CLIMATE CHANGE AND RENEWABLE ENERGY

NATIONAL POLICIES AND THE ROLE OF COMMUNITIES, CITIES AND REGIONS

A report from the International Renewable Energy Agency (IRENA) to the G20 Climate Sustainability Working Group (CSWG)

JUNE 2019

ISBN: 978-92-9260-136-2

Citation: IRENA (2019), *Climate Change and Renewable Energy: National policies and the role of communities, cities and regions* (Report to the G20 Climate Sustainability Working Group (CSWG)), International Renewable Energy Agency, Abu Dhabi.

About IRENA

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

www.irena.org

Acknowledgements

G20 Climate Sustainability Working Group members provided valuable comments and suggestions on this study. The report was prepared by Elisa Asmelash and Ricardo Gorini. IRENA colleagues Emma Aberg, Francisco Boshell, Yong Chen, Rabia Ferroukhi, Diala Hawila, Sandra Lozo, Divyam Nagpal, Habone Osman Moussa, Michael Renner, Costanza Strinati, Stephanie Weckend and Adrian Whiteman also provided valuable review and feedback.

Available for download: **www.irena.org/publications**

For further information or to provide feedback: **info@irena.org**

Disclaimer

CONTENTS

FIGURES

TABLES

BOXES

ABBREVIATIONS

CCA	Community Choice Aggregation
CO	Community ownership
CO_2	Carbon dioxide
CSWG	Climate and Sustainability Working Group
DER	Distributed energy resources
DG	Distributed generation
DHC	District heating and cooling
DIO	Do it ourselves (Japanese rooftop solar programme)
DIY	Do-It-Yourself
EAC	Energy Attribute Certificate
EEAP	Energy Principles and Energy Efficiency Action Plan
EJ	Exajoule
ESWG	Energy Sustainability Working Group
EV	Electric vehicle
FiT	Feed-in tariff
G20	Group of Twenty
GDP	Gross domestic product
GHG	Greenhouse gas
Gt	Gigatons
GW	Gigawatt
GWh	Gigawatt-hour
IEA	International Energy Agency
IoT	Internet of Things
IPCC	Intergovernmental Panel for Climate Change
IRENA	International Renewable Energy Agency
ISEES	Institute for Sustainable Energy and Environmental Solution
IT	Information technology
kWh	Kilowatt-hour
MW	Megawatt
NDCs	Nationally Determined Contributions
NGO	Non-governmental organisation
O&M	Operation and maintenance
PPA	Power purchase agreement
PPP	Public purchase agreement
PV	Photovoltaic
RFC	Reason for concern
SDG	Sustainable Development Goal
SIDS	Small Island Developing States
SWG	Sustainability Working Group
TEC	Total energy consumption
TEPCO	Tokyo Power Electric Company
TES	Thermal energy storage
TFEC	Total final energy consumption
TPES	Total primary energy supply
TWh	Terawatt-hour
UNFCCC	United Nations Framework Convention on Climate Change
UK	United Kingdom
USD	United States Dollar
VRE	Variable renewable energy

EXECUTIVE SUMMARY

The special report from the Intergovernmental Panel on Climate Change (IPCC) in late 2018, underlining the growing impact of global warming, calls for urgent action. This response, moreover, must happen on an unprecedented scale and at speed if the world is to avoid the most catastrophic consequences of climate change. Considering that two-thirds of greenhouse gas (GHG) emissions originate from the energy sector, the IPCC emphatically calls for an immediate transformation of the world's energy system with massive uptake of renewables and steadily increasing energy efficiency (IPCC, 2018).

Several global forums are developing action plans to accelerate this energy revolution, both through Sustainable Development Goals (SDGs) endorsed by the United Nations and through Nationally Determined Contributions (NDCs) in line with the Paris Agreement. Yet the world is currently not on track to meet those goals or to limit the rise in average temperatures at the agreed "well below 2°C" level. Indeed, the world's various climate-related policies are clearly not ambitious enough and need additional revisions to meet the required levels of ambition.

Analyses by the International Renewable Energy Agency (IRENA) show that the swift adoption of renewable energy solutions combined with energy efficiency strategies constitute safe, reliable and affordable pathways capable of achieving over 90% of the energy-related carbon-dioxide (CO_2) emission reductions required to meet nationally pledged climate goals. However, to really be impactful, this requires a global approach, engaging all levels of society – from communities, regions and governments to numerous other stakeholders across the public and private sectors. Given the ample evidence that power systems dominated by renewables can function at high levels while underpinning sustained economic growth, the transition towards 100% renewable power has now become largely a matter of political will, as the required technologies are mature and readily deployable.

With their shared economic and political interdependence combined with their power to foster the required structural changes, G20 member countries are best positioned to lead this global energy transformation. In the context of the current G20 Japanese Presidency, IRENA has produced a report identifying and elaborating upon various pillars of action beneficial to accelerating renewable energy deployment by utilising a holistic, human-centred approach. The current analysis explores several alternative pathways to close the widening climate change and sustainability gaps. In particular, it identifies distributed energy resources (DERs) as a promising solution that offers improved resource efficiency and increased flexibility, as well as concrete opportunities for the sustainable empowerment of regions, cities, communities and other local entities.

Broadly referring to small technologies that produce, store and manage energy, DERs place stakeholders and citizens at the heart of a paradigm shift. Along with reducing energy use, DERs enable the broadest possible array of energy users to become more than simply passive power consumers. Decision makers can broadly apply DER approaches throughout cities, islands and rural off-grid areas by investing in energy communities and by embracing corporate sourcing where energy remains inefficient, expensive, sporadic or unavailable.

This report identifies and analyses different applications and methodologies for the adoption of renewable energy and DERs. It then concludes by noting several common challenges, which can be grouped under four key points:

- policy and regulations;
- finance innovation;
- resources and capacity building; and
- products and services innovation.

Programmes must be shaped to raise awareness and understanding of the potential of DER solutions, not only for direct users but also for society as a whole. Through such discussions, policy makers can actively engage with communities on DER design, construction, operation and maintenance, in order to increase social acceptance. By encouraging technological innovations, they can also facilitate their accessibility through the development of so-called “plug and play” solutions. Moreover, by fostering various policies supporting DER equipment commercialisation, including the definition of adequate standards and quality control measures, policy makers can also help pave the way for the industry’s growth.

To finance this transformation, IRENA recommends the establishment of dedicated international funding and investment facilities, the promotion and support of “combo” loans and crowdfunding platforms, and the development of additional innovative financing solutions in partnership with multilateral agencies. By enabling access to long-term, affordable financing for end-users of DER solutions, and by encouraging institutions to finance community energy projects, specifically in developing countries, governments have the ability to shape the development of alternative business models.

Beyond financial resources, investing in capacity building and establishing training courses are also needed to ensure the successful incorporation of DER renewable power options in cities, islands and rural off-grid areas. Curricula should also include “do-it-yourself” approaches as well as specific certification programmes for off-grid skills development. Fostering the necessary production and services innovation enables the creation of dedicated platforms and networks of experts who are then able to help customise the applied DER solutions and share best practices.

To ensure fair access for all market participants, utilities must also be actively engaged, adjusting and simplifying different aspects related to energy distribution, including grid connections, licensing and permitting requirements. To facilitate this, G20 members should consider establishing authorities with the sole purpose of supporting community-energy projects, particularly by providing advisory as well as funding services and opportunities.

G20 countries can provide a strong foundation for the development of off-grid solutions by supporting countries with energy-access issues to integrate them into their national energy-access strategies. The co ordination of policies on both vertical (local and national) and horizontal levels among ministries could in turn help stabilise and clarify policies and regulations crucial for the development of DER systems. Also, by linking sector-level policies, such as urban or transport policies for the application of DERs, policy makers can further accelerate both the adoption of renewable energy and the fulfilment of SDGs. Pursuit of these aims can be further enhanced by constructing DERs and increasing energy efficiency in public buildings, such as hospitals and schools.

Based on these identified challenges, this report also explores how G20 countries, through their proven leadership, are able to foster the development and global spread of DERs and energy efficiency solutions. When aimed at developing effective market frameworks for investment and development, IRENA's recommended, customisable policies and regulations could be applied broadly throughout G20 member countries or could be individually tailored to specific contexts and national priorities.

1. INTRODUCTION

Climate change is already affecting regions around the world. Unabated, its future negative impacts will likely be vast, costing much more than preventing it. The recent IPCC *Special Report on Global Warming of 1.5°C* has underlined the urgency of taking decisive steps to tackle climate change, including through the transformation of global energy use. Considering that two thirds of greenhouse gas (GHG) emissions originate from the energy sector, the IPCC unequivocally calls for an immediate, large-scale shift to renewable energy and energy efficiency (IPCC, 2018).

Several forums around the world have been taking actions and negotiating the acceleration of the energy transformation since the outcome of international climate change negotiations in 2015 that resulted in the adoption of the Paris Agreement and the 2030 Agenda for Sustainable Development, which included the Sustainable Development Goals (SDGs).

A report from the International Renewable Energy Agency (IRENA), Global Energy Transformation: A Roadmap to 2050 (IRENA, 2019a), estimates that meeting the objectives of the Paris Agreement would require reducing global energy demand through energy efficiency, increasing the electrification pathway for all end-use sectors, and increasing the share of renewables in the energy matrix, including biofuels. Thus, renewables would need to comprise at least two-thirds of the total final energy supply by 2050. At the same time, the share of renewable energy in the power sector would need to increase from 25% in 2017 to 86% in 2050. The good news is that there are technically feasible and economically attractive solutions at hand to achieve this goal. Indeed, there is a unique opportunity to accelerate transformation towards digitalised, distributed and decarbonised energy systems.

The envisioned global energy transformation – itself a culmination of energy transitions that are already occurring in many countries – can create a world that is more prosperous and inclusive. Accelerated deployment of renewables promises multiple benefits, ranging from economic growth and job creation to the mitigation of climate change and the reduction of air pollution.

IRENA analysis (IRENA, 2019a) shows that a combination of renewable energy, energy efficiency and electrification represent a safe, reliable, affordable and already deployable pathway capable of achieving over 90% of the energy-related CO_2 emission reductions needed to meet pledged climate goals, and that such a transformation constitutes the most effective strategy going forward. However, to really be impactful, this energy transformation requires a global approach, engaging all levels of society – from communities, regions and governments to stakeholders from the public and private sectors.

Beyond government action around climate change, communities (rural and cities), non-governmental organisations (NGOs) and the private sector in general can also combine their knowledge, expertise and decision-making processes to take immediate action. In fact, the combination of energy and information technology (IT) innovations and renewable energy's growing competitiveness are transforming the landscape of energy services. The role of distributed energy resources (DER) is increasing as a solution for sourcing buildings, lighting communities in cities and rural areas, as well powering companies. Several benefits are linked to DERs and society-wide engagement, and empowering all stakeholders constitutes an effective action to accelerate the energy transition.

G20 countries as a group are those best positioned, in terms of economic power and leadership capacity, to foster a global energy transformation. Together they account for 85% of the world's economy, almost three-quarters of global trade, two-thirds of the world's population (WEF 2016) and four-fifths of global energy consumption (IRENA, 2018a). Not only do G20 members host around 81% of the world's installed renewable power generation capacity, they also hold 75% of its deployment potential, as estimated by IRENA for the period 2010 to 2030 (IRENA, 2016a).

As the current G20 Japanese Presidency said in its opening message, "G20 policies should be human-centered and focused on productivity and technologies enabling the development of Society 5.0" (GoJ, 2018). In effect, this means resolving various social challenges by incorporating the innovations of the fourth industrial revolution, such as the Internet of Things (IoT), big data, artificial intelligence, robotics and the sharing economy throughout industries and social life. Decentralised renewable energy technologies, moreover, are a natural and unavoidable fit with visions to create a "super-smart" and sustainable society for the future. This is the context in which the G20 Presidency requested the present study.

The crucial theme of "climate change and renewable energy" is examined through the lens of national policies and the role of communities, cities and regions. The study particularly looks at innovation opportunities in relation to DERs. It also considers options for societal empowerment through accelerating the sustainable energy transformation, particularly through corporate sourcing of renewable energy and through community applications of renewables, whether in cities or in island and rural off-grid areas.

Among the key findings to be presented and explained:

- The world faces costly risks if countries are not able to meet the well-below 2°C climate change threshold set forth in the Paris Agreement.

- SDGs are a global responsibility requiring engagement by all nations, but especially by G20 countries, which are also leaders on renewable energy.

- The world is still struggling to reach the "well below 2°C" threshold under the current policies because Nationally Determined Contributions (NDCs) as a whole are not ambitious enough to achieve renewable energy and energy efficiency targets.

- Renewable energy and energy efficiency are complementary, and they need to be stepped-up in parallel. This requires detailed mapping at the country level to develop different pathways and solutions tailored to local conditions, resource endowments and priorities.

- The dynamics of the energy innovation landscape, combined with social empowerment trends, are reshaping energy supply in favour of prosumers and Do-It-Yourself (DIY) behaviour.

- DER can play a concrete and effective role in accelerating the sustainable energy transformation, particularly through corporate sourcing, as well as community applications in cities or rural and island off-grid settings.

Box 1: Ongoing work: The G20, IRENA and the Climate and Sustainability Working Group

Over the past five years, renewable energy combined with efforts to accelerate renewable deployment have featured prominently on G20 agendas. IRENA's various analyses have deepened the world's understanding of the key roles accelerated renewable energy deployment can play in energy transitions, illustrating the significant economic opportunities that await early adopters. By actively supporting G20 meetings, IRENA continues to provide science-based evaluations of options for decarbonising the energy sector.

In order to assist this transition, the G20 Climate and Sustainability Working Group (CSWG) has been tasked with "influencing G20 countries and working with relevant stakeholders to ensure that G20's policies promote sustainable development, with a particular focus on increasing investments into energy efficiency and renewable energy, ensuring development planning in line with full decarbonisation and to make financing available to poorer countries to ensure that these countries can adapt to climate change and put infrastructure and policies in place that are climate friendly" (CAN, 2018).

Originally, the CSWG was part of the wider Sustainability Working Group (SWG), which also included the Energy Sustainability Working Group (ESWG). However, in 2014, during the Australian Presidency, the Group focused on energy efficiency and strengthening energy markets, culminating in the adoption of the G20 Energy Principles and Energy Efficiency Action Plan (EEAP).

In 2015, during the Turkish Presidency, the focus shifted as nations worked together to produce the Energy Access Action Plan in Sub-Saharan Africa and the G20 Toolkit for Renewable Energy deployment (IRENA, 2016a). As a result, IRENA was tasked with being the central co ordinator of the Toolkit's implementation, in co operation with other international organisations, across five action areas: i) analysis of renewable energy costs, cost reduction estimates and good practices; ii) exchange of good practices in the design of national policy frameworks and in the integration of larger shares of variable renewables into power systems; iii) development of risk-mitigation facilities dedicated to renewable energy; iv) assessment of the potential benefits of renewable energy technology at the national level; and v) development of adoption roadmaps and deployment of modern bioenergy.

At the 2016 meeting in Beijing, presided over by the Chinese G20 Presidency, energy ministers reviewed the progress made since the implementation of the Toolkit. They adopted the G20 Voluntary Action Plan on Renewable Energy with the aims of substantially increasing the share of renewable energy by 2030 and continuing to advance the Toolkit's implementation. As well, they developed a long-term plan for energy efficiency (the G20 Energy Efficiency Leading Programme) and a G20 Energy Access Action Plan for the Asia-Pacific.

