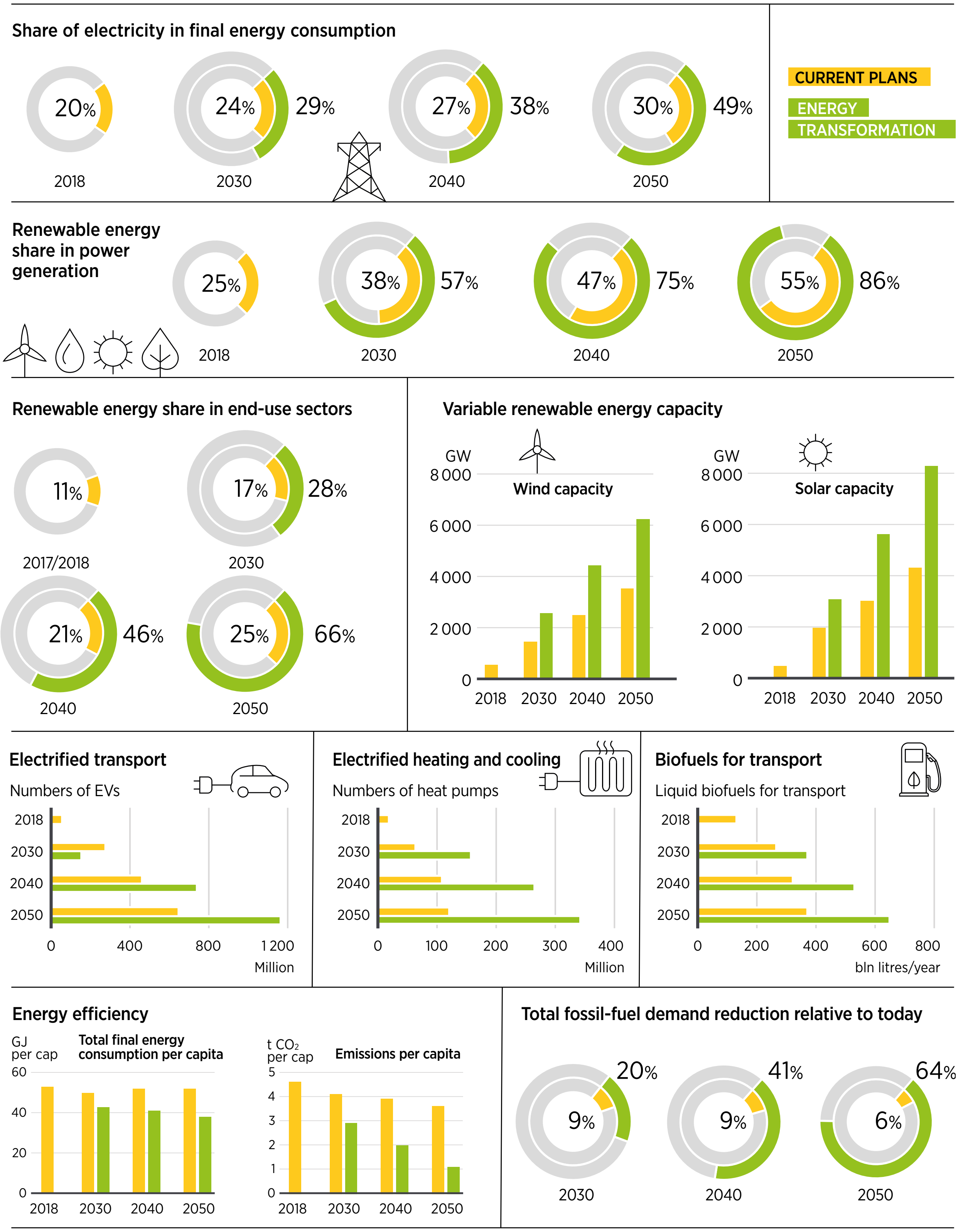
Global Energy Transformation: A Roadmap to 2050 (IRENA, 2019b) analyses and compares these two investment and development pathways as far as mid-century.

The ongoing roadmap analysis, updated annually, involves several key steps:

- Identifying the **Current Plans** for global energy development as a baseline scenario (or Reference Case) for comparing investment options worldwide as far as 2050. This presents a scenario based on governments' current energy plans and other planned targets and policies, including climate commitments made since 2015 in Nationally Determined Contributions under the Paris Agreement;
- Assessing the **additional potential** for scaling up or optimising low-carbon technologies and approaches, including renewable energy, energy efficiency and electrification, while also considering the role of other technologies;
- Developing a realistic, practical **Energy Transformation** scenario, referred to in other publications as the REmap Case. This calls for considerably faster deployment of low-carbon technologies, based largely on renewable energy and energy efficiency, resulting in a transformation in energy use to keep the rise in global temperatures this century as low as 1.5°C compared to pre-industrial levels. The scenario focuses primarily on cutting energy-related carbon-dioxide (CO_2) emissions, which make up around two-thirds of global greenhouse gas emissions;
- **Analysis of the cost, benefits and investment needs** for low-carbon technologies worldwide to achieve the envisaged energy transformation.

For more on the global roadmap and its underlying analysis, see **www.irena.org/remap**

Figure 1.2: Key indicators for two scenarios: Current Plans vs. Energy Transformation



IRENA analysis

Note: Total wind capacity includes both on-shore and off-shore wind; total solar photovoltaic capacity includes both utility and small scale. EVs = electric vehicles; GJ = gigajoule; GW = gigawatt.

1.2. What a climate-safe energy transformation looks like –

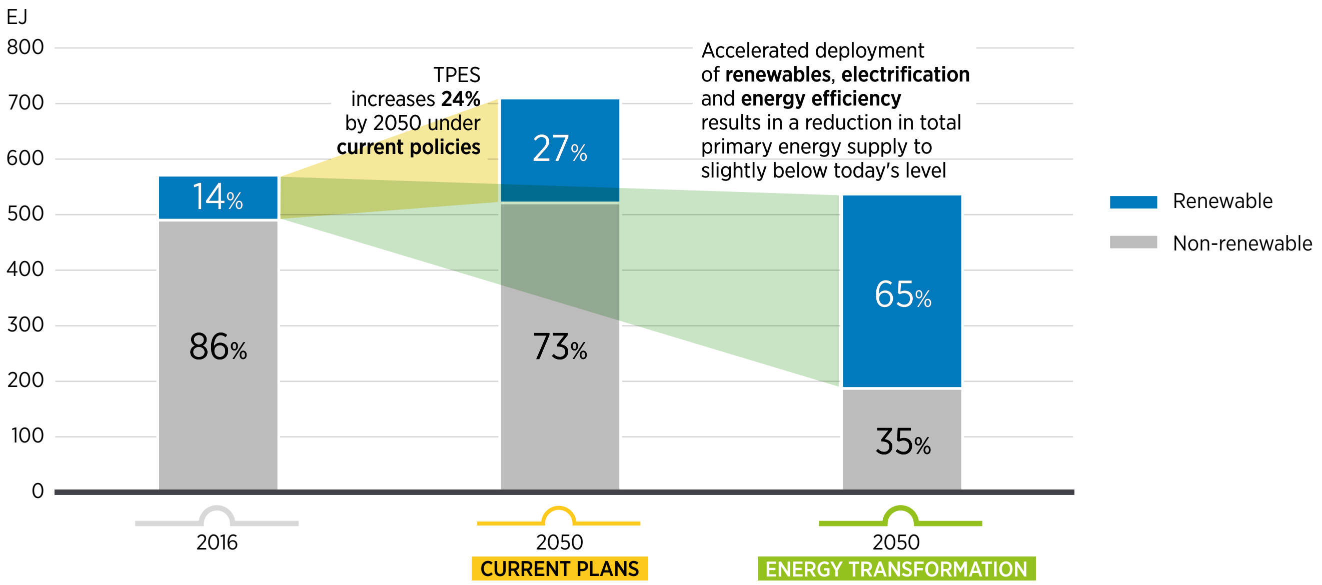
To maintain the 1.5°C pathway, the share of renewable energy in total primary energy supply (TPES) will have to rise from 14% today to at least 65% in 2050 (Figure 1.3). Under IRENA's Energy Transformation scenario,the use of renewable energy would nearly quadruple by 2050.TPES would also fall slightly below today's levels. From 2010 to 2016, with growth in population and economic activity, TPES grew 1.1% per year. Current plans would reduce this figure to 0.6% per year to 2050, whereas, under the Energy Transformation scenario, it would turn negative and show a decline of 0.2% per year to 2050 (IRENA, 2019b).[5]

To protect the climate, the global energy supply must become more efficient and more renewable

Electrification with renewables is the single-largest driver for change in the global energy transformation. The share of electricity in total final energy consumption (TFEC) increases under the Energy Transformation scenario from just 20% today to 49% by 2050. The share of electricity consumed in industry and buildings doubles to reach 42% and 68%, respectively, in 2050, and in transport it increases from just 1% today to over 40% in 2050. The most substantial growth in the use of clean electricity over other fuels will need to come from the building sector (for space heating) and cooking, and in the transport sector for passenger and road freight (IRENA, 2019b).

The increasing use of electricity generated from renewable sources reduces inefficient fuel consumption. Under the Energy Transformation scenario, energy efficiency thus improves, owing to an increase in renewables-based electrification, especially in transport and heat.

Figure 1.3: Renewable and non-renewable shares of total primary energy supply until 2050: Two scenarios



Based on IRENA, 2019b

Note: EJ = exajoule; TPES = total primary energy supply.

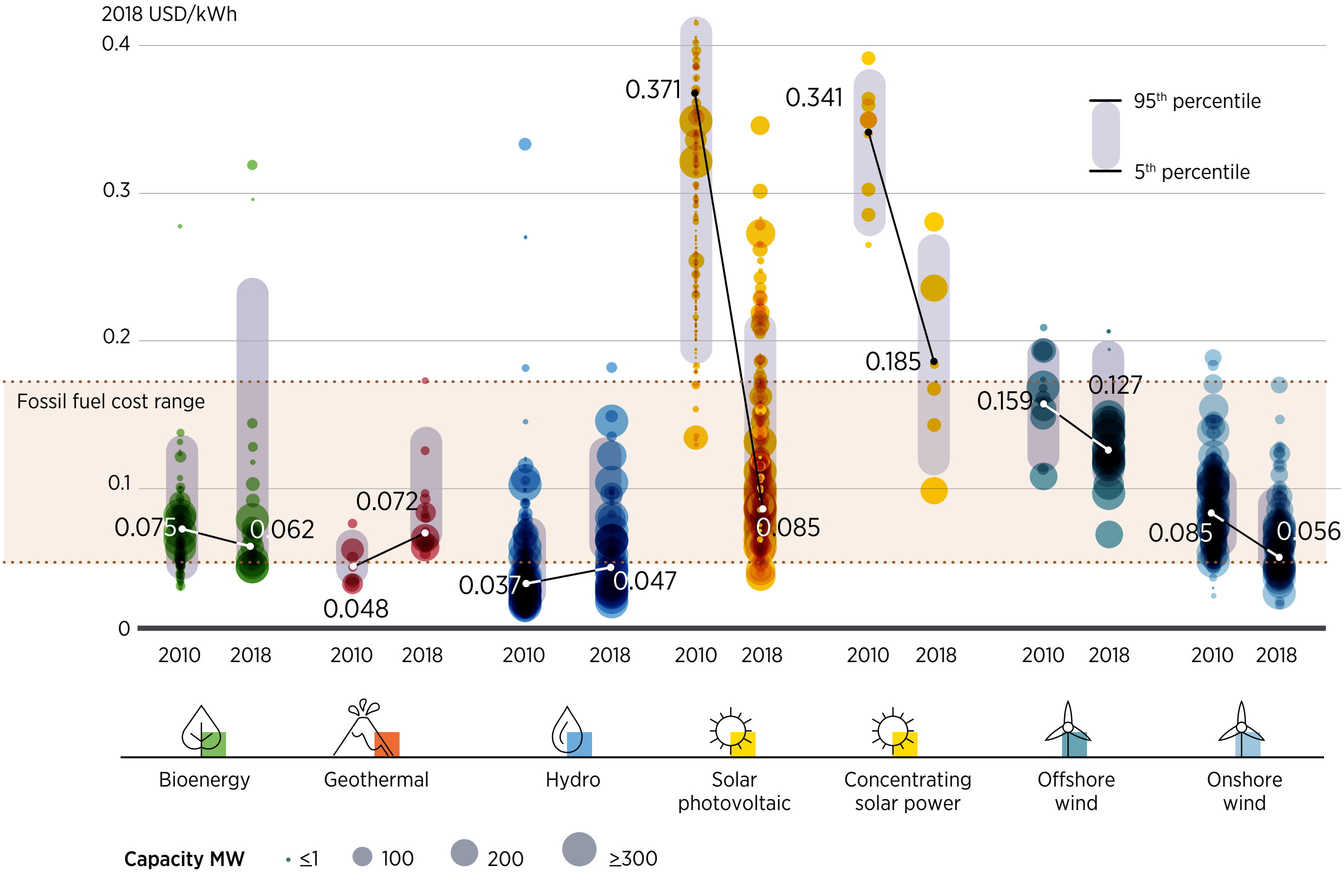
5 For more about the REmap methodology, see www.irena.org/remap/methodology

With the electricity mix significantly transformed, the carbon intensity of electricity drops by 90%. The power sector sees the wide-scale deployment of renewable energy and increasingly flexible power systems, supporting integration of variable renewable energy (VRE). The share of renewable energy in the power sector increases from 24% today to 86% in 2050. This transformation will require new approaches to power system planning, system and market operations, and regulation and public policies (IRENA, 2019b).

The most important synergy of the global energy transformation is created by the combination of increasingly inexpensive renewable power technologies (Figure 1.4) and wider adoption of electric technologies for end-uses in transport and heat. That synergy alone could provide two-thirds of the energy-related emissions needed to set the world on a path to fulfillment of the Paris Agreement and the IPCC 1.5°C recommendation.

Deploying the solutions and technologies required to reduce the carbon intensity of the global economy by two-thirds by 2050, as in the Energy Transformation case, would result in lowering total primary energy supply in that year slightly below 2016 levels, even though the economy would be three times larger than today.

Figure 1.4: Global electricity costs from utility-scale renewable power generation, 2010–2018



Source: IRENA, 2019c.

Note: These data are for the year of commissioning. The diameter of the circle represents the size of the project, with its centre the value for the cost of each project on the Y axis. The thick lines are the global weighted average levelised cost of electricity (LCOE) for plants commissioned in each year. The real weighted average cost of capital (WACC) is 7.5% for countries of the Organisation for Economic Co-operation and Development and China, and 10% for the rest of the world. The beige band represents the cost range of fossil fuel–fired power generation cost; the grey bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

MW = megawatt; USD/kWh = US dollar per kilowatt-hour.

Renewable-based technologies are fast becoming the least-cost energy supply option

1.3. – and what it would deliver

Transforming the energy system would cost less than not doing so, even without factoring in the estimated payoffs of mitigating climate change and achieving sustainability. Through 2050, the amounts saved by reducing (net) subsidies and curtailing the damage to human and environmental health from emissions and other forms of energy pollution exceed the investment costs by three to seven times (Figure 1.5).

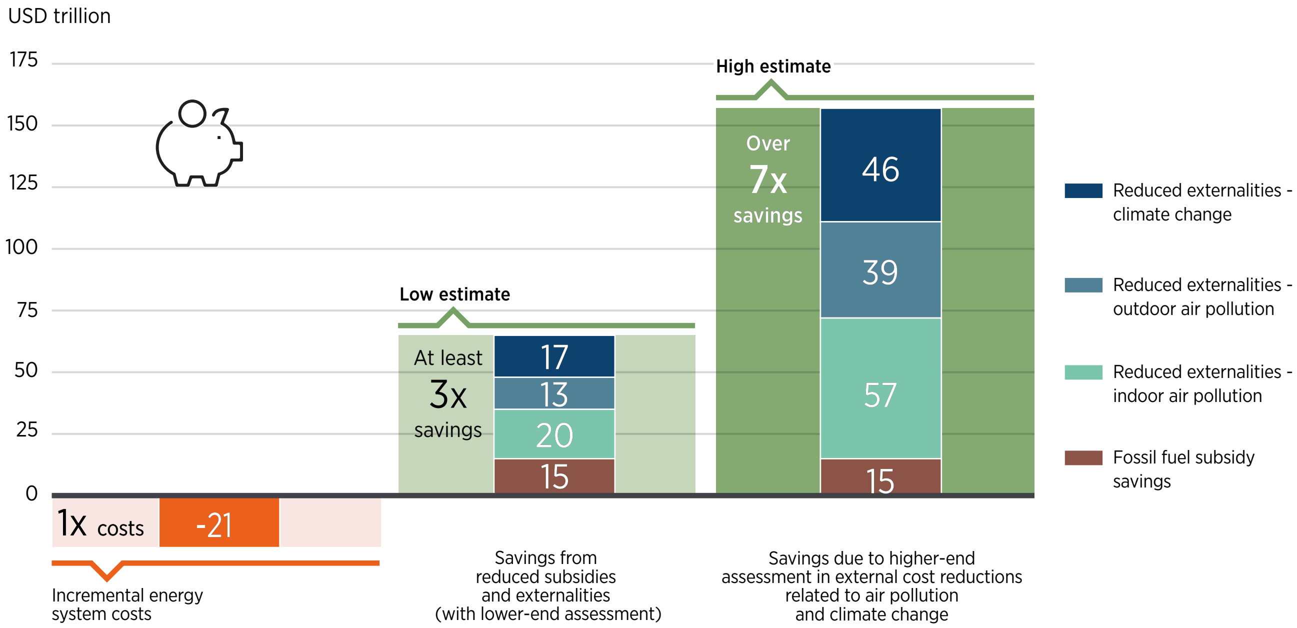
In other words, every additional dollar spent on the energy transformation between now and 2050 will pay back USD 3 to USD 7 in fuel savings, avoided investments and reduced externalities.

