Role of IRENA for Global Transition to 100% Renewable Energy

Elisa Asmelash, Gayathri Prakash, Ricardo Gorini and Dolf Gielen

Abstract The global energy transformation is more than a simple transformation of the energy sector—it is a multi-faceted transformation of our societies and economies. The transition towards a decarbonised global energy system can be realised much more cost-efficiently than previously thought due in part to the rapidly falling costs of renewable energy technologies. This chapter highlights the urgent need for an accelerated energy transition to 2050. Since the signing of the Paris Agreement in 2015 and despite the growth of renewable energy technologies, energy-related CO_2 emissions have risen by around 4%. In this context, the next years and decades are critical and the revisions of the NDCs in 2020 in combination with Long-term Strategies must yield a convincing outcome for an energy transition that puts the world on a global pathway to reduced emissions. Technologies for these systems are available today, are deployable and cost-competitive at a large scale and there are quite a lot of studies exploring 100% RE scenarios, indicating that it is clearly topic of growing interest. On this context, the analysis—part of International Renewable Energy Agency's (IRENA) latest global energy transformation roadmap details an energy transition pathway for the global energy-system to meet the Paris Agreement of "well-below 2 °C". By 2050, renewable energy in the power sector could reach 86%, while representing two-third of total primary energy supply mix. The pace of energy transition can be ramped up by several inter-related factors, ranging from technologies to socio-economics, to institutional drivers and different forms of finance.

Keywords Energy transition · Renewables · Decarbonisation · Sustainable development and energy policy

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1 Why 100% RE Systems

1.1 Rationale and Drivers

The Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of* 1.5 °C (SR1.5), estimates that human activities have already caused approximately 1.0 °C of global warming above pre-industrial levels. Unless significant counter measures are taken, global warming would not be limited to/stabilise at 1.5 °C between 2030 and 2052 (IPCC Special Report on Global Warming of 1.5 °C 2018).

Pathways limiting global warming to 1.5 °C require rapid and extensive transitions in all sectors (i.e., energy, agriculture, urban infrastructure and buildings, transportation, and industrial systems). These system transitions are unique in terms of scale and more pronounced in terms of speed and they require cross-sector emissions reductions, a wide portfolio of mitigation options and a significant increase in investments. In addition, efforts to limit warming to 1.5 °C are closely linked to sustainable development, which balances social well-being, economic prosperity and environmental protection.

Reducing energy-related CO_2 emissions is the heart of the energy transition. Rapidly shifting the world away from the consumption of fossil fuels causing climate change toward cleaner, renewable forms of energy is key if the world is to reach the agreed-upon climate goals. There are many drivers behind this transformation.

Firstly, **falling costs of renewable energy (RE)**, which have continued to decline rapidly. As an example, electricity costs from utility scale solar photovoltaic (PV) projects since 2010 has been remarkable—between 2010 and 2018 the global weighted-average levelized cost of energy (LCOE) of solar PV declined to 77%. With the right regulatory and institutional frameworks in place, recent record low auction prices for solar PV in Dubai, Mexico, Peru, Chile, Abu Dhabi and Saudi Arabia have shown that an LCOE of USD 0.03/kWh is possible in a wide variety of national contexts (IRENA Renewable Power Generation Costs in 2018 2019). Similarly, in Europe, offshore wind can now compete at market prices, while in the US, non-hydroelectric renewable energy resources such as solar PV and wind are expected to be the fastest growing source of electricity generation in the next two years.

Secondly, **air quality improvements**. Air pollution is a major public health crisis, mainly caused by unregulated, inefficient and polluting energy sources, namely fossil fuels. The switch to clean renewable energy sources would bring a greater prosperity, improving the air quality in cities, preserving and protecting the environment.

Thirdly, **reduction of carbon emissions**. The transformation of the global energy system needs to accelerate substantially to meet the objectives of the Paris Agreement, which aim to keep the rise in average global temperatures "well below" 2 °C and ideally to limit warming to 1.5 °C in the present century, compared to pre-industrial levels.

Finally, transforming the global energy system will also **improve energy security and enhance affordable and universal energy access**. For countries heavily dependent on imported fossil fuels energy security is a significant issue, and renewables can provide an alternative by increasing the diversity of energy sources through local generation and thus contribute to the flexibility of the system and resistance to shocks. Similarly, energy access is an area of great inequality and renewable energy technologies can be adopted and applied in the rural areas where the national grid has not yet been extended through rural electrification, energy community projects, as well as through distributed renewable energy resources (DER).

Also, The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide a framework for assessing links between global warming of 1.5 °C or 2 °C and development goals including poverty eradication and reducing inequalities (IPCC, 2018). SDG 7, which calls for ensuring "access to affordable, reliable, sustainable and modern energy for all" by 2030, has a strong connection with the majority of SDGs, illustrating how energy is central to fostering the pathways necessary to keep the world well below 2 °C of warming and meet a wide range of SDG targets.

The decarbonisation of the energy sector and the reduction of carbon emissions to limit climate change is at the heart of IRENA's energy transition series, which examines and provides accelerated and feasible low carbon technology deployment pathway towards a sustainable and clean energy future (IRENA Transforming the energy system and holding the line on the rise of global temperatures 2019) (Fig. 1).

1.2 Mixed Progress in the Energy Transition

Despite clear evidence of human-caused climate change, support for the Paris Agreement on climate change, and the prevalence of clean, economical and sustainable energy options, the world is still not on track and efforts and progress are still well below the levels needed. Indeed, the world is starting from a baseline that it is still far away from what is needed for the decarbonisation of the energy sector. Recent trends are also not encouraging, as they show slow progress and slow improvements towards the final objective.

The Fig. 2 summarises the need for acceleration by looking at five key indicators, namely: (i) renewable energy share in power generation; (ii) total final energy consumption per capita; (iii) share of electricity in final energy consumption; (iv) emissions per capita; and (v) energy intensity improvement rate.