During the German Presidency in 2017, the specific topic of climate change was included for the first time in the CSWG programme, particularly the importance of building resilience against the impacts of climate variability. To address it, both IRENA and the International Energy Agency (IEA) were requested to analyse options for decarbonising the energy sector to meet the objectives of the Paris Agreement, along with the investment implications of doing so.

At the same time, the Climate and Energy Action Plan for Growth attached to the 2017 G20 Leaders' Declaration called upon IRENA to support the G20's efforts by providing a regular update on the energy sector's global transformation and further investment needs. The plan noted the progress already made while requesting the continued implementation of the Voluntary Action Plan on Renewable Energy and the Toolkit to further support the global scale-up of renewable energy.

The 2018 G20 Argentinian Presidency highlighted the commitment to work towards low GHG emissions and increased innovation on sustainable and cleaner energy systems while also acknowledging that each G20 member has specific and unique energy system characteristics, needs and priorities. Also, the CSWG's work programme concentrated on building on the achievements made under the German Presidency and serving as a reference for future presidencies. The goals were to share best practices and promote enhanced efforts and adaptation and resilience improvements, not only at a national level, but also in co operation with partner countries (G20 Argentina, 2018).

As part of IRENA's active support of the G20 and the on-going analysis of options for decarbonising the energy sector, for the Argentinian Presidency IRENA also produced a report entitled Opportunities to Accelerate National Energy Transitions through Advanced Deployment of Renewables (IRENA, 2018a).

2. CLIMATE CHANGE, SUSTAINABILITY AND RENEWABLE ENERGY

2.1 SDGs AND SYNERGIES WITH RENEWABLE ENERGY

The United Nations 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 (Figure 1). However, despite the availability of energy and renewable solutions, the world is currently not on track to meet SDG 7, and further improvements will require increased policy commitments, simultaneous with more funding and a willingness to embrace developing technologies widely (IRENA, 2017a).

Figure 1: Linkages between SDG 7 and other SDGs

Source: IRENA (2017a)

SUSTAINABLE DEVELOPMENT GOALS

1: NO POVERTY

2: ZERO HUNGER

3: GOOD HEALTH AND WELL-BEING

4: QUALITY EDUCATION

5: GENDER EQUALITY

6: CLEAN WATER AND SANITATION

7: AFFORDABLE AND CLEAN ENERGY

8: DECENT WORK AND ECONOMIC GROWTH

9: INDUSTRY, INNOVATION AND INFRASTRUCTURE

10: REDUCED INEQUALITY

11: SUSTAINABLE CITIES AND COMMUNITIES

12: RESPONSIBLE CONSUMPTION AND PRODUCTION

13: CLIMATE ACTION

14: LIFE BELOW WATER

15: LIFE ON LAND

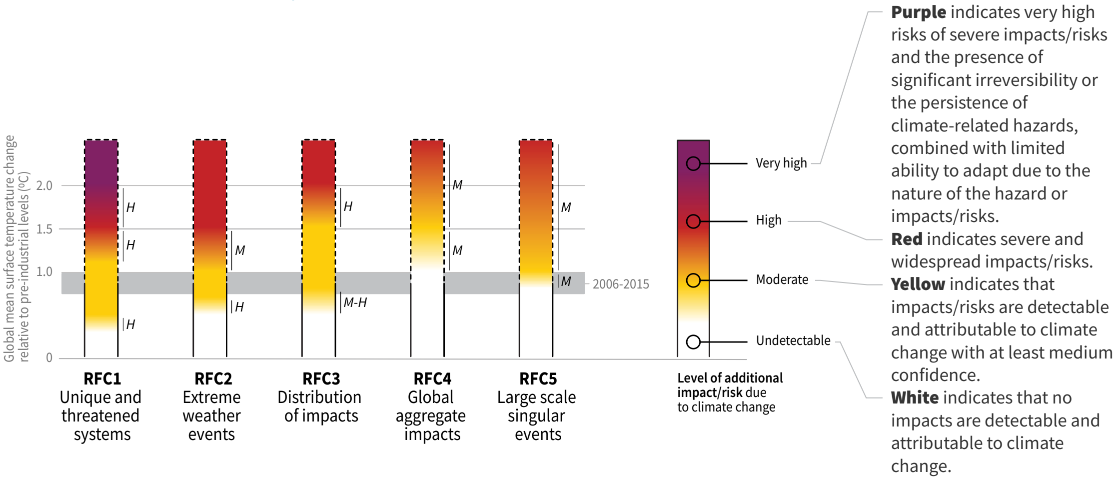
16: PEACE, JUSTICE AND STRONG INSTITUTIONS

17: PARTNERSHIPS FOR THE GOALS

2.2 THE RISKS OF NOT MEETING ESTABLISHED CLIMATE GOALS AND THE OPPORTUNITY FOR SUSTAINABLE SOLUTIONS

The IPCC Special Report on Global Warming of 1.5°C (SR1.5), released on 8 October 2018, estimates that human activities have already caused approximately 1.0°C of global warming above pre-industrial levels. Unless significant countermeasures are taken, global warming would not be limited to/stabilise at 1.5°C between 2030 and 2052 (IPCC, 2018).

Figure 2: How the level of global warming affects impacts and risks associated with the reasons for concern (RFCs) and selected natural, managed and human systems



Source: IPCC (2018)

Figure 2 illustrates the five integrative reasons for concern (RFCs) and provides a framework for summarising key impacts and risks across sectors and regions.

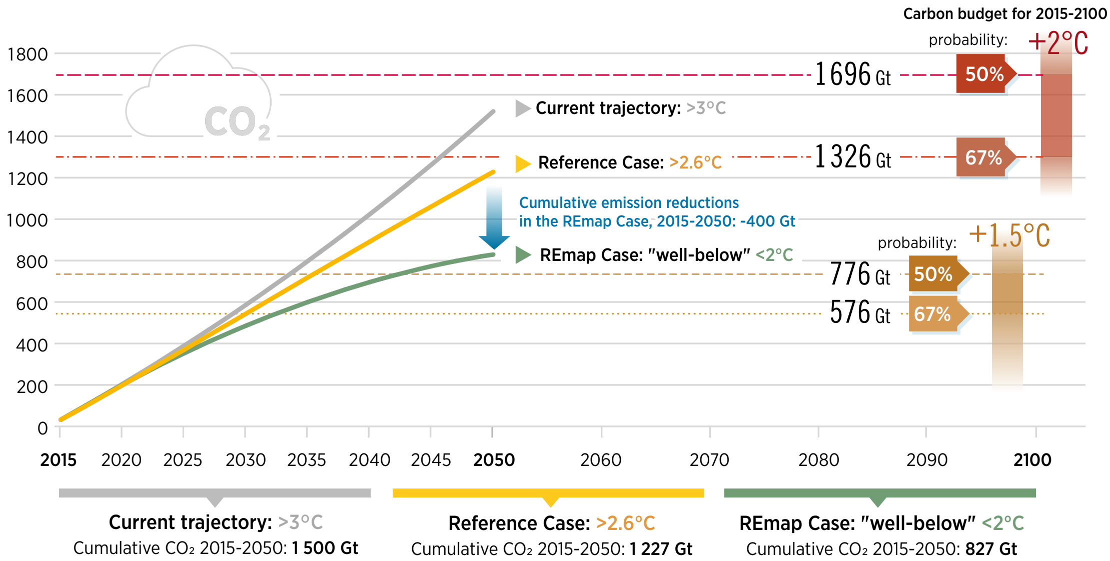
Pathways limiting global warming to 1.5°C require rapid and extensive transitions in all sectors (i.e., energy, agriculture, urban infrastructure and buildings, transportation, and industrial systems). These system transitions are unique in terms of scale and more pronounced in terms of speed. As such,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

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.

Reducing energy-related CO_2 emissions is the heart of the energy transition. Because many governments have strengthened efforts to reduce national emissions in recent years, projected energy-related CO_2 emissions in the IRENA REmap Reference case[1] between 2015 and 2050 have declined from a projected 1 380 Gigatons (Gt) based on 2017 analysis to 1 230 Gt based on 2018 analysis – an 11% drop. However, this improvement is not yet reflected in current CO_2 emissions, which unfortunately actually grew by around 1.4% in 2017 (IEA, 2018).

Many governments' plans still fall short of the necessary emission reductions. The IRENA REmap Reference case indicates that under current and planned policies, the world would most likely exhaust its energy-related CO_2 emission budget. 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 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 (Figure 3).

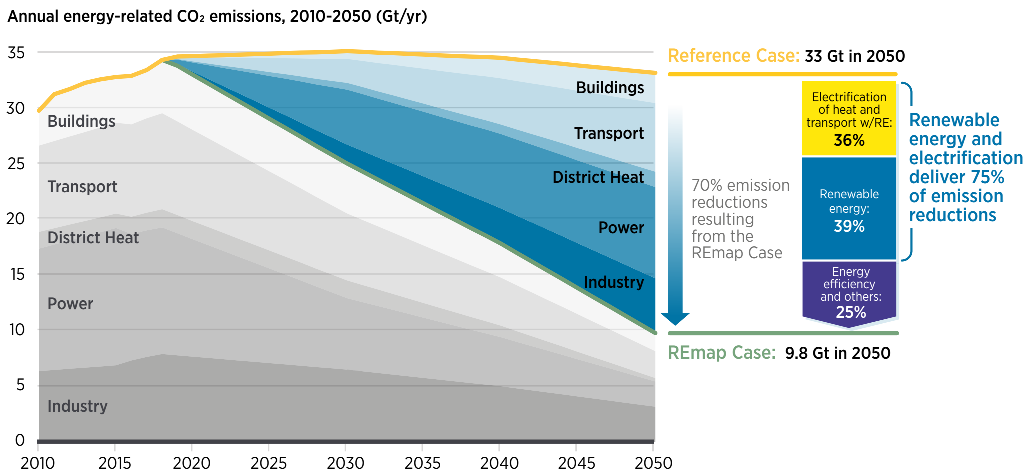
Figure 3: Cumulative energy-related CO_2 emissions and emissions gap, 2015-2050 (Gt CO_2)



Source: IRENA (2019a)

1 This scenario takes into account the current and planned policies of countries. It includes commitments made in NDCs and other planned targets. It presents a "business-as-usual" perspective, based on governments' current projections and energy plans. For more information about the REmap approach and methodology, please visit www.irena.org/remap/methodology.

Figure 4: Annual energy-related CO_2 emissions and reductions, 2015-2050 (Gt/yr)



Source: IRENA (2019a).

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" includes efficiency measures deployed in end-use applications in the industrial, 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 electric vehicles (EVs).

2.3 CHARACTERISING THE GAP: SETTING NDCs IN PURSUIT OF THE 2050 GLOBAL ENERGY TRANSFORMATION

IRENA's pathway analysis concludes that renewable energy and energy efficiency, coupled with deep electrification of end-uses, could provide over 90% of the required reduction in energy-related CO_2 emissions (Figure 4). The remainder would be achieved by a mix of options, including fossil fuel switching (to natural gas) and carbon capture and sequestration in industry. Nuclear power generation would remain at 2016 levels. Simultaneously, a significant effort would be required to reduce carbon emissions generated by industrial processes and by land use to less than zero by 2050. The climate goal cannot be reached without progress in those areas.

However, there are good examples of initiatives and action. Many governments are setting renewable energy targets, and a rapidly expanding number worldwide are aiming for 100% renewables by or before mid-century. While pioneering this movement, sub-national and local governments are simultaneously becoming incubators of regionally appropriate best practices and policies. Also, the integration of renewable energy in power systems broke records in 2017 and 2018, as many jurisdictions deployed higher levels of renewable power, for longer durations, than ever before.

There is now ample evidence that power systems dominated by renewables can function at high levels while underpinning sustained economic growth. The transition towards deep decarbonisation and high shares of renewable energy is now largely a matter of political will as the required technologies are already at hand.

Box 2: NDCs: Current status and trends

Nationally Determined Contributions (NDCs) are a cornerstone of the Paris Agreement (IRENA, 2017b). They set out the actions planned by countries in pursuit of shared global climate objectives. In essence, this means striving to limit the rise in average global temperatures to "well below 2°C" above pre industrial levels and ideally to 1.5°C during the present century.

Renewable energy components featured prominently in the first round of NDCs created under the 2015 Agreement. Of the 152 NDCs that were formally submitted by the end of November 2018, some 111, or nearly three quarters, cite specific renewable energy targets. Another 34 acknowledge renewables as an important way to reduce GHG emissions and adapt to climate change impacts.

All Parties to the United Nations Framework Convention on Climate Change (UNFCCC), however, still have the opportunity to further strengthen their targets for renewables in the next round of NDCs planned for 2020.

Over USD 1.7 trillion would be needed by 2030 to implement renewable energy targets contained in NDCs worldwide, IRENA's 2017 report found (IRENA, 2017b). At least 1.3 terawatts of renewable power capacity would be added globally by 2030 as a result of NDC implementation. This would amount to a 76% increase in installed global renewable energy capacity compared to 2014. The cost-effective potential for renewables, however, is much higher than what is captured in current NDCs.

In fact, the rapid deployment of renewables, coupled with increased energy efficiency, could achieve around 90% of the emission reductions in the energy sector needed by 2050, while at the same time advancing economic growth and development, IRENA's analysis found (IRENA, 2017b).

3. REDUCING THE CLIMATE CHANGE AND SUSTAINABILITY GAPS: PATHWAYS AND INNOVATION TRENDS

NDCs and other climate-related policies are clearly not ambitious enough to meet the necessary global targets. They should be upgraded to better reflect the level of ambition and improvements needed.

Changes should take into account and be in line with three key pillars for the reduction of climate change and closing the sustainability gap, namely:

1. increasing the share of renewables in the energy matrix
2. reducing global energy demand through energy efficiency
3. increasing the electrification pathway for all end-use sectors.

Closing the climate change and sustainability gaps will involve exploring possible alternative pathways, tailored to a nation's specific needs and capabilities. In this context, decentralised energy resources (DER) offer several environmental and sustainability opportunities, including reductions in the carbon intensity of energy use, improvements in resource efficiency, increased energy security and increased flexibility in the creation of business opportunities. The decentralisation of energy supply also offers a concrete opportunity for the empowerment of regions, cities, communities and other local entities.

Box 3: Global Energy Transformation: A Roadmap to 2050

The IRENA report Global Energy Transformation: A Roadmap to 2050 represents IRENA's vision for the global energy transformation. The analysis is defined by the need to reduce energy-related CO_2 emissions, which is at the heart of the energy transition and needed to meet the carbon budget. It provides a global perspective on both opportunities (i.e., enhancement of energy efficiency, renewable energy, bioenergy and electrification of end-uses) as well as challenges (i.e., integration of variable renewable sources, design of new business models, etc.) related to the energy transformation towards full decarbonisation of the energy sector.

Some of the key messages of the 2019 report are:

- Transforming the global energy system will require a fundamental shift in the way energy systems are conceived and operated.
- A 70% CO_2 emissions reduction between today and 2050 is technically and economically feasible, but it requires immediate action and strong commitments.
- 75% of emissions reduction can be attributed to renewable power, direct use of renewable heat and fuels, and electrification of end-use sectors through renewable energy.
- The share of electricity needs to increase in transport, buildings and industry and reach nearly 50% of final energy use.
- Substantial additional investment of around USD 15 trillion in low-carbon technologies will be required between now and 2050 compared to current and planned policies.
- Annual energy-sector subsidies can fall by around one fifth (USD 135 billion) between now and 2050 and can be rebalanced towards energy efficiency and renewable energy.
- To achieve both the medium-term and longer-term milestones set out in the REmap analysis, innovation efforts are needed that focus on fostering the development and deployment of solutions that create the flexibility needed to integrate high shares of variable renewable energy.
- The transition can substantially increase overall employment in the energy sector and boost Gross Domestic Product (GDP) growth globally. The shift to renewables would create more jobs in the energy sector than are lost in the fossil fuel industry.