Cumulative net savings over the period would be between USD 45 trillion and USD 140 trillion – about two years of current global GDP.

Up to 2030, these benefits can be reaped with low additional investments over Current Plans. After 2030, no additional investments are needed (compared with Current Plans). Indeed, required investments drop in the Energy Transformation case because of the declining costs of renewable technologies.

The investments that will have to be made through 2050 to ensure that the Energy Transformation scenario becomes a reality are laid out in the next section – by sector and by world region. Section 3 then analyses the socio-economic footprint associated with variants of the energy transformation before the focus shifts to policy in the concluding section.

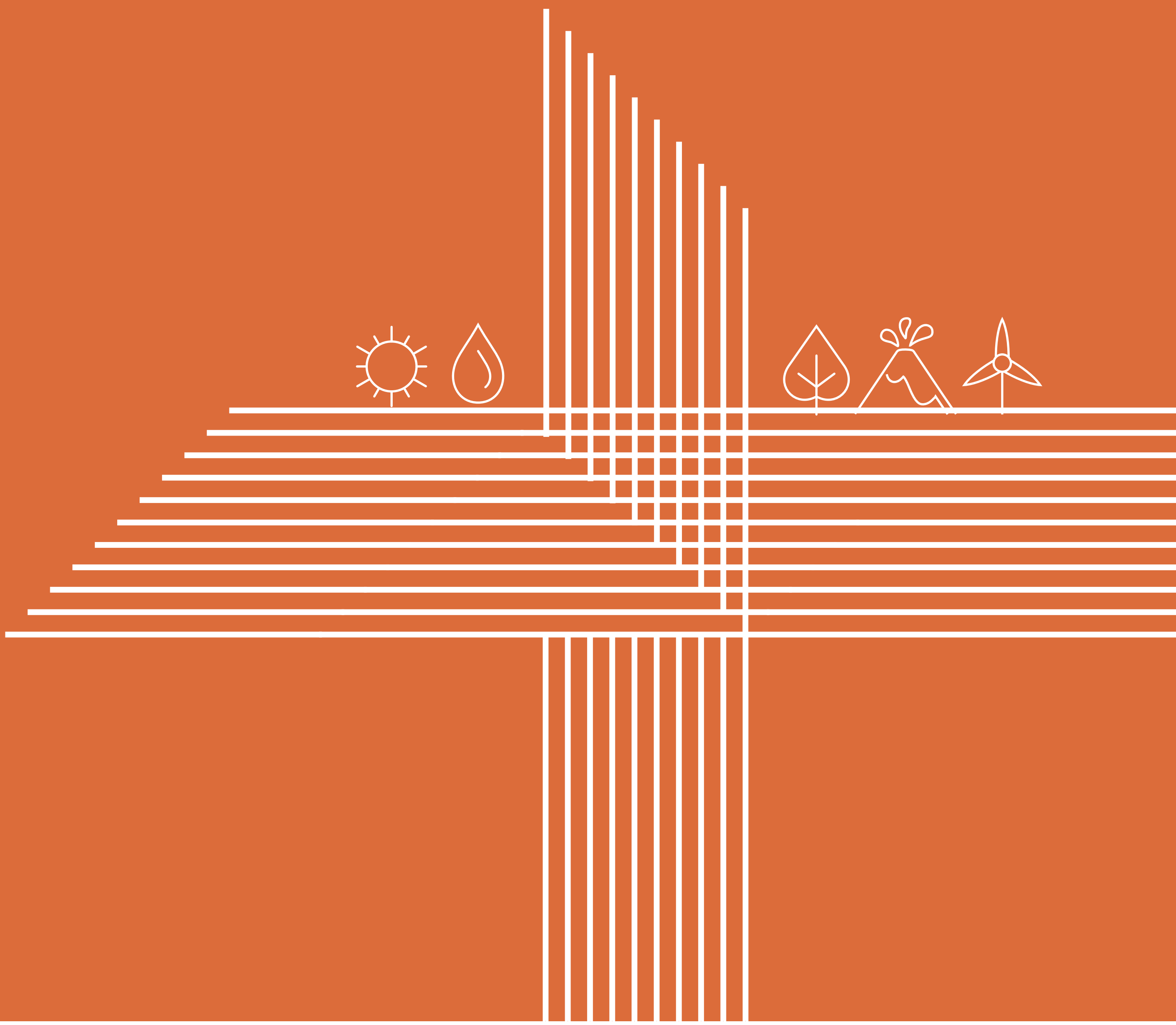
Figure 1.5: Costs and savings under Energy Transformation until 2050, compared with Current Plans



IRENA, 2019b

Every dollar spent on Energy Transformation will deliver a payoff between three and seven dollars, depending on how externalities are valued. As use of renewables rises, net energy subsidies fall, as do health costs from air pollution and climate effects. Half of the additional spending under the Energy Transformation case could be recovered through avoided subsidies

INVESTMENTS NEEDED TO HOLD THE LINE



02

Investments in clean energy stalled over the last three years while investments in fossil fuel sectors rose, indicating a clear mismatch between current trends and the decarbonisation pathway envisaged by the Paris Agreement, which is also reflected in the 1.5°C limit recommended by the IPCC (IEA, 2019a).

IRENA estimates that global investment in renewable power came to USD 309 billion in 2018, down slightly from the 2017 level.[6] Another USD 20 billion was invested in end-use renewables (solar thermal, bioenergy for heating, geothermal heat, etc.), bringing the year's total renewable energy investment to USD 329 billion. Investment is also taking place in innovation and research and development. An estimated USD 50 billion was invested in "smart energy," considered to be equity raising by companies focusing on smart grids, digital energy, energy storage and electric vehicles. Global public investment in R&D related to low-carbon energy technologies grew by 5% over the year, according to the International Energy Agency, reaching USD 23 billion, while corporate investment in clean energy amounted to around USD 90 billion (IEA, 2019b).

Under current plans and policies, investments will need to increase by 50% from recent volumes to meet growing global energy demand. Getting on the 1.5°C pathway will require a doubling of current annual investments in clean technologies. From now through 2050, cumulative investments in the energy system – including infrastructure and clean technologies – would be USD 95 trillion under the Current Plans scenario; and USD 110 trillion under Energy Transformation.

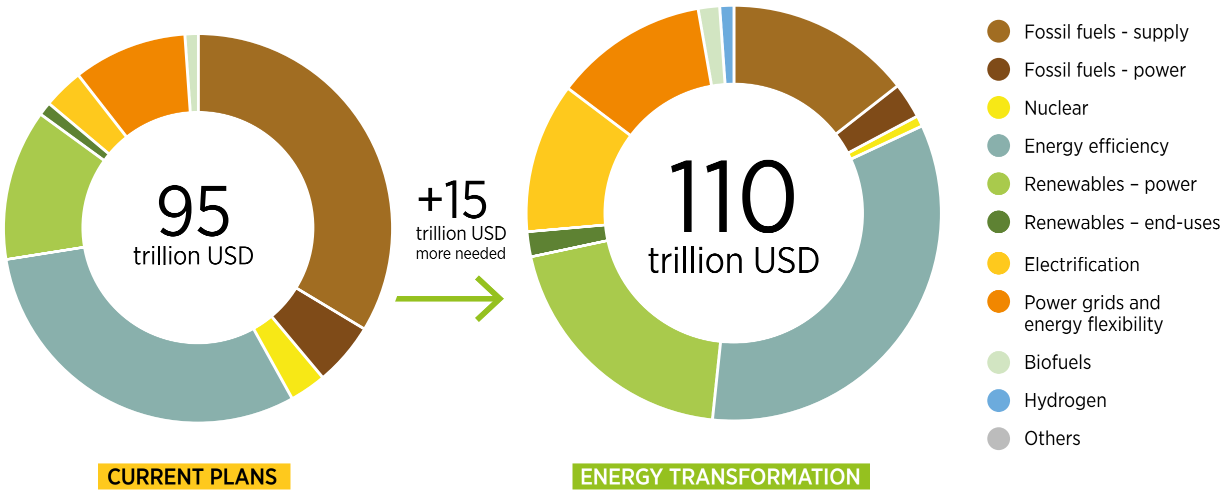
Around USD 3.2 trillion would have to be invested each year (representing about 2% of average global gross domestic product [GDP] over the period) to achieve the low-carbon energy system (Figure 2.1), some USD 0.5 trillion more than under Current Plans. To put this in perspective, 2017 investment in the global energy system was USD 1.8 trillion (IEA, 2018). Renewable energy and associated infrastructure would account for just under half of the difference between the two scenarios, with energy efficiency and electrification of transport and heat applications absorbing the rest.

Deploying the solutions and technologies required to reduce the carbon intensity of the global economy by two-thirds by 2050, as in the Energy Transformation case, would result in lowering total primary energy supply in that year slightly below current levels, even though the economy would be three times larger than today.

For the 1.5°C pathway, energy investments will have to shift toward renewables, energy efficiency and electrification of heat and transport applications

6 Bloomberg New Energy Finance estimates that global investment in renewable power technologies, excluding large hydropower, totalled USD 272 billion in 2018 (BNEF, 2019). IRENA estimates that investment in large hydropower was approximately USD 37 billion.

Figure 2.1: Cumulative investment in Current Plans and Energy Transformation scenarios until 2050



Source: IRENA analysis.

Note: USD throughout the report indicates the value in 2015.

For the 1.5°C pathway, energy investments will have to shift toward renewables, energy efficiency and electrification of heat and transport applications

Looking further at how investment volume changes over time in the Energy Transformation case, average annual investments in the energy sector would amount to USD 4.3 trillion until 2030, more than double the historical average level of USD 1.85 trillion. The bulk is needed for energy efficiency measures in end-use applications and investments in the power sector, with most of the remainder going to upstream primary energy supply, plus a small amount for renewable energy in end uses.

Average annual investments in 2030-50 would drop to between USD 2.6 trillion and USD 2.8 trillion owing to lower investments in fossil fuels, both in terms of upstream supply and as the basis for power generation. The drop represents an overall savings of USD 0.1 trillion to USD 0.3 trillion/per year compared with Current Plans.

However, greater incremental investments would still be needed for energy efficiency improvements in end-use sectors and for measures to enable power grids to accommodate rising shares of variable renewable energy. Investments in direct end-use renewable energy technologies would also need to triple between 2030 and 2050.

The transition toward a decarbonised global energy system will require scaling up investments in the energy sector by a further 16% over Current Plans – an additional USD 15 trillion by 2050 – with the composition of investments shifting away from the fossil fuel sector (Table 2.1). Overall, the Energy Transformation case would require an additional investment of USD 36 trillion in energy efficiency, renewable energy, power grids and flexibility, and other technologies. But it would also render unnecessary USD 18.6 trillion in investments in fossil fuels, leaving an overall incremental investment need of USD 15 trillion to 2050 (or USD 441 billion/year), a 16% increase in investment over Current Plans.

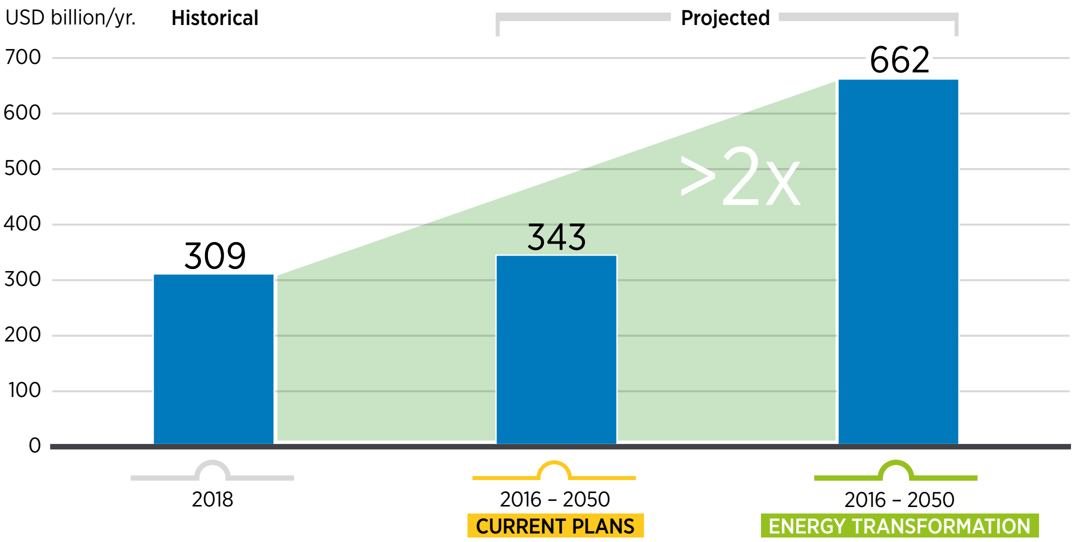
With an eye to realising the Energy Transformation scenario in practice, each of the renewable-based technology categories represented in Table 2.1 is considered separately in the subsequent sections. Those are followed by a breakdown of investment needs by region and an examination of how investment flows will need to shift.

2.1. Investments in renewable power generation

The decarbonisation options of the Energy Transformation scenario would require investment of nearly USD 22.5 trillion in renewable power generation capacity through 2050, almost double the amount under Current Plans (USD 11.7 trillion). Annual investments would double to more than USD 660 billion per year (Figure 2.2). Much of the total would go into wind (45%) and solar PV (30%), followed by bioenergy (9%), hydropower (7%) and concentrated solar power (4%) (Figure 2.3).