Some indicators do not show positive trends. In the period from 2010 and 2016, the share of renewable energy in final energy consumption stayed at roughly the same levels, electrification of final uses of energy has mostly stagnated, global CO_2 emissions from the energy sector increased by almost 13% and estimates indicate that emissions continued to rise and may have reached a new record high of 34.3 Gt CO_2 in 2018 (Carbon Brief Analysis: Fossil-Fuel Emissions in 2018 Increasing at Fastest

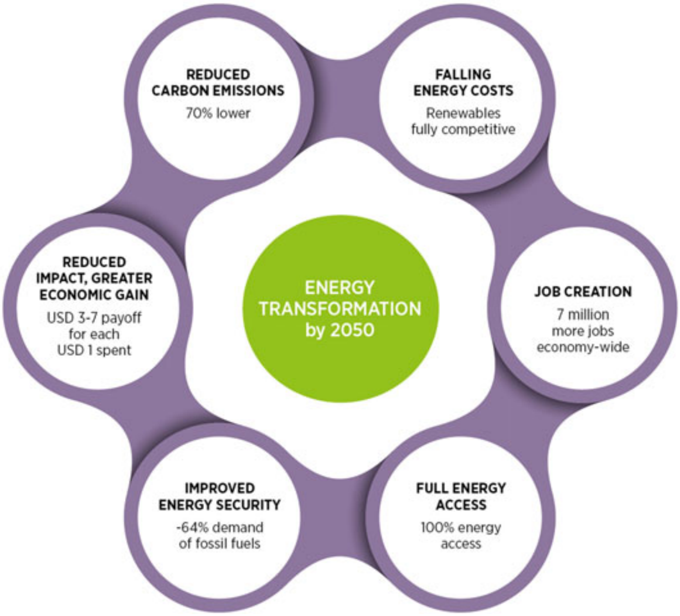


Fig. 1 Needs and opportunities

Rate for Seven Years 2018). In addition, investment in renewable energy declined in 2017 after several years of growth (IEA World Energy Investment 2018). Despite an increase in investment in energy efficiency, the combined investment in renewable energy and energy efficiency showed a slight reduction of 3% in 2017, compared to the previous year. That is unfortunate in a world where a strong acceleration in investments in energy efficiency and renewable energy is needed. Partly because of that decline and partly due to a modest increase in fossil fuel investment, the share of investment in fossil fuels in the energy supply increased in 2017 (IEA World Energy Investment 2018).

However, **despite the very slow progress, there are two positive trends. First, in the power sector, the share of renewable energy in electricity generation has been increasing steadily**. Renewable electricity generation share increased from around 20% to nearly 24% from 2010 to 2016 (or 3.1% per year on average) (IRENA Hydrogen from Renewable Power: Technology Outlook for the Energy Transition 2018). An estimate for 2018 indicates a further increase to 26%. **The second positive sign is the consistent improvement in the energy intensity of GDP**.

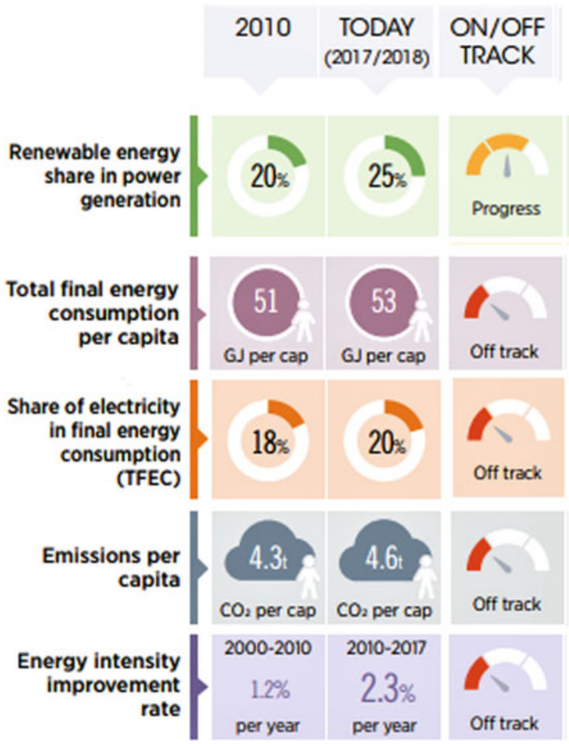


Fig. 2 Summary of recent trends and required levels of selected indicators

1.3 *What Exactly is 100% Renewable Energy: Implications for Supply and Demand Sectors*

There are quite a lot of studies exploring 100% RE scenarios, indicating that it is clearly a topic of growing interest. However, there seems to be some confusion between 100% RE in energy supply mix and 100% RE in power generation mix, which are indeed very different concepts. Having 100% RE in energy supply mix implies the complete phase out of fossil fuels in the complete energy sector (including power, transport, buildings, industry) and the creation of an energy system that runs entirely on renewable energy sources. On the other hand, 100% RE in power means that the entire generation of electricity will be covered by renewable energy sources, while fossil fuels could only be used as back-up in extreme circumstances or even not used with emerging low-carbon technologies such as hydrogen and other flexibility measures like energy storage.

Given the above, IRENA sees possibilities for many more countries with 100% RE power in the coming decades but for many countries 100% RE energy is unlikely for economic and technical reasons. In fact, according to IRENA's latest global REmap analysis, renewable energy in the power sector could reach levels towards 100%, representing 86% of the total power generation by 2050, while renewable energy in total primary energy supply would be lower and represent 67% of the total supply (IRENA Global Energy Transformation 2019).

The transition towards a 100% RE power system is not smooth and does not come without any challenges, and some technical and political uncertainties also remain on how closed power systems with dominant variable renewable energy shares would operate.

On the technical point of view, *inflexible power system* is among the most frequently mentioned barriers, as it reduces the grid capacity available for renewables and therefore causes frequent curtailment of renewable energy. Moreover, for the electricity sector, higher penetration of variable renewables requires a number of changes in *the way systems are developed and operated*. However, barriers and obstacles delaying or impeding target setting for 100% renewable energy and policy development for implementation are not only technical but also of a political/economic nature and are mainly related to policy, market design and business models, which all need to be redesigned to accommodate higher levels of VRE.

Figure 3 illustrates the main innovations taking place in the electricity supply chain to overcome technical and political/economic challenges.

Indeed, there is no one-size-fits-all approach to achieving 100% renewable energy, and that targets and enabling frameworks need to be adjusted to local circumstances. In general, reaching a 100% renewable energy system will require further analysis and dialogue on what is needed on national as well as sub-national level regarding target setting, policies and planning (IRENA Towards 100% Renewable Energy: Status, Trends and Lessons Learned 2019).

2 How to Achieve 100% Renewable Energy System: IRENA's Pathway for Global Transition to Renewable Powered Future

2.1 IRENA's Energy Transition Study

The global energy transformation is more than a simple transformation of the energy sector—it is a multi-faceted transformation of our societies and economies. As such, the direction and future shape of a Paris Agreement compatible energy system will be determined by several inter-related factors, ranging from technologies to socio-economics, to institutional drivers and different financial instruments.