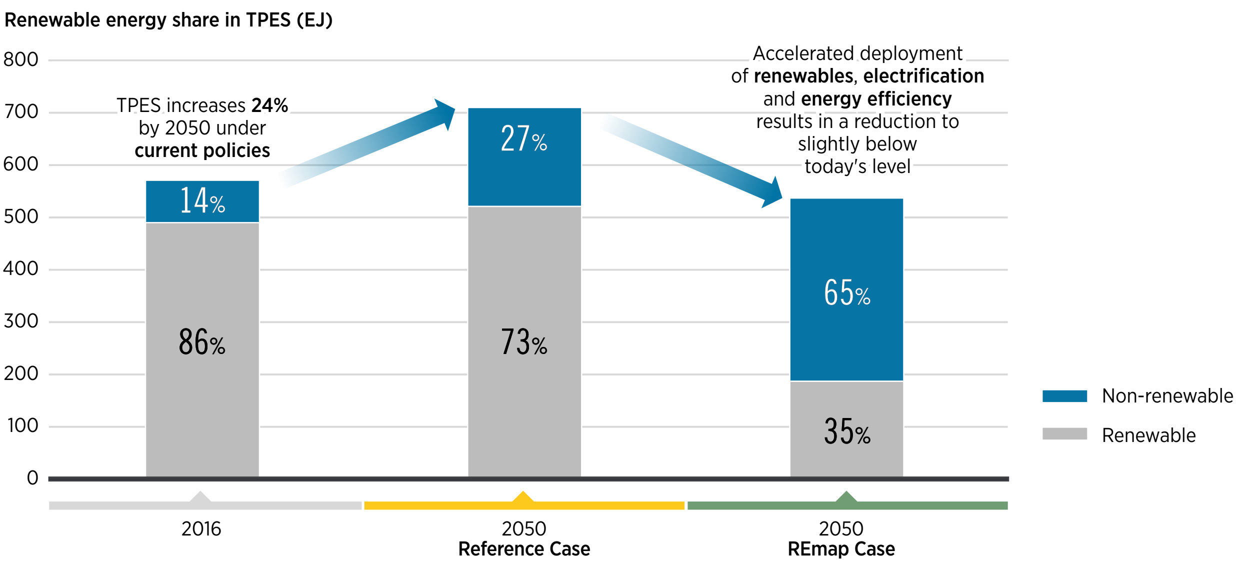
Source: IRENA (2019b).

3.1 THREE PILLARS OF ACTION FOR CLOSING THE GAP IN THE BUILDINGS, INDUSTRY, POWER AND TRANSPORT SECTORS

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** (Figure 5). Under the IRENA REmap Case,[2] 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, 2019a).

The REmap Case results in two major shifts. First, energy efficiency increases due to the increase in renewable electrification, especially in transport and heat. The increasing use of renewable electricity reduces inefficient fuel consumption. Second, the electricity mix is significantly transformed, and the carbon intensity of electricity drops by 90%. The result is that the power sector in the REmap Case would more than double in terms of generation – to over 55 000 terawatt-hours (TWh) (up from around 24 000 TWh in 2016). The sector would see 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 would increase from 24% in 2016 to 86% in 2050. This transformation would require new approaches to power system planning, system and market operations, and regulation and public policy (IRENA, 2019a).

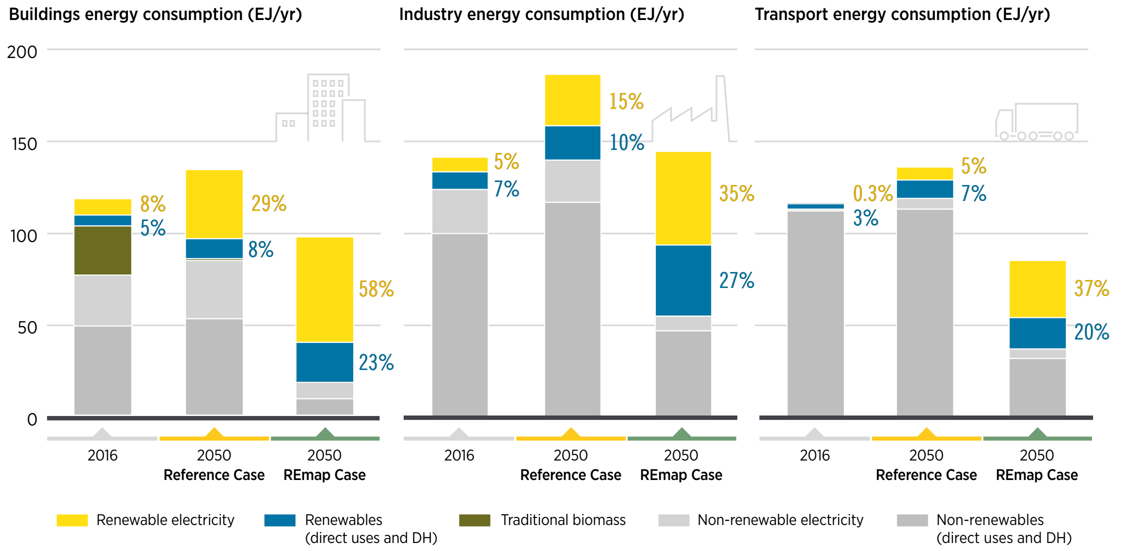
Figure 5: TPES and renewable and non-renewable shares in the Reference and REmap cases, 2016-2050



Source: *Global energy transformation: The REmap transition pathway* (Background report to IRENA, 2019a)

2 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 this report 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.

Figure 6: Scaling up renewables not just for power, but also for heat, building uses and transport



Note: Hydrogen in transport and industry sectors are included in electricity part. Non-renewable includes direct uses of fossil fuels (e.g. for heating, cooking, transportation, etc.); Renewable includes direct uses of renewables (e.g. solar water heating) and district heating with renewables.

Source: IRENA (2019a)

Increasingly, electrification with renewables is seen as a major solution, and the contribution of renewable electricity will be the single largest driver for change in the global energy transformation. The share of electricity in total final energy use will need to increase from just 20% today to 49% by 2050. The share of electricity consumed in industry and buildings needs to double to reach 42% and 68%, respectively, in 2050, and in transport it needs to increase from just 1% today to over 40% in 2050. Likewise, other subsectors or activities will also need to significantly increase their share of electricity use. Some of the largest growth in electricity share will need to be seen in the building sector for space heating and cooking, and in the transport sector for passenger and road freight (IRENA, 2019a).

Despite the growth of renewable electricity use in end-use sectors, direct use of renewable energy would still be responsible for a sizeable proportion of energy use in industry, building and transport. Much of it would involve direct use of biomass, with important contributions from solar thermal and some use of geothermal and other renewable sources.

As a consequence of renewable electrification and direct renewables use, the share of renewable energy in total final energy consumption (TFEC) would also rise considerably. In the REmap Case, a more than seven-fold increase would be needed to raise the overall share from 17% to 18.5% in the first year. In subsequent years, the increase would be incremental, reaching 66% in 2050.

Renewable energy and energy efficiency, in combination with electrification, are the key ingredients for a successful energy transition. By 2050 in the REmap Case, renewables will dominate the transport and buildings sectors, reaching 57% and 81%, respectively, of sectors' TFEC. Renewables will also be relevant in industry, with 25% of final energy use. In all sectors, electrification with renewables will constitute the largest share of renewable energy carriers, complemented by direct uses of biomass, geothermal and solar thermal.

The power sector

For the energy transition to succeed at the required pace and scale, the electricity sector needs to be almost completely decarbonised by 2050. This can 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. **Annual additions of renewable power capacity would exceed 600 gigawatts (GW) per year, 84% of which will be from solar and wind technologies.** These sources would lead the way for the transformation of the sector, rising from around 514 GW of wind capacity and 385 GW of solar photovoltaic (PV) in 2017 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. Decentralised renewable power generation grows from just 2% of total generation today to around one-quarter by 2050, an over ten-fold increase.

Investment in new renewable power capacity should increase to over USD 650 billion per year over the period to 2050. Transforming the power systems to produce around an 86% share for renewable power will 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 the decarbonisation of the power system would need to reach an average of nearly USD 1 trillion per year to 2050 (IRENA, 2019a).

However, the deployment of renewables in the power sector still faces multiple barriers, and policy support is needed to advance the transformation. Policies range from pricing instruments to financial and fiscal incentives, quotas and obligations, and voluntary programmes, among others (IRENA, IEA and REN21, 2018).

The industrial sector

Responsible for one-third of emissions worldwide, the industrial sector is the second-largest emitter of energy-related CO_2. However, to date this sector has been struggling the most with respect to the energy transition. In 2016, renewables provided only around 14% of the industry sector's energy demand, and most of this was derived from bioenergy. Electricity supplied almost 23% of the energy consumed by this sector.

Under the IRENA REmap Case, industry would need to increase the share of renewable energy in direct-uses and fuels to 63% by 2050. Under the energy transition, electricity would meet more than 40% of industry's energy needs by 2050. In percentage terms, the largest growth would be in the use of solar thermal heat for low-temperature processes. Its use would rise steeply to 2.4 billion square metres of solar thermal collectors (concentrated and flat plate), providing 4% of industry's heat demand. Additionally, by 2050, more than 80 million heat pumps would also be installed to meet similar low temperature heat needs.

However, renewables for heating and cooling in the industry sector have received much less policy attention than for the power sector. There has been a steady, if slow, growth in the global share of renewables used to meet the demand for heat in recent years, but the pace is much slower than the growth in renewable electricity, and renewable cooling solutions are even less prevalent. The use of renewables for heating and cooling faces multiple economic and non-economic barriers. Policy interventions are necessary to overcome those barriers, and they should be carefully designed to reflect specific national and local circumstances. Various policies are already being used to support the deployment of renewable heat, often in packages that include a combination of several instruments, such as financial incentives (i.e., grants, tax credits), heat generation-based incentives, technology-specific mandates (i.e., requiring installation of solar water heaters), renewable portfolio standards (i.e., setting a quota for renewable heat) (IRENA, IEA and REN21, 2018).

Indeed, the industrial sector can play an important role in decarbonisation by increasing self-production and consumption from renewable energy (Corporate sourcing). Wind and solar technologies in combination with energy efficiency can easily be applied, and together constitute a distributed energy resource application. This is explored below in this report.

The transport sector

The transport sector is also still working towards the energy transition. Globally, its share of renewable energy was only 3% in 2016. **Under the IRENA REmap Case, this sector would significantly increase the electrification of passenger transport, especially as hydrogen produced from renewables is introduced as a transport fuel.** Biofuels and the combination of electrification and so-called Power-to-X Gas would lead to a nearly 70% drop in oil consumption in the sector by 2050 compared to 2016. From 2015 to 2050, the share of electricity throughout the transport sector would rise from just above 1% to 43%, of which fully 86% would be renewable. Additionally, in the same period, biofuels would increase their share from just below 3% to around one-third. Similarly, the IRENA REmap Case also foresees 1 billion passenger electric vehicles by 2050.

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

Realising the transformation under the IRENA REmap Case would require nearly USD 14 trillion of total investment in the transport sector by 2050. Around USD 2 trillion would be needed to develop the biofuel industry (predominantly advanced biofuels) and USD 0.5 trillion for hydrogen.

Decarbonising the transport sector is key to decarbonising the energy sector. It is a huge task that requires a fundamental change in the nature and structure of the overall transport sector. This transition requires technology developments and behavioural changes, as well as a major policy push. In general, policies need to address three dimensions in an integrated way: 1) the availability of energy carriers/fuels produced from renewable energy sources; 2) the deployment of vehicles that can use renewable energy fuels; and 3) the development of infrastructure for energy and fuel distribution. Some of the key policy measures to overcome the challenges in the transport sector include but are not limited to eliminating fossil fuel subsidies and implementing carbon and energy taxes, designing financial instruments for research and development and demonstration as well as for de-risking, and implementing standards for vehicles, vehicle emissions and low-carbon fuel, as well as mandates (IRENA, IEA and REN21, 2018).

The buildings sector

Although buildings significantly contribute to global emissions, the sector is still struggling to promote the energy transition. **By 2050, the buildings sector would see its overall energy consumption decrease by around 15% in the REmap Case, mainly due to efficiency, especially in cooling, but also due to electrification of heat.** The sector will also see its share of renewable energy increase to 81%, up from one-third today, largely due to consuming a large share of renewable electricity.

However, despite improvements in appliance efficiency, **electricity demand in the building sector is projected to increase by 80% by 2050.** To accommodate this development, shifting cooking technologies from fuel to electricity will promote renewables as more clean energy comes on line. Additionally, electric stoves, such as induction cookstoves, could cut energy demand by three to five times. New as well as renovated buildings can be made more energy efficient and rely largely on renewable technology to supply their remaining energy demand. Most efficiency investments (88% under the REmap Case) will be spent on making buildings more energy efficient. Early action is required to avoid stranded assets and meet future reinvestment needs.

Policies for the buildings sector are mainly focused on renewable heating and cooling and are in many instances linked to energy efficiency measures for appliances, which is a fundamental and cost-effective first step toward shifting to renewables. For example, buildings need to be well insulated for heat pumps to operate effectively, while biomass boilers will require less fuel and become more cost-effective if heat demand is reduced through improvements in energy efficiency (IRENA, IEA and REN21, 2018). Other effective policy measures include, amongst others, building codes, financial incentives and technology-specific mandates.

The building sector is where DERs and the DIY approach can play a decisive role. Individuals at home, managers at offices, as well as different types of buildings can easily accommodate renewable energy and energy efficiency solutions. But this is possible only if the right enabling conditions are in place and barriers against these measures are removed.

3.2 DISTRIBUTED ENERGY RESOURCES (DER) CHANGING THE POWER-SECTOR PARADIGM: ELECTRIFICATION,DECENTRALISATION AND DIGITALISATION

The investment opportunities and the ambitions related to the changing energy matrix will not occur without a profound shift in technologies and human behaviours. DERs are an important part of this transformation. Decision makers, consumers and investors are responsible for embracing the innovative technologies and service solutions.

'Distributed energy resources (DER) are small technologies — including rooftop solar, energy storage, microgrids, load control, energy efficiency, and communication and control technologies — that produce, store, manage, and reduce the use of energy. They are small enough to be "distributed" all around the grid, close to customers and away from centrally located power plants' (Paulos, 2018). DER solutions can serve a whole community, with the capacity to be built out across entire cities. Rapidly deployable, they can efficiently increase the resilience of energy systems, improve energy security, empower communities, reduce local and regional CO_2 emissions and, depending on which systems are adopted, foster energy price decreases.

DER are at the heart of the ongoing power-sector transformation which, in turn, is being accelerated by three main innovation trends: i) electrification; ii) decentralisation; and iii) digitalisation. These paradigm changing trends are unlocking system flexibility, enabling an increasingly high share of VRE penetration (Figure 7). Simultaneously, this transformation is altering the roles and responsibilities of existing actors while opening doors to new entrants throughout the sector (IRENA, 2019b).

Decentralisation of power systems

The emergence of DERs connected at the consumer's end, such as rooftop solar PV, micro wind turbines, "behind the meter" battery energy storage systems, heat pumps and plug-in electric vehicles are decentralising the power system. Though wind and PV electricity generation are largely centralised today, distributed generation, notably rooftop PV, which currently accounts for only around 1% of all electricity generation, is growing at an accelerated pace. Distributed storage has also gained momentum. A behind-the-meter storage business model allows customers to store the electricity generated by their rooftop solar panels and use it later when needed or sell it on to the grid (IRENA, 2019b). DERs can be important sources of flexibility through, for example, demand response measures and aggregator business models.