Under the Energy Transformation scenario, USD 22.5 trillion would be invested in renewable power

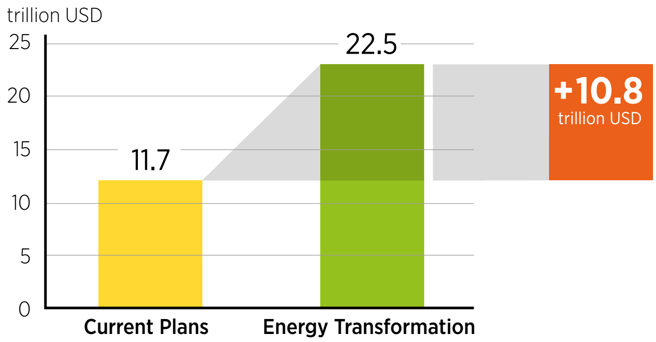
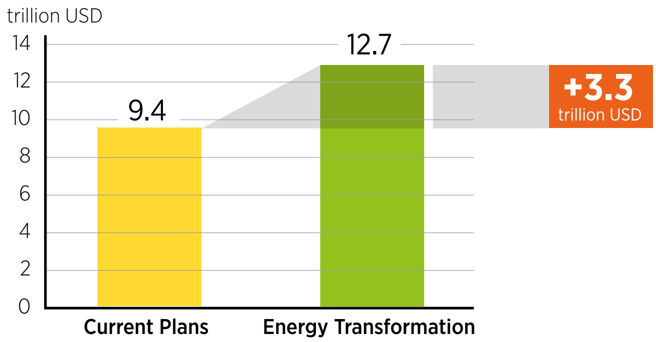
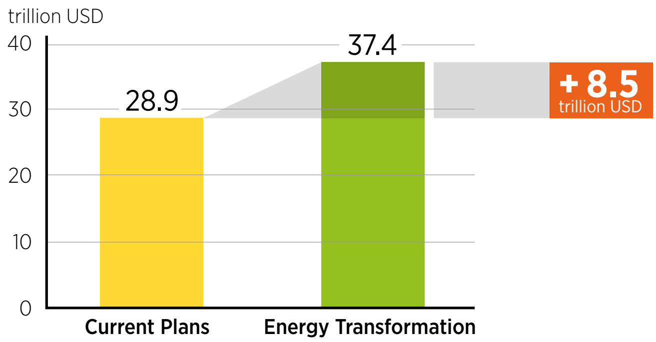
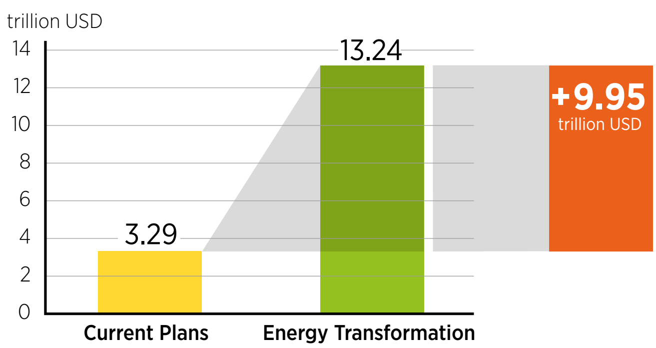
Figure 2.2: Average annual investments in renewable power generation capacity until 2050



Source: IRENA analysis

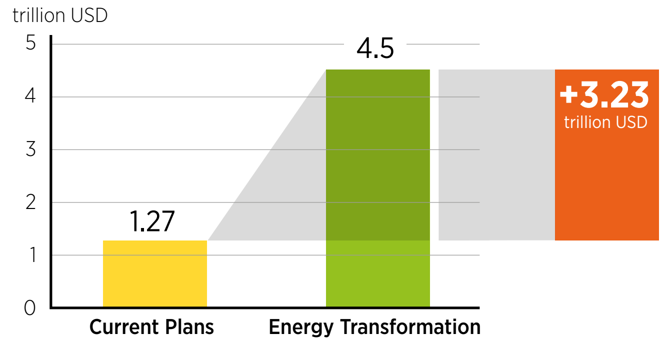
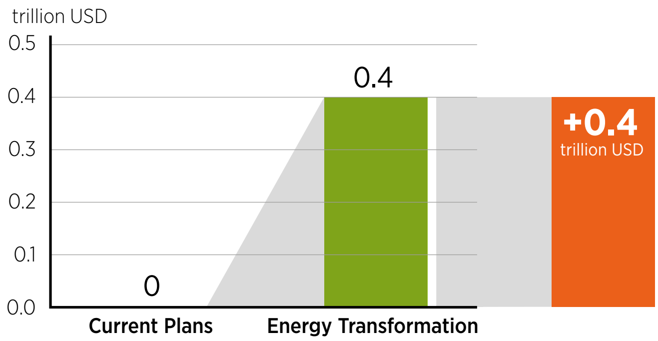
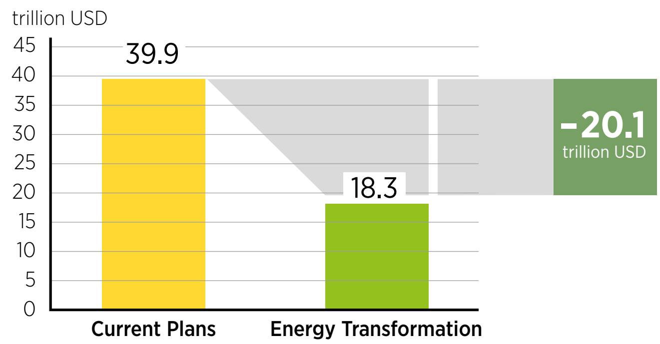
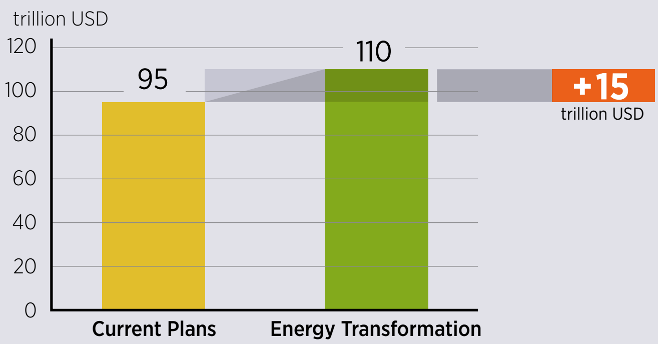
Note: 2018 data is based on BNEF (2019) and IRENA estimates.

Table 2.1: Investment needs through 2050 under the Current Plans and Energy Transformation scenarios, by technology

Category	Cumulative investments between 2016 and 2050	Difference	Comments
Renewables-based power generation capacity (excl. electrification)		+10.8 trillion USD	• Chiefly, construction of generation capacity fuelled by wind and solar PV
Power grids and flexibility		+3.3 trillion USD	• 80% for extension and reinforcement of transmission and distribution networks • Balance for smart meters, energy storage (pumped hydro, battery storage), and retrofitted or new generation capacity to ensure adequate reserve capacity
Energy efficiency in end-use sectors (excluding electrification)		+ 8.5 trillion USD	• 50% for building renovations and construction of new efficient buildings • Balance for improvements in transport and industry
Electrification of end-use sectors		+9.95 trillion USD	• 80% for charging infrastructure for electric vehicles and electrification of railways • Balance for heat pumps in buildings (12%) and industry (8%) • Fraction of 1% for 1 TW of electrolyser capacity to produce 19 exajoules of hydrogen.

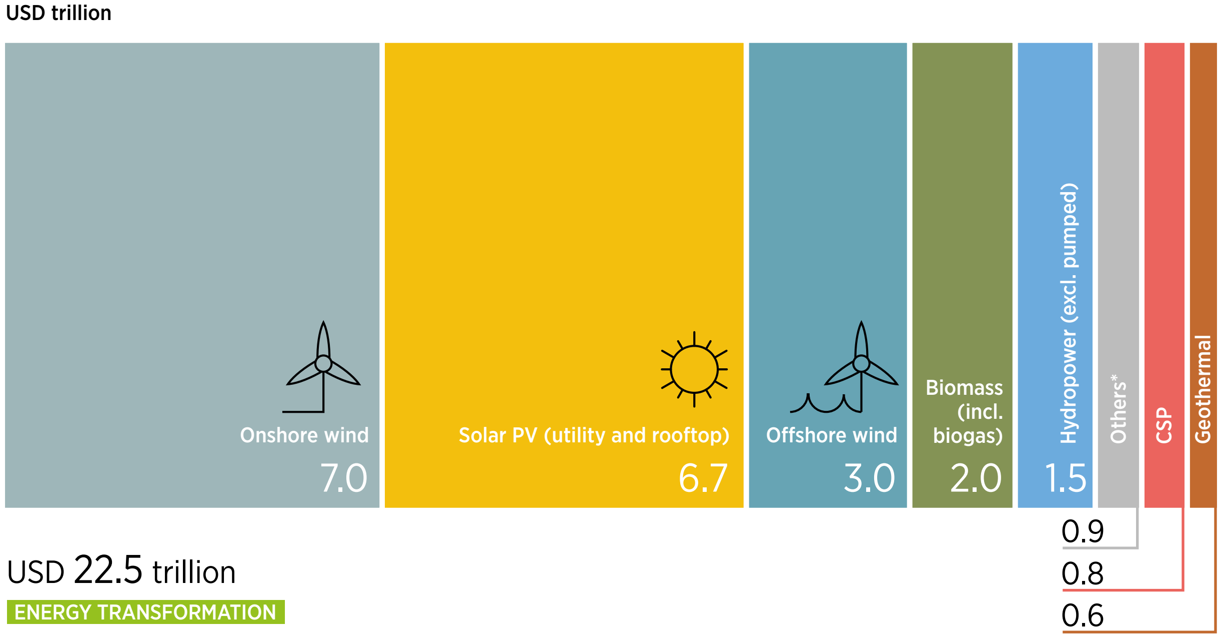
Note: EJ = exajoule; PEM = polymer electrolyte membrane; PV = photovoltaic; TW = terawatt.

Table 2.1: (continued)

Category	Cumulative investments between 2016 and 2050	Difference	Comments
Direct applications of renewables			• 42% for biofuel production to decarbonise the transport sector, especially aviation and shipping • 40% for solar thermal deployments in industry (primarily) and buildings • 11% for modern biomass; balance for geothermal deployment
Other			• Includes carbon capture and storage in industry and efficiency improvements in materials
Non-renewables			• More than 90% of change due to lower spending on fossil fuels (upstream supply, generation capacity) • Balance reflects avoided investments in nuclear power generation capacity
Total difference			**Overall incremental investment needs are USD 15 trillion.**

Source: IRENA analysis.

Figure 2.3: Cumulative investment in renewable power generation capacity until 2050, by technology



Source: IRENA analysis.

Note: Others include marine, floating solar and hybrid renewable capacities. CSP = concentrated solar power; PV = photovoltaic.

Beyond generation, additional investment will be needed to ensure adequate and flexible operation of an expanded power system capable of reliably absorbing growing volumes of variable renewable energy. The components include transmission and distribution networks, smart meters, pumped hydropower, decentralised and utility-scale stationary battery storage (coupled mainly with decentralised PV systems), and retrofitted and new power generation capacity to ensure generation adequacy.

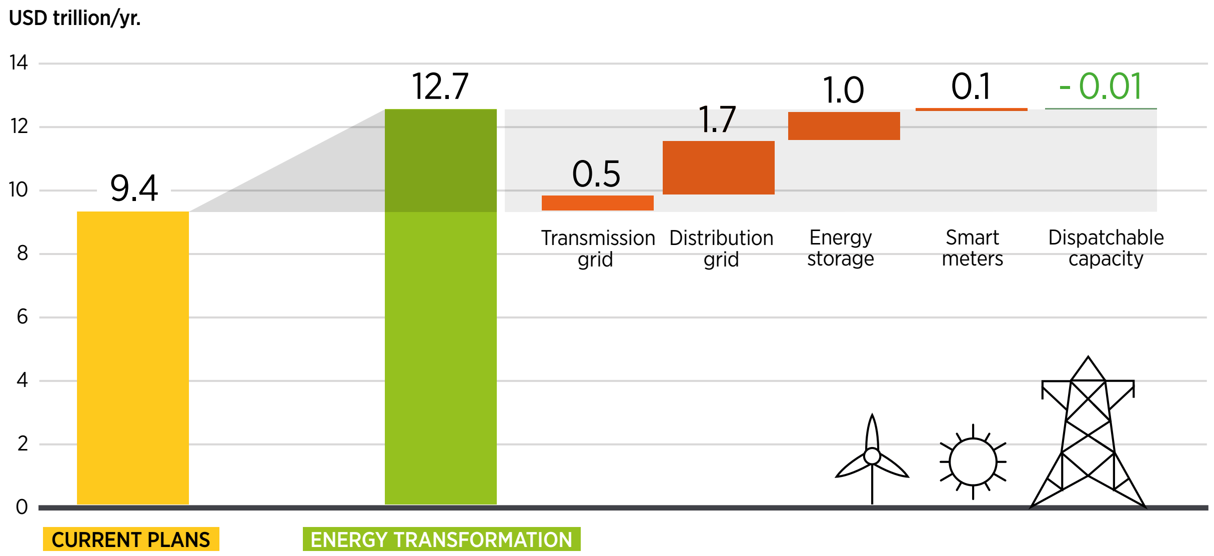
These investments approach USD 13 trillion in the Energy Transformation case, a third higher than the USD 9 trillion under Current Plans. Nearly two-thirds of the increment will be needed to extend and enhance transmission and distribution grids, with the remaining third going to support measures to ensure the adequacy and flexibility of the power system as well as the installation of smart meters (Figure 2.4). In annual terms, nearly USD 374 billion/year is required over the period to 2050 to ensure safe, reliable, and flexible operation of a power system fuelled primarily by renewables.

Globally, investment in maintaining, extending and improving electricity networks dipped by 1% in 2018 from 2017, with overall investments of USD 293 billion (IEA, 2019a). Meanwhile, investment in utility-scale and behind-the-meter battery storage reached a record level of over USD 4 billion in 2018, 45% higher than 2017 levels (IEA, 2019a).

Additional investments will be required for energy infrastructure

Under the Energy Transformation scenario, total installed capacity of wind energy would rise from around 564 GW in 2018 to more than 6 000 GW in 2050. Solar PV would rise from and 480 GW to 8 500 GW during the same period. The scale-up would absorb more than 60% of the overall investment in renewables-based power generation capacity in the decades leading to 2050.

Figure 2.4: Investments in transmission and distribution networks, energy storage, smart meters and dispatchable fossil-fuel power capacity until 2050



Source: IRENA analysis

The costs of variable renewable energy are tied to the inherent characteristics of the energy sources and the challenges of integrating them into power systems. Variability, uncertainty and location-dependency all make it more difficult for systems to balance real-time supply and demand and to recover quickly and efficiently from unexpected events. A power system that can effectively perform the above functions is said to possess sufficient flexibility (IRENA, 2019d).

Experience shows that integrating very high shares of variable renewable energy is already technically possible. The constraint on deployment and higher penetration is mainly economic (IRENA, 2019d).

As the share of variable renewable energy grows, significant investments are also needed in equipment and systems to enhance grid flexibility.

The targets of those investments include quick-ramping thermal generation backups, pumped hydropower, reinforced transmission and distribution grids, digital control equipment, vastly expanded storage capacity (stationary, seasonal, and directed toward electric vehicles), and flexible demand (demand-side management, heat pumps and electric boilers).

Local circumstances determine the capital expenditure required to transform any given power system. Similarly, the requirement for investments in enabling technologies depends on existing levels of flexibility, anticipated growth in demand (owing to economic growth and electrification), the amplitude of seasonal fluctuations (particularly pertinent for electric heat), new construction vs. retrofitting (enhancing flexibility is less costly in a greenfield investment), and consumer preferences (e.g., for electric vehicles).

2.2. Investments in energy efficiency

For the world to set itself on a path toward meeting long-term decarbonisation targets, investments in energy efficiency will have to be scaled up to USD 1.1 trillion per year, almost five times higher than their 2018 level (USD 0.240 trillion[6]) (Figure 2.5). Compared to fossil fuels, most types of renewables inherently entail lower energy losses when converted into useful energy services. Renewables thereby reinforce the benefits of energy efficiency measures that reduce demand. This effect may be further amplified as larger shares of transport, heating and other end-uses come to be electrified (IRENA, 2019e).

The major share of efficiency measures would be directed at cars and similar passenger vehicles (87%), followed by other passenger modes (buses, railways, and two- and three-wheelers). Efficiency measures include the modal shift from passenger cars to public transport (electric railways or trams) and, in case of freight, moving from trucks to electric railways. Such shifts can help greatly to decarbonise transport in many countries while also helping to reduce fuel costs.

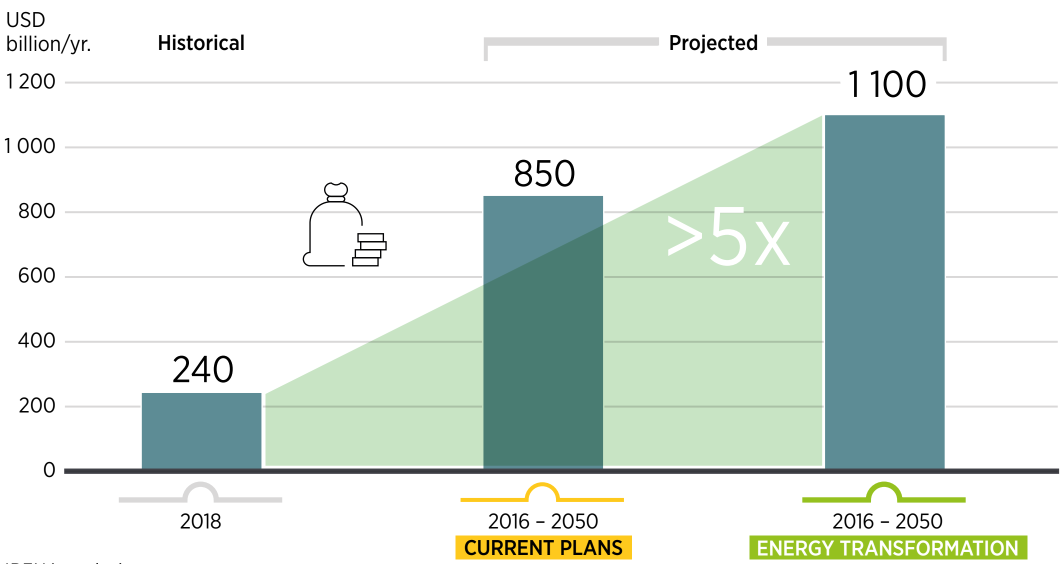
The remainder would pay for efficiency measures in marine and aviation applications in heavy- and light-duty vehicles.

In addition to USD 2.5 trillion total investments in renewable heating, fuels and direct uses, nearly USD 2 trillion is needed in the Energy Transformation case until 2050 for biofuel production to decarbonise transport, especially aviation and shipping.