The findings in this section are based on latest analysis conducted by the International Renewable Energy Agency (IRENA)'s "Global Energy Transformation—A Roadmap to 2050", which details an energy transition pathway for the global energy-system to meet the Paris Agreement aim of "well-below 2 °C".

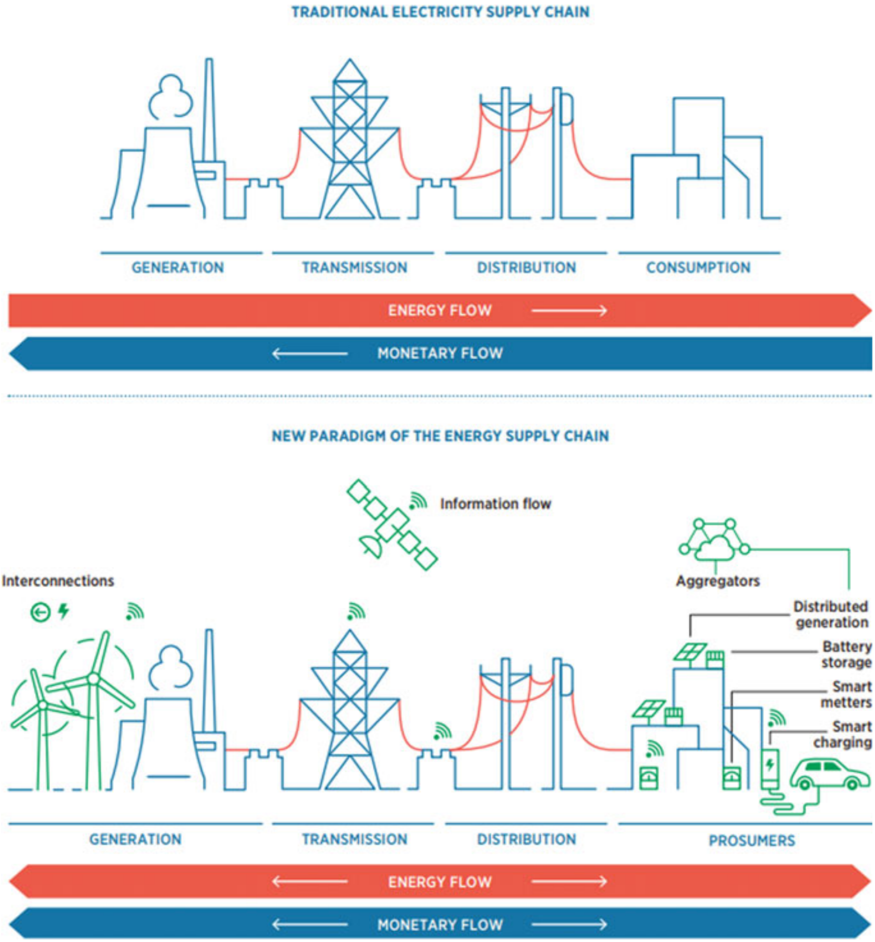


Fig. 3 Innovations taking place in the electricity supply chain

Box 1: Practical Options for Global Energy Decarbonisation

IRENA's renewable energy roadmap, or REmap approach [1] and analysis, includes several key steps:

- Identifying the current plans for global energy development as a baseline scenario (or Reference Case) 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 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 well below 2°C and closer to 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.
- **Analysing the costs, benefits and investment needs** of low-carbon technologies worldwide to achieve the envisaged energy transformation.
- Note: The findings in this chapter consider policy targets and developments until April 2019. Any new policy changes and targets announced since then are not considered in the analysis and therefore could influence the findings.
- For more on the global roadmap and its underlying analysis, see https://www.irena.org/remap.

The gap between aspiration and reality in tackling climate change continues to be significant, as highlighted by the Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of global warming of 1.5 °C (IPCC Special Report on Global Warming of 1.5 °C 2018). Rising CO_2 emissions, an uneven distribution of efforts among countries and short-sighted fossil fuel investments all increase the risks of the world going further off course. The urgency of action to combat climate change—and the impacts of the policies needed to get the world back on track—need to be fully grasped by decision makers, consumers and businesses. IRENA's energy transition study shows that global fossil fuel production under current and planned polices of the Reference Case will peak between 2030 and 2035; whereas for a pathway aligned with the Paris Agreement goals, the peak would need to occur in 2020.

In 2017 and 2018 energy-related CO_2 emissions rose, driven largely by increased use of fossil fuels; on average, energy-related CO_2 emissions have risen around 1.3% annually over the last five years (Carbon Brief Analysis: Fossil-Fuel Emissions in 2018 Increasing at Fastest Rate for Seven Years 2018). **If governments' long-term plans, including their Nationally Determined Contributions (NDCs), were followed, annual energy-related CO_2 emissions will decline only slightly by 2050, and will put the world on track for at least 2.6** °C **of warming by mid-century, and higher warming after**. Based on a carbon budget from the latest IPCC special report on the impacts of global warming of 1.5 °C (IPCC Special Report on Global Warming of 1.5 °C 2018), the Reference Case indicates that, under current and

[1] https://irena.org/remap.

planned policies, the world will exhaust its energy related CO_2 emissions budget in 10–18 years

To set the world on a pathway towards meeting the aims of the Paris Agreement, energy-related CO_2 emissions would need to be scaled back by at least an additional 400 gigatonnes (Gt) by 2050 compared to the Reference Case; in other words, **annual emissions would need to be reduced by around 3.5% per year from now until 2050 and continue afterwards**. Energy-related emissions would need to peak in 2020 and decline thereafter. By 2050 energy-related emissions would need to decline by 70% compared to today's levels. While the REmap analysis is focused only on energy-related CO_2 emissions, additional efforts are needed to reduce emissions in non-energy use (such as using bioenergy and hydrogen feedstocks); industrial process emissions; and efforts outside of the energy sector to reduce CO_2 emissions in agriculture and forestry (Fig. 4).