Electrification of end-use sectors

Electrification with renewable power constitutes a cornerstone for the decarbonisation of the end-use sectors: transport, buildings and industry. As new electricity loads are connected to power systems, they can become sources of flexibility helping to further integrate renewables. However, if not well managed, these new loads could result in high additional power capacity needs, straining the grid and requiring additional investment to reinforce electric infrastructure. On the other hand, many of these new loads are inherently flexible. They include batteries (such as electric vehicle batteries) and thermal storage (such as heat pumps or electric boilers with hot water tanks) with uses that can be shifted over time, helping to smooth out demand patterns to match the availability of generation and grid capacity.

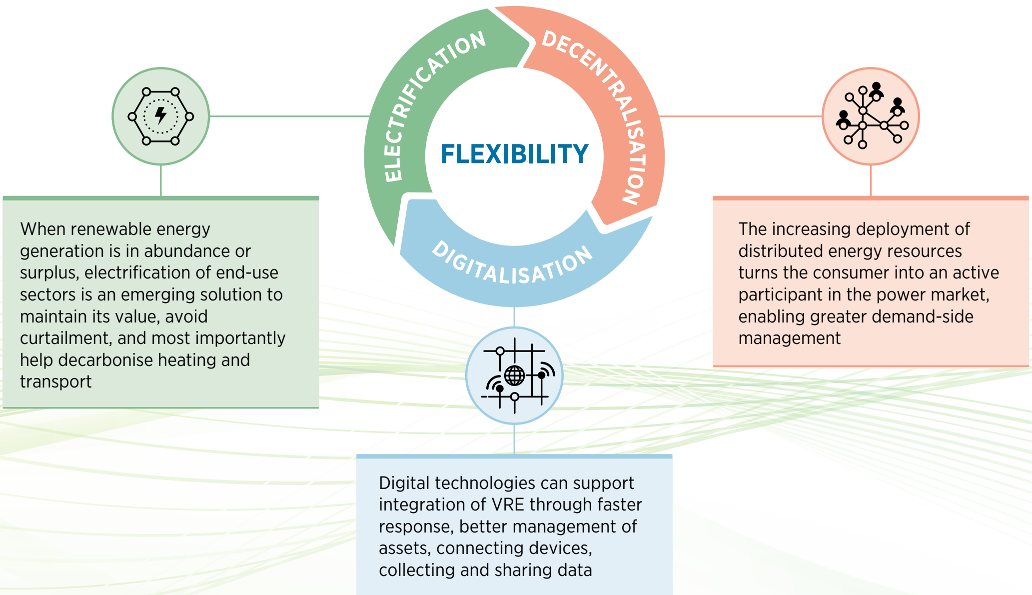
Digitalisation of the power sector

The application of digital monitoring and control technologies – so-called "smart technology" – into electrical generation and transmission systems has been an important trend for several decades. Penetrating deeper into power systems, the wider usage of smart meters and sensors, the application of the Internet of Things (IoT) plus the use of large amounts of data with artificial intelligence have created opportunities to provide new services throughout the system. Digital technologies support the transformation of the power sector through improved monitoring of assets and their performance, more refined operations and closer to real-time control, implementation of new market designs, and the emergence of new business models.

Digitalisation is a key enabler to amplify the energy transformation by managing large amounts of data and optimising systems with many small generation units. Enhanced communication, automated smart contracts based on blockchain technology and enhanced controls enable DERs to be bundled, creating so called "aggregators". Aside from offering a range of useful energy services, distributed generation and enabling technologies have become sources of valuable data that can provide insights into consumer behaviour and enable better planning by grid operators. Improved communication enables system operators to obtain valuable information about the location of distributed energy sources and their provision of energy and energy services in real time. It also becomes possible to enhance forecasts of production and consumption levels. Overall, these developments provide greater flexibility to integrate variable energy sources, as well as better management of assets and operations.

Moreover, the growing relevance of digitalisation is also due to advances in decentralisation and electrification. Decentralisation results in large numbers of new small generators, mainly rooftop PV. Electrification of transport and heat involves large quantities of new loads, such as EVs, heat pumps and electric boilers. All these new assets on the supply side (due to decentralisation) and demand side (due to electrification) have an impact on power systems, making monitoring, management and control crucial for the success of the energy transformation.

Figure 7: Innovation trends

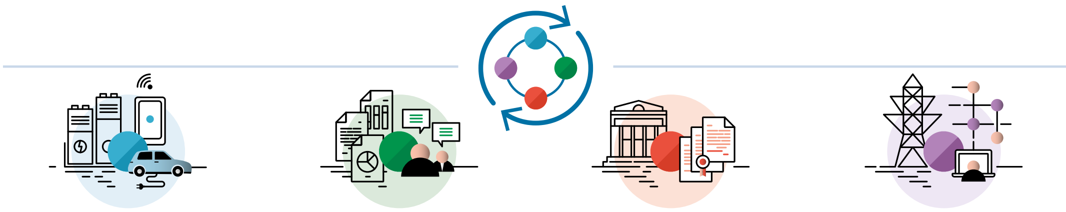


Source: IRENA (2019b)

The dynamic landscape of innovations for the energy transformation includes innovations in enabling technologies, market design, business models and systems operation

Though there is no lack of innovation to address the integration of VRE in power systems, IRENA has investigated the landscape of innovations and identified 30 innovation types across **four innovation dimensions: enabling technology, business model, market design and system operation,** as depicted in Figure 8 (IRENA, 2019b).

Figure 8: The landscape of innovations for the power-sector transformation



ENABLING TECHNOLOGIES

1 Utility-scale batteries
2 Behind-the-meter batteries

3 Electric-vehicle smart charging
4 Renewable power-to-heat
5 Renewable power-to-hydrogen

6 Internet of things
7 Artificial intelligence and big data
8 Blockchain

9 Renewable mini-grids
10 Supergrids

11 Flexibility in conventional power plants

BUSINESS MODELS

12 Aggregators
13 Peer-to-peer electricity trading
14 Energy-as-a-service

15 Community-ownership models
16 Pay-as-you-go models

MARKET DESIGN

17 Increasing time granularity in electricity markets
18 Increasing space granularity in electricity markets
19 Innovative ancillary services
20 Re-designing capacity markets
21 Regional markets

22 Time-of-use tariffs
23 Market integration of distributed energy resources
24 Net billing schemes

SYSTEM OPERATION

25 Future role of distribution system operators
26 Co-operation between transmission and distribution system operators

27 Advanced forecasting of variable renewable power generation
28 Innovative operation of pumped hydropower storage

29 Virtual power lines
30 Dynamic line rating

Source: IRENA (2019b)

Many modifications are necessary to enable and foster the necessary energy matrix transformation. Individuals continue to play a key role in this innovation landscape. **In fact, prioritising the expansion of renewable energy mini-grids, community ownership models and DERs will help significantly to create new business models that empower consumers. This can turn individuals into active players in the energy transition.**

4. DECENTRALISED SOLUTIONS FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY DEPLOYMENT

Decades of investment in research have produced well-established technology solutions to reduce the energy sector's GHG emissions. A low-carbon agenda moving away from fossil-based energy production, increasing renewables' share of the energy mix and pushing economies along sustainable pathways is now being adopted globally. However, whilst these strategies are mainly focused on shifting the energy production processes to cut emissions, they still do not include and consider the role that people, and communities as a whole, can play (NCC, 2016).

In fact, people are at the heart of this paradigm shift, functioning together as instruments of change. Consumers can be more than passive energy users and act as active stakeholders engaged in the development of new social practices around energy use. Embracing these perspectives allows decision makers to formulate new ways to engage the public on climate and energy issues, ultimately encouraging society to adopt more low-carbon behaviours (NCC, 2016).

However, such changes require a more thorough understanding of society's complex interactions with energy systems and ultimately a re-conceptualisation of the role people play in the transformation of energy systems.

There are various methods by which to engage in the energy transformation through DERs. These include traditional direct investment from consumers in distributed renewable energy; through energy communities, which can be applied to any societal type or context, namely cities, islands and rural off-grid areas; and through corporate sourcing for renewable energy.

4.1 METHODS FOR UTILISING DISTRIBUTED ENERGY RESOURCES

DERs can be integrated through direct investment by consumers, corporate sourcing or community ownership models.

Traditional direct investment from consumers in DERs

More traditional and well-established methods to accelerate consumers' investments in renewable energy technologies are represented by feed-in tariffs (FiTs), net metering and virtual net metering. While all three methods allow energy producers (i.e., homeowners) to be compensated for the energy they feed back into the grid, they differ in the implementation mechanism.

A **Feed-in Tariff (FiT)** is an energy supply policy involving administratively set feed-in pricing policies focused on supporting the development of new renewable energy projects by offering long-term purchase agreements for the sale of renewable energy electricity. FiTs have been instrumental in encouraging renewable energy projects worldwide, since they provide a stable income to generators and help increase the bankability of projects. By 2017, FITs had been adopted by more than 80 countries, up from just 34 in 2005. Their main challenge involves getting the tariff or premium level just right and adjusting it as needed. For example, an inefficient tariff can result in a price that is too low to attract developers or one that is too high – leading to windfall profits, potentially high consumer tariffs or a strain on the government budget (IRENA, IEA and REN21, 2018).

Net metering is a measure that promotes the use of distributed generation (DG) for local consumption by providing compensation to distributed generators owners. A self-consumption scheme usually allows DG system owners to reduce or eliminate the variable charge portion of their electricity bills. In a net metering scheme, the compensation is in energetic terms (i.e., credit in kilowatt-hours [kWh]), and the credit can be applied to offset consumption of electricity within the current billing cycle (e.g., one month) and often in future billing cycles as well (IRENA, IEA and REN21, 2018).

Finally, **virtual net metering** utilises the same compensation mechanism and billing schemes as net metering without requiring that a customer's DG system (or share of a DG system) be located directly on site. Virtual net metering has been implemented as a mechanism to facilitate participation in shared renewable energy projects, in which multiple customers can receive net metering credits tied to their portion of a single DG system (NREL, 2017).

Corporate sourcing for renewable energy

A growing number of companies around the world are voluntarily and actively procuring or investing in self-generation of renewable energy. Global electricity markets are constantly evolving to meet the growing demand for renewable energy required by all categories of consumers, including companies. While some markets offer multiple procurement strategies, sourcing remains challenging, if not impossible, in others. The models available to companies and entities depend greatly on established policy frameworks, companies' operations and their capacities to procure and produce electricity (IRENA, 2018b).

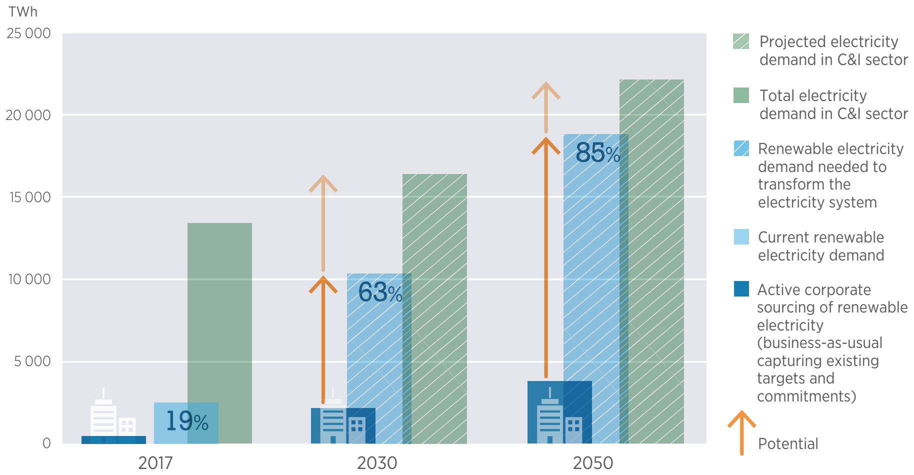
IRENA estimates that at the end of 2017, the overall corporate renewable electricity market reached 465 TWh, representing approximately 3.5% of total electricity demand in the commercial & industrial sector. This estimate is based on available market data and a conservative extrapolation of data reported by some 2 400 companies (IRENA, 2018b).

Most of the active corporate sourcing of renewables was self-generated through other DERs. Other models to source renewable energy include the purchase of unbundled energy attribute certificates (EACs), signing of a longer-term power purchase agreement (PPA) directly with an independent power producer, and green electricity procurement.

IRENA estimates that the production of renewable energy for the self-consumption market was 165 TWh in 2017. This production, commonly from distributed energy resources, takes place in almost every country that permits some form of grid connection at a rate of compensation, through net-metering, or FiT schemes. As of 2016, 83 countries had FiTs or premium payment policies in place and 55 countries had net metering policies (IRENA, 2018b)

While most of the corporate self-generation of renewable electricity is grid-connected, generating renewable energy off the grid has become an attractive option for companies with operations in remote areas that want to secure a stable energy supply. Renewable energy off-grid solutions are increasingly being deployed by the materials sector including, for example, mining companies.

Figure 9: Potential for corporate sourcing of renewable electricity



Note: C&I = commercial and industrial
Source: IRENA (2019b)

Corporations can significantly contribute to the needed acceleration of renewable energy deployment through active and more direct procurement. Active sourcing of renewable energy is estimated to reach 2 150 TWh by 2030 and 3 800 TWh by 2050. Corresponding to only 20% of the total renewable electricity demand in the commercial and industrial sector in 2050, it is far from meeting the objectives of the Paris Agreement. Figure 9 outlines active corporate renewable electricity procurement to 2050 and illustrates the potential for companies to drive the global energy transformation.

If corporations continue to raise their ambitions with support from enabling frameworks, the potential for corporate sourcing is vast. Its contribution to the energy transformation could reach up to 100% of the total renewable electricity demand (22 000 TWh) in the commercial and industrial sector. Indeed, more than 110 companies were already obtaining at least 85% of their electricity from renewable sources at the end of 2017, demonstrating that high ambitions are feasible. But all companies will have to strive for higher shares of direct renewable electricity in their energy consumption.

Implementation challenges

- **Political**
  - » lack of internal as well as shareholders' commitment to a renewable energy target
  - » lack of a credible and solid system of certification and tracking of renewable energy attributes
- **Regulatory**
  - » artificial barriers making it less likely that renewable electricity will make economic sense for a company
- **System transparency**
  - » lack of a well-established internal self-reporting process following available best practices
  - » weak international guidelines on corporate reporting and lack of commitment from companies to adopt them.

Renewable energy community approach

Community ownership (CO) in the energy sector refers to the collective ownership and management of energy-related assets, such as energy generation systems, energy storage systems, energy efficiency systems, and district heating and cooling (DHC) systems. Normally, these energy-related assets are handled by a group of people from the community through a number of different legal models, depending on the country or geography of operation. The innovative aspect of CO models lies in the role of the community and its participants, which goes beyond renewable energy generation. Nowadays, CO models cover the entire energy value chain. They can provide localised generation and supply of power and heat, energy services (for example, storage, energy sales to surrounding communities), enable efficient energy use, and provide flexibility to the energy system (IRENA, forthcoming).

CO structures involve participation from households, individuals and businesses to jointly invest in the development and operation of energy-related assets. It allows participants to unite and act on energy needs that are specific to their local requirements while encouraging leadership and democratic control. Community energy production operated with the participation and under the ownership of citizens or members of a defined community takes place on both large and small scales. Requirements for communities to qualify as a community energy project depend on the respective policy's actual intent to democratise the energy assets and to create a distributed energy system.