Achieving 1.5°C requires quintupling investment in energy efficiency measures

6 www.iea.org/wei2019/end-use/.

Figure 2.5: Average annual investments in energy efficiency measures through 2050



IRENA analysis

Note: 2018 data based on IEA (2019a) and data on IRENA estimates.

2.3. Investments in electrification and direct uses

Significant electrification in end-use sectors is critical for decarbonising energy. The Energy Transformation scenario requires a cumulative investment of USD 2.5 trillion in direct end uses and heat applications through 2050, plus an additional USD 2 trillion to produce biofuels for use primarily in aviation and shipping.

By sector, transport requires the most significant transformation, but renewable heating and cooling solutions for buildings, urban development projects, and industries are also critical. Electrolyser capacity also would need to grow substantially. The next paragraphs and Figure 2.6 expand on these points.

Electrification in transport. To decarbonise by 2050, fossil fuel emissions from the transport sector must be significantly reduced, most notably by replacing conventional vehicles with electric vehicles. Under the Energy Transformation scenario, the number of electric vehicles would exceed 1 billion by 2050. This will require yearly investments of around USD 298 billion in charging infrastructure for electric vehicles and for the electrification of railways (Figure 2.6).

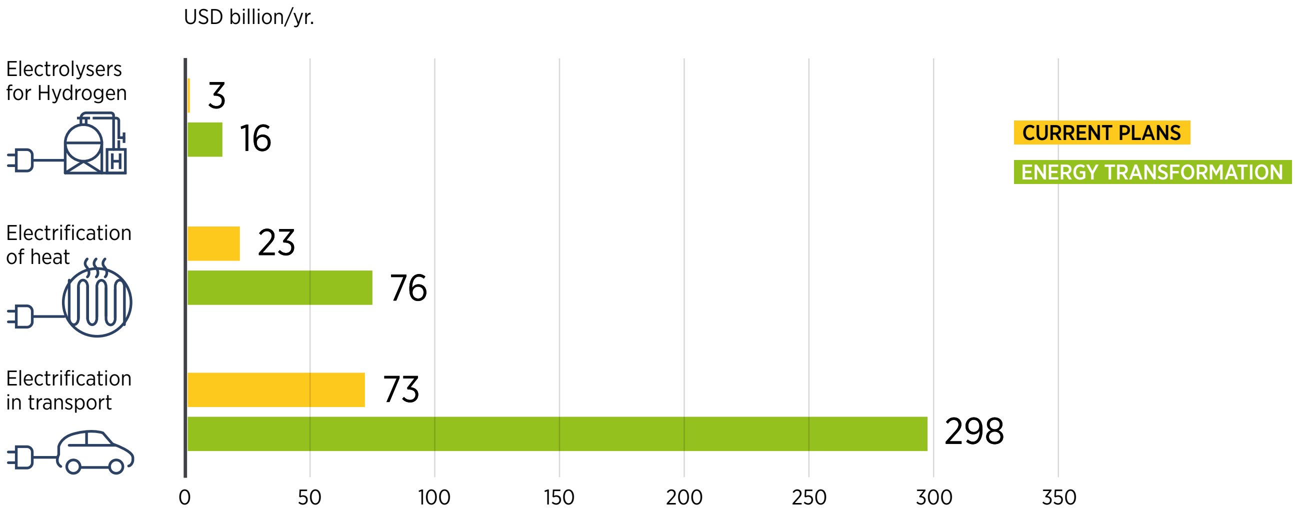
The Energy Transformation case calls for a quadrupling of investment in the electrification of heat and transport

Additional investments would also be needed in battery factories to build battery packs for electric vehicles. The largest incremental investment needs are concentrated in charging infrastructure.

Electrification of heat. Rising demand for heat in low-temperature regions of the world requires alternative technology options to replace existing fossil-fuel systems. Heat pumps offer a low-carbon technology solution for heat demand in some end-use applications. They are now an attractive option in Europe and are expected to gain momentum in other regions. Under the Energy Transformation scenario, the number of heat pumps used in the buildings and industry sectors would increase to over 300 million, ten times the number in operation today. This would require annual investments of USD 76 billion.

Solar thermal technology will meet more than half of demand for direct heat in industry and buildings under the Energy Transformation scenario

Figure 2.6: Average annual investments to electrify heat and transport through 2050



Source: IRENA analysis

More than two-thirds would be deployed in buildings and the rest in industry.

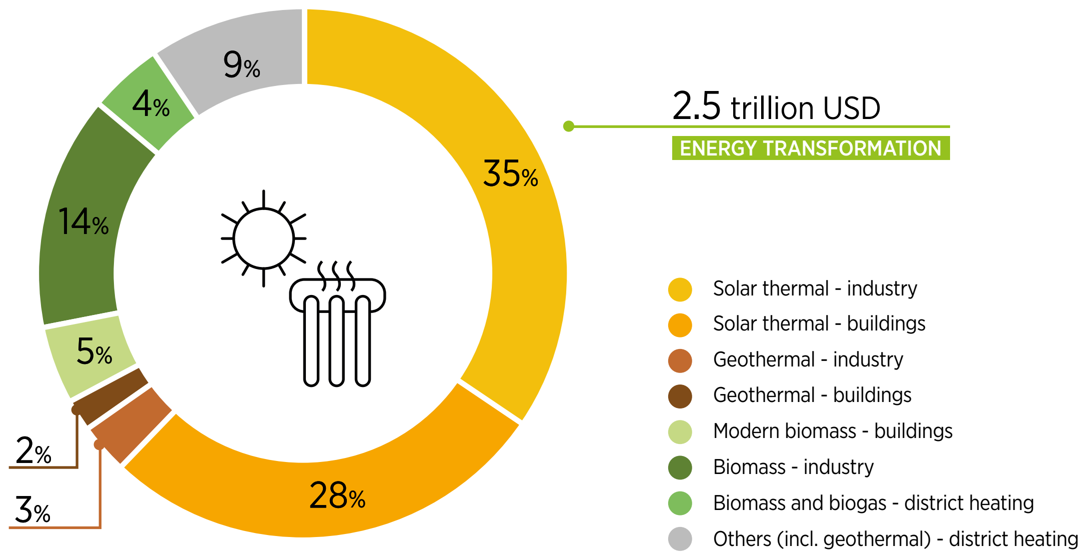
Hydrogen. The Energy Transformation case specifies that by 2050 nearly 19 EJ of global energy demand could be supplied by renewable hydrogen – that is, hydrogen produced from renewable sources (IRENA, forthcoming). To achieve this, almost USD 16 billion in average annual investment would be needed through 2050 for the deployment of nearly 1 TW of electrolyser capacity (alkaline and polymer electrolyte membrane).

Overall, to achieve the goals of the Energy Transformation scenario, investments in renewable heating, fuels and direct uses would need to triple from around USD 25 billion in 2018 (IEA, 2019a) to just under USD 73 billion per year over the period to 2050. More than half of the investments would be needed for rapid deployment of solar thermal technologies in industry and buildings, followed by a reasonable amount (14%) to be invested in the use of biomass in industrial heat processes (Figure 2.7).

The Energy Transformation case also contemplates some investment in deployment of carbon capture and storage, along with improvements in industrial materials and processes, valued at a total of USD 0.4 trillion from now through 2050.

Investment levels around the world will vary widely

Figure 2.7: Cumulative renewable energy investments needed for direct end-uses and heat applications until 2050



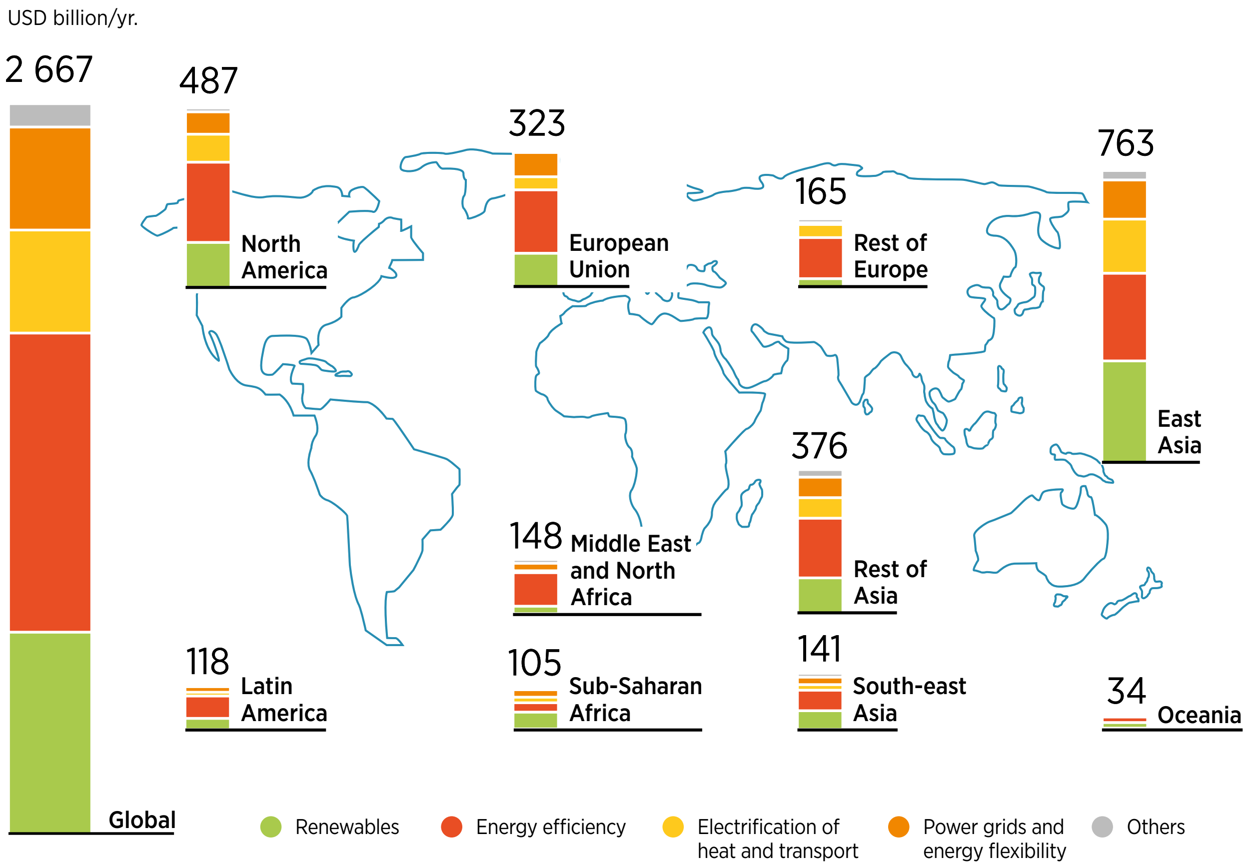
Source: IRENA analysis.

2.4. Breakdown of investment by region

The levels of investment in renewable energy needed to implement the Energy Transformation scenario vary greatly by region and are not necessarily correlated with current shares of renewable energy, owing to the size of the energy systems, different resource endowments and differing starting points. The highest shares of renewable energy in primary energy supply in 2050 will be reached in sub-Saharan Africa and Oceania, with levels far above 80%, followed by Latin America and the European Union (EU), with levels above 70%. In contrast, the Middle East and North Africa (MENA) region will have the lowest share, at just 26%.

The highest level of average annual clean energy investments over the period to 2050 will be seen in East Asia, at USD 763 billion, followed by North America, at USD 487 billion (Figure 2.8 and Table 2.1). Sub Saharan Africa and Oceania will have the lowest average annual investments in clean energy technology deployments, at USD 105 billion and USD 34 billion, respectively.

Figure 2.8: Annual clean energy investments for Energy Transformation by region through 2050



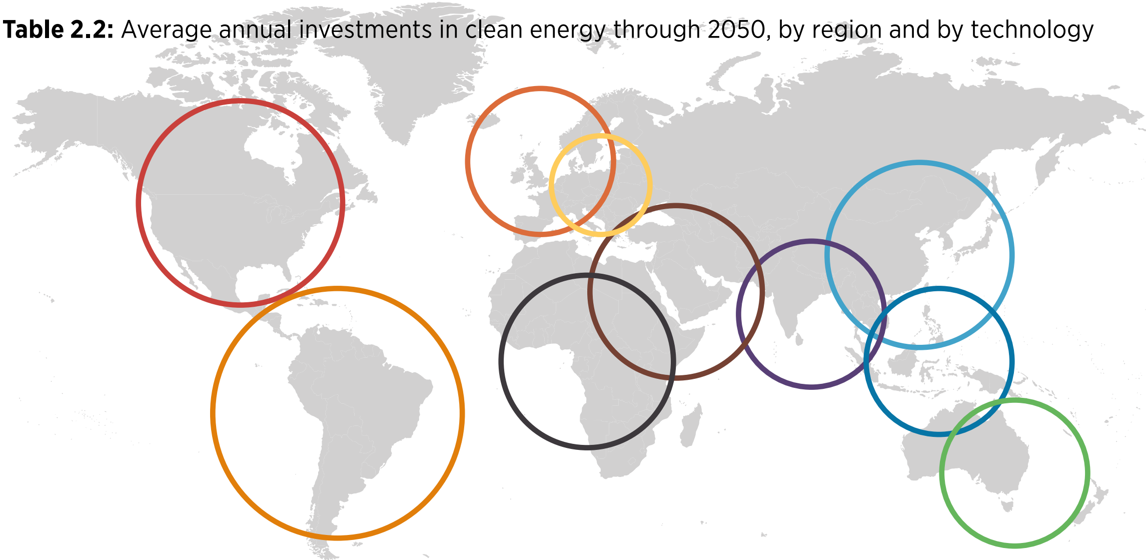
IRENA analysis.

Note: Others include electrolysers for hydrogen production, biofuel production and CCS in industry and material improvements.

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA

East Asia and North America will require almost 50% of the total energy investment in the Energy Transformation case due to increasing energy demand.

Table 2.2: Average annual investments in clean energy through 2050, by region and by technology



	Annual investments (USD billion/year)	Share (%) of each region's annual investment total				
		Renewables (power and end-use)	**Energy efficiency**	**Electrification of end-uses**	**Power grids and flexibility**	**Others**[a]
East Asia	763	35	30	18	14	3
North America	487	24	45	15	13	2
Rest of Asia	376	25	42	14	14	5
European Union	323	25	45	10	17	2
Rest of Europe	165	15	57	18	4	6
Middle East and North Africa	148	12	65	4	16	4
Southeast Asia	141	32	40	8	15	5
Latin America and the Caribbean	118	26	50	8	13	3
Sub-Saharan Africa	105	41	24	15	17	3
Oceania	34	37	39	8	12	4

IRENA analysis.

a. Electrolysers for hydrogen production, biofuel supply, and carbon capture and storage for use in industry and material improvements.

- **East Asia** comprises China, Japan, Mongolia, Democratic People's Republic of Korea, Republic of Korea.
- **North America** comprises Canada, Mexico, United States of America.
- **Rest of Asia** comprises Afghanistan, Armenia, Azerbaijan, Bangladesh, Bhutan, India, Kazakhstan, Kyrgyzstan, Maldives, Nepal, Pakistan, Sri Lanka, Tajikistan, Turkey, Turkmenistan, Uzbekistan.
- **European Union** comprises all EU member states.
- **Rest of Europe** comprises Albania, Andorra, Belarus, Bosnia and Herzegovina, Iceland, Lichtenstein, Monaco, Montenegro, North Macedonia, Norway, Republic of Moldova, Russian Federation, Serbia, Switzerland, Ukraine.
- **Middle East and North Africa** comprises Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates, Yemen.
- **Southeast Asia** comprises Brunei Darussalam, Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Vietnam.
- **Latin America and the Caribbean** comprises Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Uruguay, Venezuela.
- **Sub-Saharan Africa** comprises Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe.
- **Oceania** comprises Australia, Fiji, Micronesia, New Zealand, Papua New Guinea, Samoa, Solomon Islands, Vanuatu.