IRENA's REmap Case presented in this chapter outlines an aggressive, yet technically feasible and economically beneficial, route for accelerated climate action. It shows that the accelerated deployment of renewables, combined with deep electrification and increased energy efficiency, can achieve over 90% of the energy-related CO_2 emissions reductions needed by 2050 to reach the well-below 2 °C

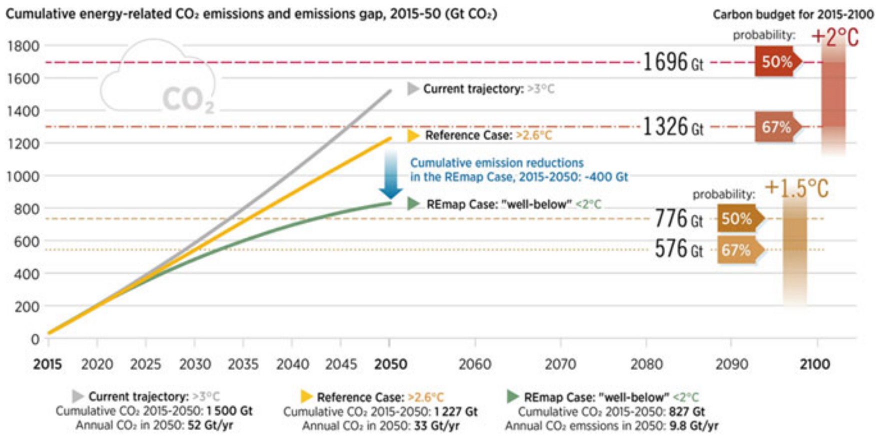


Fig. 4 REmap offers a pathway for a well-below 2 °C climate target, towards 1.5 °C. *Notes* (1) Taking into account 2015–2017 emissions on top of the budget provided in IPCC (2018) (Table 2.2—with no uncertainties and excluding additional Earth system feedbacks); (2) Budgets exclude industrial process emissions of 90 Gt; for this study, the assumption is that CO_2 emissions from land use, land-use change and forestry (LULUCF) fall from 3.3 Gt in 2015 to zero by mid-century. LULUCF subsequently becomes a net absorber of CO_2 over the remainder of the 21st century, and, as a result, cumulative CO_2 emissions from LULUCF between 2015 and 2100 are close to zero; (3) Current trajectory shows the recent historical trend line, assuming the continuation of the annual average growth in energy-related CO_2 emissions from the last five years (2013–2018) of 1.3% compound annual growth up to 2050; (4) Emissions budgets represent the total emissions that can be added into the atmosphere for the period 2015–2100 to stay below 2 or 1.5 °C at different confidence levels (50 or 67%) according to the IPCC (2018) report

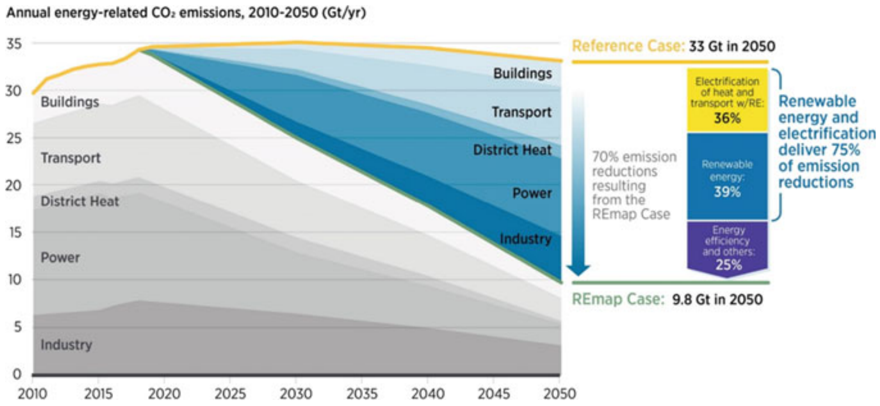


Fig. 5 Renewables and energy efficiency, boosted by substantial electrification, can provide over 90% of the necessary reductions in energy-related carbon emissions. *Note* "Renewables" implies deployment of renewable technologies in the power sector (wind, solar PV, etc.,) and end-use direct applications (solar thermal, geothermal, biomass). "Energy efficiency" contains efficiency measures deployed in end-use applications in industry, buildings and transport sectors (e.g., improving insulation of buildings or installing more efficient appliances and equipment). "Electrification" denotes electrification of heat and transport applications, such as deploying heat pumps and EVs

aim of the Paris Agreement.[2] Electrification with renewable power is key, together making up 60% of the mitigation potential; if the additional reductions from direct use of renewables are considered, the share increases to 75%. When adding energy efficiency, that share increases to over 90% (Fig. 5).

Going forward, the share of renewable energy should rise from around 14% of total primary energy supply (TPES) in 2016 to around 65% in 2050 (Fig. 6). Under the IRENA REmap Case[3] renewable energy use would nearly quadruple, from 81 exajoule (EJ) in 2016 to 350 EJ in 2050. TPES would also have to fall slightly below 2016 levels, despite significant population and economic growth. In the period from 2010 to 2016, global primary energy demand grew 1.1% per year. In the Reference case, this is reduced to 0.6% per year to 2050, whereas in REmap the energy demand growth turns negative and results in a decline of 0.2% per year to 2050 (IRENA Global Energy Transformation 2019) (Fig. 6).

[2]According to the IPCC, 67% 2 °C up to 1.326 Gt; the REmap case, with 827 Gt by 2050 is well below the 2 °C pathway, and towards the 50% 1.5 °C. More information about the carbon budget, and assumptions for non-energy greenhouse gas emissions, is included in the full report available online at www.irena.org.

[3]This analyses the deployment of low-carbon technologies, largely based on renewable energy and energy efficiency, to generate a transformation of the global energy system which for the purpose of the REmap analysis has the goal of limiting the rise in global temperature to below 2 °C above pre-industrial levels by the end of the century (with a 66% probability). For more information about the REmap approach and methodology, please visit www.irena.org/remap/methodology.

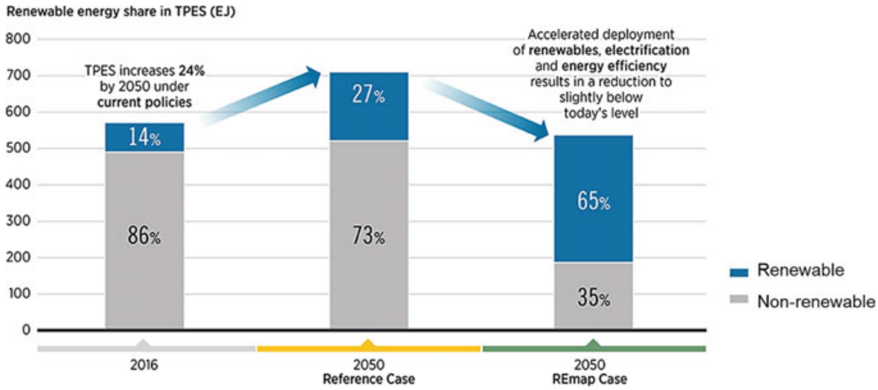


Fig. 6 The global energy supply must become more efficient and more renewables

2.2 Pathway for the Electricity Sector: Towards 100% Renewables Power

Delivering the energy transition at the pace and scale needed would require the almost complete decarbonisation of the electricity sector by 2050. This can largely be achieved by using renewables, increasing energy efficiency and making power systems more flexible. Under the REmap Case, electricity consumption in end-use sectors would increase 130% by 2050, to over 55 000 TWh, compared to 2016. By 2050, the share of renewable energy in generation would be 86%, up from an estimated 26% in 2018. Meanwhile, the carbon intensity of electricity generation would decline by 90%.