A community's economic and operational participation in renewable energy projects is a key factor for building community acceptance and support for the development of renewable energy projects (REN21, 2017).

Embracing a diverse range of approaches is key to successful community energy development and accelerated renewable energy deployment. Policy makers should be aware of the specific circumstances related to regional, economic, social and cultural differences, as well as the various technology potentials (IRENA, 2017a).

Industrialised countries have created and conducted national programmes dedicated to the support of community-based planning and ownership, which typically involve energy co-operatives and local ownership of projects combined with FiT schemes. This type of structure creates a double benefit, as it enables local engagement and acceptance of projects, as well as lower energy bills for all connected consumers.

In developing countries in general, there is a significant need to scale up energy access programmes for the hundreds of millions of people who still do not have access to electricity. Despite the wide range of national and international programmes supporting electrification schemes, the capital and human resources needed are huge and the current programmes are not sufficient. The key obstacles for rural electrification projects are: i) availability of finance at reasonable cost; ii) mobilising/ capitalising equity for rural communities; iii) availability of technical and economic information; and iv) availability of trained staff.

CO can have different legal models based on the main purpose of the legal entity, ownership structure, distribution and sharing of profits, and the level of democratic governance or control. In particular, these are detailed in the table below.

Table 1: Community ownership legal models: Legal forms and examples

Legal form	Description	Example
Co-operatives	Jointly owned by its members for fulfilment of their common economic, social and/or cultural goals.	In Brixton, London, three solar rooftop PV projects have been set up under the co-operative structure. The projects have been implemented on council estates, and residents of these estates are the members of the co-operative society. Each member earns an equal dividend of about 3-5% of their initial investment. Through a dedicated fund, 10-20% of annual revenue is used for energy efficiency improvements, education initiatives and reducing cold draughts (Smedley, 2014).
Partnerships	Composed of individual partners limited by the liability of their share amount in the partnership firm and sharing benefits/profits from the project.	Windcentrale is a Dutch crowdfunding platform that sells shares to individual investors for ownership in wind turbines. Each turbine is owned by a co-operative. Holding shares of the turbine does not give financial gains but provides, on average, 500 kWh of electricity per year generated through the turbine (Windcentrale, n.d.).
Not-for-profit organisations	Formed by investments from its members, who, however, do not receive any profits. These are instead used for further re-investment in projects focused on community development.	Sun Co-operative Inc. is a not-for-profit organisation based in Ontario, Canada. The organisation builds solar energy projects in the Greater Sudbury area with proceeds going to reThink Green, a network of local community organisations, and a Community Environmental Fund for the development of local community environmental projects (SUN Co-operative Inc., 2018).
Community trusts and foundations	Use the returns from investments made in community projects for specific local purposes. These benefits are also shared with people who are not able to directly invest in these projects. Content	The University of Nottingham and Meadows Partnership Trust (MPT), Nottingham, UK have begun developing a network of household battery storage systems in Nottingham. The batteries will store excess solar energy during off-peak hours when the electricity rates are lower for utilisation in peak hours when the grid electricity rates are higher. This will help consumers save on peak load charges in their energy bills (University of Nottingham, 2017).
Housing associations	A form of not-for-profit private organisations that offer housing to low-income families and individuals.	In Denmark, Hvidovrebo Section 6 is a housing estate located on the outskirts of Copenhagen. Based on a model of "tenants' democracy", the tenants decided through consensus to install rooftop solar and solar thermal units on roofs that were already in need of renovations. The project will span ten roofs throughout the estate and is expected to produce 120 160 MWh electricity per year. This will be financed by residents through additional rent payments or mortgage payments. (Roberts, Bodman and Rybski, 2014).

Source: IRENA (forthcoming)

Implementation challenges

- **Regulatory**
  - » lack of support programmes favouring community energy-based models
  - » discrimination against smaller investors
- **Financial**
  - » communities' inability to raise equity
  - » communities' lack of access to third-party finance
- **Unclear legal definition and lack of awareness**
  - » unclear definitions can result in business advantages for investments that in substance would not fall under the above-suggested definition of community energy
- **Cultural**
  - » lack of democratic decision-making and shared ownership rules
  - » unequal distribution of benefits of energy community projects within the hosting community

Box 4: Japan's "Do it Ourselves" installation model for rooftop solar

Aided by FiTs, renewable energy community projects have significantly increased in Japan following the 2011 Great East Japan Earthquake and subsequent Fukushima nuclear disaster (The Beam Magazine, 2017).

A community group in Tama City initiated a community project, with the support of the Ministry of the Environment. In September 2016, a community solar start-up company, Tama Empower, was established to develop a new participatory installation model for rooftop solar called "Do it Ourselves" (DiO). This model provides customers not only with electricity from PV, but also a deep understanding and a tangible feeling of community ownership.

The DiO scheme consists of four main pillars:

- Building owners' and tenants' participation in installation
- Customers participate in training sessions given by Tama Empower about the solar PV equipment they are going to install.
- Cost reduction through process breakdown and role sharing
- Since solar installation costs in Japan are very high, DiO targeted reducing them through standardising and breaking down the construction process into three categories: 1) processes workable by lay people; 2) processes workable by people trained by professionals; and 3) processes workable only by professionals.
- Carefully selected solar PV equipment
- The DiO solar PV equipment is carefully selected to meet both durability and simplicity requirements enabling participatory installation.
- Institutional operation and maintenance (O&M) support
- DiO covers the O&M of installed solar PV under a partnership with professional construction builders and electrical engineers.

4.2 CITY AND ISLAND/OFF-GRID APPLICATIONS: DIFFERENT USES OF DISTRIBUTED ENERGY RESOURCES

DER application: Cities

The world's largest cities currently consume about two-thirds of global energy demand and create over 70% of global CO_2 emissions (C40, 2012). Urbanisation is expected to continue to 2050 and likely beyond, demanding ever more energy sources. To reduce carbon emissions to well under the 2°C climate target set under the Paris Agreement, low-carbon energy systems must be scaled up and adopted. Along with measures to improve energy efficiency, the use of solar PV, solar thermal and geothermal technologies for heating, heat pumps, electric vehicles, energy storage, DERs and other systems can contribute to closing the gap without putting more pressure on the environment (IRENA, 2016b). By doing so, multiple social and economic benefits could be also gained at the local level.

Characteristics

Broadly, DERs for cities can be divided into two categories: 1) on-site generation, for instance, rooftop or building integrated solar PV for power and solar thermal for heating; and 2) distribution networks with smart local grids for power generation and DHC for thermal use.

Distributed renewable energy generators can also help increase the reliability and resilience of power grids by making them less vulnerable to disruptions caused by natural disasters.

In addition to benefitting from the technology improvements in, for example, solar PV modules performance, technical advances in manufacturing automation, economies of scale and reductions in balance of system costs – which have driven down installed costs globally – on-site generation also minimises the needs for electricity transmission, leading to further reductions of the system cost.

Thermal energy storage (TES) systems can be used in buildings and industrial processes to help balance energy demand and supply on a daily, weekly and even seasonal basis. In normal applications, approximately half of the energy consumed by buildings is in the form of thermal energy, the demand for which may vary during any given day and from one day to the next (IRENA, 2017c). Therefore, TES systems can reduce peak demand, the need for fossil fuels, CO_2 emissions and costs, while increasing overall energy efficiency.

DHC systems can also be more efficient and cost-effective ways to heat and cool urban areas, subject to the population density. The economies of scale and increased generation efficiency associated with centralised production can significantly reduce costs if the demand is high enough without the network areas. As cities expand their DHC networks, careful planning provides more freedom to set the system's operating parameters, thereby allowing higher shares of renewables (IRENA, 2017c).

Cities as planners and regulators

Cities play multiple roles in promoting the use of renewable energy, including as target-setters and planners, consumers (generating or procuring energy services; aggregating urban demand), regulators and facilitators (conducting consultations with urban stakeholders), and financiers (IRENA, 2016b). This section focuses on the planning and regulatory aspects, followed by a discussion of the roles of investors and consumers.

Setting renewables energy targets

A growing number of cities have set targets to increase the share of renewables in their energy mix. Many are using these targets to align policies across infrastructure networks (water supply, transport, electricity, heat, waste, etc.) to create synergies and align renewable targets with climate and efficiency targets. Their effectiveness, however, critically rests on political commitment and public and private support (IRENA, 2015). In some countries, cities have exceeded national targets. Canberra, Malmö and Vancouver, for example, are working towards 100% renewable energy (IRENA, 2018c). Many cities aiming for 100% renewables include a diversity of target types and strategies. Some are short-term and directly within the control of cities' jurisdiction, such as targets aiming for 100% renewable electricity consumption in municipal buildings. Others are more ambitious, aiming to induce deep structural transformation beyond the electricity sector to both heating and transport and across both public and private users.

Integrated urban planning

Integrated urban planning requires urban decision makers to co-ordinate both horizontally across municipal departments and local stakeholders, as well as vertically across multiple levels of governance. Incorporating renewable energy targets into planning and sectoral policies can significantly increase energy efficiency both for urban infrastructure systems and on the neighbourhood level (IRENA, 2016b).

Distributed renewable energy generators can also help increase the reliability and resilience of power grids by making them less vulnerable to disruptions caused by natural disasters. Following the 2011 tsunami, Higashimatsushima City, Japan, which suffered heavily from both lives lost and electricity outages, began building the nation's first disaster-proof microgrid community powered by solar PV and bio-diesel generators (Movellan, 2015a).

Cities as regulators

City governments can also promote renewable energy in their role as regulators. Mechanisms include land-use planning and zoning, business and residential building permitting, urban building codes, solar ordinances, grid connection regulations, technical standards, land-use planning, and public housing programmes (IRENA, 2016b).

Municipal governments can help streamline municipal building codes and develop social housing programmes (WWI, 2016). Municipal thermal mandates, also known as Solar Ordinances, are a compelling example of how cities can encourage solar deployment. Ordinances adopted by Barcelona were eventually replicated by many other cities in Spain. Likewise, an ordinance developed in Sao Paulo, Brazil, became a model for other municipalities in the country. The Dubai Electricity and Water Authority's (DEWA) net metering programme, called "Shams Dubai", is another inspiring initiative. Grid-connected solar PV plants are compensated for the surplus electricity fed to the grid that is "banked" for later consumption. The programme only allows for the offsetting of demand and does not allow any payments for excess generation. DEWA has received many applications for installation, including the Dubai Ports Authority, which announced in 2015 that they will add between 30 to 40 megawatts (MW) of capacity on their premises under the programme (IRENA, 2016b).

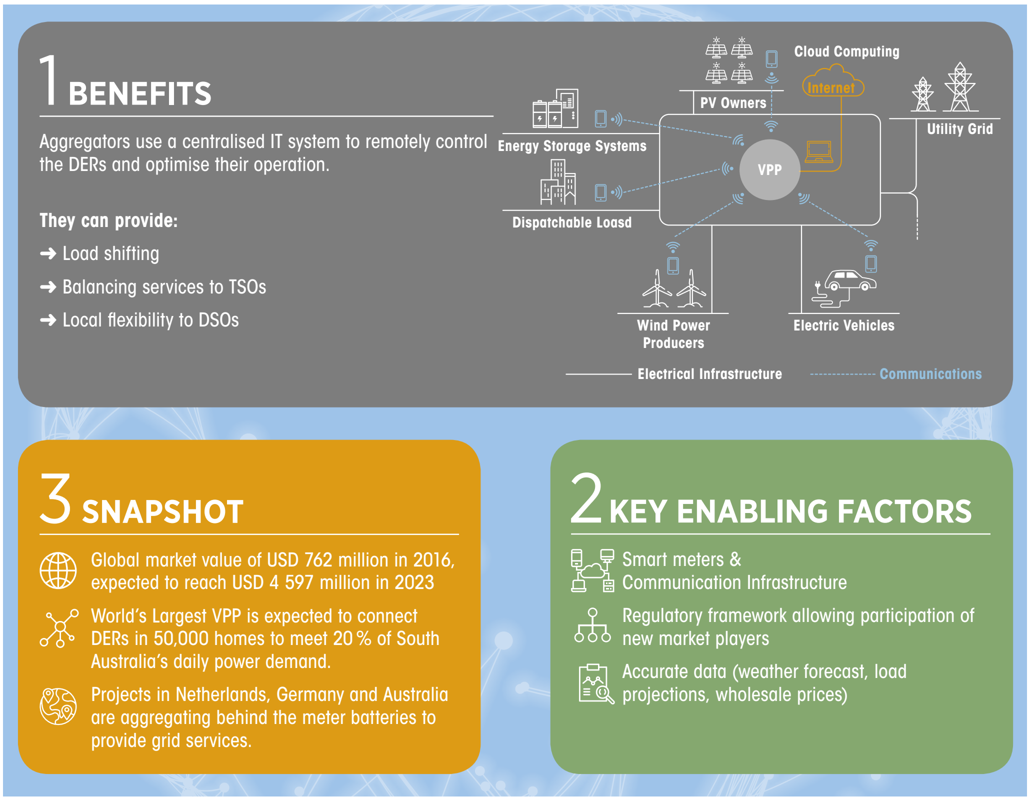
Cities as financiers of renewable energy projects

One innovative financing mechanism used by local governments is to subsidise low-interest loans for homeowners to invest in renewable energy or energy efficiency, which they gradually pay back through slightly higher property taxes. This mechanism underpins the property-assessed clean energy (PACE) financing model used in the United States. Municipal green bonds are another mechanism to finance renewable energy investment. Green bonds can provide municipal governments with access to low-cost capital to meet their energy investment needs (IRENA, 2016b). For urban residents with limited disposable income or savings to invest in energy alternatives, so-called "on-bill financing" relies on projected future electricity bill savings as a revenue stream to fund investments in renewables or energy efficiency.

Cities as advocates and facilitators

Cities can pilot demonstration projects, conduct stakeholder consultations and feasibility studies, and disseminate relevant information to companies, educational facilities and media outlets. Studies show that despite their relatively limited formal powers over key energy decisions, cities can considerably leverage their actions and resources, in particular by collaborating with the private sector and civil society (C40 and ARUP, 2015). Cities can also greatly benefit from sharing experiences with partner communities worldwide.

Figure 10: Aggregators: Key facts and figures



Source: IRENA (2019c)

Cities as aggregators of demand

Community Choice Aggregation (CCA) allows municipalities or groups of municipalities to form new entities known as community choice aggregators that procure electricity in bulk to cover the combined load of residents and businesses. By aggregating energy demand, cities can negotiate competitive rates with power suppliers and developers, often between 3% and 10% lower than utility rates (US LEAN, 2015). Much of the electricity comes from independent power producers that provide renewable energy to the CCA under long-term PPAs. The local utility remains responsible for the transmission and distribution of the power, as well as for billing, collection and other customer services.

Increasingly popular worldwide, recent CCA examples include several municipal governments in the Japanese prefectures of Yamagata and Gunma providing renewable energy to consumers. In Nakanojo, Gunma Prefecture, where the city owns 60% of Nakanojo Electric, they are buying electricity from town-owned PV systems and reselling it to 30 public facilities, including schools and community centres, at rates lower than those offered by Tokyo Power Electric Company (TEPCO), the major national utility. Neighbouring Yamagata Prefecture is also planning to set up the publicly owned Yamagata Power Company to offer renewable energy to its consumers based on a CCA programme (Movellan, 2015b).

Cities as investors and consumers

Cities own municipal infrastructure, and city institutions are also direct energy consumers.