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA

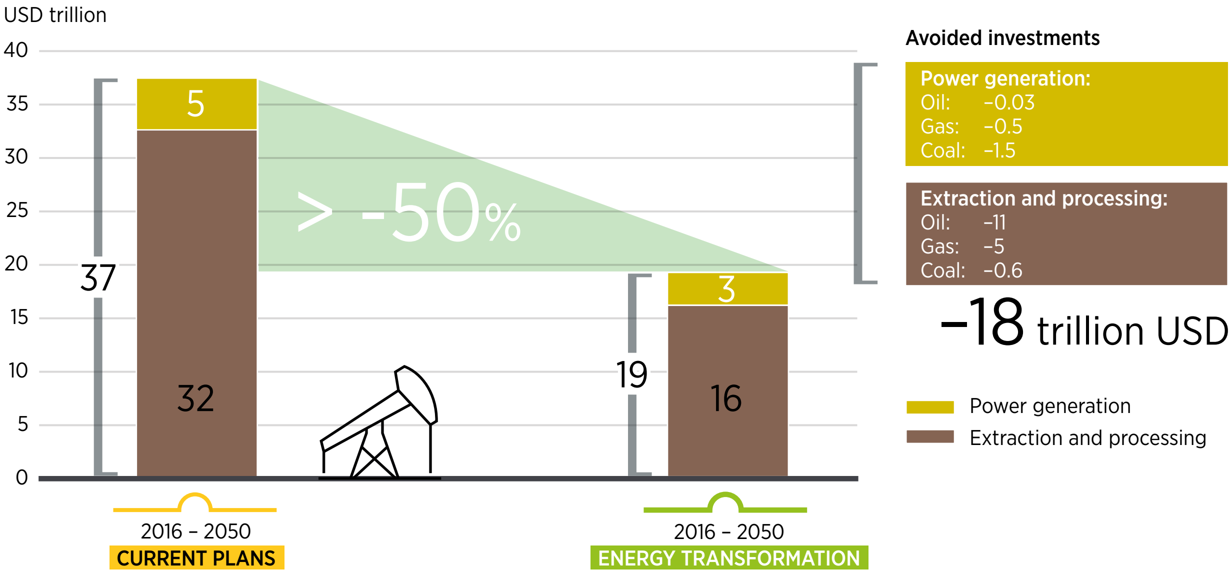
2.5. Shifting investment

To stay below the 1.5°C limit recommended by the IPCC, investments of nearly USD 18.6 trillion will have to be switched from fossil fuels to low-carbon technologies between now and 2050. The necessary switch would reduce annual fossil fuel investments to USD 547 billion – about half of what was invested by the fossil fuel industry in 2017 (IEA, 2018). Most (89%) of the reductions would be made in upstream supply (Figure 2.9). Oil would account for almost 64% of the cumulative avoided fossil fuel upstream investments, with natural gas accounting for 33% and coal for 4%. Cumulative investments in fossil fuel power plants would be reduced to USD 2.6 trillion through 2050, half of the amount projected under Current Plans (USD 5 trillion). Most of the remaining investments would be needed for refurbishing existing thermal power plants, while a small amount would be invested for already- commissioned plants nearing completion.

The avoided fossil fuel investments offset more than half of the USD 36 trillion required for investments in renewable energy technologies under the Energy Transformation scenario, bringing the net incremental investment of that scenario down to USD 15 trillion over Current Plans. Reductions in subsidies under the Energy Transformation scenario far-reaching positive externalities (discussed later in this report) ensure that the benefits gained would clearly outweigh the residual investment cost.

The Energy Transformation scenario would avoid trillions in fossil fuel investments, freeing the funds for investment in clean energy

Figure 2.9: Cumulative fossil-fuel investments for extraction, processing and power generation until 2050: Current Plans vs. Energy Transformation



Source: IRENA analysis.

Figure 2.10: Immediate actions needed at the sector level to transform the global energy system

Power

ACCELERATE RENEWABLE CAPACITY ADDITIONS TO GENERATE ADEQUATE POWER WITH LOW-CARBON TECHNOLOGIES

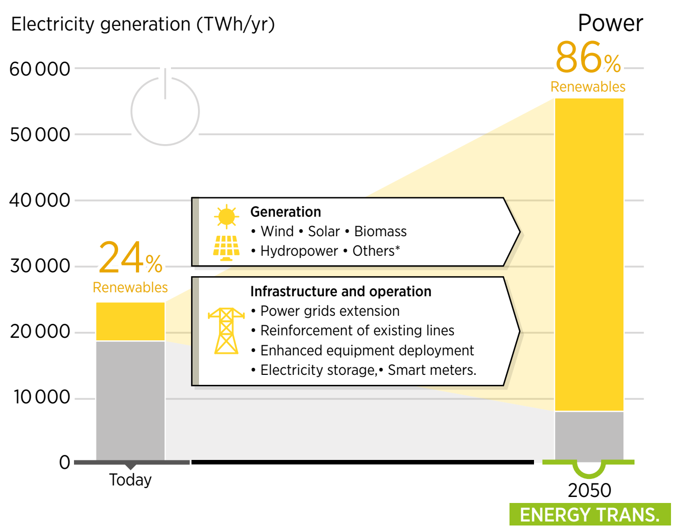
1) Identify and map renewable energy resources and develop a portfolio of financeable projects for the medium to long term.
2) Construct no new coal power plants and plan and implement an end-of-life phase-out of coal capacities.

UPDATE GRID PLANNING TO ACCOMMODATE RISING SHARES OF VARIABLE RENEWABLE (SOLAR AND WIND) ENERGY

1) Develop a flexible power system (with flexible supply, storage, demand response, power-to-X, electric vehicles, digital and ICT technologies, etc).
2) Update grid codes.
3) Deploy micro-grids to improve resilience and expand energy access with renewable sources.
4) Deploy super-grids to interconnect regions.
5) Deploy cost-reflective tariff structures by properly readjusting the balance between volumetric charges (USD/kWh), fixed charges (e.g., USD/metre-month) and, where applicable, demand charges (USD/kW).

SUPPORT DISTRIBUTED ENERGY RESOURCE (DER) DEPLOYMENT

1) Incentivise energy consumers to become prosumers.
2) Support regulatory and pricing policies, including rights to generate and sell electricity, tariff regulation and grid-arrival policies.
3) Enable energy aggregators to foster use of DERs.



Source: IRENA (2019b).

Transport

REDUCE TRANSPORT VOLUME AND CONGESTION

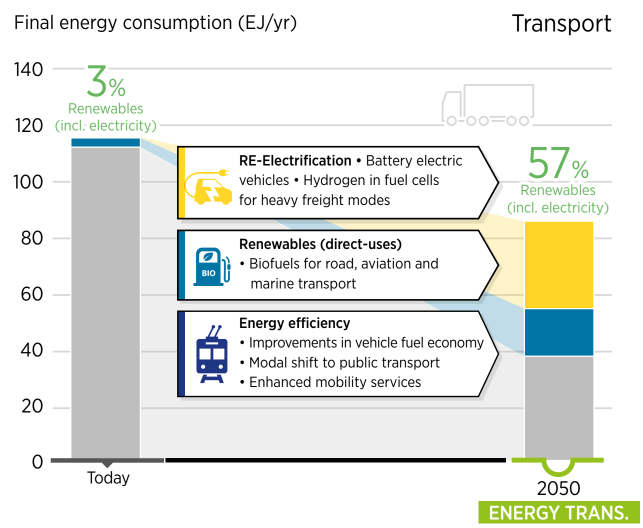
1) Adopt advanced digital communication technologies to improve urban transport planning and services (e.g., re-routing to reduce traffic congestion).
2) Promote mobility services (e.g., automonous driving, vehicle-sharing).
3) Accelerate the shift from passenger cars to public transport (electric railways, trams or buses).
4) Deploy low-emissions city trucks.

ACCELERATE THE SHIFT TO ELECTRIC MOBILITY

1) Set minimum standards for vehicle emissions. 2) Give electric vehicles (EVs) priority in city access.
2) Incentivise the development of charging infrastructure.
3) Strengthen links between the power and transport sectors with integrated planning and policy designs (vehicle-to-grid services).

PRIORITISE BIOFUELS IN ROAD FREIGHT, AVIATION AND SHIPPING

1) Introduce specific mandates for advanced biofuels, accompanied by direct financial incentives and financial de-risking measures.
2) Adopt supporting policies to scale up sustainable production of first- and second-generation biofuels.
3) Eliminate fossil-fuel subsidies and implement carbon and energy taxes to increase the competitiveness of renewable-fuelled shipping and aviation.



Source: IRENA (2019b).

Note: The base year of the analysis is 2016. "Energy Transformation 2050" refers to IRENA's REmap case (www.irena.org/remap).

■ = Renewable electricity; ■ = Renewables (Direct-use and DH); ■ = Non-renewables

Industry

REDUCE ENERGY CONSUMPTION IN INDUSTRIES

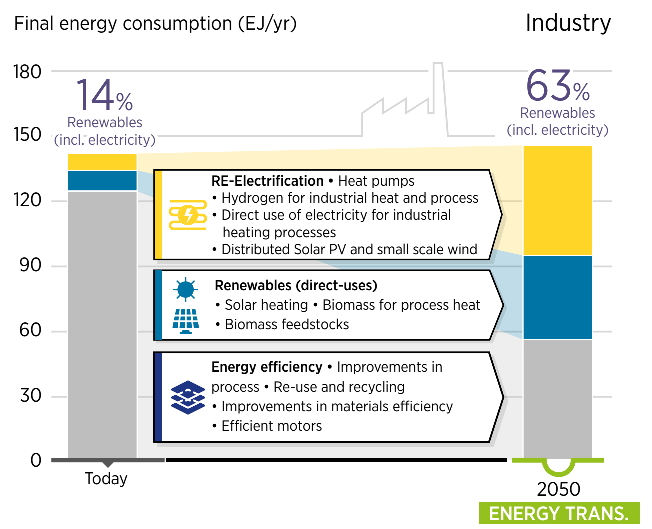
1) Promote circular economy (material recycling, waste management, improvements in materials efficiency, and structural changes such as reuse and recycling).
2) Establish energy efficiency standards and ramp up actual efficiency levels.

ENABLE CORPORATE SOURCING OF RENEWABLES

1) Support a credible and transparent certification and tracking system for corporate renewable energy use.
2) Consider an energy market structure that allows for direct trade between companies of all sizes and renewable energy developers – e.g. through power purchase agreements (PPAs).
3) Work with utilities and other electricity suppliers to provide green corporate procurement options.
4) Empower companies to invest directly in self-generation.

ACCELERATE LOW-CARBON TECHNOLOGY DEPLOYMENT FOR INDUSTRIAL PROCESS HEATING

1) Remove existing barriers and Incentivise low-carbon heating methods (e.g., solar thermal heating, modern bioenergy and heat pumps).
2) Support emerging biomass and hydrogen technologies. Replace fossil fuel-based feedstocks and process heat (e.g., iron and steel subsectors, ammonia production) with renewable-based.



Source: IRENA (2019b).

Buildings

REDUCE ENERGY CONSUMPTION IN BUILDINGS

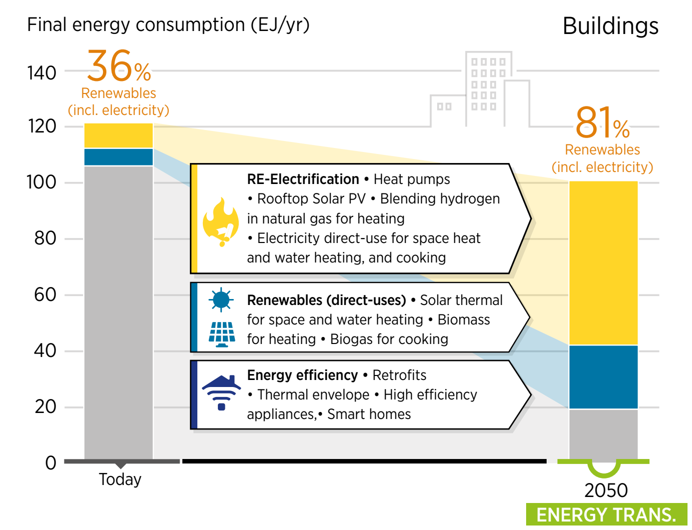
1) Establish or enhance-energy efficient building codes and standards (including for appliances and equipment).
2) Adopt retrofitting and renovation programmes, including financing schemes.
3) Incentivise retrofits and adjust construction codes in cities and states.
4) Combine energy efficiency and renewable energy measures (e.g., public policies to integrate these technologies in renovations of public buildings).

SUPPORT AND FOSTER DER DEPLOYMENT

1) Remove barriers that prevent prosumers from actively helping to transform the energy system.
2) Promote community ownership models and innovative financing schemes.
3) Accelerate the roll-out of smart meters.
4) Capitalise on smart-home and digitalisation schemes to allow demand management and strengthen grid services.

SCALE UP THE RENEWABLE SHARE IN THE BUILDINGS SECTOR

1) Promote low-carbon heating technologies (e.g., heat pumps, solar heating, modern bioenergy for heating and cooling).
2) Apply these renewable energy technologies through district heating.
3) Phase out traditional biomass as a cooking fuel and replace it with clean and efficient cookstoves (biogas, modern solid biomass, electricity).



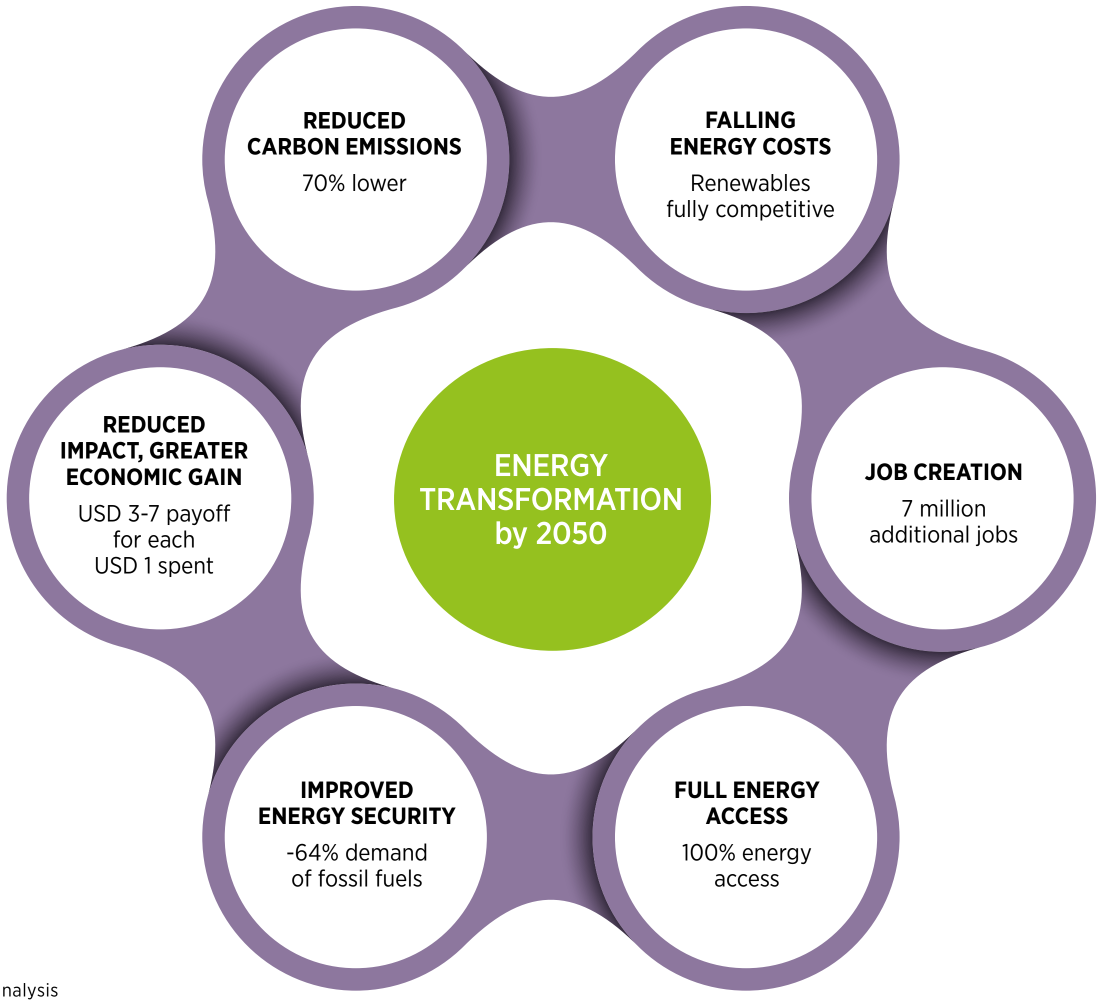
Source: IRENA (2019b).

DRIVERS OF THE ENERGY TRANSFORMATION – AND THEIR SOCIO-ECONOMIC FOOTPRINT

03

Pressing needs and attractive opportunities are driving the ongoing energy transformation. Renewables and other low-carbon technology options reduce carbon emissions, deliver socio economic benefits, improve energy security, create jobs and help expand access to modern energy (Figure 3.1). Each of these benefits is brought closer by the steadily falling costs of renewables. But investment in the energy transformation can no longer be pursued in isolation from broader socio-economic considerations.

Figure 3.1: Needs and Opportunities



IRENA analysis

The power and energy systems are embedded within that system, which in turn is embedded within the earth and its climate. For the energy transformation to succeed, plans and investment strategies must be based on an appreciation of how the energy system interacts with the broader economy.