By 2050, variable renewable energy, mainly wind and solar PV, would account for three-fifth of total global electricity generation rising from their current shares of 7% and 3%, to 35% and 25% respectively (Fig. 7). These sources would lead the way for the transformation of the electricity sector, rising from around 564 GW of wind capacity and 480 GW of solar PV in 2018 to over 6 000 GW and 8 500 GW by 2050, respectively. In addition, strong growth in geothermal, bioenergy and hydropower would be seen as well (Fig. 7).

Investment in new renewable power capacity would increase to over USD 650 billion per year over the period to 2050. Transforming the power system to produce around an 86% share for renewable power would require investments in infrastructure and energy flexibility of another USD 350 billion per year (a total of USD 12 trillion for the period 2016–2050). In all, investment in decarbonisation of the power system will need to reach an average of nearly USD 1 trillion per year to 2050. Over the period between 2016 and 2050, investments in renewable power generation capacity would total USD 23 trillion in the REmap Case, more than double the investment requirements in the Reference Case of USD 11 trillion. Three-fourths of the additional investments are required to deploy variable renewables, mainly wind and solar PV (Fig. 8).

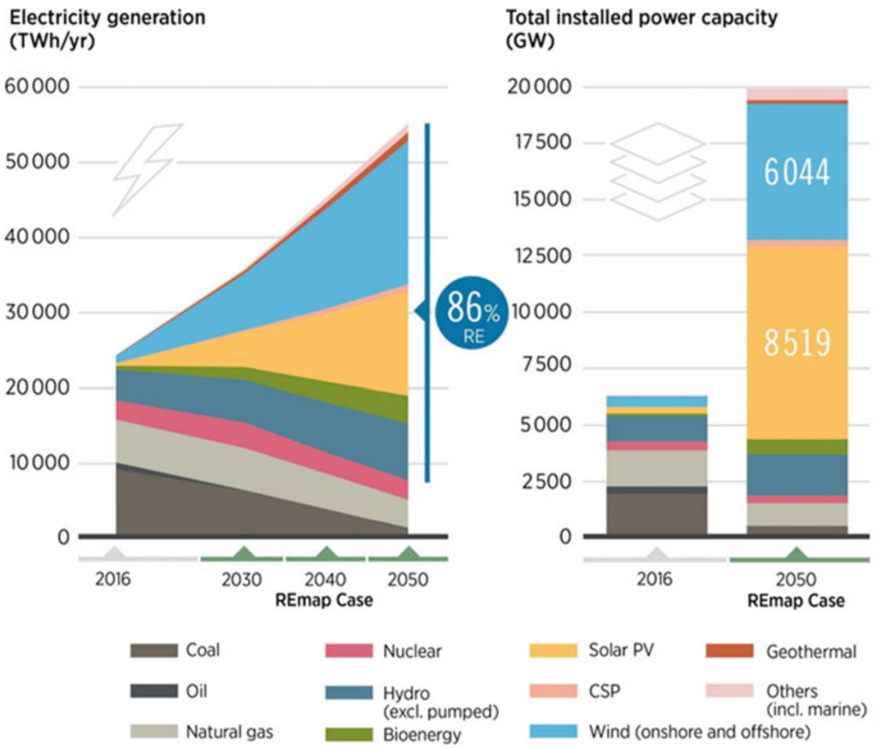


Fig. 7 Wind and solar power dominate growth in renewable-based generation. *Note* In electricity consumption, 24% in 2016 and 86% in 2050 is sourced from renewable sources. CSP refers to concentrated solar power

2.3 Electricity: The Central Energy Carrier

The most important synergy of the global energy transformation comes from the combination of increasing low-cost renewable power technologies and the wider adoption of electric technologies for end-use applications in transport and heat. Electrification of end-use sectors utilising renewable power would lead the transition. The renewable energy and electrification synergy alone can provide two-thirds of the emissions reductions needed to set the world on a pathway to meeting the goals of the Paris Agreement.

Overall, the share of electricity in final energy would need to increase from just 20% today to almost 50% by 2050. On sectorial level, the share of electricity consumed in industry and buildings would double. In transport it would need to increase from just 1% today to over 40% by 2050 (Fig. 9).

The transport sector sees the largest transformation. As performance improves and battery costs fall, sales of electric vehicles, electric buses and electric two- and three-wheelers are growing. By the end of 2018, over 5 million light electric cars