Municipal infrastructure ownership

The ownership of energy systems and their regulatory links with city governments is a key aspect in understanding the role of municipal governments in promoting the use of renewable energy (Rezessy et al., 2006).

- **Power supply**

  The mandate for energy supply and urban electrification in cities often lies with national energy utilities and national regulatory authorities. Globally, however, many cities are "re-municipalising" their utilities into local public and collective ownership (WWI, 2016). While the specific local circumstances vary, the concept of local community participation is important given the broad socio-economic benefits they bring to regional residents, mainly in terms of local jobs and value creation while also addressing renewable energy needs. In Nordic countries, where numerous cities directly own their municipal energy utilities, they are often the leading developers, investors and owners of wind, hydro and bioenergy power (and in the case of bioenergy, also heat) generation. In Germany, local utilities gained in importance after electricity liberalisation began in the late 1990s, playing a key role in the nation's clean energy transition, the so-called "Energiewende". In Japan, as of the end of 2015, 14 cities had formed companies to generate renewable power from local resources. Following the full deregulation of Japan's electricity market beginning in 2016, the government now aims to have 1 000 such city-operated power companies established by 2021 (Negishi, 2015).

- **District energy**

  While many cities have authority over the public distribution of electricity, gas, heating and cooling, some also own the underground networks through which energy and communications services are supplied. Vienna, Austria, for example, owns its utility companies for district heating, gas and electricity and exerts control to promote the share of sustainable energy (Grubler et al., 2012).

- **Street lighting**

  With an estimated 300 million street lights worldwide, public lighting plays an important role in global energy consumption and can consume as much as 40% of a city's annual energy budget. Though almost all cities have some degree of control over outdoor street lighting, most have full control (IRENA and ICLEI, 2013). Local governments can play a proactive role by providing funding and managing the procurement, installation and oversight of lights. Stand-alone PV-powered street lighting is particularly beneficial for areas that do not have power grids, especially in rapidly urbanising areas. In informal settlements, or in underdeveloped areas of a city, stand-alone powered street lights can enable increased social productivity at night in areas such as education, community meetings and improved security. Renewable energy can also be used in areas where the grid is present but not reliable. In Brazil, the local government of Rio de Janeiro installed more than 4 300 solar lights along a 73-km stretch of the Arco Metropolitano motorway. This has enhanced the level of security on the highway, without further stressing the local energy grid (IRENA and ICLEI, 2013).

City institutions as direct consumers of renewables

Through their energy use in hospitals, schools, offices and street lighting, local governments are significant energy consumers in their own right. Their high market share means they can create a critical mass in favour of renewable energy, especially when efforts are co-ordinated at regional and national levels. To do this, cities can use a range of policy instruments – such as green procurement and auctions – and in some cases, act as off-takers in PPAs (NREAL, 2014). Many cities can control or influence the source of energy they purchase, particularly when they own their own utilities. In other cases, franchise agreements between cities as consumers and utilities as suppliers can be instrumental, and auctions can be used to procure renewable energy. In 2011, Austin, Texas, made history as the largest local government in the United States to procure 100% renewable energy for all its municipal buildings and facilities, through a programme called GreenChoice (IRENA, 2016b).

Implementation challenges

- **Political landscape and target setting**
  - challenging cross-department co-ordination
  - lack of reforms in energy governance mechanisms
  - lack of long-term political commitments

- **Operation**
  - in some cases, cities are both owners and operators of municipal energy utilities and they can influence the energy mix as well as develop and invest in renewable power plants

- **Regulatory landscapes**
  - lack of a solid regulatory framework, including building codes, grid-connection rules, technical standards, land-use planning, public housing programmes and other specific measures such as solar ordinances to promote renewable energy (IRENA, 2016b)

- **Financing**
  - lack of incentives or low-interest loans to promote the uptake of renewable energy solutions (IRENA, 2016b)
  - lack of funding for local governments and difficulties to identify and select successful business models

- **Advocacy, awareness and knowledge**
  - lack of skilled personnel
  - lack of awareness-raising programmes for citizens as well as training programmes for practitioners.

Box 5: Energy transition strategy for Zhangjiakou City, China

With an abundance of renewable energy resources, Zhangjiakou, a city adjacent to Beijing, China, plays an important role in maintaining regional environmental sustainability and is supporting the capital city in delivering a low-carbon Winter Olympics in 2022.

For a city that has traditionally relied on coal for energy production and on energy-intensive industries for economic growth, this has raised an array of daunting challenges.

The metropolitan region is a large producer of wind power – enough to cover its own energy demand. However, curtailment issues need to be resolved, and increasing self-consumption by the city might be preferable to feeding the wind electricity into the grid (i.e., addressing curtailment more effectively). The relationship among local, provincial and central governments plays an important role in decision-making.

To facilitate the city's transition, the Chinese State Council gave Zhangjiakou the opportunity to establish a National Renewable Energy Development Demonstration Zone – the first of its kind in China – to capitalise on the city's 40 GW of wind and 30 GW of solar energy potential.

With the policy support in place, Zhangjiakou has developed not only medium-term targets on scaling up the shares of renewables in the energy mix, but also explored the strategic alignment of the energy transition with the transformation of the industrial and economic sectors. The municipal decision makers envision that the local economy will gradually be weaned off conventional industries such as coal mining, iron and steel making, and cement and glass manufacturing. This was a challenging decision to make given that the city has almost 300 million tonnes of coal reserves, accounting for nearly 20% of the regional total, and that the closure of the local steel mill would affect the lives of over 130 000 people.

However, the municipal leaders realised that new industries, such as the production of hydrogen fuel cells and the production of hydrogen through electrolysis using renewable electricity, coupled with smart grid technologies and management of data facilities powered by renewable electricity, fit well with the local situation, offering the city a unique leapfrogging opportunity. As renewable energy technology costs continue to fall, the marginal cost of electricity generation from solar and wind is soon expected to be cost-competitive with conventional energy sources. Combined with energy storage facilities and smart control systems, the reliability of the power supply can be ensured.

By implementing this strategy, Zhangjiakou hopes to attractively position itself in the next wave of industrial and technology innovations. It also hopes to attract more sustainable businesses which in turn will enable the development and creation of more high-end jobs.

Source: The Municipal Government of Zhangjiakou City, based on interviews with the key policy makers of the city including Mr. GUO Junfeng, Director of Zhangjiakou Energy Agency and Mr. Liu Feng, Division Chief, Renewable Energy Division of Zhangjiakou Energy Agency

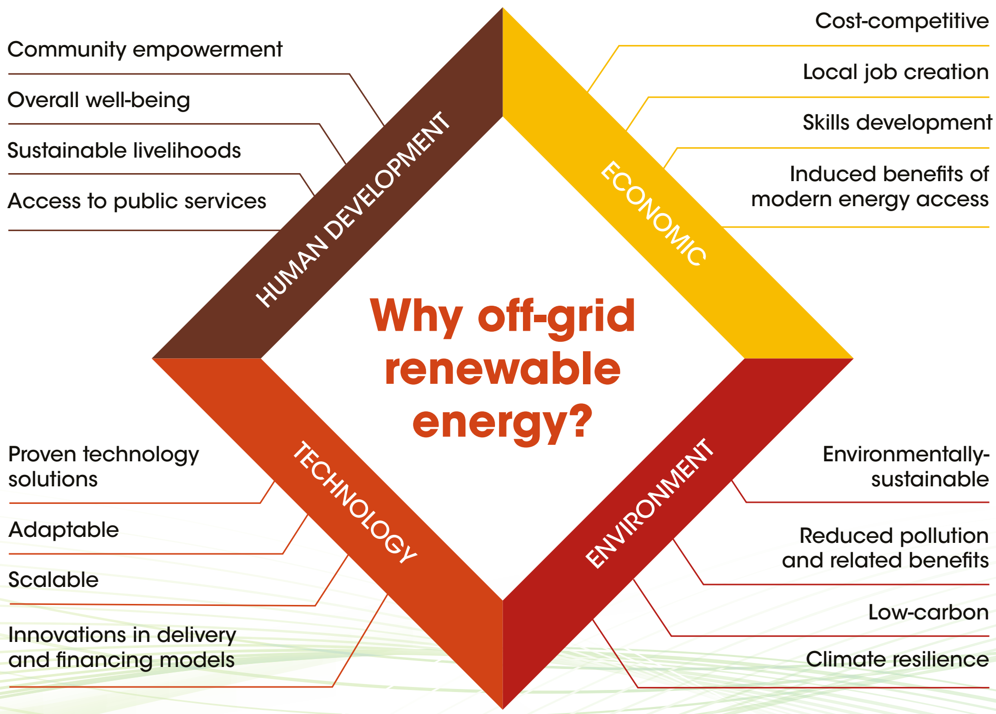
DER application: Islands and rural off-grid solutions

Characteristics

Dramatic cost reductions, technology advancements and enabling policies have driven the adoption of off-grid renewable energy technologies globally. IRENA estimates that approximately 133 million people were served by such technologies in 2016, including stand-alone systems and mini-grids. An estimated 9 million people connected to renewable mini-grids in 2016 and 124 million utilised solar lighting and solar home solutions (IRENA, 2019d).

The convergence of several powerful factors has opened a window of opportunity for achieving universal access to electricity supported by off-grid solutions (Figure 11). Rapid decreases in technology costs have meant that off-grid renewable energy solutions are now the cost-competitive choice for expanding electricity access in many unelectrified areas. Since 2009, for instance, solar PV module costs have fallen by more than 80% while, globally, the cost of solar PV power declined by 73% from 2010 to 2017 (IRENA, 2018d). Off-grid renewable energy capacity has witnessed a spectacular three-fold increase from under 2 GW in 2008 to over 6.5 GW in 2017. While a proportion of the deployed capacity is to support household electrification, a majority (83%) is dedicated to industrial (e.g., co-generation), commercial (e.g., powering telecommunication infrastructure) and public end-uses (e.g., street lighting and water pumping).

Figure 11: Case for off-grid renewable energy solutions



Source: IRENA (2019d)

Between 2007 and 2017, rural off-grid renewable energy capacity increased to nearly 1.2 GW in 2017. Through 2030, renewable energy sources will power an estimated 60% of new access connections, mainly through mini-grids (IEA, 2017).

Throughout Africa, the deployment of solar technologies has been a key driver of growth in off-grid capacity, with over 820 MW installed as solar lights, home systems and mini-grids and for commercial/public services. Between 2011 and 2016, the population served by off-grid solutions exploded from 2 million to over 53 million. Solar lights have driven this rapid growth, but about 10% also rely on off-grid solar. Due in part to innovative technology and financing schemes (such as Pay-As-You-Go) and other mobile payment platforms, solar home systems now serve over 4 million people (IRENA, 2018f).

In Africa, bioenergy also contributes to the development of rural off-grid renewable energy, very often complementing solar systems, as described in the recent IRENA report *Sustainable Rural Bioenergy Solutions in Sub-Saharan Africa: A Collection of Good Practices* (IRENA, 2018e). Several examples of sustainable rural bioenergy solutions are highlighted in the report. For example, the Institute for Sustainable Energy and Environmental Solutions (ISEES), a Ghanaian-based NGO, advocates, builds capacity for and deploys climate-smart, innovative renewable energy technologies (cookstoves and solar and biogas systems) to low-income households and small-scale agro-processing businesses headed by women. These clients would otherwise not have access to such technologies, which ISEES distributes through community-led business and marketing models.

One of the technologies promoted by the institute – especially to women performing agro-processing in rural areas – is the biomass gasifier stove. This technology allows for raw agricultural waste to be reused/recycled as fuel for heating during the processing of crops. This is a waste-to-energy concept. Common agro-processing industries in Ghana include cassava, shea butter, palm kernel oil, mushroom sterilisation, palm oil, gari, groundnut, fish, and even fruit and leaf drying. The biomass gasifier stoves are able to burn raw waste without smoke, thus contributing to efficient cooking. The ash from biomass gasifier stoves can also be used to improve soil fertility.

Another interesting example is the biomass gasification system developed by Mandulis Energy in co-operation with Imperial College London. The system processes solid biomass in a low-oxygen environment, converting it into gas fuel (syngas) and biochar (a solid biomass fuel, similar to coal). The syngas can be used to generate electricity as well as heat. Biochar is used to make briquettes as an alternative to wood charcoal. Mandulis Energy has already started 8 MW (16 sites of 500 kW) of off-grid power generation sites as well as briquette production.

In Asia, off-grid renewables electrical service capacity has increased almost eight-fold over the last decade to over 76 million users, with total capacity increasing to over 4.3 GW. Solar lights serve around 50 million people, while solar home systems provided electricity services to over 20 million people. Off-grid solar is being deployed to provide a wide range of services, including household, commercial, public and industrial electrification. Simultaneously, off-grid hydropower capacity had expanded to over 127 MW by 2017. As an example, in Bangladesh, solar home systems now serve over 18 million people, while mini-grids, often powered by micro-hydro power, had reached over 7 million people by 2016 (IRENA, 2018f).

In South America, where electricity access rates are among the highest in the developing world, off-grid renewable energy solutions are considered key for last-mile electricity delivery and for industrial and commercial applications (IRENA, 2018f).

Lack of access to electricity, however, is not only a problem in developing countries; it also affects industrialised nations.

A good example is the Brazilian programme “Luz para Todos”, which aimed to provide energy to remote communities through grid extension, decentralised grids and stand-alone systems and to achieve universal electric power usage in targeted rural areas (GNESD, 2019). Approximately 72% of the programme’s total funding came from two sources: the Reserva Global de Reversão, a fund providing loans collected from concession fees and fines paid by distribution companies, and the Conta de Desenvolvimento Energético, a fund providing subsidies collected from a tariff paid by all electricity consumers. The programme, initially meant to end in 2014, was extended to 2018 due to its success. Almost 3.4 million previously un-electrified households were connected to the grid, and by 2014, the programme had benefitted 68% more households than the original target of 2 million families. The programme also brought social and economic benefits to the assisted communities.

The programme’s results have attracted the interest of countries where barriers to the universalisation of electricity still stand. Brazil has established technical exchanges with Angola, Argentina, Bolivia (Plurinational State of), Burkina Faso, Cameroon, China, Colombia, Costa Rica, Cuba, Guatemala, India, Kenya, Nicaragua, Nigeria, Peru, South Africa and Zambia to bring the experiences of “Luz para Todos” to these countries (GNESD, 2019).

Other G20 countries, like Australia and the Russian Federation, also have to address grid access issues in their rural remote areas. In the Russian Federation, 70% of the territory’s electrical supply is decentralised, and the majority of these areas face severe environmental conditions (i.e., Siberia, the Far East and the Far North) (Surkov, 2013). In Australia, only 2% of the population lives within the off-grid electricity market, representing 6% of the country’s total electricity demand, including small communities, agricultural processing facilities, off-grid mines and off-grid infrastructure (AECOM, 2013). In both cases, electricity is provided by natural gas and diesel fuel, creating an opportunity for investment in stand-alone clean energy solutions, in particular hybrid power stations. These opportunities consist of hybridising mature renewable energy technologies with existing off-grid generation systems (i.e., gas and liquid fuels). These systems would overcome the challenges of power deficiency through the use of renewable energy sources while improving the quality and stability of the electrical supply.

Sharing some of the same challenges as rural off-grid served areas, Small Island Developing States (SIDS), a distinct group of developing countries spread throughout the world’s oceans and seas (UN-OHRLLS, 2011), often rely upon narrow resource bases, which deprives them of the benefits of economies of scale. They also have small domestic markets with high energy and infrastructure costs. Despite their growing populations, they generally have little resilience to natural disasters as well as fragile natural environments.