IRENA uses an integrated macroeconomic model to evaluate the likely socio-economic footprint created by different combinations of energy policies and socio-economic factors. Measuring those footprints provides a comprehensive view of the outcomes of the Energy Transformation scenario, showing likely effects on GDP, employment and human welfare (Figure 3.2). Outcomes are analysed in terms of various drivers, described in the Annex, that interact with region-specific socio-economic systems, leading to diverging outcomes.

IRENA's model disaggregates the evolution of GDP into four main drivers:

- trade
- consumer spending in response to tax changes
- consumer spending in response to indirect and induced effects
- investment

The evolution of employment is disaggregated into three main drivers:

- trade
- consumer spending (in response to tax rates and indirect and induced effects)
- investment

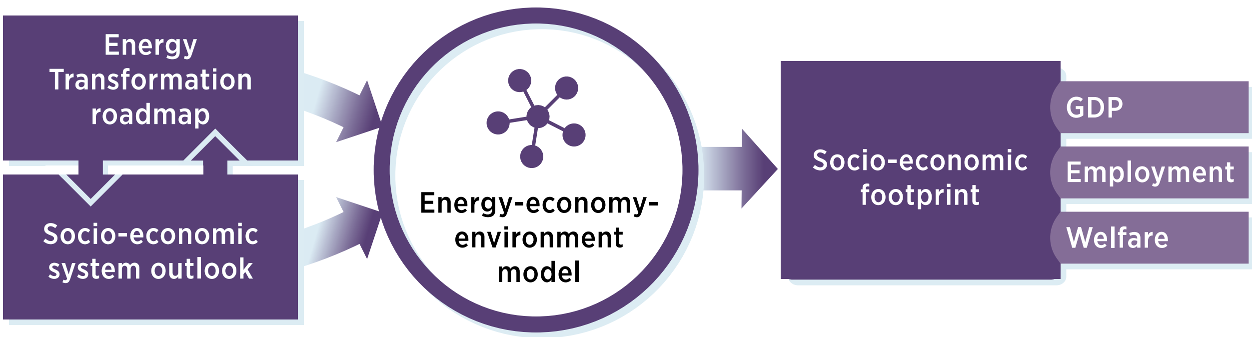
3.1. Global GDP and job creation

Across the world economy, GDP increases from 2019 to 2050 under both the Current Plans and Energy Transformation scenarios, almost tripling overall GDP and more than doubling per capita GDP. GDP grows more under Energy Transformation than under Current Plans (Figure 3.3 and Table 3.1), with a cumulative difference of USD 97.7 trillion (2015 USD) between 2017 and 2050.

Global GDP would grow more with Energy Transformation than under Current Plans

Investment has a positive effect on GDP in the short term and then fades away. This effect is due primarily to front-loaded investment in renewable energy generation capacity, energy efficiency and energy system flexibility to support the energy transformation. Trade's effect is slightly positive on GDP over the entire period, reflecting the fact that global trade must always balance in nominal terms. Consumer spending in response to tax rate changes is the dominant driver of GDP gains between 2022 and 2050. This driver captures the impact of changes in government income brought about by carbon taxes,

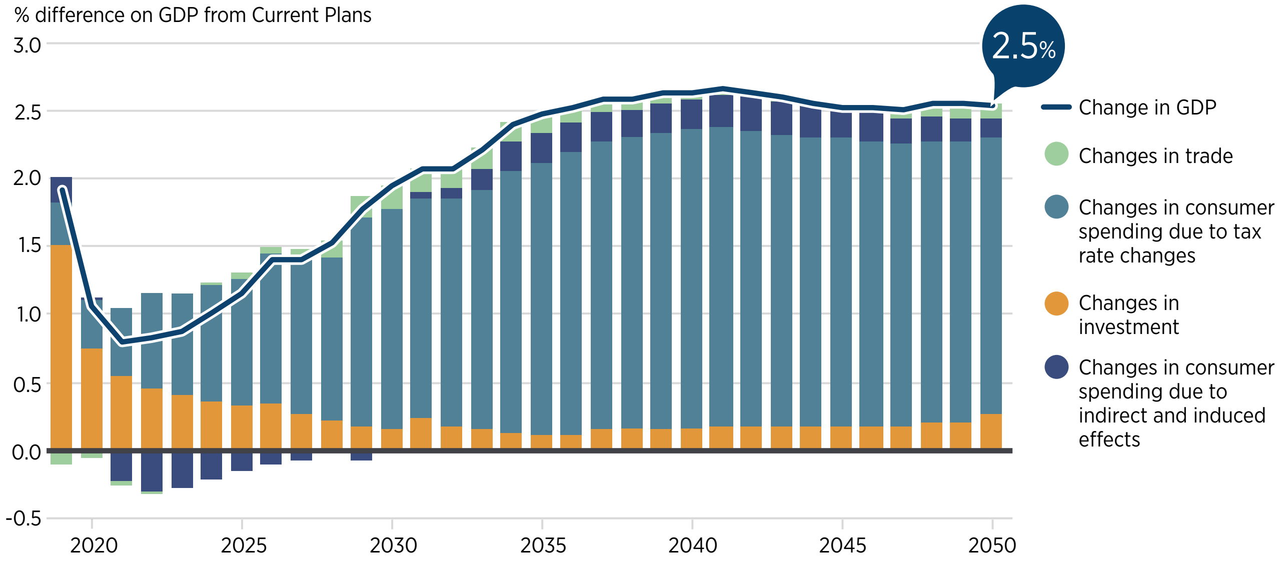
Figure 3.2: The energy transformation and its socio-economic footprint



Based on IRENA, 2018b.

Note: GDP = gross domestic product.

Figure 3.3: Global GDP, trade, consumer spending and investment differences (%) between Current Plans and Energy Transformation, 2019–2050



Based on IRENA, 2019b.

Note: GDP = gross domestic product.

fossil fuel phase-outs, changes in fossil fuel royalties and other taxes (Annex). Carbon taxes and related government revenue-balancing policies (explained in the Annex) are the main variables responsible for the GDP impact of this driver. The footprint analysis of the Energy Transformation case assumes that carbon taxes are aligned with a 1.5°C limit.

The positive effects of increased carbon taxation on GDP can mask other, negative socio-economic effects. Increased carbon taxation can trigger price increases in energy and other consumption products across the economy. The population in the lower quintile of income may bear a disproportionate share of this burden (see Annex). Hence, without policies to distribute the burden, carbon taxes can increase inequality and hinder energy transformation.[7]

Across the economy, jobs increase 17% in 2050 over 2017 in both scenarios, while population increases by

Table 3.1: Global GDP under Energy Transformation and Current Plans scenarios

	Scenario	CAGR (2017 to 2050)	2050 to 2017 ratio
Population	Both	0.67%	1.25
GDP	Current Plans	3.17%	2.80
	Energy Transformation	3.25%	2.87
GDP per capita	Current Plans	2.49%	2.25
	Energy Transformation	2.56%	2.30

IRENA analysis.

Note: Two decimal points are used to contrast the two scenarios.

GDP = gross domestic product.

25% in the same period. However, employment grows slightly faster in the Energy Transformation case than under Current Plans, with 0.15% higher employment in 2050 (see Table 3.2, Figure 3.4 and Annex).

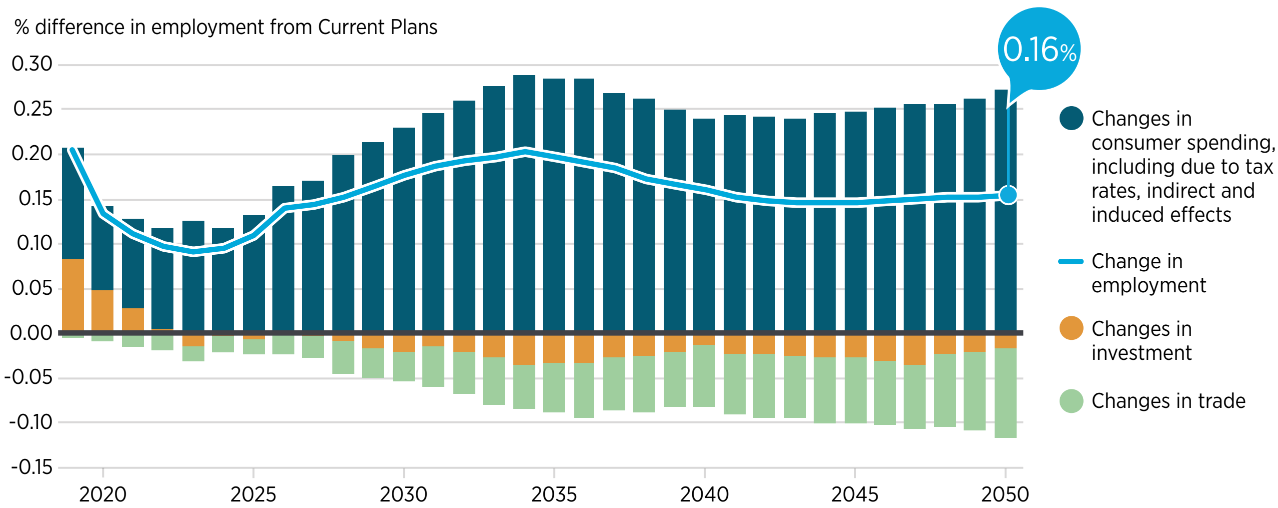
The difference in global economy-wide employment between the Energy Transformation and Current Plans scenarios is illustrated in Figure 3.4. The investment driver has a positive effect on jobs in the short run, mirroring the front-loading of investment and the crowding out of other sectors of the economy having higher employment intensities.[8]

The consumer spending driver is positive and dominates the impact on global employment, largely owing to carbon taxation. The trade driver has a negative impact on the employment footprint indicator, initially because of changes in net trade in fuels, but reinforced after 2035 by changes in non-energy trade.

The energy sector plays the dual role of fuelling economy-wide development and supporting many jobs. Jobs in the sector increase under both the Energy Transformation and Current Plans scenarios (Figure 3.5). The growth in energy sector jobs through 2050 is 14% higher under the Energy Transformation scenario than under Current Plans (Table 3.2). Decreases in fossil fuel jobs are significantly smaller than the increases in jobs linked to Energy Transformation (renewables, energy efficiency and energy flexibility).

Both scenarios would raise employment across the economy, with Energy Transformation holding a slight edge

Figure 3.4: Global employment difference (%) between Current Plans and Energy Transformation, 2019–2050



Based on IRENA, 2019b.

7 IRENA is analysing the distributional aspects of the Energy Transformation scenario to understand how these can be addressed to improve the socio-economic impact beyond GDP.

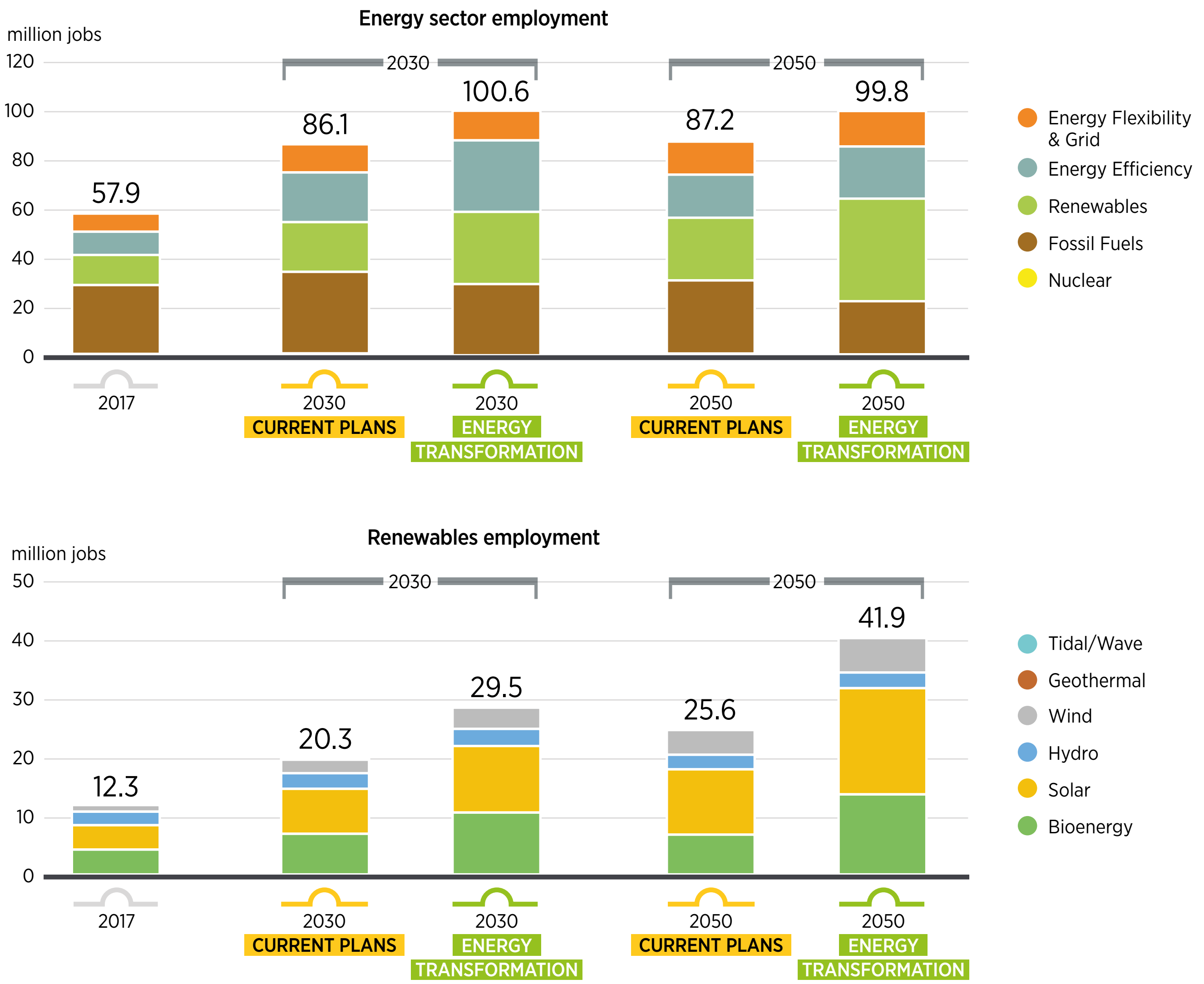
8 A 50% crowding-out effect has been assumed for this analysis, whereby the additional investment required for the energy transformation drains investment from other sectors.

The Energy Transformation scenario results in a 64% increase in renewable energy jobs by 2050, distributed across technologies. The lower increase in energy sector jobs (14%; 12.5 million jobs) than in renewable energy jobs (64%; 16.3 million jobs) is a consequence of jobs being lost in the fossil fuel industry.

The fact that Energy Transformation causes a slight increase (0.15%; 7 million jobs) in economy-wide jobs over Current Plans, while the increase in the energy sector jobs is much higher, indicates that during the transformation jobs are being lost in other sectors of the economy.

Employment in the energy sector and in renewables would grow under both scenarios, but faster under Energy Transformation

Figure 3.5: Global employment in the energy sector and renewables, 2017, 2030 and 2050



Source: IRENA analysis.

Table 3.2: Employment differences between Current Plans and Energy Transformation: Economy-wide, in the energy sector and in renewable energy

	Millions of jobs		Percentage	
	2030	2050	2030	2050
Economy-wide	7.13	6.57	0.18%	0.15%
Energy sector	14.50	12.53	16.83%	14.37%
Renewable energy	9.24	16.32	45.49%	63.82%

Source: IRENA analysis.

Note: This table includes two decimal digits to contrast the economy-wide job results of the two scenarios.

Employment in the energy sector and in renewables grows over time under both scenarios, especially Energy Transformation. The increase in jobs in renewables outweighs the loss of fossil fuel jobs and comes hand in hand with new jobs related to energy flexibility and grid development.

Even if it causes only a slight increase in the sheer number of jobs, the Energy Transformation scenario brings about a very important modification of the labour market structure, requiring the enactment of comprehensive labour policies that address the many misalignments (temporal, spatial, educational and sectoral) between jobs lost and jobs gained.