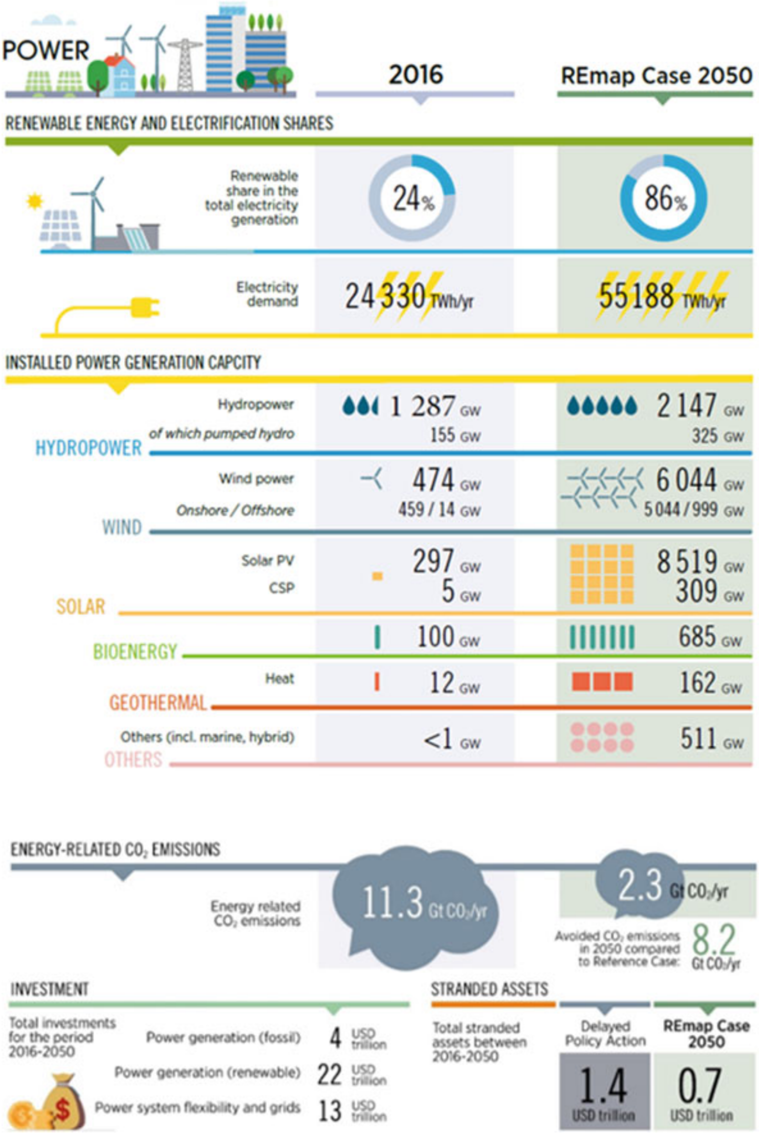


Fig. 8 Power sector key indicators

were on the road (IEA Global EV Outlook 2018). Under the REmap Case, the number would increase to over 1 billion by 2050. (That number could double if it includes all types of electric two- and three-wheelers). To achieve this, most of the passenger vehicles sold from about 2040 on would need to be electric. Under the REmap Case, while over half the stock of passenger vehicles would be electric by 2050, closer to

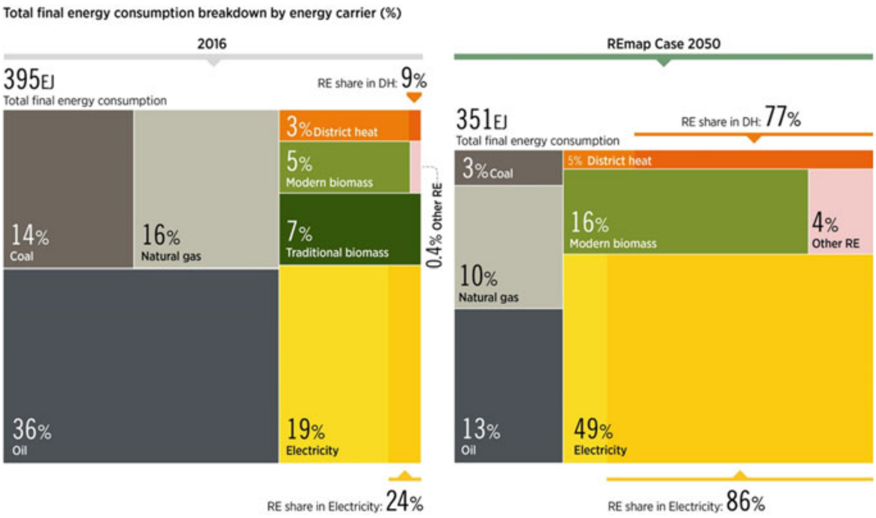


Fig. 9 Electricity becomes the main energy source by 2050. *Note* For electricity use, 24% in 2016 and 86% in 2050 comes from renewable sources; for district heating, this share is 9% and 77%, respectively. DH refers to district heat

75% of passenger car activity (passenger-kilometres) would be provided by electric vehicles (Fig. 10).

Electricity demand in the building sector is projected to increase by 80% by 2050. The increase occurs despite improvements in appliance efficiency because of strong growth in electricity demand (particularly in emerging economies) and

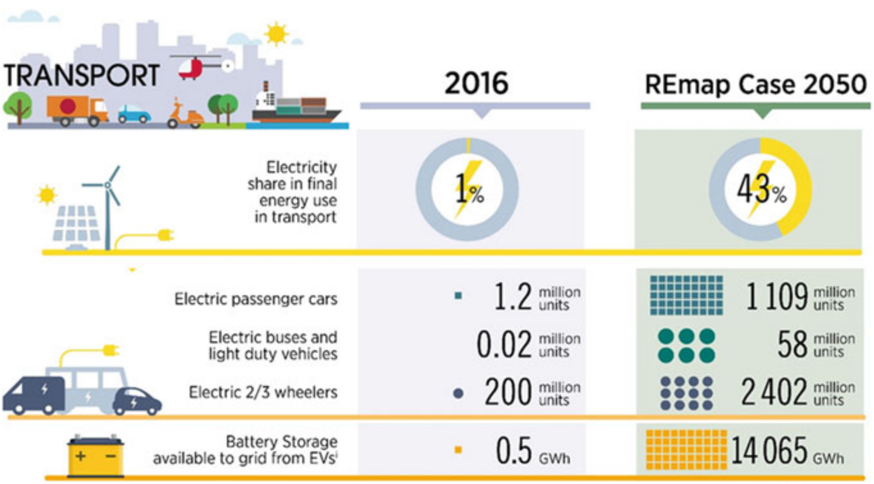


Fig. 10 Transport sector key indicators

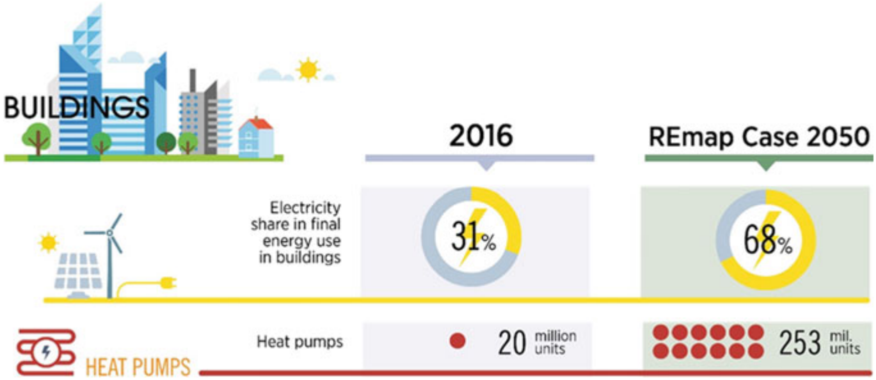


Fig. 11 Buildings sector key indicators

increases in the electrification of heating and cooling. The REmap Case considers deployment of highly efficient appliances, including smart home systems with advanced controls for lighting and air conditioning, improved heating systems and air conditioners, better insulation, replacement of gas boilers by heat pumps and other efficient boilers, and retrofitting of old and new buildings to make them more energy efficient.