However, SIDS possess significant potential for renewable energy development and can meet most, if not all, of their domestic energy needs through a combination of renewable energy technologies. Decreasing system costs offer opportunities to speed the transition from fossil fuels to renewables that will, in turn, reduce electricity costs, improve energy access, create jobs and boost energy security (IRENA, 2016c).

Given that most SIDS depend on electricity generated from imported refined petroleum products, they generally have some of the highest electricity costs in the world. Because of fossil fuels' long supply chains combined with SIDS' limited purchasing power, generation costs often range from USD 0.30 per kWh to over USD 1.00 per kWh. Conversely, renewables offer a lower-cost alternative for many islands and are already playing key demonstration roles worldwide (IRENA, 2016c).

Because islands with small-scale grid systems are more affected by fluctuations in renewable energy power supply than areas connected to larger-scale grids, grid stability is a particularly important issue when increasing the renewable energy penetration rate in these areas. However, the sustainable operation of electricity systems with high shares of renewables has already been demonstrated on numerous islands (e.g., Barbados, Cabo Verde, Fiji, Kiribati, etc.) (IRENA, 2016c) across the world using a combination of renewable energy, solar PV and battery storage to support high shares of renewable electricity.

In the Dominican Republic, for example, approximately 400 000 people live without electricity, relying instead on kerosene lamps or pine kindling for lighting at night, which in addition to being expensive also creates serious health hazards. Since 2008, 13 communities that were otherwise excluded from the national power grid have been supported through renewable energy projects for rural electrification. The Rural Electrification Programme promoted access to renewable energy in rural communities by supporting the development of community enterprises focused on strengthening collaboration between communities and local governments with the aim of better managing electricity. The programme specifically supported small-enterprise income generation and integrated energy production, environmental protection, social needs, institutional capacity building, and local community co operatives. The impact was successful. Villagers were organised to work in teams to participate in the construction of micro hydropower plants, promoting a strong sense of ownership. At the same time, a number of small micro hydropower plants have been installed to provide sustainable energy for more than 3 000 families across the country. Going forward, sustainable energy considerations have been incorporated into future plans and management policies in over 70% of municipalities where new plants are located (IRENA, 2016c).

Islands in industrialised countries face challenges similar to those in developing countries.

For instance, G20 member Japan, an archipelago of 6 852 small islands, faces grid stability challenges. In light of this, in 2015 the Japanese government developed a series of projects on ten rural islands (six in Kagoshima Prefecture and four in Okinawa Prefecture) to improve grid operation. This is particularly important on remote islands because they are isolated from the national grid, and grid sizes in these areas are generally much smaller than elsewhere. These projects were able to improve grid operation through the use of battery storage to stabilise short-term and long-term fluctuations of solar power supply and distribution, thus improving energy security. For instance, on Kurimajima, a small island southwest of Miyakojima with about 90 households and about 200 citizens, a pilot project aimed at 100% reliance on renewable energy has been deployed. The island's peak power demand is about 200 kW. To meet this need, two 176 kWh battery units were installed to support the island's small grid. Based on this pilot project, the solar power generated and later stored in the battery system can now meet at least half the island's annual electrical demands (IRENA, 2016c).

Implementation challenges

The renewable transition both in rural off-grid areas and within SIDS nations has been slowed by numerous technical, policy, regulatory and economic barriers. One fundamental challenge is moving from fossil fuel-based power systems, where costs are driven by fuel consumption, to systems dominated by solar PV and wind, where costs are driven by significant upfront capital investment. There is also often a lack of local capacity to plan, operate and maintain electricity systems with high shares of variable renewables (IRENA, 2018f).

- **Political**
  - » Off-grid renewables lack integration within energy access strategies/plans.
  - » Lack of dedicated policies and regulations for the off-grid sector, such as quality standards, legal and licensing provision, cost recovery and tariff regulation, etc.
  - » Lack of clarity on main grid arrival plans.
  - » Need for a holistic approach when designing policies and regulations for off-grid renewables in order to create an enabling ecosystem for deployment and maximise socio-economic development (IRENA, 2018g).

- **Financial**
  - » Lack of access to commercial debt financing in large volumes to scale-up off-grid renewables (and not through grants and non-commercial equity).
  - » Difficulties in raising financing for off-grid renewable energy projects, especially in countries with underdeveloped financial markets or where traditional financing is not easily accessible.
  - » Public finance is not playing an active role in bridging the financial gaps.

- **Institutional framework**
  - » Lack of clearly defined roles among relevant institutions.
  - » Cumbersome and complicated administrative procedures.
  - » Lack of international standards for off-grid technology solutions.

- **Human capacity**
  - » Lack of an appropriate capacity needs assessment at all levels of the value chain to determine the gaps.
  - » Lack of a dedicated project facilitation tools that can support the deployment of projects by helping project developers secure financing more efficiently.
  - » Lack of entrepreneurship support schemes.
  - » Lack of skills development programmes, including certification initiatives.

- **Other**
  - » Lack of cross-sectoral linkages (i.e., technology innovation with livelihoods, etc.).
  - » Lack of gender-sensitive policies and gender-sensitive training opportunities; gender perspectives are not included and integrated into energy access programmes (IRENA, 2019e).

5. CHALLENGES AND ACTIONS TO FURTHER DISTRIBUTED ENERGY RESOURCE UTILISATION

This report has highlighted the urgent need for G20 members to lead the global implementation of a cleaner energy matrix to avoid the worst impacts of the continued burning of fossil fuels that cause climate change.

By acknowledging the positive synergies among renewable energy, SDGs and climate change mitigation, this report serves as a call for action and for the adoption of new solutions that will drive the necessary energy transition, specifically the development of DERs and the empowerment of societies. Currently, the status of the world's pathways towards renewable energy development and climate change mitigation are not in line with the objectives of the Paris Agreement's central aim to keep global temperature rise this century well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to only 1.5°C (UNFCCC, 2019). Therefore, more aggressive actions to reduce climate change and enhance sustainability are imperative.

This report has identified and analysed existing successful decentralised solutions for renewable energy and energy efficiency applications in the context of cities, islands and rural off-grid areas. Additionally, it has explored the creation of renewable energy communities and the enhancement of corporate sourcing solutions within these three different areas as effective energy transformation strategies.

Mobilising societies to expand renewable energy and DERs in several areas requires flexibility and adaptation, while recognising the different contexts, endowments, competencies and priorities of the various stakeholders involved in this transition. From the analysis and examples mentioned in the previous chapters (cities, islands, rural off-grid areas, energy communities and corporate sourcing) and by maintaining a human-centred approach (DIY) at the core, several common challenges and actions have emerged. These are divided into four key topics (Figure 12):

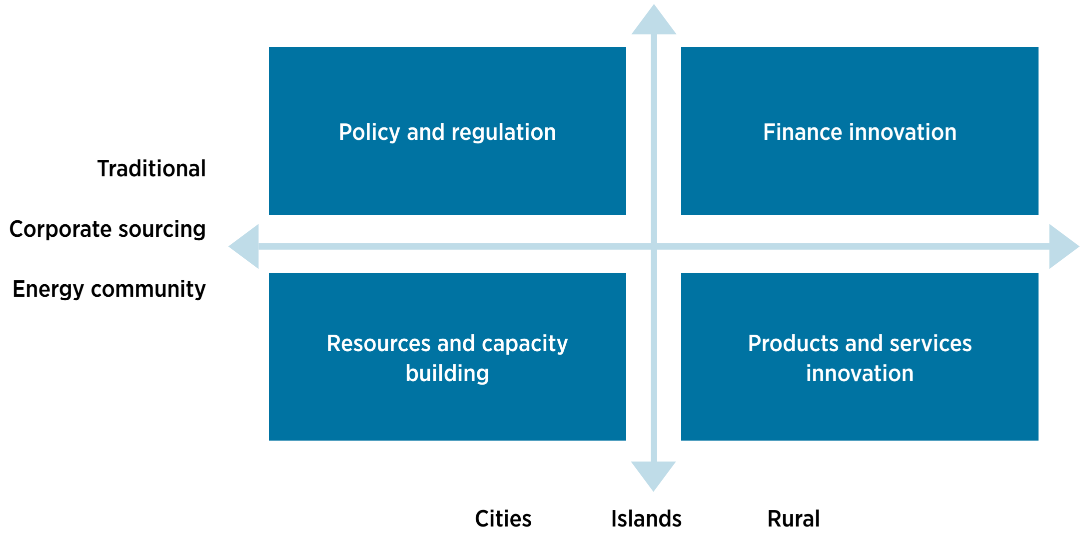
i) policy and regulation;

ii) finance innovation;

iii) resources and capacity building;

iv) products and services innovation

Figure 12: DERs: G20 framework for action



Using this framework, G20 countries, acting together or individually, can take actions that will help develop DERs via energy communities in cities, islands and rural areas, as well as corporate sourcing practices.

The strong economic and political interdependence shared by all G20 members creates a common interest in combining efforts to create a sustainable and steady global environment, which indeed also applies to the world's energy, climate and environmental situation. As explored in this report, G20 countries as a group can to foster the changes needed for DER development and to spread such change on a global level. In terms of the G20 framework for action (Figure 12), this specifically involves actions on policy and regulation; finance innovation; resources and capacity building; and innovation in products and services. These are outlined in Table 2.

Furthermore, under the proposed framework, there are customisable actions that could be applicable to the whole G20 or for individual G20 members, according to their specific status, context and priorities.

Table 2: Concrete actions for G20 countries

Framework	Concrete actions
Policy and regulation	• Promote **multilateral assessments in international programmes and initiatives to foster alignment** of policies and initiatives from multilateral agencies to incorporate renewable energy solutions and convergence towards SDG 7. From this analysis, additional synergies can be fostered.
Finance innovation	• Set up dedicated **international financing and investment facilities** at a global level specifically dedicated to lending and supporting communities for the implementation of DER technical solutions, as well as for organising training and capacity-building activities. • **Promote combo loans.** Encourage multilateral banks to innovate and facilitate the financing of renewable energy projects in different regions and countries under the same funding operation. This financing operates like a "combo loan", allowing small projects with higher risks in non-developed countries to be deployed. As a condition to access multilateral agency funding, large renewable energy projects from developed nations could include small projects from non-developed ones in their financial cash-flow analysis, diluting the risk of small projects. • Promote and support **innovative solutions for crowdfunding platforms**. These can encourage societies and individuals in different regions of the world willing to invest in renewable energy projects to directly invest in renewable energy in regions beyond their localities or countries. This would reduce transaction costs, as someone in Europe, for instance, could directly invest in DER projects in Africa via crowdfunding platforms. Under such schemes, DER solutions can directly benefit from having upfront capital for investment and can bring societies around the world closer by promoting the exchange of best practices and experiences. • Set up a **global programme for finance collection** based on Brazil's "Luz para Todos". The programme would consist of increasing electricity tariffs by several cents in developed nations to fund and finance DER programmes in developing ones. • Develop **innovative financing solutions in partnership with multilateral agencies**. Such financial markets would re-evaluate the normal cash flow of monthly expenditures for diesel consumption used by off-grid generation (islands, rural off-grid areas, etc.) and transform it into upfront capital for investment in renewable DER solutions. • Set up a platform providing comprehensive, easily accessible and practical information, tools and guidance to assist in the **development of bankable renewable energy projects**. • Develop mechanisms for **improving risk management and cash flow**. This could include, for instance, setting up **blended finance schemes**, combining private capital (i.e., equity) and donors' money (i.e., multilateral banks, etc.).
Resources and capacity building	• Set up **training courses, educational programmes and "Do it Ourselves" approaches** recognised on international levels (both online and onsite). These courses should target both consumers and citizens involved in energy communities, as well as policy makers and sector experts. • Set up specific **certification programmes** for off-grid skills development.
Products and services innovation	• Create a **dedicated platform and network of experts** for the discussion and exchange of renewable energy and DER best practices and benchmarks at a global level. • Customise the applicability of DER solutions and promote **specific funds for innovation** in DER solutions for islands, rural areas and cities, including setting up pilot projects for DER technologies and innovative solutions. • Set up a **mapping and showcase platform for DER innovation solutions** to enable replicability and facilitate entrepreneurial access across different markets. • Encourage the production of **appliances with embedded solutions**, such as batteries that increase resilience and flexibility.

Topic 1: Policy and regulatory enhancement

Status and challenges:

Accelerating progress towards the SDG 7 goal of universal electricity access requires concerted action across multiple elements of an enabling environment. These include new policies and regulations, updated delivery and financing models, re-imagined institutional frameworks, enhanced capacity building, increased technology adaptation, and expanded cross sector-linkages. There is no one-size-fits-all solution. Each specific element of the enabling environment needs to be tailored to the selected DER methods and local context. In many countries, existing policies lack a holistic approach or the needed co-ordination between different levels of government to properly tackle climate change and meet the SDGs.

Also, there are several specificities required under DER solutions. These include possible market barriers related to lack of access to the energy market, possible discrimination against smaller investors, issues affecting tariff structures, governance issues and the lack of appropriate institutional frameworks. There are inherent difficulties involved in moving from fossil fuel-based power systems, where costs are driven by fuel consumption, to systems dominated by solar PV and wind, where costs are driven by significant upfront capital investment. Furthermore, future developments can be hindered by a lack of local capacities to plan, operate and maintain electricity systems with high shares of variable renewables.

RECOMMENDATION: ***Adjust planning, markets and regulation to make them enablers of DERs***

Actions:

1. **Develop effective market frameworks for investment.** Ensure that the electricity market is open to all types of players and that regulations allow utilities and independent power producers to profitably invest in cost-effective renewable power options and projects. Consider an energy market structure that allows for direct trade between companies of all sizes and renewable energy developers – such as through PPAs.
2. **Create equal market access for all market participants.** In this framework, auctions are not the preferred instrument to stimulate community energy deployment. Equally, policy makers could also consider fostering decentralised, community-based renewable energy systems. In tendering procedures, for instance, specific targets and regulations for community projects could be set up, driving corporate procurement innovation and global change management across private and public sectors.
3. **Engage with utilities to adjust and simplify aspects related to energy distribution (i.e., grid connection), licensing and permitting requirements.** Adapt and review economic regulations, including existing tariffs, with the aim of developing tariffs that recognise the added services provided by utilities.
4. **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. New institutions, such as the Rural Electrification Agencies, have been established in several sub-Saharan African nations mandated with supporting rural electrification activities. Although approaches differ according to national contexts, successful strategies generally include clearly defined roles and responsibilities to give sector participants certainty about administrative procedures; requiring simple and streamlined administrative processes designed to reduce transaction licencing and permitting costs; and ensuring that institutions charged with implementing electrification strategies have adequate technical, financial and budgetary oversight capabilities.

RECOMMENDATION: ***Co-ordinate policies – both vertically (local/national) and horizontally (among ministries)***

Actions:

1. **Stabilise and clarify policies and regulations crucial for the development of renewable-based DER solutions.** Policies, including incentive structures, need to be designed to attract investments and to encourage local enterprises to contribute to long-term market development.
2. **Link sectorial policies to renewable energy and SDGs, such as through urban or transport policies for the application of DERs.** Integrating energy planning into urban planning requires not only challenging cross-department co-ordination, but in many cases, reforming energy governance mechanisms.
3. **Involve the public sector by encouraging the application of DERs and energy efficiency in public buildings (i.e., hospitals, schools, etc.).** The public sector also plays a crucial role in supporting the delivery of model innovation through research and pilot projects.
4. **Mainstream off-grid solutions within national energy access strategies to provide a strong foundation for market development.** This incentivises different stakeholders to devise tailored solutions to provide energy services.