Designing appropriate labour market policies will require deeper knowledge of the structure of the new jobs being created by the transformation. Figure 3.6 helps fill the gap by analysing a subset of renewable energy jobs under the Energy Transformation scenario by segment of the value chain and occupational requirement.[9]

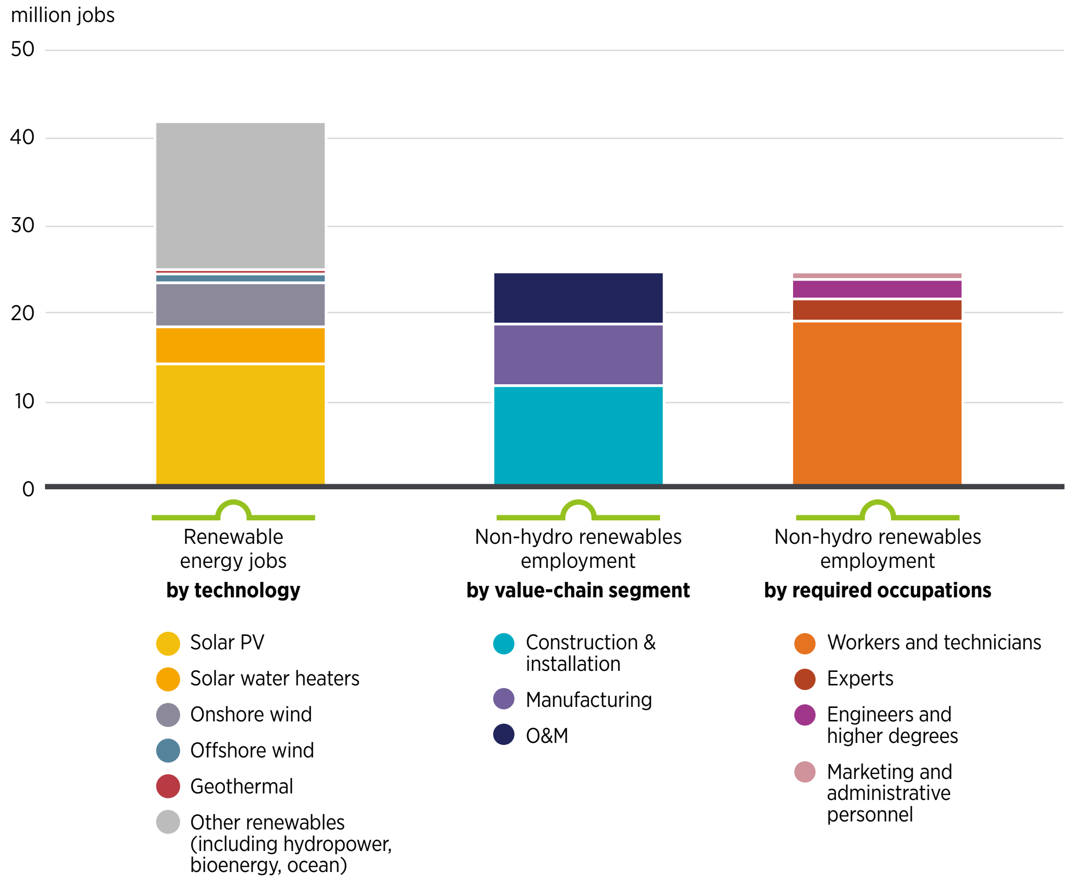
With respect to the value chain, ample opportunities will exist to localise renewable energy jobs in such a way as to reinforce domestic supply chains (Figure 3.6). Manufacturing, which is the segment of the value chain most difficult to localise, accounts for just 29% of the jobs in the subset of renewable energy technologies included in the figure, while construction and installation account for 47% and operation and maintenance (O&M) for 24%.[10] Workers and technicians account for 77.2% of the jobs associated with this subset of renewable energy technologies; 10.3% are experts; 9.1% are engineers 9.1%; 3.4% are marketing and administrative personnel. (Experts generally require tertiary education; engineers, postgraduate qualifications.)

Energy Transformation provides ample opportunities to localise renewable energy jobs and reinforce domestic supply chains

9 The subset of renewable energy technologies used in this figure (PV, onshore wind, offshore wind, solar water heating and geothermal) is determined by the availability of information on occupational requirements. Most of the information comes from IRENA's series of reports (2019c, 2018b, 2017a, 2017b) on the economic leveraging of various renewable technologies (IRENA, 2019c, 2018b, 2017a, 2017b). As additional technologies are covered in forthcoming reports, the analysis will be extended to cover those technologies.

10 Localising manufacturing is much simpler for renewable energy technologies than for fossil fuel or nuclear technologies.

Figure 3.6: Global employment in Energy Transformation 2050, disaggregated by technology, value segment and required skills



Source: IRENA analysis.

Note:

O&M = operation and maintenance;

PV = photovoltaic.

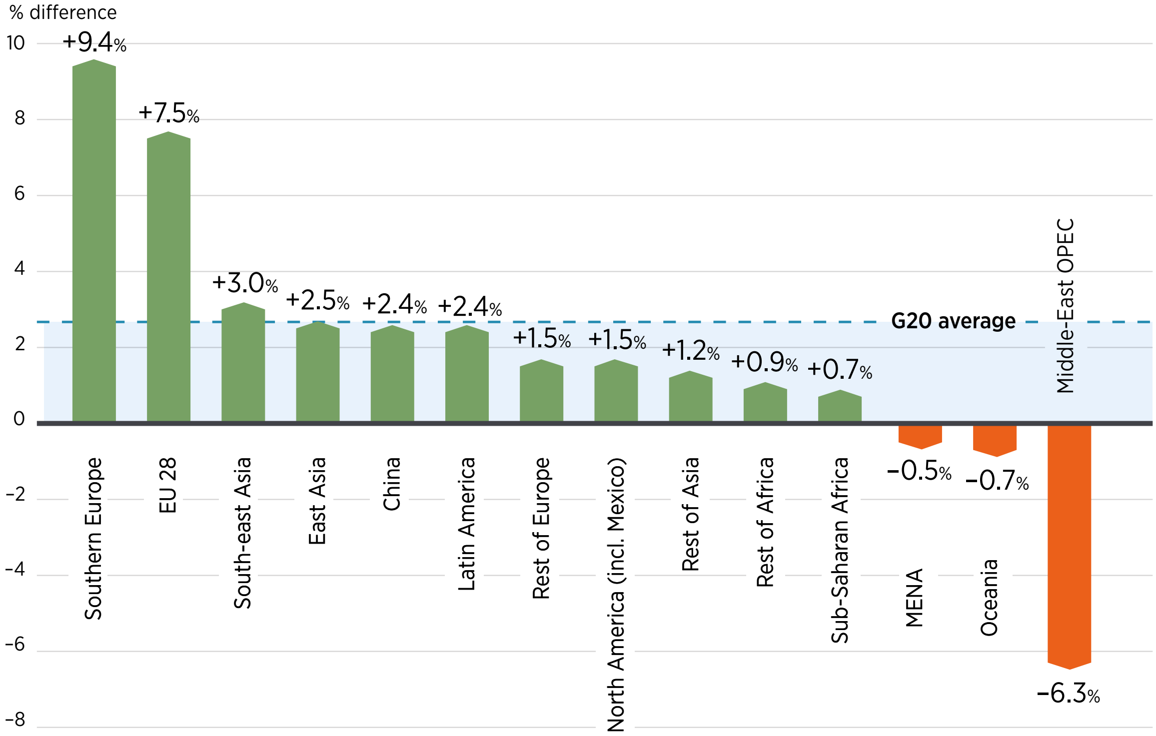
For the considered subset of renewable technologies, the distribution of jobs over the value chain is dominated by construction and installation (47%), while manufacturing represents 29% of the jobs. Occupational requirements are strongly dominated by workers and technicians (77% of jobs).

3.2. Regional GDP and employment

The socio-economic footprint of the energy transformation in any given country or region will vary from the global footprint, owing to the diversity of socio-economic structures and their complex interactions with the energy transformation (Figures 3.7 and 3.8). Results are presented for ten regions (the Association of Southeast Asian Nations, East Asia, the rest of Asia, the EU28, the rest of Europe, Latin America and the Caribbean, the Middle East and North Africa, North America, Oceania and sub-Saharan Africa), plus four additional countries or sub-regions (China, the Middle Eastern member countries of the Organization of the Petroleum Exporting Countries, Southern Europe and the rest of Africa).

The impact on GDP over Current Plans ranges from a 9% increase to being almost neutral. Most regions/countries show a positive impact on GDP (Figure 4.7), owing largely to increased investment, trade gains, and indirect and induced effects from tax changes.

Figure 3.7: Effect of Current Plans vs. Energy Transformation on GDP in selected regions and countries by 2050 (% difference)



Source: IRENA analysis.

Note: EU28 = Member states of the European Union;
GDP = gross domestic product;
MENA = Middle East and North Africa;
OPEC = Organization of the Petroleum Exporting Countries.

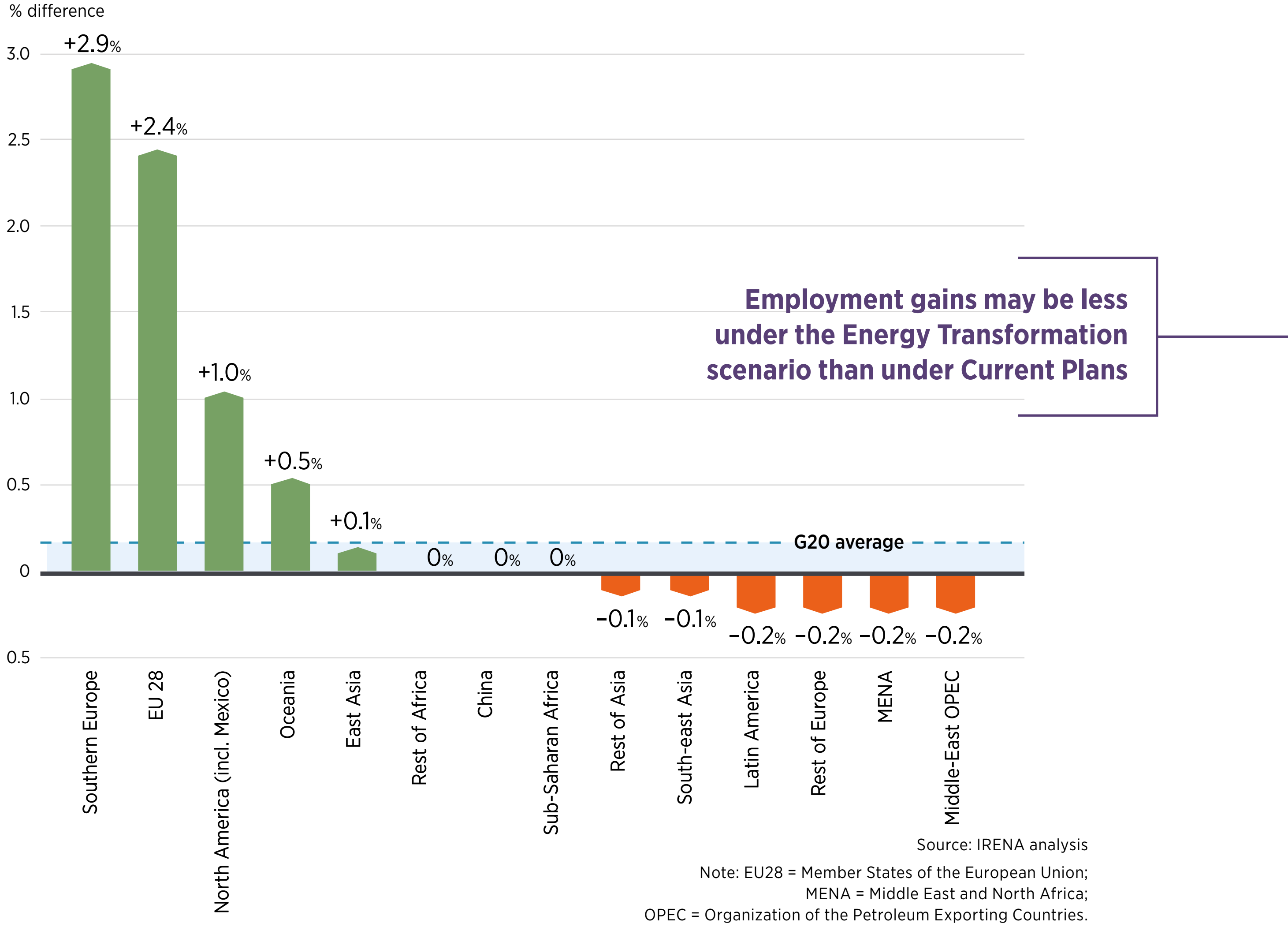
The socio-economic footprint of the Energy Transformation scenario varies across regions and countries, with some performing better than others. Most show better GDP resultsthan under Current Plans.

Energy Transformation will raise GDP in most regions and countries over the level expected from Current Plans

However, countries and regions with economies that are heavily dependent on oil exports do worse under the Energy Transformation scenario than they would under Current Plans, because global demand for oil is further reduced. Employment gains (in percentage terms) are less under the Energy Transformation scenario than under Current Plans because additional demand in the global economy also pushes real wages up (Figure 3.8).

11 In general terms, employment gains are expected to be less significant than GDP gains because additional demand in the global economy also pushes up real wages. The additional wage volume can be translated into wage increases for all workers, an increase in the number of jobs, or a mix of both. Historical trends show that wage effects tend to produce smaller increases in employment than in GDP.

Figure 3.8: Effect of Current Plans vs. Energy Transformation on employment in selected regions and countries by 2050 (% difference)



Source: IRENA analysis

Note: EU28 = Member States of the European Union; MENA = Middle East and North Africa; OPEC = Organization of the Petroleum Exporting Countries.

3.3. Varying effects of the shift to renewables

The socio-economic footprint analysis presented in the previous section shows that the Energy Transformation path, when accompanied by appropriate policies (such as carbon taxation, fossil fuel phase-out and revenue recycling) will have a positive impact on GDP and jobs at the global level.[11] However, this will not occur in isolation nor be confined in its effects on levels of energy consumption or access.

Rather, it will interact continually with each country's underlying socio-economic circumstances. This has ramifications for macroeconomic stability, trade, investment, supply chains, production capacity and employment. As the energy transformation unfolds, policies will be needed to maximise its benefits and minimise economic misalignments, cushion shocks and ensure equity.

A disaggregation of the socio-economic footprint at the regional level sheds light on how the costs and benefits of the transition will differentially impact various parts of the world.

The regional differences are mainly due to:

- Countries embarking on the transition from different starting points;
- Different levels of national ambition and means of implementation;
- The depths, strengths and diversity of supply chains;
- The degree to which economies depend on the production and sale of fossil fuels.

These factors shape how the energy transformation affects economies. For example, regions with a robust industrial base, comparatively high capabilities and diversified economies reap the most benefits, as they are able to localise segments of the value chain. In such regions, growing economic activity along the value chain triggers demand for more intermediary industrial inputs and services from various sectors of the economy, creating positive feedback loops between changes in the energy system and the wider economy.

Along with stimulating demand for intermediary industrial inputs, greater production and supply chain activity in the renewables sectors boosts consumption through induced and indirect effects, while a larger GDP spurs demand for new economic activities in non-energy sectors. Thus, the shift creates sectoral spillovers that boost productivity and consumer expenditure, reinforcing new employment in both energy and non-energy sectors. This will not be the case in other regions, most notably those dependent on fossil-fuel supply chains or with weak or less diverse economic structures.

The transition will bring about a profound change in labour patterns, producing significant misalignments in all regions. These misalignments fall into four categories:

- **Temporal misalignments:** The creation of new jobs does not necessarily take place at the same time as the loss of employment.
- **Spatial misalignments:** New jobs are not necessarily created in the same locations – communities, regions or countries – where job losses occur.
- **Educational misalignments:** The skills associated with vanishing jobs do not always match those required by emerging jobs.
- **Sector misalignments:** Job gains and losses may affect different sectors of the economy, given different supply-chain structures and diverging sets of inputs between rising and declining industries.

These misalignments will unfold against the broader reality of structural unemployment that remains a critical issue for almost all countries. While the energy sector as a whole sees a significant increase of jobs from the energy transformation (14% at the global level in 2050), economy-wide employment experiences a meagre 0.16% increase compared with Current Plans.

Comparison of the Energy Transformation scenario with the GDP footprint in the report also shows that country performance on the jobs front is different from their forecasted GDP performance (compare Figures 3.7 and 3.8). That is, while some economies and regions will continue to see GDP rises, the additional demand will translate only partly into more jobs and even less into increased wages. These findings only underscore the urgency of policies to address labour market rigidities and deficiencies. They also reinforce the importance of the energy sector as a critical enabler of overall growth and development, pointing to the opportunity to devise policies to guide the indirect and induced effects of the Energy Transformation case for the maximum benefit of the rest of the economy.

12 For example, equipment manufacturing; project planning and development; engineering, procurement and construction; and O&M in the energy sector

04

POLICIES TO ENSURE EQUITABLE OUTCOMES

Maximising the benefits of investment in the energy transformation while minimising its adjustment costs requires a wider conceptualisation of the *just transition*, underpinned by a commitment to sustainable, climate-proof development. A failure to fully exploit the system-wide synergies between energy and the broader economy will not only limit the mobilisation of the finance and investments needed to propel the transition – it will also threaten macroeconomic stability.

Synergising the effects of energy investments into the economy can help poor and vulnerable regions use energy as part of a long-term growth strategy to reduce the costs of trade, create employment, promote efficient production, raise living standards, and increase consumption of goods and services.