Developing and deploying renewable heating and cooling solutions for buildings, urban development projects and industries is also key. Heat pumps achieve energy efficiencies three to five times higher than fossil-fuelled boilers and can be powered by renewable electricity. Under the REmap Case, the number of heat pump units in operation would increase from around 20 million in 2016 to around 253 million units in 2050. They would supply 27% of the heat demand in the buildings sector (Fig. 11).

Under the energy transition, electricity would meet more than 40% of industry's energy needs by 2050. By 2050, 80 million heat pumps would also be installed to meet similar low-temperature heat needs, more than 80 times the number in use today (Fig. 12).

Direct electrification in these sectors can be challenging for certain uses, however, unless renewable-based power can be further converted and stored via other energy carriers. **One such promising energy carrier is hydrogen** (IRENA Hydrogen from Renewable Power: Technology Outlook for the Energy Transition 2018). The production of hydrogen by splitting water into hydrogen and oxygen using electricity could be significantly increased. **As an energy carrier, hydrogen made from renewables could be seen as complementary to electricity since it offers a way to transport renewable energy over long distances**. It has the technical potential to channel renewable electricity to subsectors in which decarbonisation is otherwise difficult. The REmap Case shows that by 2050 hydrogen has the potential to supply nearly 29 EJ of global energy demand, two-thirds of which would come from renewable sources.

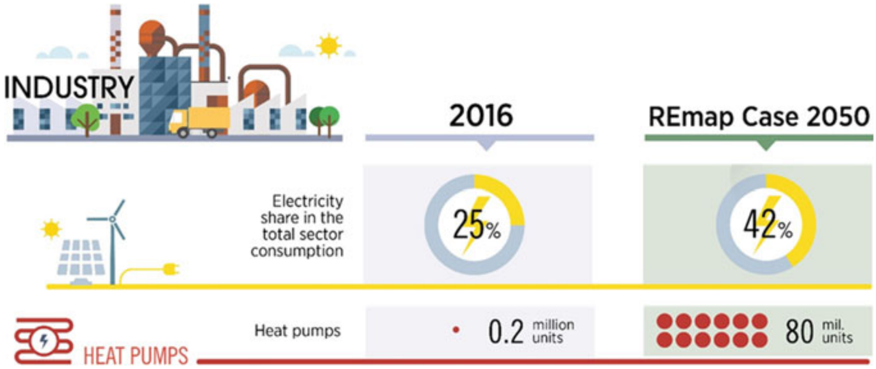


Fig. 12 Industry sector key indicators

Box 2: Best Practice Example—Sweden: 100% Renewable Electricity by 2040

IRENA is establishing a dialogue of best practice and is advising on innovative solutions to aid the development of national 100% renewable electricity strategies for Sweden (IRENA Innovative solutions for 100% renewable power in Sweden 2020).

In 2016, the Swedish government concluded an agreement on Sweden's long-term energy policy. The agreement consists of a roadmap for a transformation of the energy system including a target to reach 100% renewable electricity production by 2040.

In order to achieve such an ambitious target, **a new Climate Act** entered into force in 2018, as part of a climate policy framework imposing on current and future governments the obligation to pursue a climate policy in line with its climate goals, present a climate report every year and develop a climate policy action plan every four years to monitor progress. There are several instruments driving the overall renewable energy transformation. Firstly, **the carbon tax**. Initially introduced at USD 30/ton CO_2, the tax on fossil fuels based on carbon content has increased to USD 140/ton CO_2 at current levels. Secondly, **mandatory renewable energy quota system**. This aims at further increase the share of renewables in the electricity system, as it requires consumers to cancel renewable electricity certificates in proportion to their consumption. The certificates are generated by producers of renewable electricity from new plants and sold in an open market.

Since the carbon tax was implemented, the economy has grown by 75% while the country's emissions declined by 26%. Renewable energy technologies already contribute more than half (54%) of Swedish energy use, and hydropower is the largest renewable electricity source in Sweden, followed by wind and biomass. Hydropower generation in recent years has varied between

62 and 78 TWh, and renewable energy has contributed 60–75% of electricity consumption.

As the country moves towards 100% RE, no increase in hydropower generation is expected, and owners have decided to close two nuclear reactors by 2020. Since 2000, wind power has increased from 240 MW to 6 520 MW in 2017, passed 10% of generation and is projected to double by 2021. To promote implementation, the government in 2015 appointed a co-ordinator of Fossil Free Sweden. The initiative is open to all relevant stakeholders in Sweden, and more than 350 actors have signed up for the initiative. So far, a set of roadmaps for the development of different carbon-intensive industries has been produced. Although other challenges remain, such as decarbonising the transport sector, the success of carbon pricing provides an example for other countries of how to develop a competitive market for bioenergy and for other renewable energy technologies.

3 Actions Needed Now to Transform to 100% Renewable Energy System

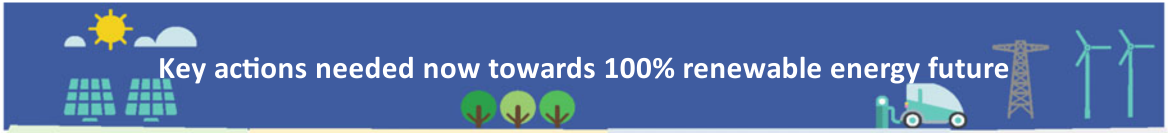
This chapter makes clear that an energy transition is urgently required, and that developing 100% renewable energy systems is a key cornerstone in this process. Technologies for these systems are available today, are deployable at a large scale quickly and are cost-competitive.

The Paris Agreement was signed in 2015. Since then energy-related CO_2 emissions have risen by around 4%. The coming years are critical: there is a need for a leap in national collective ambition levels. The revisions of the NDCs in 2020 in combination with Long-term Strategies must yield a convincing outcome for an energy transition that puts the world on a global pathway to reduced emissions, despite differing views on the mitigation measures needed and the rapid evolution of renewable technologies

- The power sector needs to be transformed to accommodate growing shares of variable renewables.
- Digitalisation is a key enabler to amplify the energy transformation.
- Accelerating the electrification of the transport and heating sectors is crucial for the next stage of energy transformation.
- Hydrogen produced from renewable electricity could help to reduce fossil-fuel reliance.
- Supply chains are key to meet growing demand for sustainable bioenergy.
- Decarbonising the global energy system requires swift and decisive policy action.

Table 1 summarises some of the key decisive actions that are needed now for fostering the transition to 100% renewable powered future.