Topic 2: Finance innovation

Status and challenges:

The financial sector has made significant progress in off-grid solutions; however, a wider potential for new DER applications remains that needs to be unlocked and explored.

RECOMMENDATION: ***Review finance schemes***

Communities (cities, islands or rural) are often financially challenged by i) difficulties in raising equity due to the lack of access to third-party finance; ii) deficiency of project development skills, which could make projects more or less attractive to investors; iii) lack of specific finance schemes that fit the needs of new DER applications; and iv) reluctance among financial institutions to finance new DER applications due to inadequate knowledge of such technologies.

Actions:

1. **Ensure access to long-term, tailored and affordable financing for end-users.** This can improve the accessibility of DER solutions, whether products (e.g., solar home systems) or services (e.g., mini-grid connection fees). Designing end-use financing in a manner that engages local financial institutions can also help unlock a wider range of financial services for households beyond energy.
2. **Improve financial institutions' knowledge and understanding of available DER solutions.**
3. **Design specific funding lines and schemes for DER solutions.** Financial instruments, such as crowdfunding, can facilitate access to capital for decentralised projects when traditional financing is not available or proves too costly. Public financing, crowdfunding and other enabling conditions play key roles in filling the funding gaps while supporting delivery model innovation through research and pilot projects.
4. **Allow current funds to lend and invest in renewable energy development.** Also, provide dedicated project facilitation tools to support deployment of projects by helping project developers secure financing more efficiently.
5. **Ensure government support to develop alternative business models.** This encourages financial institutions to dispense loans. Public guarantees can play an important role in this area.
6. **Mobilise international backing.** An appropriate international finance institution could establish a facility specifically dedicated to financing community energy projects in developing countries.

Topic 3: Resources and capacity building

Status and challenges:

Currently, more progress can be made in the development of educational programmes and specialised training that would fully exploit the employment generation potential of the renewable sector, as well as the penetration of DER and DIY solutions. Capacity building is a central pillar of an enabling environment for decentralised renewable energy development, and the presence of adequate skills is key for the sustainability of the decentralised renewable energy sector.

RECOMMENDATION: ***Promote networks to facilitate and invest in capacity building and education for behaviour change***

Actions:

1. **Build the human capacity to incorporate renewable power options for DER (cities, islands or rural).** A variety of skills are needed to plan, finance, manage, operate and maintain the power grid. Fostering, developing and maintaining the necessary skills regionally can ensure on-going local economic impacts.

2. **Build adequate capacity within public and financial institutions to support the implementation of the national energy access strategies.** Awareness raising about and sensitising stakeholders to the characteristics of renewable-based DER solutions can address some of the barriers faced by the new technologies.

3. **Create groups for exchanging knowledge and expertise.** This can be done at a corporate level, as well as at a geographical level (i.e., for cities). Create a dedicated agency or platform to assist companies and communities throughout the whole process.

4. **Design entrepreneurship support schemes.** These must be accessible to the local private and public sector, schools and universities, and energy communities that could support the development of a sustainable market for decentralised solutions.

5. **Provide dedicated project facilitation tools.** These should support deployment projects by helping developers secure financing more efficiently.

6. **Design programmes to raise awareness and understanding of the potential of DERs.** These should be not only for direct users, but also for the society as a whole to foster wiser behavioural changes.

7. **Actively engage communities in the design, construction, operation and maintenance phase of the projects.** These should increase community buy-in and enhance sustainability.

Topic 4: Products and services innovation

Status and challenges:

The existing DER solutions still have large and unexplored potential to innovate and allow any customer from cities, islands or rural areas, regardless of expertise, to independently use the application. DER solutions usually require a specific skill set, which is often limited among users. Such innovations are, at this point, very useful given that the consumers are increasingly playing more active roles, moving from traditional DERs in households and corporate sourcing towards energy community approaches and DIY applications. Therefore, technology adaptation, innovation and improvements – in generation, balance-of-system components and end-use applications – are essential for the success of DER solutions.

RECOMMENDATION: ***Encourage innovations in DER products and services while facilitating technology accessibility***

Actions:

1. **Provide market policies to support commercialisation of DER equipment.** Policy makers play a critical role in paving the way for the industry's growth.

2. **Define adequate standards and quality-control measures for DERs to foster the robustness of the applications.** This would avoid the proliferation of low-quality products and rather focus on adopting standards that encourage sustainable development without discouraging adaptation and delivery model innovation

3. **Customise the application of "plug and play" DER systems**. Make them adaptable to different market characteristics, such as those in cities, islands and rural areas.

4. **Facilitate the economic affordability and availability of DER technologies.** This allows innovation from the supply side to make such products generally available within the market

5. **Encourage the incorporation of DER solutions into buildings.** Building codes can ensure sustainable design, construction and energy use.

.

REFERENCES

» **AECOM (2013)**, *Australian Remote Renewables: Opportunities for Investment* www.assorinnovabili.it/public/sitoaper/AperNelMondo/Internazionale/Report%20 Australia.PDF.

» **CAN (Climate Action Network International) (2018)**, *G20 Working Group*, CAN, www.climatenetwork.org/working-group-pages/g20 (viewed 7 January 2019).

» **C40 and ARUP (2015)**, Climate Action in Megacites 3.0 – Networking works, there is no global solution without local action, www.cam3.c40.org/images/C40ClimateActionInMegacities3.pdf.

» **C40 (2012)**, *Why Cities are the Solution to Global Climate Change*, C40, www.c40.org/ending-climate-change-begins-in-the-city.

» **G20 Argentina (G20Argentina 2018) (2018)**, *G20 Climate Sustainability Working Group Adaptation Work Program (2018-2019)*, www.argentina.gob.ar/sites/default/files/g20_adaptation_work_program_adopted_version.pdf (viewed 7 January 2019).

» **GNESD (2019)**, Energy access program in Brazil: "Light for all", GNESD Energy Access Knowledge Base, https://energy-access.gnesd.org/projects/32-energy-access-program-in-brazil-lighting-for-all.html.

» **GoJ (Government of Japan-Public Relations Office) (2018)**, *Society 5.0*, www.gov-online.go.jp/cam/s5/eng/ (viewed 7 January 2019).

» **Grubler, A., X. Bai, T. Buettner, S. Dhakal, D. J. Fisk, T. Ichinose, J. E. Keirstead, G. Sammer, D. Satterthwaite, N. B. Schulz, N. Shah, J. Steinberger and H. Weisz (2012)**, Urban Energy Systems, Chapter 18 in Global Energy Assessment – Toward a Sustainable Future, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 1307-1400. www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-EnergyAssessment/GEA-Summary-web.pdf.

» **IEA (2018)**, *Global Energy & CO_2 Status Report 2017*, IEA, Paris, www.connaissancedesenergies.org/sites/default/files/pdf-actualites/geco2017.pdf.

» **IEA (2017)**, *Energy Access Outlook 2017: From Poverty to Prosperity*, IEA, Paris, www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf.

» **IPCC (2018)**, *Special Report on Global Warming of 1.5°C,* IPCC, Geneva, www.ipcc.ch/sr15/.

» **IRENA (forthcoming)**, *Community-ownership models: Innovation Landscape Brief*, International Renewable Energy Agency, Abu Dhabi.

» **IRENA (2019a)**, *Global Energy Transformation: A Roadmap to 2050 (2019 Edition)*, IRENA, Abu Dhabi

» **IRENA (2019b)**, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables*. IRENA, Abu Dhabi, www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future.

» **IRENA (2019c),** *Aggregators: Innovation Landscape Brief*, IRENA, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Landscape_Aggregators_2019.pdf?la=en&hash=388A36E4EB2723D2324C4B08329055F3121FD534.

» **IRENA (2019d)**, *Off-grid renewable energy solutions to expand electricity access: An opportunity not to be missed*, IRENA, Abu Dhabi, www.irena.org/publications/2019/Jan/Off-grid-renewable-energy-solutions-to-expand-electricity-to-access-An-opportunity-not-to-be-missed.

» **IRENA (2019e)**, *Renewable energy: A gender perspective*, IRENA, Abu Dhabi, www.irena.org/publications/2019/Jan/Renewable-Energy-A-Gender-Perspective.

» **IRENA (2018a)**, *Opportunities to accelerate national energy transitions through advanced deployment of renewables (Report to the G20 Energy Transitions Working Group),* IRENA, Abu Dhabi, www.irena.org/publications/2018/Nov/Opportunities-to-accelerate-national-energy-transitions-through-advanced-deployment-of-renewables.

» **IRENA (2018b)**, *Corporate sourcing of renewables: Market and industry trends – REmade Index 2018*, IRENA, Abu Dhabi, www.irena.org/publications/2018/May/Corporate-Sourcing-of-Renewable-Energy.

» **IRENA (2018c)**, *Scaling-up renewables in cities: Opportunities for municipal governments*, IRENA, Abu Dhabi, www.irena.org/publications/2018/Dec/Scaling-up-Renewables-in-Cities.

» **IRENA (2018d)**, *Renewable power generation costs in 2017*, IRENA, Abu Dhabi, www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017.

» **IRENA (2018e)**, *Sustainable rural bioenergy solutions in Sub-Saharan Africa: A collection of good practices*, IRENA, Abu Dhabi, www.irena.org/publications/2019/Jan/Sustainable-Rural-Bioenergy-Solutions-in-Sub-Saharan-Africa-A-collection-of-good-practices.

» **IRENA (2018f)**, *Off-grid renewable energy solutions: Global and regional status and trends*. IRENA, Abu Dhabi, www.irena.org/publications/2018/Jul/Off-grid-Renewable-Energy-Solutions.

» **IRENA (2018g)**, *Policies and regulations for renewable energy mini-grids*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Sep/Policies-and-regulations-for-private-sector-renewable-energy-mini-grids.

» **IRENA (2017a)**, *REthinking Energy 2017: Accelerating the global energy transformation*, IRENA, Abu Dhabi, www.irena.org/publications/2017/Jan/REthinking-Energy-2017-Accelerating-the-global-energy-transformation.

» **IRENA (2017b)**, *Untapped potential for climate action: Renewable energy in Nationally Determined Contributions*, IRENA, Abu Dhabi, www.irena.org/publications/2017/Nov/Untapped-potential-for-climate-action-NDC.

- **IRENA (2017c)**, *Renewable energy in district heating and cooling: A sector roadmap for REmap*, IRENA, Abu Dhabi, www.irena.org/publications/2017/Mar/Renewable-energy-in-district-heating-and-cooling.

- **IRENA (2016a)**, *G20 toolkit for renewable energy deployment: Country options for sustainable growth based on REmap*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Jun/G20-Toolkit-for-Renewable-Energy-Deployment-Country-Options-for-sustainable-growth-based-on-Remap.

- **IRENA (2016b)**, *Renewable energy in cities*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Oct/Renewable-Energy-in-Cities.

- **IRENA (2016c)**, *A path to prosperity: Renewable energy for islands (3rd edition)*, IRENA, Abu Dhabi, www.irena.org/publications/2016/Nov/A-Path-to-Prosperity-Renewable-Energy-for-Islands-3rd-Edition.

- **IRENA (2015)**, *Renewable energy target setting*, IRENA, Abu Dhabi, www.irena.org/publications/2015/Jun/Renewable-Energy-Target-Setting.

- **IRENA and ICLEI (International Council for Local Environmental Initiatives) (2013)**, *Renewable energy policy in cities: Selected case studies*, IRENA, Abu Dhabi, www.irena.org/publications/2013/Jan/ Renewable-Energy-Policy-in-Cities-Selected-Case-Studies.

- **IRENA, IEA and REN21 (2018)**, *Renewable energy policies in a time of transition*, IRENA, OECD/IEA and REN21, www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition.

- **Movellan, J. (2015a)**, "Born from disaster: Japan establishes first microgrid community", *Renewable Energy World*, www.renewableenergyworld.com/articles/2015/05/born-from-disaster-japans-first-microgrid-community-represents-future-of-energy.html.

- **Movellan, J. (2015b)**, "Tokyo's renewable energy transformation to be showcased in the 2020 Olympics", *Renewable Energy World*, www.renewableenergyworld.com/articles/2015/06/tokyo-s-renewable-energy-transformation-to-be-showcased-in-the-2020-olympics.html.

- **NCC (Nature Climate Change) (2016)**, "The role of society in energy transitions", *Nature Climate Change, Vol. 6*, www.nature.com/articles/nclimate3051.pdf?origin=ppub (viewed 7 January 2019).

- **Negishi, M. (2015)**, "Japanese towns bank on renewable energy", *The Wall Street Journal*, 20 December, www.wsj.com/articles/japanese-towns-bank-on-renewableenergy-1450640000 (paywall).

- **NREL (2017)**, *Net Metering*, National Renewable Energy Laboratory, www.nrel.gov/state-local-tribal/basics-net-metering.html (viewed 15 January 2019).

- **NREL – National Renewable Energy Laboratory (2014)**, *Using Power Purchase Agreements for Solar Deployment at Universities*, www.nrel.gov/docs/gen/fy16/65567.pdf.

» **Paulos, B. (2018)**, *The growth of distributed energy: Implications for California*, Next10, https://next10.org/sites/default/files/California-Growth-DERs-op.pdf.

» **REN21 (2017)**, *Renewables 2017 global status report*, REN21, Paris, www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf.

» **Rezessy, S. et al. (2006)**, "Municipalities and energy efficiency in countries in transition: Review of factors that determine municipal involvement in the markets for energy services and energy efficient equipment, or how to augment the role of municipalities as market players", *Energy Policy*, Vol. 34.

» **Smedley, T. (2014)**, "The local energy co-operative revitalising London estates", *The Guardian*, www.theguardian.com/sustainable-business/blog/local-energy-community-cooperative-london-estate-agamemnon-otero.

» **SUN Co-operative Inc. (2018)**, About SUN Co-operative Inc., https://suncooperative.com/about-2/.

» **Surkov, M. (2013)**, *Power supply systems for stand-alone consumers with high renewable energy penetration*, Tomsk Polytechnic University, Russia, http://pstu.ru/files/file/2015/conf/surkov_power_supply_systems_for_stand_alone_consumers_with_high_renewable_energy_penetration.pdf.

» **UN-OHRLLS (Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States) (2011)**, *Small Island Developing States: Small islands big(ger) stakes*, UN-OHRLLS, New York, http://unohrlls.org/custom-content/uploads/2013/08/SIDS-Small-Islands-Bigger-Stakes.pdf.

» **UNFCCC (2019)**, *What is the Paris Agreement?*, UNFCCC, https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement.

» **University of Nottingham (2017)**, "Pioneering community energy storage project in Nottingham connects its first household battery storage system to the grid", University of Nottingham, www.nottingham.ac.uk/news/pressreleases/2017/may/pioneering-community-energy-storage-project-in-nottingham-connects-its-first-household-battery-storage-system-to-the-grid.aspx.aspx (viewed 28 March 2019).

» **US LEAN (US Local Energy Aggregation Network) (2015)**, *What is CCA?*, US LEAN, http://leanenergyus.org/.

» **WEF (World Economic Forum) (2016)**, *What you need to know about the G20*, WEF, Geneva, www.weforum.org/agenda/2016/09/what-you-need-to-know-about-the-g20/ (viewed 7 January 2019).

» **Windcentrale (n.d.)**, Windcentrale homepage, www.windcentrale.nl/.

» **WWI (Worldwatch Institute) (2016)**, *Can a City be Sustainable?* State of the World Report, WWI, Washington, DC, www.worldwatch.org/http%3A/%252Fwww.worldwatch.org/bookstore/publication/state-world-can-city-be-sustainable-2016.

International Renewable Energy Agency

www.irena.org