Levelling out the regional and country-level effects of the transformation depends on a policy framework that operates on two fronts. The framework should promote the deployment of renewables both to reduce energy consumption and to increase energy access. Simultaneously, it should firmly embed the deployment of renewables into a broader policy framework that makes energy a catalyst of economic, inclusive and sustainable growth. Such a just transition policy framework rests on three transformative sets of policies: deployment policies, enabling policies and integration policies (Figure 4.1).[13]

4.1 Deployment policies

Deployment policies should steadily enhance the share of renewables in total energy supply through policies that accelerate capacity installation. This includes:

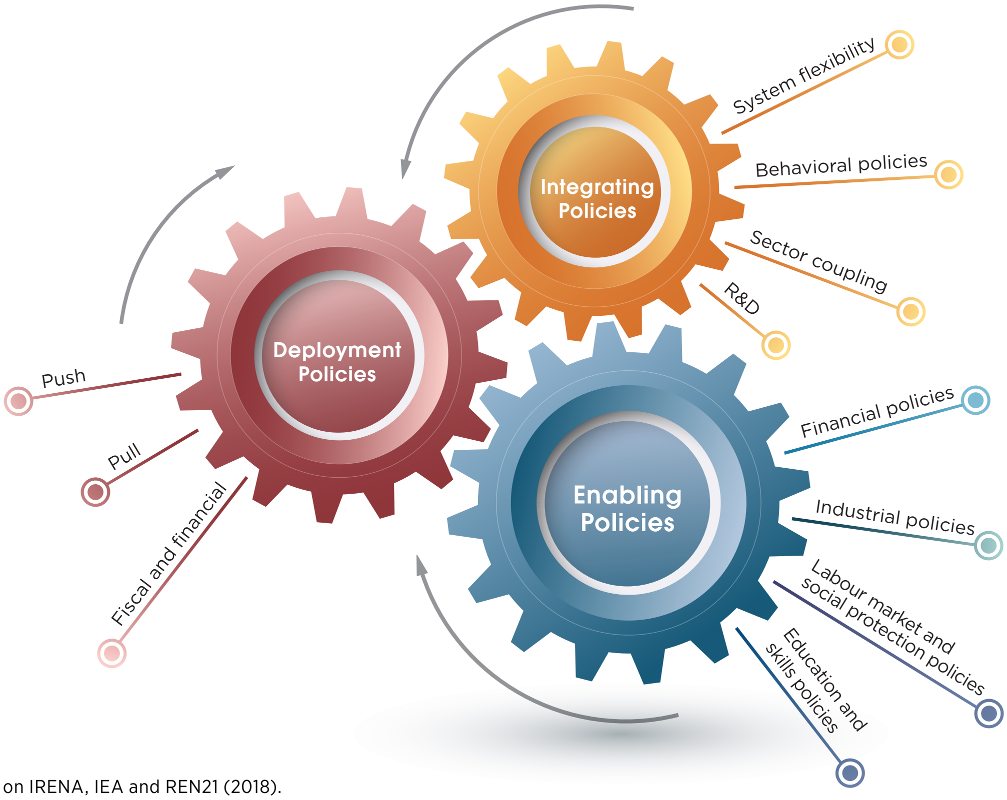
- Push policies such as binding targets, quotas and obligations, as well as codes and mandates.
- Pull policies include pricing policies, tradable certificates and renewable energy regulations that create markets for the various technologies – these will also be crucial to counteract and balance the effects of push policies.
- Fiscal and financial measures such as tax incentives, subsidies and grants, in addition to concessional financing for renewable energy technologies, will accelerate the uptake of renewable energy.

4.2 Enabling policies

Strengthening policy connectivity and co-ordination between energy and the rest of the economy will draw maximum systemic benefits from the energy transformation. Such policies must focus on building capabilities for renewables production, use and application, as well as reform of the broader institutional architecture to enable systemic effects between the energy sector and the broader economy. The enabling framework links four crucial national policies: industrial policy, labour market and social protection policy, education and skills policy, and financial policy.

13 The primary source for the material in this section is IRENA, IEA and REN21, 2018.

Figure 4.1: The policy framework for a just transition



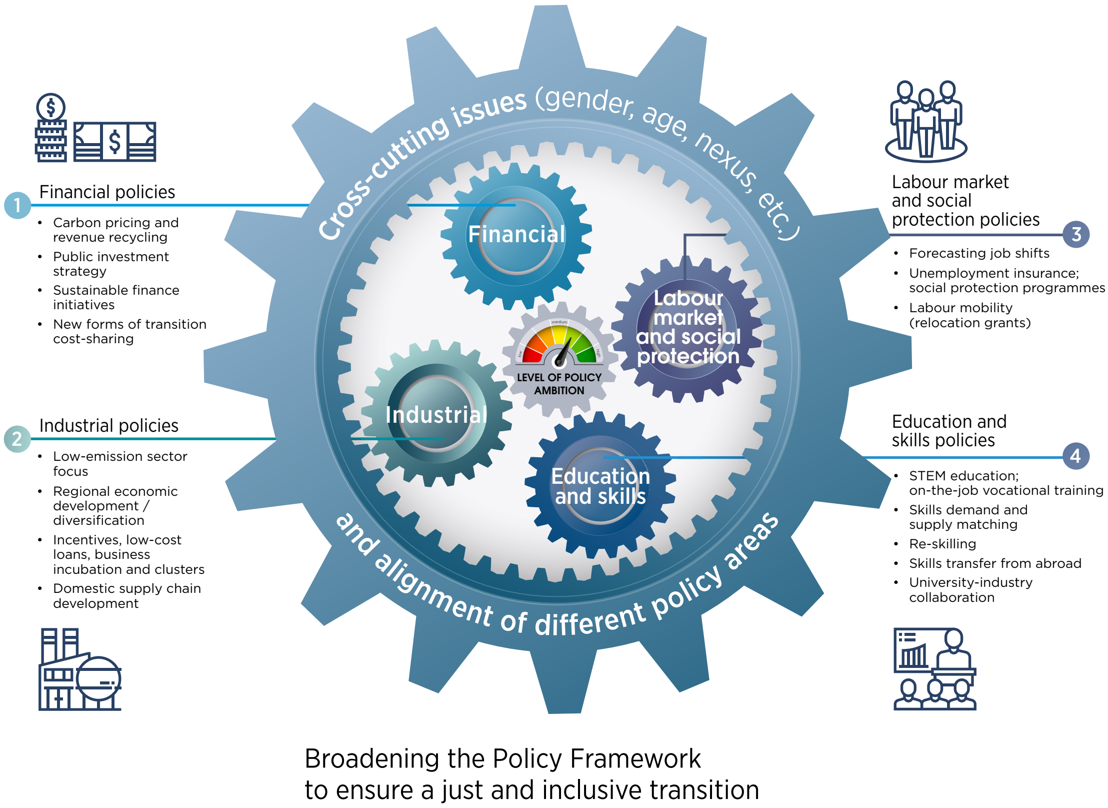
Based on IRENA, IEA and REN21 (2018).
Note: R&D = research and development.

Industrial policies. Industrial policies support economic diversification. Leveraging and enhancing domestic capabilities requires business incubation initiatives, supplier development programmes, support for small and medium enterprises, and promotion of key industry clusters. As its first task, a transition-enabling industrial policy should make the energy sector into a lead sector of the economy. By doing so, governments can take a more direct role in the following areas:

- Foster renewable energy technologies as strategic sectors in the industrial plans;
- Offer incentives for energy efficiency investments in industry, and promote consumer awareness;
- Promote renewables-based research and development strategies, as well as institutions to advance their uptake in the public and private sector;
- Enable targeted public investment to support the steady deployment of renewables across all industrial sectors;
- Link industrial targets directly to labour policy to create jobs;
- Promote public investment into renewable energy sectors to create jobs and capabilities in selected areas, thereby coupling these objectives effectively;
- Facilitate the creation of technical capacities and technology transfer in renewables;
- Incentivise supply chain participation in renewable sectors by local firms, and actively support the creation of partnerships.

Labour market and social protection policies. Forecasting skill needs and mapping labour market outcomes are pre-requisites for effective interventions. Relevant policies include those that promote employment services (matching jobs with qualified applicants; promoting employee well-being; facilitating on- and off-job training; and providing safety nets) and measures to facilitate labour mobility and job security.

Figure 4.2: Enabling policy components of the just transition framework



IRENA analysis.

Note: STEM = science, technology, engineering and mathematics.

Income stability for workers displaced during the transition is essential, along with policy incentives for employers to retain (and train) workers. Flexible, longer-term employment contracts, unemployment insurance, and programs that target affected workers proactively through employment transition promote employee stability and welfare with employer needs are some possible measures to promote job stability and employee welfare in a manner consistent with the needs of employers. Finally, social protection measures lighten the load of the weak and the vulnerable, including women and marginalised communities, to ensure that the impact of the transformation is equitably distributed.

Education and skills policies. Capitalising on the job opportunities offered by the transformation calls for a strong focus on education in science, technology, engineering and mathematics (STEM) education that can help build/augment technical capacity and technological learning and know-how.[14] These skills and education programs should be introduced at universities and as short-term and certificate courses that help workers gain additional skills. Specialised training could be offered in parallel, in collaboration with universities or research labs, to provide specialised opportunities.

14 STEM education emphasises the redesign of curriculum with a strong focus on the four disciplines and promotes the idea of stronger inter-disciplinary and applied approaches to education and training.

University-industry co-operation on renewables could achieve several goals at once: knowledge incubation and a focus on industry-relevant work in public research, labour mobility for scientists and researchers, increased scientific attention to local production and a stronger focus on technical aspects of production – all of which will strengthen the local supply chain in renewable energy sectors. Governments should also promote collaboration and technology-transfer opportunities from foreign suppliers as part of a long-term skill-building strategy.

Finance policies. None of these tasks can be achieved without adequate funding. In addition to private sector funds, governments will need to mobilise significant revenue streams through carbon pricing and other measures, including green bonds, and to devise revenue recycling schemes to ensure a just transition. Revenues can support strategic investments to build new infrastructure and reallocate and recycle budgets in a way that benefits education, health care and other sectors. Carbon taxation revenues can be used to foster new employment creation and to limit the financial burdens of carbon pricing on low-income families and small businesses.

The choice between revenue recycling, reducing non-energy taxes and other options depends on each country's needs and circumstances. Many countries without robust economic structures will face additional challenges in mobilising the financial investments for the transition. In these countries, there may be a need to deploy programs to enlarge the fiscal space and to foster sector diversification to finance the transition process in the medium and long term.

4.3 Integration policies

Integrating policies such as national infrastructure, sector coupling, or R&D policies, promote planning and co-ordination. Integrating measures, meanwhile, enhance system flexibility as the share of variable renewables rises (IRENA, IEA and REN21, 2018). Such policy integration should include:

- **Infrastructure policies.** National policies should promote energy transformation planning as part of a wider infrastructure development, thereby integrating renewables as a core strategy of infrastructure expansion.
- **Policies for sector coupling.** Examples include making of electronics with energy efficiency – with the dual role of reinforcing capabilities and generating demand for renewable energy products.
- **R&D policies.** These are essential for cross-sectoral integration and broader application of renewable energy technologies across the economy.

Policy co-ordination, planning and coherence in these three areas will remain a challenge because they entail the integration of the energy transformation with countries' economic ambitions and social outcomes, such as employment, welfare, inclusion and overall prosperity.

Governments will be challenged to combine these policies and measures in line with the economic and social contexts of their country and region. Above all, policy-making needs to be cross-cutting and coherent, strategic and ambitious to secure a prosperous, inclusive and climate-safe future for all.

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ABBREVIATIONS

BNEF	Bloomberg New Energy Finance
CCS	carbon capture and storage
CO_2	carbon dioxide
CSP	concentrated solar power
EU	European Union
EV	electric vehicle
GDP	gross domestic product
GJ	gigajoule
Gt	gigaton
GW	gigawatt
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LCOE	levelised cost of electricity
MENA	Middle East and North Africa
NDC	Nationally Determined Contributions
O&M	operation and maintenance
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PV	photovoltaic
R&D	research and development
REmap	Renewable Energy Roadmap
STEM	science, technology, engineering and mathematics
SWH	solar water heating
TFEC	total final energy consumption
TPES	total primary energy supply
USD	U.S. dollar
VRE	variable renewable energy

ANNEX

THE SOCIO-ECONOMIC FOOTPRINT OF CURRENT PLANS VS. ENERGY TRANSFORMATION

The socio-economic footprint analysis presented here is based on the Energy Transformation scenario (REmap) and an accompanying set of policy assumptions (carbon taxation, fossil fuel subsidies, revenue recycling, etc.) deployed in the current socio-economic system structure. The results provide insights into both the advantages and the challenges of placing the transformation roadmap in its wider socio economic context. The goal is to inform policy making and foster synergies between changes in energy use and socio-economic development, so that the transformation delivers sustainability and resiliency.

Energy transformation roadmaps exist only on paper, and the ability to implement them relies on understanding their interactions with the system in which they would be applied. By revealing these interactions, the socio-economic footprint provides tools to facilitate successful deployment by overcoming potential challenges and barriers.

Changes are not limited to the scope of the Energy Transformation scenario, and neither are the resulting socio-economic structures. insights gained from this socio-economic footprint analysis, however, is intended to help policy makers to reach informed decisions that can improve the outcome of the transformation. Notably, the transformation of energy use can be closely aligned with broader goals of sustainability, resiliency and prosperity.

Socio-economic footprint in terms of GDP and jobs

The footprints for gross domestic product (GDP) and jobs present the relative performance of the Energy Transformation and Current Plans scenarios, and the drivers must be interpreted in this context. Each of the drivers has to be understood as quantifying a differential impact. For instance, the investment driver presents the effect on GDP or employment of the differential investment under the two scenarios.

The drivers capture the impact on the footprint of the following elements:

- **Changes in investment.** This driver evaluates the impact on GDP and jobs of overall investment in the economy. It includes the effect of transformation-related investment (renewables, energy efficiency, energy flexibility, grids, etc.), of fossil fuel and nuclear investment, and of investment in other sectors in the economy. Often investment in one category moves in opposition to that in another (e.g., growing investment in renewables and shrinking investment in fossil fuels). The investment driver presents the net effect of these trends.
- **Changes in trade.** This driver evaluates the impact on GDP and jobs on trade as a whole: energy trade and non-energy trade.

Changes are not limited to the scope of the Energy Transformation scenario

- **Changes in consumer spending due to tax rate changes.** The macroeconomic modelling assumes government revenue balancing via income tax rate adjustments. A change in government tax revenues (whether via carbon taxes or reduced revenues from fossil-fuel production) is compensated by a change in income taxes (up with an overall decrease in government revenues and down with an increase). These adjust consumer incomes and hence expenditure, contributing to changes in overall GDP.
- **Changes in consumer spending due to indirect and induced effects**. This driver captures all other changes in consumer expenditure. It includes reallocations of expenditure (e.g. where energy price rises reduce expenditure on energy, the resulting increase in consumption of other goods and services would be captured here), along with GDP impacts of changes to aggregate consumer expenditure through the indirect and induced effects. This category also covers the impact of aggregated consumer prices (including energy and general prices).

Revenue balancing in government budgets

How government budgets are managed has an important effect on socio-economic results. The analytical methodology applied in this report assumes that governments will balance their revenues through income taxes. Other policies – carbon taxation, phase-outs of fossil fuel subsidies or reductions in fossil fuel royalties caused by falling sales of fossil fuels – have a direct impact on government revenues.

Under revenue balancing, government revenues are balanced over the entire analysed period. Gains and losses are recycled to the population by way of a reduction or increase in income taxes, which raises or lowers households' disposable incomes and consumption, causing GDP to rise or fall.

Other government budgetary policies are possible, including approaches to revenue balancing with an eye to reducing inequality, using increased revenue to raise public investment (sustaining the transformation), or even using deficit spending to fund public investment over a transitional period. Each of these would lead to different socio-economic impacts. The International Renewable Energy Agency (IRENA) is currently exploring the impact of various budgetary policies on the socio-economic footprint.

Differential performance: Current Plans vs. Energy Transformation

The socio-economic footprint of the Energy Transformation scenario is defined and measured in terms of differential performance relative to that of the Current Plans scenario. This approach makes it possible to draw direct conclusions about whether the former performs better or worse than the latter and places the focus on differential performance, which might otherwise be lost among the high numerical value of the absolute performance indicators (GDP, jobs, welfare).

Hence, for any footprint performance indicator, such as jobs, instead of presenting the results in terms of the absolute evolution of jobs under the two scenarios, a jobs indicator is used which evaluates the differential performance of the Energy Transformation scenario against that of the Current Plans scenario, in such a way that at each point in time the jobs indicator is evaluated as:

$$\text{Jobs Indicator} = \frac{\textit{Transition Scenario Jobs} - \textit{Current Plans Scenario Jobs}}{\textit{Current Plans Scenario Jobs}}$$

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