Table 1 Actions now



Policy shift	Energy Planning shift	Investment shift	Cognitive shift
Institution/ R&D/Innovation	**Planning/regulation/operation**	**Finance/markets/business models**	**Society**
Promote holistic policies design approach involving coordination among various energy and environmental ministries. Co-operate with and strengthen international programmes (such as IRENA, the IEA, and its Technology Collaboration Programmes and Mission Innovation) to define a joint agenda for setting long term energy strategies and renewable technology innovation.	Establish long-term energy planning strategies that aligns both climate and energy needs, considering action plans in the power sector and in each end-use sectors (couple with the SDGs and the NDCs).	Promote financing schemes for accelerating deployment of renewables and energy efficiency measures for energy demand and supply projects.	Consumers can evolve from passive energy users, to active stakeholders engaged in the development of new social practices around energy use.
All stakeholders will need new management and governance skills to enhance transparency, accountability and enforcement of clean energy policies.	Identify and map renewable energy resources and develop a portfolio of financeable projects over the medium and long terms. Set up a platform providing comprehensive, easily accessible and practical information, tools and guidance to assist in the development of bankable renewable energy projects.	Align the financial system needs with broader sustainability and energy transition requirements.	Promote" Do it Ourselves" approaches with adequate traning and education programmes targeting both consumers and citizens involved in energy communities to practively involve in energy transition.
Promote actions towards circular economy (material recycling, waste management, improvements in materials efficiency and structural changes such as reusing and recycling).	Build no new coal power plants and accelerate the decommissioning of existing coal capacity.	Promote community-based finance that can help lower the overall cost of borrowing for the transition, while simultaneously facilitating the involvement of society in the transition.	Use information communication technology and digitalisation, along with demand side management, to reduce peak electricity demand, lower the need to invest in power capacity, and reduce operational costs.

(continued)

Table 1 (continued)

Combine energy efficiency and renewable energy measures (for example, public sector policies that integrate renewable technologies in the renovation of public buildings).	Promote systemic innovation by creating a regulatory environment that enables smarter energy systems through digitalisation (eg., artificial intelligence, the Internet of Things, blockchain), to promote the coupling of sectors through greater electrification and to embrace decentralisation trends. This innovation needs to be expanded beyond technology and into markets, regulations, new operational practices in the power sector and new business models.	Set up specific funds for innovation and innovative financing and investments mechanisms for the implementation of DER technical solutions. These include, inter alia: combo loans, crowdfunding platforms, financing solutions in partnership with multilateral agencies, and blended finance schemes.	Actively engage communities in the design, construction, operation and maintenance phase of the projects in order to increase community buy-in and enhance sustainability.
Create a central goal of a just transition policy must be to create structures that enable individuals, communities and regions that have been trapped in a fossil fuel energy system to participate in the benefits of the transition.	Revise tariff structures and price regulations. Support regulatory and pricing policies including the right to generate and sell electricity, tariff regulation and grid-arrival policies. Adjust regulations to increase space and time granularity of system operation and pricing.	Potential stranded assets should be internalised in overall risks assessment.	Raise awareness and understanding of the potential of DER, not only for direct users, but also for the society as a whole to foster wiser behavioural changes.
Align public policies with private sector initiatives.	Adapt regulations and aid in the development of an active market to allow energy consumers to participate in ancillary service markets.	Facilitate competitive environments in which reduction in the cost of energy is both rewarded through the right to deliver new projects and supported through the provision of targeted public research and development (R&D) funding.	Promote initiatives that provide additional income (i.e. lease to land owners, creating jobs during project installation and operation) and clean energy for its members, also redirecting funds into educational visits to renewable plants (i.e. wind and solar) for social understanding and acceptance.
Create and promote education and training policies, including an assessment of the occupational patterns and skill profiles in rising and declining industries, and how workers might most successfully be retrained.	Deploy cost-reflective tariff structures by properly readjusting the balance between volumetric charges (USD/kWh), fixed charges (e.g., USD/meter-month) and, where applicable, demand charges (USD/kW).	Redesign power markets to enable the optimal investments for systems with high levels of VRE and enable sector coupling.	Promote equitable distribution of economic benefits and costs.
Establish carbon pricing, together with the elimination of fossil fuel subsidies, not only provide important signals to the market in favor of decarbonisation of the economy, but can also generate significant additional revenue flows.	Consider establishing community energy authorities with the sole purpose of supporting community energy projects through providing advisory services and funding opportunities. By facilitating stakeholder engagement and increasing public awareness, authorities could significantly accelerate their development.	Create stable and predictable market conditions for investment in clean energy to facilitate the reallocation of capital toward low-carbon solutions and to minimise the spectre of stranded assets and avoid long-term lock-in into a carbon intensive energy system.	Create a dedicated platforms and networks of experts as well as groups for exchanging knowledge and expertise for the discussion and exchange of renewable energy and DER best practices and benchmarks at a global level.

(continued)

Table 1 (continued)

Encourage the development of internationally harmonised technical standards and quality control standards to facilitate cross-border trade and exchange of innovative technologies.	Planners, regulators and operators must develop new skills and competences.	Promote institutional investors (pension funds, insurance companies, endowments and sovereign wealth funds) and growth of new capital market instruments, such as green bonds, through which investors can more easily invest in the energy transition.	Accelerate modal shift from passenger cars to public transport (electric railways or trams or electric buses).
Set up a stable and supportive policy framework for emerging technologies such as hydrogen.	Prioritize to improve flexiblity of power system (with flexible supply, storage, demand response, power-to-X, electric vehicles, digital and information and communciation technologies technologies, etc.,). Update grid codes.	Promote innovative business models that enhance the system's flexibility and incentivise deployment of renewable technologies. Examples include virtual power plants, innovative forms of power purchase agreements, platform business models such as peer-to-peer trading, and business models that enhance demand side response.	Cooperate with grid operatirs to schedule charging of EVs and batteries during off-peak hours
Concentrate RD&D efforts to assist sectors that lack commercially available decarbonisation solutions. Relevant sectors include energy intensive industries (iron, steel and cement production) and transport (freight, aviation and shipping).	Deploy microgrids to improve resilience of the grid and energy access rate with renewable sources. Deploy super grids to strengthen the interconnections among countries within a region.	Create business models that focus on mobility services rather than car ownership – such as car sharing, Uber and autonomous vehicles – could transform the way private and public mobility operates.	Mainstreaming gender perspectives through audits and awareness training, gender targets and quotas, better work-life balance, creating networks and supporting mentorship and transparent workplace practices.

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